CENTRE FOR SCIENCE
& SECURITY STUDIES

Navigating nuclear and radiological security in North Africa: a case study handbook

Edited by Dr Zenobia Homan and Clara Guest

2023

Commonly used abbreviations

AAEA	Arab Atomic Energy Agency
ACSIS	Arab Institute for Security Studies
ANNuR	Arab Network of Nuclear Regulators
ANSC	Tunisia's National Agency for Cybersecurity
CBRN	Chemical, Biological, Radiological and Nuclear
CNSTN	Tunisia's National Centre for Nuclear Science and Technology
CPPNM	Convention on the Physical Protection of Nuclear Material
CSSS	Centre for Science & Security Studies, King's College London
DBT	Design Basis Threat
EAEA	Egyptian Atomic Energy Authority
ENRRA	Egyptian Nuclear and Radiological Regulatory Authority
EPR	Emergency Preparedness and Response
EYGN	Egypt Young Generation Nuclear
GNSSN	IAEA Global Nuclear Safety and Security Network
IAEA	International Atomic Energy Agency
INSEN	International Nuclear Security Education Network
INSSPs	Integrated Nuclear Security Support Plans
IPPAS	International Physical Protection Advisory Service
IRS	Ionising Radiation Sources
LNA	Libyan National Army
NAUSS	Naif Arab University for Security Sciences
NSSCs	National Nuclear Security Support Centers
NPP	Nuclear Power Plant
NRR	Nuclear Research Reactor
NSS	Nuclear Security Summits
NTI	Nuclear Threat Initiative
RDD	Radiological Dispersal Device
RED	Radiological Explosive Device
UN	United Nations
UOC	Uranium Ore Concentrate
WINS	World Institute for Nuclear Security

Table of contents

Commonly used abbreviations 2
Nuclear and radiological security culture in North Africa 4
About the Centre for Science & Security Studies 4
About the editors 4

I: Introduction 5
- Background 6
- Overview of nuclear developments in North Africa 8
- Common challenges 14

II: Case studies 15
- The complex diplomacy of nuclear crisis management: the Sidi Slimane incident, Morocco 16
- Lessons from Stuxnet: developing nuclear cybersecurity policies for Tunisia 19
- Lost and found part I: the Setif gamma radiography source, Algeria 25
- Lost and found part II: the Meet Halfa gamma radiography source, Egypt 29
- Lost and found part III: the Sabha uranium barrels, Libya 33
- Industrial radiology vulnerabilities in North Africa 38
- Tools to enhance nuclear security in North Africa 41
- Scenario: radioactive source security during civil unrest 46

III: Conclusion 51
- Navigating nuclear and radiological security in North Africa 53
- Looking beyond North Africa 54

Nuclear and radiological security culture in North Africa

North Africa has emerged as a critical region in the realm of nuclear security, with several countries facing unique challenges and opportunities. This handbook delves into the development of nuclear security systems in Morocco, Tunisia, Algeria, Libya, and Egypt. It sheds light on these countries' efforts to enhance control and accountability of nuclear and radiological sources. The collected case studies have been crafted by North African experts, presenting their distinctive perspectives and addressing security concerns specific to their region.

About the Centre for Science & Security Studies

The Centre for Science & Security Studies (CSSS) is a research centre in the Department of War Studies, King's College London. Since 2003, CSSS has been bringing together multidisciplinary teams of experts from academia, government and industry, with backgrounds in sciences, social sciences and humanities. Members of the centre conduct academic and policy-relevant research on non-proliferation, disarmament, arms control, verification, open source intelligence and mass effect terrorism, with emphasis on the chemical, biological, radiological and nuclear (CBRN) dimension.

About the editors

Dr Zenobia Homan is a project coordinator and Research Fellow at CSSS. She organises international professional development courses and related engagements in a number of regions, including North Africa. She conducts research relating to CBRN security, particularly focussing on language, communication, and education.

Clara Guest is a former researcher from CSSS, currently working as a freelance research consultant and translator (Arabic, French, Spanish). She specialises in proliferation finance and sanctions implementation. She also has expertise with capacity-building, delivering training programmes in various countries.

I: Introduction

Background

This handbook draws upon experiences and policies in North Africa from the 1950s to the present. Historical instances of discovery, theft and sabotage have revealed the critical importance of human behaviour. Consequently, evolving security culture has played a pivotal role in mitigating threats posed by terrorism and political tensions.

The International Atomic Energy Agency (IAEA) stresses the value of nuclear security – aiming to protect people, property, society and the environment from harmful effects of ionising radiation. It defines nuclear security culture as 'the assembly of characteristics, attitudes and behaviour of individuals, organisations and institutions which serves as a means to support and enhance nuclear security'.[1] It emphasises the prevention of malignant use of nuclear and radiological materials, and the potential consequences of incidents. The IAEA urges its member states, including those in North Africa, to prioritise nuclear security measures.

The aftermath of the September 2001 terrorist attacks in the United States and subsequent 2010–16 Nuclear Security Summits (NSS) prompted a renewed focus on nuclear security globally. Several North African countries were active participants in the full NSS process, which fostered high-level cooperation and substantial changes in international security endeavours.[2] However, despite displaying active engagement, all states face challenges in enhancing nuclear security.

The Nuclear Threat Initiative (NTI) Index for Nuclear Security places particular emphasis on societal factors that may impact nuclear security in North Africa. The neighbouring countries share common concerns, including the need to enhance tracking mechanisms and regulatory oversight. Other relevant factors include the presence of terrorist groups attempting to acquire nuclear materials, government capacity to address nuclear security challenges, and support for regional initiatives and commitments. Equally important are societal perception of nuclear security, and work with international organisations like the IAEA.

Through the comprehensive examination of nuclear security efforts North Africa, this handbook strives to contribute to the collective knowledge and understanding of effective security practices in the region.

Impact of colonialism on nuclear security

The historical legacy of colonialism in North Africa shapes its nuclear security landscape. Western countries have been criticised for attempting to export their value systems to others, as well as trying to guard and control technology.[3] This influence has permanently affected the development of democracy in North Africa. While the UK has been a representative democracy since 1928 (when it secured the right to vote for all women)[4] – political systems in North Africa are still changing and emerging. This makes it challenging to create and sustain long-term strategies – which are an unavoidable characteristic of nuclear planning.

Looking back to the Cold War period, nuclear weapons played a significant role in North African power dynamics. For example, the US secretly stockpiled nuclear weapons in Morocco – nearly leading to a catastrophic incident in Sidi Slimane on one occasion (see page 16).[5] Between 1942 and 1980, the UK and France both sourced uranium from their colonies in Africa.[6] Perhaps most

1 IAEA, 'Nuclear Security Culture', *IAEA Nuclear Security Series,* No. 7, Vienna, 2008. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1347_web.pdf
2 NSS, 'Past Summits,' 2010. http://www.nss2016.org/past-summits/2010
3 Molly Hurley, 'Global nuclear policy is stuck in colonialist thinking. The ban treaty offers a way out,' *Bulletin of the Atomic Scientists,* 15 January 2021. https://thebulletin.org/2021/01/global-nuclear-policy-is-stuck-in-colonialist-thinking-the-ban-treaty-offers-a-way-out/
4 UK Parliament, 'Women get the Vote,' 2023. https://www.parliament.uk/about/living-heritage/transformingsociety/electionsvoting/womenvote/overview/thevote/
5 The Bulletin of the Atomic Scientists, 'Where They Were,' 1999. https://www.archives.gov/files/declassification/pidb/meetings/where-they-were.pdf
6 Gabrielle Hecht, 'Colonial Networks of Power: The Far Reaches of Systems,' *Annales historiques de l'électricité,* Vol. 1, No. 2, 2004.

shockingly however, France conducted atomic bomb tests in the Algerian Sahara – despite the 1961 Algerian referendum in favour of self-determination. This caused irreversible contamination, and the region remains heavily polluted today.[7] Furthermore, Israel's alleged nuclear weapons programme has actively influenced threat perception in both Egypt and Libya to this day.[8]

Not all connections have only negative connotations, however. For example, France has committed to help both Morocco and Tunisia develop civil nuclear technology.[9, 10] Algeria's struggle for independence and self-reliance ultimately enhanced its national defence capabilities. In Egypt, nuclear security contributed to techno-nationalism – the connection between investment in science and technology, national pride, and the ambition to fulfil a regional leadership role. Consequently, Egypt launched a civilian nuclear programme two years after its independence from the UK.[11]

This historical context, in conjunction with regional dynamics and energy requirements, is inexorably intertwined with approaches to nuclear security. What is more, the impact of colonialism expands beyond physical remains and political history. Colonialism also strongly influences scholarship and knowledge production. Racial, civilisational, imperialist and ideological discourse continue to influence international policy.[12] This imbalance of power between the West and the rest of the world, but also between individual nations and their indigenous communities, has received increased attention in recent years – but much more work remains to be done.[13]

Nuclear security during conflict

Amid volatile risk environments, many governments struggle to meet today's nuclear security challenges. North Africa continues to grapple with several protracted conflicts that have implications for nuclear security. This context forms a strong contrast with other regions: although France has lately experienced a series of violent protests, the most recent war and occupation that took place within its borders was World War II (1939–1945).

In North Africa, enduring unrest caused by the Israeli-Palestinian conflict contributes to regional instability and, consequently, heightened focus on CBRN (chemical, biological, radiological, nuclear) security. Since the 1970s, Morocco and Mauritania have been involved in extended conflict in the Western Sahara, and since 2002 an insurgency has been taking place in the Maghreb – involving Morocco, Algeria, Mauritania, Niger and Mali. In 2010–2011, a revolution in Tunisia led to the ousting of President Ben Ali. This was followed by extended political reformation including a series of elections which have seen decreased turn-out every time. The subsequent 'Arab Spring' entangled North Africa in the Libyan crisis (two civil wars, foreign military intervention, and the ousting and death of Muammar Gaddafi) and the Egyptian crisis (a revolution characterised by mass protests, a series of popular elections, deadly clashes, and military reinforcement).

Regional instability has resulted in the loss of significant military arsenals, which ended up in the hands of non-state actors, including Boko Haram in northern Nigeria and Ansar Al-Sharia in Tunisia. The common theme across these conflicts is the potential disruption to governance, the proliferation of weapons and technology, and the compromised security of nuclear materials and facilities.

> **France conducted atomic bomb tests in the Algerian Sahara – despite the 1961 Algerian referendum in favour of self-determination. This caused irreversible contamination.**

7 Samia Henni, 'Nuclear powers: France's atomic bomb tests in the Algerian Sahara,' *Architectural Review,* 23 June 2022. https://www.architectural-review.com/essays/nuclear-powers-frances-atomic-bomb-tests-in-the-algerian-sahara

8 Abdel Monem Said Aly, 'In the Shadow of the Israeli Nuclear Bombs: Egyptian Threat Perceptions,' *The Brown Journal of World Affairs,* Vol. 3, No. 2, 1996.

9 Reuters, 'France seals nuclear, aid deals with Tunisia,' 23 April 2009. https://www.reuters.com/article/idUKLN941296

10 Mail and Guardian, 'France seals nuclear deal with Morocco,' 24 October 2007. https://mg.co.za/article/2007-10-24-france-seals-nuclear-deal-with-morocco/

11 Heba Taha, 'Nuclear energy and techno-nationalism in Egypt,' *The South African Institute of International Affairs Policy Briefings,* 23 September 2020. https://saiia.org.za/research/nuclear-energy-and-techno-nationalism-in-egypt

12 Jasmine K Gani and Jenna Marshall, 'The impact of colonialism on policy and knowledge production in International Relations,' *International Affairs*, Vol. 98, No. 1, 2022.

13 Sneha Nair, Ian Fleming Zhou, Louis Reitmann, Monalisa Hazarika and Almuntaser Bluwi, 'Beyond the Echo Chamber: Creating a More Equitable, Diverse and Inclusive Nuclear Weapons Policy Field,' BASIC, De-siloing Existential Threats: Challenging Identity, Power, and Inclusivity in the Nuclear Policy Field, 2023. https://vcdnp.org/wp-content/uploads/2023/08/Beyond-the-Echo-Chamber.pdf

Overview of nuclear developments in North Africa

Nuclear power is an emerging topic in North Africa. While military considerations have dominated the nuclear landscape in some countries, there is growing interest in developing civil nuclear sectors. At present, there are no operational civil nuclear power plants (NPPs) in North Africa. However, some countries have expressed intentions to pursue nuclear energy for electricity generation – with particularly Egypt making rapid progress in recent years.

Contributors

This collection of case studies has been carefully curated and authored by international relations and nuclear security experts hailing from North Africa. Their selection of topics mirrors the pressing concerns within this region. The handbook incorporates publicly accessible data (summer 2023), supplemented by the valuable perspectives of the contributors and their peers.

Mohammed Allam is a nuclear and radiological security expert from Egypt and holds an MA in Economics and Defence from the University of National and World Economy (UNWE).

Dr Lamiaa Fiala is Professor of Public Health and Preventive Medicine at Suez Canal University (Egypt) and dedicated member of the International Nuclear Security Education Network (INSEN).

Amine Ghoulidi is a PhD candidate at King's College London. He is the convenor of the Middle East and North Africa (MENA) Research Group, a research unit under the Institute of Middle Eastern Studies at King's.

Marwa Ibrahim is a Nuclear Engineer. She holds an MA in Nuclear Safeguards from Politecnico di Milano. She is also the President of Young Generation Nuclear Egypt (EYGN).

Dr Fawzi Ikraiam is a Professor of Physics at Omar Al-Mukhtar University (Libya). He specialises in microelectronic device characterisation and high energy physics, with a particular interest in harsh environments.

Dr Mostafa Kofi is the Director of the Training Centre of Public Health and Safety at Suez Canal University (Egypt) as well as Professor of Occupational Medicine.

Dr Wafaa Mohamed Moustafa is a Professor of Environmental Isotope Hydrology. She also works for the Siting and Environmental Department at the Egyptian Atomic Energy Authority (EAEA) Nuclear and Radiation Safety Research Centre.

MOROCCO[14]

In 2007, Morocco developed its first nuclear facility – Maamora Nuclear Research Centre – for research in nuclear energy, neutron activation analysis, geochronology research, education, and training. Currently the National Centre for Nuclear Energy, Sciences, and Techniques (CNESTEN) operates a US-supplied TRIGA Mark II nuclear research reactor (NRR) there. It is dedicated to the production of radiopharmaceuticals, the management of radioactive waste, industrial and environmental applications, and calibration of radiation protection equipment. Subsequently, Morocco has been described by the IAEA as 'a model for monitoring nuclear research reactors in Africa and beyond' with a 'central role in nuclear security'.[15]

As of 2022, nuclear medicine accounts for more than 80 per cent of activities in Morocco using ionising radiation sources (IRS) – with over 7000 units (scanners, electron accelerators). Furthermore, two cyclotrons managed by private companies in Bouznika and Bosker produce radiopharmaceuticals. Industrial activities using IRS include control of the production of sugar, cement, paper, oil refining, mining, metallurgy, and civil engineering works (construction of buildings, roads). The National Institute of Agronomic Research also operates a semi-industrial irradiator using a very high activity cobalt-60 source.[16] Finally, following initial exploration by Russian and French geologists, Morocco's National Office of Hydrocarbons and Mines is studying uranium sources in three regions, of which two have palaeochannel deposits. In addition, the OCP group (Office Chérifien des Phosphates) is investigating recovery of uranium from phosphoric acid.[17]

Morocco has looked into developing an nuclear power plant (NPP), initiated by the National Electricity Utility Office. They conducted feasibility studies in the 1980s and 1990s, selecting the Sidi Boulbra site as a suitable location. Further studies during 2002–2005, in collaboration with the IAEA, reaffirmed the technical feasibility and competitiveness of nuclear energy.[18] A 2006–2007 pre-selection process involved inviting nuclear reactor suppliers to submit non-binding offers for engineering, procurement, construction, operation, maintenance, and fuel services. Accordingly, Morocco now follows the IAEA's milestones approach.[19, 20] While no further steps have been taken as of yet, the Moroccan government still aims to introduce nuclear energy beyond 2030.

Morocco has a Nuclear Safety and Regulatory Body (known by the acronym AMSSNuR) intended to regulate nuclear and radiological safety and security and nuclear safeguards. In 2014, Morocco adopted a new law (number 142–12) for nuclear and radiological safety and security. Significantly, Morocco has built an international reputation for contributions to nuclear emergency preparedness and response (EPR).[21] In 2013, Morocco hosted delegates from Canada, New Zealand, Spain, Sudan, and the US for a two-day emergency exercise assessing response to a 'dirty bomb' explosion a – full-scale ConvEx-3 exercise, the highest level and most complex emergency exercise run by the IAEA. Since 2019, Morocco has also operated the IAEA EPR Capacity Building Centre for Africa.[22]

---

14 With thanks to Khadija Bendam, Head of Nuclear and Radiological Safety and Security audits at CNESTEN, for evaluating this section.

15 Morgan Hekking, 'IAEA Illuminates Morocco as Model in Nuclear Research Monitoring,' Morocco World News, 18 May 2020. https://www.moroccoworldnews.com/2020/05/303022/iaea-illuminates-morocco-as-model-in-nuclear-research-monitoring

16 Khammar Mrabit, 'Building the Nuclear and Radiological Safety and Security Authority in the Kingdom of Morocco: Sharing Experience and Lessons Learned,' *Nuclear Law.* The Hague: T.M.C. Asser Press.

17 World Nuclear Association, 'Emerging Nuclear Energy Countries,' 2023. https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

18 IAEA, 'Country Nuclear Power Profiles: Morocco,' 2018. https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2018/countryprofiles/Morocco/Morocco.htm

19 A sequential framework to establish the essential elements of a new nuclear programme, helping newcomer countries to prepare for the commitments and obligations associated with the development of safe, secure, and sustainable nuclear power. See Sarah Tzinieris, Zenobia Homan and Şebnem Udum, 'Nuclear Security for Newcomer Countries,' *The Oxford Handbook of Nuclear Security,* 2023. Oxford: Oxford University Press.

20 Rachid Sekkouri Alaoui, 'The Moroccan NPP Project and Partnerships Perspectives,' 18th INPRO Dialogue Forum on Partnerships for Nuclear Development and Deployment, 18–21 May 2021. https://nucleus.iaea.org/sites/INPRO/df18/3.4-R.Sekkouri-Morocco.pdf

21 IAEA, 'IAEA Reviews Morocco's Nuclear Emergency Preparedness and Response,' 2022. https://www.iaea.org/newscenter/pressreleases/iaea-reviews-moroccos-nuclear-emergency-preparedness-and-response

22 Rebecca Campbell, 'IAEA says Morocco's nuclear emergency response capability is solid; suggests refinements,' *Engineering News,* 7 November 2022. https://www.engineeringnews.co.za/article/iaea-says-moroccos-nuclear-emergency-response-capability-is-solid-suggests-refinements-2022-11-07

ALGERIA[23]

Algeria started operating the Nur NRR in 1989, at the Draria nuclear complex just east of Algiers. This is a 1MW, light water moderated, pool type reactor constructed by Argentina. It is used for operator training and research in nuclear sciences, technology and techniques. In 1992 Algeria also began operating the Chinese Es-Salem NRR, further south in Ain Oussera. This is a 15MW, heavy water moderated, tank type reactor used for the testing of materials and radioisotopes production. Then in 1999, Algeria introduced a Nuclear Fuel Fabrication Pilot Plant at the Draria complex as well, aimed at the development of rod and plate type nuclear fuel elements.[24] Algeria further holds significant uranium reserves, primarily concentrated in the southern part of the country.[25] These are estimated at around 19,500 tonnes, all in the high-cost category.

The French nuclear programme also left behind significant infrastructure. Its bases in the Sahara comprised of 82,000m^2 of buildings, 7,000m^2 of underground laboratories, and 100km of roads.[26] There have been reports of members of the public stripping abandoned items for resources, using plates, beams and electrical cables in the construction of their homes – unaware of the dangers of these materials (see page 25).[27]

Opportunity and feasibility studies for the construction of an NPP were conducted between 1975 and 1984 – in collaboration with the IAEA as well as companies from Germany, France, and Canada. Incidents such as Chernobyl combined with economic instability have halted progress however. Algeria signed a cooperation agreement with China in 2015,[28] and most recently Russia's NPP operator Rosatom has expressed an interest in supporting Algeria's nuclear power ambitions.[29] Algeria announced plans to realise a reactor in 2020, then 2025; but thus far no practical steps have been taken.

In 1996 Algeria created a Commission of Atomic Energy, which merged into the Ministry of Energy and Mines in 2006. In 2019, Algeria adopted a law (number 19–05) which led to the creation of the National Authority for Nuclear Safety and Security.[30] This is an independent administrative body which has legal authority and financial autonomy. Furthermore, Algeria has ratified the Convention on the Physical Protection of Nuclear Materials (CPPNM) and its amendment, as well as the International Convention for the Suppression of Acts of Nuclear Terrorism. Algeria also adheres to the IAEA Code of Conduct on the Safety and Security of radioactive sources.

23 While we have been in contact with Algerian experts, none were available to make a full case study contribution at this time and we worked with scholars from other North African countries.

24 Brahim Meftah, 'Outlook of Nuclear Energy in Algeria,' *Proceedings of an International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century,* Vienna, Austria, 27–30 October 2009. https://www-pub.iaea.org/MTCD/publications/PDF/P1500_CD_Web/htm/pdf/topic1/1S02_B.%20Meftah.pdf

25 Nuclear Energy Agency and the IAEA, 'Uranium Resources, Production and Demand,' 2023. https://www.oecd-nea.org/upload/docs/application/pdf/2023-04/7634_uranium_-_resources_production_and_demand_2022.pdf

26 Samia Henni, 'Naming French Radioactive Matter in the Sahara,' E-Flux Architecture, 2022. https://www.e-flux.com/architecture/half-life/508392/jerboasite-naming-french-radioactive-matter-in-the-sahara/

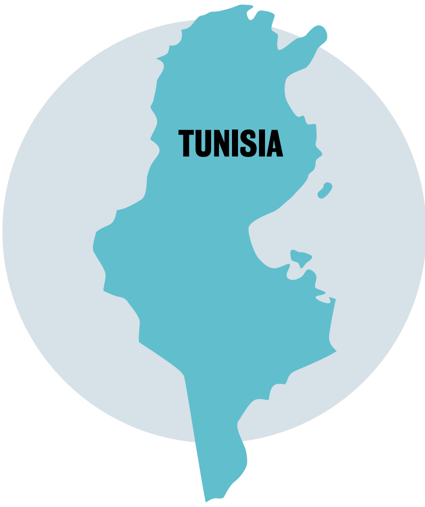
27 Johnny Magdaleno, 'Algerians suffering from French atomic legacy, 55 years after nuke tests,' Aljazeera, 1 March 2015. http://america.aljazeera.com/articles/2015/3/1/algerians-suffering-from-french-atomic-legacy-55-years-after-nuclear-tests.html

28 World Nuclear Association, 'Emerging Nuclear Energy Countries,' 2023. https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

29 Rosatom, 'ROSATOM and Algerian Atomic Energy Commission discussed nuclear energy solutions in a jointly organized workshop in Algeria,' 15 March 2023. https://www.rosatom.ru/en/press-centre/news/rosatom-and-algerian-atomic-energy-commission-discussed-nuclear-energy-solutions-in-a-jointly-organi/

30 Brahim Meftah, 'Outlook of Nuclear Energy in Algeria,' *Proceedings of an International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century,* Vienna, Austria, 27–30 October 2009. https://www-pub.iaea.org/MTCD/publications/PDF/P1500_CD_Web/htm/pdf/topic1/1S02_B.%20Meftah.pdf

TUNISIA[31]



While Tunisia has investigated options for both nuclear power and nuclear research, it does not currently operate any nuclear reactors.[32] In 2006, conducted a technical feasibility study for a potential NPP, and announced intentions to establish an institutional and legal framework and develop human resources. However, due to political and civic unrest (primarily because of the 2011 revolution), Tunisia has had nearly a dozen different prime ministers since – and it has not been able to proceed down the IAEA milestones approach.[33]

With that said, radioactive sources are used in medical, industrial, agricultural and educational activities. Like other countries in North Africa, Tunisia has been witnessing a surge in nuclear medical applications nationwide: while in 1990 there was only one nuclear medicine centre, by 2013 there were twelve.[34] These work with positron emission tomography (PET) computerised tomography (CT), cobalt therapy, linear accelerator units, high dose Curie therapy, interventional radiology, mammography, and gamma cameras.[35]

Relevant national authorities are the Ministry of Industry, Energy and Small and Medium Enterprises, the Ministry of Higher Education, Scientific Research and Technology, the Ministry of the Interior and Local Development, the Ministry of Transport and the National Atomic Energy Commission. They are responsible for policies relating to nuclear security, physical protection, and preparedness in case of radiological emergencies. Tunisia has established a National Centre for Nuclear Science and Technology (CNSTN), which carries out research on the peaceful uses of nuclear materials and techniques. CNSTN operates two irradiation facilities: a pilot-scale cobalt-60 gamma irradiator with a capacity of 100KCi and a semi-industrial 10MeV-5KW electron beam accelerator. Tunisia also has a National Centre for Radiation Protection, which acts as regulatory authority at the national level regarding radioactive sources.

The National Centre for Radiation Protection (CNRP) is member of the Arab Network of Nuclear Regulators (ANNuR), which is working on 'strengthening and harmonizing the regulatory infrastructure in Arab countries as well as exchanging regulatory knowledge and experiences with other international and regional networks under the IAEA Global Nuclear Safety and Security Network (GNSSN).'[36] In line with this, Tunisia also hosts the offices of the Arab Atomic Energy Agency (AAEA). Furthermore, Tunisia has accepted, signed and ratified a number of international agreements, including the CPPNM.[37]

31 Please note that while we communicated with Tunisian experts to compose this handbook, they wished for their contributions to remain anonymous.
32 'IAEA, 'Country Nuclear Power Profiles: Tunisia,' 2017.' https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2017/countryprofiles/Tunisia/Tunisia.htm
33 Khalil Miri, 'Nuclear Energy in Tunisia,' Stanford University, 2022. http://large.stanford.edu/courses/2022/ph241/miri1/
34 M. Jemai Ghezaiel et al., 'Radiation safety for patients in nuclear medicine: Current situation in Tunisia,' *Medecine Nucleaire Imagerie Fonctionnelle et Metabolique,* Vol. 37, No. 12, 2013.
35 Republic of Tunisia, 'Convention on Nuclear Safety,' 2019. http://large.stanford.edu/courses/2022/ph241/miri1/docs/nrt-aug19.pdf
36 IAEA, 'Arab Network of Nuclear Regulators,' 2022. https://gnssn.iaea.org/main/ANNuR/Pages/default.aspx
37 IAEA Office of Legal Affairs, Republic of Tunisia,' 2022. https://ola.iaea.org/Applications/FactSheets/Country/Detail?code=TN

LIBYA

During the 1970s and 1980s Libya explored plans for an NPP with the Soviet Union as well as Belgium. However, international economic sanctions halted discussions. In the early 2000s, negotiations with France took place, and Libya did review the steps of the IAEA milestones approach.[38] However, the Civil War, ongoing political violence, and recent natural disasters have made it nearly impossible to move forward with any plans.[39]

In 1989 Libya began operating a controversial Russian 10MW pool-type NRR in Tajoura, just east of Tripoli. The reactor was intended for research in nuclear physics, activation analysis, and production of radioisotopes. However, in 2003, Libya disclosed that the Tajoura Nuclear Research Centre had served as the headquarters for its covert nuclear weapons programme. To support these activities, Libya had relied heavily on importing materials and technologies, processed uranium from Niger and equipment from the AQ Khan network.[40] Upon discovery and dismantlement of the programme, the reactor's fuel was changed from high enriched uranium (HEU) to low enriched uranium (LEU) in 2006 – but in 2013 Tajoura NRR was placed under an extended shut-down.[41]

Fragmented governance combined with limited financial resources have also affected the health sector in Libya, which is sometimes supported through foreign aid.[42] There are six radiation oncology units in Libya, with nuclear medicine departments in Tripoli, Benghazi, Misrata, and Sabratha. Only Tripoli offers PET CT.[43] In 2016, the IAEA reported it had 'helped repair Libya's only operational radiotherapy machine.'[44]

Libya's nuclear history involved the creation of an Atomic Energy Establishment and the Libyan Secretariat of Atomic Energy.[45] Its national legislative framework includes 'Act 2: Regulating the use of ionising radiation and the protection from its hazards' and 'Act 4: Transportation of dangerous materials on the national roads.' These outline requirements for radioactive sources, but do not cover nuclear security, radioactive waste management or decommissioning.[46] Libya has a tumultuous history with signing and breaking international agreements, but since 2006 Libya has ratified the CPPNM and CPPNM/A.[47]

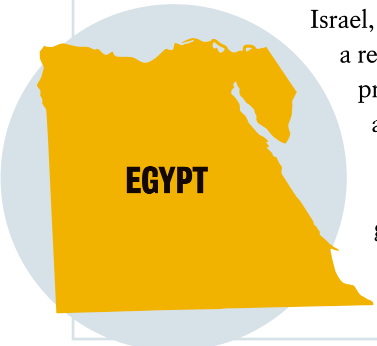
Like Algeria, Libya struggles with the physical remains of its nuclear past. Although the IAEA inspects Libya's remaining nuclear-related stockpiles, it is likely that there are unsafeguarded materials in the country.[48] A 2023 incident (see page 33) highlighted the challenges of resource constraints for IAEA monitoring in unstable regimes and a lack of prioritisation for uranium stockpile oversight. Additionally, it underscored ongoing difficulties in implementing nuclear safety and security provisions in many African nations.[49]

38 Fatma Ghangir, 'Nuclear Energy in Libya,' Joint ANNuR-FNRBA Workshop on Milestones and Infrastructure for New Research Reactor Projects, 10–14 May 2015, Cairo, Egypt.
39 NTI, 'Libya Nuclear Overview,' 2015. https://www.nti.org/analysis/articles/libya-nuclear/
40 Michael Laufer, 'A. Q. Khan Nuclear Chronology,' Carnegie Endowment for International Peace, 7 September 2005. https://carnegieendowment.org/2005/09/07/a.-q.-khan-nuclear-chronology-pub-17420
41 Usamah Amara Ben Nail and Fathi Mohamed Haj, 'IRT-1 Research Reactor Decommissioning: Preliminary Plan,' *Arab Journal of Nuclear Sciences and Applications,* Vol. 56, No. 2, 2023.
42 WHO, 'Review of Health Sector in Libya,' 2017. https://www.refworld.org/pdfid/5b644bd84.pdf
43 Adel Attia, Ismail Siala & Fathi Azribi, 'General Oncology Care in Libya,' Cancer in the Arab World, 2022.
44 IAEA, 'IAEA Helps Repair Libya's Only Radiotherapy Machine for Cancer Care,' 3 May 2016. https://www.iaea.org/newscenter/pressreleases/iaea-helps-repair-libyas-only-radiotherapy-machine-for-cancer-care
45 NTI, 'Libya Nuclear Overview,' 2015. https://www.nti.org/analysis/articles/libya-nuclear/
46 Amal Hasan Elgahwaji, 'Safety and Licensing of Research Reactor In Libya,' Annual Meeting of ANNuR Regulators on Safety and Licensing of Research Reactors, n.d.
47 IAEA Office of Legal Affairs, 'State of Libya,' 2022. https://ola.iaea.org/Applications/FactSheets/Country/Detail?code=LY
48 NTI, 'Libya Nuclear Overview,' 2015. https://www.nti.org/analysis/articles/libya-nuclear/
49 Olamide Samuel, 'Libya lost, then found, 2.5 tonnes of uranium – a red flag for nuclear safety,' *The Conversation,* 1 May 2023. https://theconversation.com/libya-lost-then-found-2-5-tonnes-of-uranium-a-red-flag-for-nuclear-safety-203775

EGYPT

Egypt established its Atomic Energy Commission, now the Egyptian Atomic Energy Authority (EAEA) in the 1950s. It started operating a 2MWt light water NRR (ETRR-1) supplied by the Soviet Union at Inshas, northeast of Cairo, in 1961. The IAEA updated ETRR-1 in the 1980s, and today it is still operational. In 1997, Egypt also started operating a 22MWt light water NRR (ETRR-2) purchased from Argentina.[50] It produces radioisotopes, and it is used for research in neutron physics, materials science, nuclear fuel, and boron neutron capture therapies. Besides the NRR, EAEA facilities also include a fuel manufacturing plant, a radioisotope production facility, two cobalt radiation facilities, two accelerators, and a liquid waste treatment facility.[51]

Radiological materials commonly used in Egypt include technetium-99m, iodine-131, and cobalt-60, among others. These materials are used in procedures such as nuclear imaging, radiation therapy, and other diagnostic and treatment modalities. Facilities in Egypt make use of gamma cameras, PET scanners, and linear accelerators for radiation therapy. The agricultural sector uses radiological techniques for soil and crop analysis, and in industry radiological sources are utilised for non-destructive testing (NDT) and radiography in construction, manufacturing, and engineering. Since 1962, Egypt has also engaged in uranium exploration, uncovering mineralised deposits in the Eastern Desert and Sinai Peninsula. However, full-scale mining plans faced obstacles due to insufficient funds.[52]



It has been suggested that the threat from Israel, combined with ambitions for a regional leadership position and prestige, lead to nuclear weapon ambitions in Egypt during the 1950s to 1970s.[53] Operation of the ETRR-1 would have given Egyptian scientists and nuclear engineers dual-use experience.[54] This was accompanied by political rhetoric about the acquisition of nuclear weapons, and pursuit of a natural uranium fuelled, heavy water-moderated reactor (which could be used to produce weapons useable plutonium). However, no real commitment ever emerged, and this strategy was later abandoned.

Egypt's first NPP is now under construction at El Dabaa in the Matrouh governorate on the Mediterranean coast. The site was selected as early as 1983, with plans to work with Germany (reactor), Australia, and Niger (uranium supply).[55] However, progress halted after the Chernobyl incident and was stalled further by the 2011 revolution. Eventually, Egypt connected with the Russian State Atomic Energy Corporation (Rosatom) to develop an NPP, which will have a total capacity of 4.8GW from four pressurised water reactors (PWRs). This will be owned and operated by Egypt's Nuclear Power Plant Authority, and it is anticipated to provide up to 50 per cent of Egypt's power generation capacity – although uncertainties remain due to necessary funding constraints. Egypt's poverty rate is close to 30 per cent and in 2023, Egypt's Gross Domestic Product (GDP) per capita was only $4,655 (ranking 115 out of 196 countries).[56]

Due to work with the research reactors and planned NPP however, Egypt's civil nuclear programme has a well-developed infrastructure.[57] Egypt established a Nuclear Regulatory and Safety Committee in 1982, and in 2010 the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA) became the country's independent nuclear regulatory body. Egypt has laws that protect of the environment from hazardous materials and hazardous waste including substances that emit ionising radiation (law number 4 of 1994), and a law that regulates nuclear and radiological activities (law number 7 of 2010). This last law allows ENRRA to issue regulations on safety, security and non-proliferation.[58] Egypt is also the leading proponent of establishing a Weapons of Mass Destruction Free Zone in the Middle East (WMDFZ).

50 NTI, 'Egypt Nuclear Overview,' 2014. https://www.nti.org/analysis/articles/egypt-nuclear/
51 IAEA, 'Country Nuclear Power Profiles: Egypt,' 2021. https://www-pub.iaea.org/MTCD/Publications/PDF/CNPP-2021/countryprofiles/Egypt/Egypt.htm
52 NTI, 'Egypt Nuclear Overview,' 2014. https://www.nti.org/analysis/articles/egypt-nuclear/
53 Gawdat Bahgat, 'Nuclear Proliferation: Egypt,' *Middle Eastern Studies,* Vol. 43, No. 3, 2007.
54 NTI, 'Egypt Nuclear Overview,' 2014. https://www.nti.org/analysis/articles/egypt-nuclear/
55 WNA, 'Nuclear Power in Egypt', 2023. https://world-nuclear.org/information-library/country-profiles/countries-a-f/egypt.aspx
56 Country Economy, 'Country comparison Germany vs Egypt,' 2023. https://countryeconomy.com/countries/compare/germany/egypt
57 NTI, 'Egypt Nuclear Overview,' 2014. https://www.nti.org/analysis/articles/egypt-nuclear/
58 IAEA, 'Country Nuclear Power Profiles: Egypt,' 2021. https://www-pub.iaea.org/MTCD/Publications/PDF/CNPP-2021/countryprofiles/Egypt/Egypt.htm

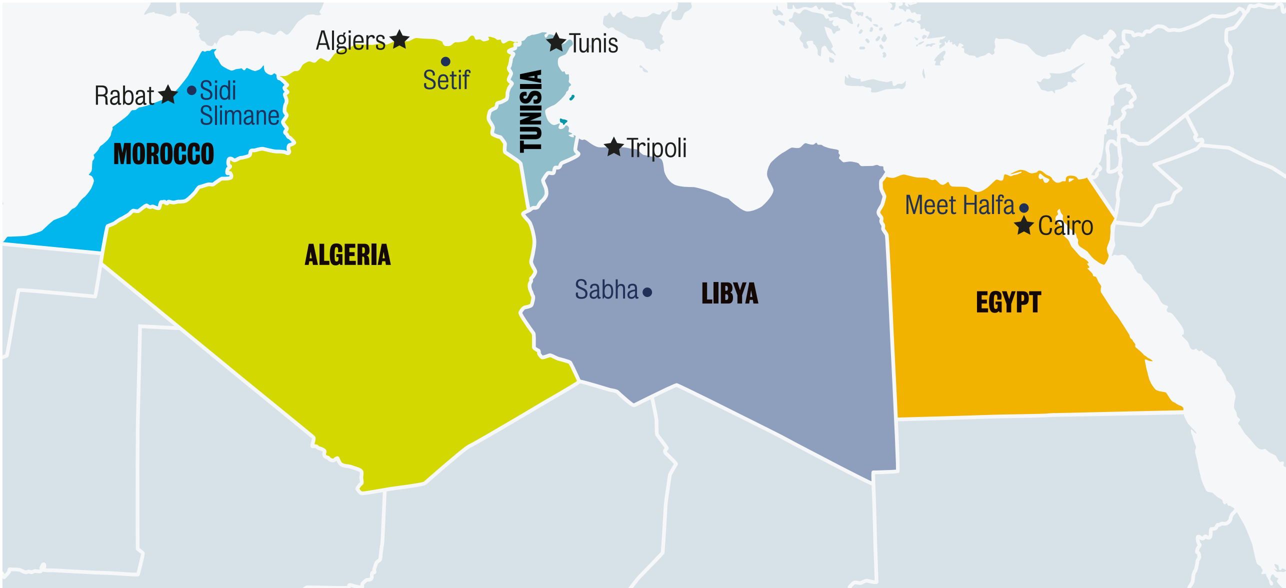
Common challenges

North African countries share several challenges and opportunities in the context of nuclear development and security. First and foremost, every country has expressed an interest in or initiated the development of NPPs. Other nuclear technologies and radiological materials have also been integrated into various sectors such as medicine, industry, agriculture, and research. To this end, all nations mentioned have established (or are in the process of establishing) regulatory bodies and legal frameworks to govern nuclear and radiological activities – underlining the importance of adhering to international conventions and standards for nuclear security. In line with this, various foreign partnerships and agreements highlight commitment to leveraging international expertise and resources to advance nuclear capabilities and infrastructures.

With that said, developments in North Africa are in strong contrast with other regions. In Europe, for example, France, the United Kingdom, and Germany, all have well-established nuclear power programmes that contribute significantly to their energy mix. These countries typically have robust and well-established nuclear regulatory bodies that closely monitor and enforce stringent safety standards and protocols. Their systems feature transparent legal frameworks and comprehensive oversight mechanisms. Overall political stability, democratic norms, and wealth in Europe cannot be compared to North Africa. Therefore, while case studies from Europe will always carry valuable lessons for North Africa, their context is not directly applicable.

The history of nuclear programmes in North Africa has been marked by remnants of past nuclear activities, fragmented governance, and limited financial resources. This has led to challenges in effectively managing nuclear facilities, ensuring the safety of radioactive materials, and addressing concerns related to nuclear waste management and decommissioning. It has also led to a much criticised 'double standard' – where mature nuclear states are suspicious that nuclear newcomers might use their civilian nuclear programmes for military ends.[59]

North Africa aims to achieve sustainable development, energy security, and advancements in various fields. By addressing pressing challenges associated with nuclear and radiological security, it will be possible to look to the future and leverage the opportunities presented by nuclear technology. Moreover, this handbook of case studies can serve as a reference for nuclear security educators in North Africa to use during the preparation and implementation of nuclear security training courses and events. Case studies explain how incidents emerged in the past and how they can be prevented going forward, supporting awareness raising and capacity building in the region.



59 Carole Nakhle, 'Nuclear Energy's Future in the Middle East and North Africa,' Carnegie Middle East Center, 28 January 2016. https://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa-pub-62562

II: Case studies

The complex diplomacy of nuclear crisis management: the Sidi Slimane incident, Morocco

By Amine Ghoulidi

Overview

The Sidi Slimane incident of 1958 highlights a number of complex issues in nuclear security and safety for North Africa. During a simulated take-off from a US air base, a B-47 bomber suffered a fuel tank rupture, igniting a fire that posed a grave threat due to the presence of a Mark 36 hydrogen bomb on board. While the immediate crisis was contained, the fire compromised the bomb's plutonium core, resulting in localised contamination. This incident was kept a secret and it remains a compelling case, pivotal for exploring and evaluating nuclear security measures. The balance between meticulous crisis management and the ethical quandaries arising from secretive operations presents rich ground for exploration, offering lessons for those developing future guidelines for enhanced nuclear security, transparent international cooperation, and diplomatically nuanced communication amidst crises – especially in the high-stakes arenas of global military operations.

Case summary

During the Cold War, the US placed nuclear weapons in various locations worldwide for national security reasons. The Sidi Slimane base in Morocco was one such location, with its nuclear presence kept secret from the French, who had a protectorate over Morocco until 1956.[60] A 1958 incident at this base, detailed below, highlights the challenge of crisis management, the importance of safety protocols, and the implications of secrecy in nuclear diplomacy.[61, 62]

On 31 January 1958, a B-47 bomber, carrying a Mark 36 hydrogen bomb, encountered a wheel failure during a simulated take-off. This led to the tail striking the runway, causing a fuel tank to rupture and a fire that lasted seven hours.[63] This fire damaged the warhead's plutonium core, posing risks to the base and nearby areas.

The Mark 36 bomb on the B-47 was an evolution of the Mark 21. The Mark 21 was based on the 'Shrimp' design, America's first 'dry' thermonuclear bomb tested in the 1954 Castle Bravo experiment.[64] After this test, the Mark 21 was quickly developed in 1955 and later improved to become the Mark 36 by April 1956. By 1957, all Mark 21s were upgraded to Mark 36s, resulting in almost 1000 Mark 36 bombs, either newly produced or converted from the original 275 Mark 21s. This four-ton bomb was among the most potent in the US arsenal at the time.

At the Sidi Slimane incident, firefighters and base staff responded to the fire but could only fight the fire for ten minutes due to the weapon's explosive nature before retreating. The aircraft itself continued to burn for seven hours total. Despite the threat of a nuclear disaster, their actions appear to have prevented a massive catastrophe.

60 US Air Force, 'History of the Strategic Air Command,' *Air Force Historical Research Center,* 1 January 1958 – 30 June 1958. https://www.nukestrat.com/us/afn/SACdep58.PDF
61 US Dept. Of State, 'Sidi Slimane Air Incident Involving Plane Loaded with Nuclear Weapon,' *The National Archives,* 31 January 1958. https://nsarchive.files.wordpress.com/2013/04/document-a.pdf
62 W. Burr, 'Atomic Energy Act prevents declassification of site of 1958 'Broken arrow' nuclear weapons accident (unredacted),' 12 April 2013. https://unredacted.com/2013/04/12/atomic-energy-act-prevents-declassification-of-site-of-1958-broken-arrow-nuclear-weapons-accident
63 Ibid.
64 Hidden History, 'H-Bomb: The Design of Thermonuclear Weapons,' 15 January 2015. https://lflank.wordpress.com/2015/01/15/h-bomb-the-design-of-thermonuclear-weapons

While the weapon did not explode, the plutonium pit melted, spreading contamination around the local area and onto the emergency crew's protective gear. In the incident's aftermath, thorough washing of the runway and asphalt surfaces was undertaken to mitigate contamination, with subsequent checks allegedly detecting no residual radiation. Nonetheless, notable contamination was discovered on a fire truck and a firefighter's attire until they were sufficiently decontaminated.

The secrecy surrounding the incident played a significant role in how its after-effects were managed. A US Air Force press release was intended to confirm that no explosion or unintentional radiation release had transpired. However, it was suppressed owing to apprehensions from the State Department about potential misinterpretation by Soviet propaganda and the stirring of anxiety in Europe.[65] While the King of Morocco was briefed on the incident, American diplomats and possibly other relevant parties were shielded from the complete reality, and simulated practice evacuations were misleadingly presented as the incident's principal objective.

Lessons learned

What went right

Swift emergency response: the immediate action of firefighters and personnel at Sidi Slimane adhered to existing safety protocols. The initial containment efforts might have averted a far-reaching catastrophe by preventing the aircraft from exploding, reflecting well-established and practiced emergency procedures.

Effective decontamination: despite complications in the aftermath, rapid decontamination efforts, like runway washing and equipment cleaning, showed strong preparedness for nuclear accidents. After the incident became public, messages, allegedly from children of Sidi Slimane base staff, described being required to give urine samples in the following days and weeks.[66] This indicates a methodical health monitoring process was followed at the base weeks after the initial incident.

What went wrong

Management of on-site crisis: the fire's duration, burning for seven hours, increased the risk of wider contamination spread. The protocol to disengage after ten minutes was clearly outlined, yet the reality of letting a nuclear device burn uncontrollably conflicts with minimising contamination risks.[67]

Secrecy and Communication Management: whilst understandable given the tensions of the time, the diplomatic handling, particularly the controlled narrative and lack of transparency with allied nations and even within various US departments, resulted in a complex web of misinformation. The secretive approach obstructed potential collaborative efforts and international support and could have potentially harmed diplomatic relationships if uncovered.

Proposed solutions and forward strategies

Reassess and adapt nuclear security protocols: enhanced crisis management – although the compliance with protocols is laudable, the incident underscores deficiencies in the prevailing emergency guidelines. Some of these shortcomings were subsequently scrutinised in a memo dated 19 February 1958 penned by a senior State Department official, indicating that the government dedicated resources to an evaluation of the response to the incident with the aim of formulating mitigative strategies for the future.[68]

Risk prevention: comprehensive maintenance and thorough pre-operation checks of all machinery involved in handling nuclear weaponry may not have been mandatory at the time of the incident but would now be an ordinary requirement, ensuring that mechanical failures like the wheel casting malfunction are pre-emptively identified and rectified.

Transparent and collaborative international relations

Strategic transparency: complete transparency in military operations may be impractical, particularly in strategically sensitive contexts like the Cold War. However, establishing a baseline level of openness during crises – especially those where risks cross borders and pose a threat of mass casualties – is crucial for preserving trust among allies.[69]

65 Ibid.
66 T. Bazza, 'Throwback to 1958: US Nuclear Bomb Nearly Exploded in Morocco,' Morocco World News, 31 July 2018. https://www.moroccoworldnews.com/2018/07/251499/1958-us-nuclear-bomb-exploded-morocco
67 Center for Defense Information, ' U.S. Nuclear Weapons Accidents: Danger in our Midst,' The Defense Monitor, Vol. X, No. 5, 1981.
68 US Dept. Of State. (1958). Correspondence between George West, Jr. and B.E.L. Timmons (The National Archives). Washington, DC: https://nsarchive.files.wordpress.com/2013/04/document-b.pdf
69 Baylis, John, and Anthony Eames, 'Conclusion', *Sharing Nuclear Secrets: Trust, Mistrust, and Ambiguity in Anglo-American Nuclear Relations Since 1939* (Oxford, 2023). https://doi.org/10.1093/oso/9780198875116.003.0014

International collaboration: developing a framework for international cooperation in managing nuclear crises may have been inconceivable in the 1950s but is now common practice.[70] Examples include the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. Such frameworks may entail creating a shared platform where nations can collaboratively develop strategies to manage and mitigate the global implications of nuclear incidents.

Communication management

Internal consistency: developing consistent and transparent messaging across all governmental branches is necessary to ensure a unified, coherent narrative, particularly during crises involving international relations and national security. A nuanced approach, which delicately balances safeguarding sensitive information and maintaining an aura of trust and reliability, is crucial. This involves establishing rigorous interdepartmental communication protocols, ensuring that accurate, timely, and consistent information is disseminated to facilitate cohesive decision-making even amidst crises.

Controlled public communication

While controlling panic and misinformation, especially during the Cold War, was vital, managing public communication transparently to some extent is crucial to maintaining trust. Constructing a communication strategy that allows for a balance between necessary secrecy and public reassurance would ensure a controlled yet honest narrative.[71]

The Sidi Slimane incident provides a valuable insight into the challenges of managing a nuclear crisis and also demonstrates the ethical and diplomatic dilemmas that pervade secrecy in international military operations. Balancing national security, international relations, and ethical considerations presents convoluted challenges that warrant nuanced approaches and adaptable strategies for future preparedness and global cooperation in crisis management.

Conclusions

The Sidi Slimane incident of 1958 represents a multi-layered narrative of challenges in nuclear security management, international relations, and ethical conundrums against the high-stakes backdrop of the Cold War. While the immediate response and decontamination efforts demonstrated a robust adherence to protocols and averted a larger-scale disaster, evident gaps in onsite crisis management and shrouded communication strategies reveal more complex, multifaceted dilemmas. Challenges related to secrecy, diplomatic navigation, and ethical considerations embedded in international military operations underscore how difficult it is for states to strike a balance between national security, nuclear safety, and preserving diplomatic relationships. Through the lens of hindsight, this incident serves as a valuable case study in understanding the imperatives of evolving and adapting strategies and protocols to navigate the intricate, convoluted processes of crisis management, transparency, and international cooperation in the context of strained geopolitical climates.

Suggested discussion points

1. In times of crisis, should some degree of military secrecy be sacrificed in order to ensure effective EPR? To what extent can this be justified?
2. In a nuclear emergency, how can you balance safety and security?
3. What are the potential ramifications of inadvertent misinformation for nuclear security?

70 Knopf, J. 'International Cooperation on Nonproliferation: The Growth and Diversity of Cooperative Efforts.' In *International Cooperation on WMD Nonproliferation*, edited by Jeffrey W. Knopf, 1–22. University of Georgia Press, 2016. http://www.jstor.org/stable/j.ctt189ts81.5

71 S. M. Becker, 'Risk communication and information in disasters and emergencies,' *Local planning for terror and disaster: From bioterrorism to earthquakes,* edited by L. Cole & N. Connell, 2012. Hoboken, NJ: Wiley-Blackwell.

Lessons from Stuxnet: developing nuclear cybersecurity policies for Tunisia

By Anonymous

Overview

In 2010, Iran's uranium enrichment facilities were targeted by a cyber-attack now known as 'Stuxnet'. This example from a different region has been included here because it highlights valuable lessons for nuclear cybersecurity in general.

Stuxnet was designed to infiltrate industrial control systems, particularly those related to centrifuges, and manipulate them to cause physical damage without being detected. The attack significantly set back Iran's nuclear programme and demonstrated the potential of cyber-attacks to disrupt critical infrastructure. Stuxnet marked a turning point in the awareness of the vulnerabilities of industrial control systems to cyber-attacks and highlighted the growing significance of cybersecurity in protecting critical facilities.[72]

Yet, a decade later, few countries have clear nuclear cybersecurity policies – even those with full, mature, nuclear cycles.[73] Considering the cybersecurity of existing facilities that contain radiological materials and potential future nuclear sites is critical for emerging nuclear energy countries such as Tunisia and indeed any of its neighbours in North Africa.[74]

Background

Critical infrastructure as a target for cyber-attacks

In recent times, many critical national facilities have been facing escalating cybersecurity threats. Notably, Ukraine has been a prominent target, experiencing a sophisticated cyber-attack in 2022 that disrupted its power grid. Ukraine's intelligence agency confirmed in a statement that Russian hackers had struck an unnamed facility near its frontline with Russia.[75] Successful hacks against industrial control systems are relatively unique, and few countries have the capability to carry out such cyber-attacks. Yet, in 2023, Denmark was targeted as well. Its critical infrastructure experienced the largest cyber-attack in the country's history, with 22 energy companies breached in just a few days.[76] Furthermore, it was recently revealed that groups linked to Russia and China had been able to hack the UK's Sellafield nuclear site – with breaches potentially dating back to 2015.[77] These incidents underscore the vulnerabilities of critical infrastructure to sophisticated cyber threats.

What is nuclear cybersecurity?

Nuclear cybersecurity specifically refers to the protection of nuclear facilities, materials, and related infrastructure from cyber threats. Cybersecurity policies are used

72 Kevin E. Hemsley & Dr. Ronald E. Fisher, 'History of Industrial Control System Cyber Incidents,' Idaho National Laboratory, 2018. https://www.osti.gov/servlets/purl/1505628

73 Zenobia Homan & Amelie Stoetzel (eds), 'Exploring nuclear and radiological security in South Asia: A case study handbook,' *CSSS Occasional Papers Series,* King's College London, 2022. https://www.kcl.ac.uk/csss/assets/exploring-nuclear-radiological-security-south-asia.pdf

74 WNA, 'Emerging Nuclear Energy Countries,' 2023. https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

75 Pearson, James. 'Russian Spies Behind Cyber Attack on Ukraine Power Grid in 2022 – Researchers,' Reuters, 9 November 2023.

76 Antoniuk, Daryna. 'Nearly Two Dozen Danish Energy Companies Hacked Through Firewall Bug in May,' The Record, 15 November 2023.

77 Anna Isaac and Alex Lawson, 'Sellafield nuclear site hacked by groups linked to Russia and China,' The Guardian, 4 December 2023. https://www.theguardian.com/business/2023/dec/04/sellafield-nuclear-site-hacked-groups-russia-china

specifically to prevent unauthorised access, attacks, and damage. They are a subset of information security, which involves the protection of data throughout its lifecycle (including storage, transmission, and disposal) regardless of its form or medium (eg digital or physical).

Given the critical nature of nuclear facilities and the potential consequences of a cyber-attack, nuclear cybersecurity is a crucial aspect of ensuring the safety and security of nuclear operations. It involves the implementation of various strategies, protocols, and technologies to prevent or mitigate data breaches and potential sabotage by malicious actors. Nuclear cybersecurity is a multidimensional approach that integrates technological solutions, personnel training, and comprehensive security protocols. Key elements often include:

- Regular assessment and management of vulnerabilities in the system, including software patches and updates, to prevent exploitation by cyber threats.
- Development of comprehensive incident response plans to address and mitigate potential cyber-attacks promptly and effectively.
- Encryption of sensitive data, regular data backups, and secure data storage to prevent data manipulation.
- Access control, such as authentication protocols and user access restrictions – to prevent unauthorised persons from accessing critical systems and information.
- Implementation of robust firewalls, intrusion detection systems, and other measures to protect networks against unauthorised access and cyber-attacks.
- Adherence to international and national standards and guidelines related to nuclear cybersecurity to ensure best practices and compliance with established security protocols.

For example, the US Nuclear Energy Institute has published a cybersecurity plan that covers monitoring and assessment, modification of digital assets, attack mitigation and incident response, contingency plans, security training and awareness, evaluating and managing cyber risks, policies and implementing procedures, roles and responsibilities, as well as document control and records retention. It also considers how a cybersecurity programme may be incorporated into physical protection programmes.[78]

Cybersecurity in Tunisia

Tunisia currently holds the 68th position (out of 176) on the National Cyber Security Index, a global assessment of countries' preparedness against cyber threats.[79, 80, 81] Recent developments in Tunisia's cybersecurity can be credited to the enactment of a new cybersecurity decree-law.[82] However, despite this positive advancement, there exists a need for primary legislation in the realm of cybersecurity.

Effective from 11 September 2023, the new legislation marks a pivotal moment in Tunisia's cybersecurity framework by expanding the role of the national computer security agency and renaming it the national agency for cybersecurity (L'Agence Nationale de la Cybersécurité, ANSC). Under the supervision of the Ministry of Communication Technology, the ANSC is dedicated to formulating security governance policies, promoting cybersecurity training, and publishing reference documents for Tunisian cyberspace. Security governance policies play a fundamental role in shielding against cyber threats, particularly in safeguarding critical infrastructure such as facilities holding nuclear or radiological materials.

The ANSC's recent involvement in steering a new electronic device and service labelling policy can be seen as a strategic move towards protecting critical infrastructure from cyber threats. The introduction of a 'secure' certification, along with the requirement for essential organisations to exclusively use hardware with this label, represents a substantial step toward enhancing cybersecurity and safeguarding critical infrastructure. Notably, critical organisations are provided continuity of service even during national crises, addressing the protection needs of critical infrastructure, including nuclear facilities.

Moreover, the ANSC is mandated to develop and implement a future 'national cyber emergency

78 US Nuclear Energy Institute, 'Cyber Security Plan for Nuclear Power Reactors,' NEI 08-09, Rev. 6, 2010. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML101180437
79 For comparison in North Africa: Morocco ranks 32, Algeria 100, Libya 154 and Egypt 61.
80 National Cyber Security Index, 'NCSI Tunisia Country Profile,' 2023. https://ncsi.ega.ee/country/tn
81 National Cyber Security Index. 'Methodology,' 2023. https://ncsi.ega.ee/methodology
82 InCyber News, 'Tunisia Expands Scope of National Cybersecurity Agency,' 8 October 2023. https://incyber.org/en/tunisia-expands-scope-national-cybersecurity-agency/

response plan' in collaboration with public and private sector Computer Security Incident Response Teams (CSIRTs).[83] This plan is crucial for responding to cyber threats and incidents, within critical infrastructure sectors such as nuclear facilities.

However, while the 2023 cybersecurity decree-law in Tunisia is a positive advancement, there does exist a fundamental need for primary legislation to establish coherence and consistency across the various regulations governing the digital landscape in the country. The absence of primary legislation on cybersecurity risks resulting in inconsistencies across different regulations related to cybersecurity. Despite the positive aspects of the new cyber regulation, a comprehensive and foundational legal framework is urgently required to prevent a fragmented and inconsistent regulatory landscape in cybersecurity.

Strengths of the new legislation

The Tunisian cybersecurity legislation has several strengths in protecting critical infrastructure against cyber threats. The creation of the ANSC (article 4) is a significant development, and the ANSC's comprehensive role enhances centralised coordination and response to cyber threats. The legislation also mandates periodic security audits (article 6) for public and private entities, including operators of critical digital infrastructure which ensures ongoing assessment and enhancement of cybersecurity measures. The ANSC's responsibility for defining conditions and procedures for certifying the security of information systems (article 11) also adds an additional layer of assurance. The 'secure' label, granted through certification, enhances transparency and informs users about the security status of systems. In addition to this, the legislation includes strict penal provisions (articles 15-20) for various cyber offences, such as unauthorised access, data interception, production or dissemination of harmful programmes, and hindering the operation of information systems. These provisions establish legal consequences for malicious cyber activities. Lastly, the establishment of a whistleblowing system (article 10) is a positive step toward encouraging individuals and entities to report violations of mandatory audit provisions, fostering a culture of cybersecurity awareness.

Gaps in the new legislation

While the legislation has these notable strengths, there are some gaps and areas that could make the Tunisia more vulnerable to attacks on nuclear infrastructure:

- The legislation exempts information systems related to public security or national defence affecting national security from its provisions (article 2). This exclusion is understandable, because it protects sensitive information from access by malicious actors. However, it remains important to consider how these sectors can adhere to cybersecurity standards as well.

- The definition of critical digital infrastructure is broad (article 3). Providing more explicit criteria or examples could enhance clarity for entities that may fall under this category, which would help them understand their obligations better.

- The legislation does not provide sufficient detail on the enforcement process or an escalation path for repeated violations of sanctions for non-compliance with mandatory audits.

- Given the dynamic nature of cybersecurity threats, the legislation misses out provisions for periodic review of existing legislation and updates. This would ensure that the legal framework remains relevant and adaptive to emerging cyber risks and technologies.

- While international cooperation is mentioned (article 5), the legislation could provide more details on mechanisms and frameworks for collaboration with foreign entities. Clear guidelines on information sharing and joint responses to transnational cyber threats would strengthen this aspect.

These gaps are areas that could be exploited by cybersecurity criminals. By addressing them however, Tunisia can further fortify its legal framework, ensuring that it remains robust, adaptable, and effective in safeguarding critical infrastructure against cyber threats.

Nuclear security in Tunisia

As outlined in the introduction to this handbook, Tunisia is categorised as a non-nuclear country with no nuclear installations. While Tunisia has shown periodic interest in nuclear energy, including conducting feasibility studies for an NPP, the decision-making process has been influenced by political transitions and other national priorities. Radioactive sources are, however, widely used in various fields within Tunisia, including medicine, industry, agriculture, education, and research. With that said, very little openly available

83 InCyber News, 'Tunisia Expands Scope of National Cybersecurity Agency,' 8 October 2023. https://incyber.org/en/tunisia-expands-scope-national-cybersecurity-agency/

information exists on Tunisia's security measures to protect radioactive sources, inspection of facilities holding radioactive sources, or licensing requirements for exporting IAEA Category 1 sources.[84]

Tunisia's original legislative and regulatory framework relating to nuclear and radiological materials was drafted in the early eighties, based on international standards and conventions from the seventies. This primarily covered radiation protection and ceased to meet the need for the safe and secure use of nuclear techniques.[85] In 2009 and 2010 recommendations were adopted to review and update the structural and institutional frameworks related to the nuclear energy and technology sector. Consequently, a national team of experts identified several gaps, particularly in the areas of nuclear safety, security, safeguards, and civil liability for nuclear damage. They drafted a comprehensive new nuclear law, which is undergoing approval at the time of writing.[86, 87]

NTI has highlighted that Tunisia is at a very high risk of social unrest, at a high risk of international disputes or tensions affecting policy in the short-term, and at a high risk of both domestic and foreign terrorist attacks.[88] To this end, Tunisia has collaborated with the Global Programme on Countering Terrorist Threats against Vulnerable Targets, conducting technical assistance activities. The aim of these was to raise awareness amongst senior Tunisian officials on key areas and international best practices related to strengthening the security of critical infrastructure, and to create a Roadmap or National Plan of Action.[89] Furthermore, the United Nations Interregional Crime and Justice Research Institute (UNICRI) has recently started online training sessions to reinforce and expand Tunisian officials' knowledge of CBRN terrorism.[90]

Stuxnet: case summary

The use of cyber-attacks by state intelligence agencies on critical infrastructure is becoming more widespread. The integration of digital technologies in nuclear facilities has increased the vulnerability to such threats. The first of such incidents was the Stuxnet cyber-attack, a worm that targeted Iran's nuclear programme.

Stuxnet, first identified in 2010, was a pioneering cyber-weapon tailored to sabotage industrial systems, specifically targeting uranium enrichment systems.[91] The revelation of Stuxnet exposed a clandestine collaboration between the United States and Israel that highlights the intersection of cybersecurity and nuclear security.[92, 93]

Stuxnet's primary objective was to sabotage Iran's nuclear programme by targeting its nuclear centrifuges. The cyber-weapon was designed to infiltrate Natanz's industrial control systems, specifically the Siemens controllers used in Iran's nuclear facilities. It aimed to disrupt the process of uranium enrichment by causing malfunctions in the spinning centrifuges. Stuxnet employed a 'Dual Warhead' strategy, whereby one component accelerated the centrifuges to destructive speeds, causing them to self-destruct, while the other, known as a 'man in the middle,' generated false sensor signals to deceive plant operators. This strategy aimed to create the illusion of normal operations while the centrifuges were tearing themselves apart.

The Stuxnet cyber strike had profound implications for Iran's nuclear capabilities. While the attacks were not fully successful, they did cause significant disruptions.[94] Described as 'the most sophisticated cyber-weapon ever deployed,'[95] Stuxnet set back Iran's nuclear programme

84 NTI Nuclear Security Index, 'Tunisia Report Summary,' 2023. https://www.ntiindex.org/wp-content/uploads/2023/07/Tunisia.pdf
85 Convention on Nuclear Safety, 'National Report for Tunisia,' 2019. http://large.stanford.edu/courses/2022/ph241/miri1/docs/nrt-aug19.pdf
86 Adel Riahi, 'Tunisia's Plan to Develop a New Legal and Regulatory Framework to Bring the Additional Protocol into Force,' presented at the IAEA Symposium on International Safeguards 5–8 November 2018, Vienna International Centre.
87 Ministry of Higher Education and Scientific Research, 'The Minister of Higher Education and Scientific Research supervises the opening of the activities of the thirtieth anniversary of the establishment of the National Center for Nuclear Science and Technology,' 25 November 2023. http://www.mes.tn/detail_evennement.php?code_menu=548&code_evennement=3932
88 NTI Nuclear Security Index, 'Tunisia Report Summary,' 2023. https://www.ntiindex.org/wp-content/uploads/2023/07/Tunisia.pdf
89 UN Counterterrorism Office, 'Strengthening the safety and security of vulnerable targets against terrorist attacks in Tunisia,' 3 June 2022. https://www.un.org/counterterrorism/fr/node/20366
90 UNICRI, 'UNICRI conducts 1st training session to enhance Tunisian officials' knowledge of chemical weapons and chemical security,' 20 June 2023. https://unicri.it/News/Enhancing-Tunisian-officials-knowledge-chemical-weapons-chemical-security
91 William J. Broad, John Markoff, and David E. Sanger, 'Israeli Test on Worm Called Crucial in Iran Nuclear Delay,' The New York Times, 15 January 2011. https://www.nytimes.com/2011/01/16/world/middleeast/16stuxnet.html
92 Mariusz Antoni Kamiński, 'Operation 'Olympic Games': Cyber-sabotage as a Tool of American Intelligence Aimed at Counteracting the Development of Iran's Nuclear Programme,' *Security and Defence Quarterly,* Vol. 29, No. 2, 2020: 63–71.
93 Guilbert Gates, 'How a Secret Cyberwar Program Worked,' The New York Times, 1 June 2012. https://archive.nytimes.com/www.nytimes.com/interactive/2012/06/01/world/middleeast/how-a-secret-cyberwar-program-worked.html?_r=0
94 Alexandra Van Dine, 'After Stuxnet: Acknowledging the Cyber Threat to Nuclear Facilities,' *Project on Nuclear Issues: A Collection of Papers from the 2016 Nuclear Scholars Initiative and PONI Conference Series,* 2017: 101–114.
95 William J. Broad, John Markoff, and David E. Sanger, 'Israeli Test on Worm Called Crucial in Iran Nuclear Delay,' The New York Times, 15 January 2011. https://www.nytimes.com/2011/01/16/world/middleeast/16stuxnet.html

by several years, according to statements by Meir Dagan, the retiring chief of Israel's Mossad intelligence agency, and former US Secretary of State Hillary Rodham Clinton.[96] Although neither country has openly admitted responsibility, the attacks were attributed to a joint effort by the United States and Israel aimed at disrupting Iran's nuclear ambitions.[97]

The covert nature of Stuxnet's development and deployment reflects a shift in the landscape of nuclear security. While some parts of Iran's nuclear operations ground to a halt, others survived, and the true extent of Stuxnet's impact remains a subject of speculation. The Stuxnet case study highlights the evolving dynamics of cybersecurity and its potential impact on critical infrastructure, especially in the context of nuclear facilities. The covert collaboration between two states showcases the blurred lines between traditional warfare and sophisticated cyber tactics in the realm of global security.

Lessons learned

Nuclear cybersecurity lessons from Stuxnet

The Stuxnet case holds significant relevance to nuclear cybersecurity in Tunisia and provides lessons that can be applied to enhance the security of nuclear facilities. The lessons learned from Stuxnet include the difficulty in detecting new and unknown malware, the exploitation of vulnerabilities, and the potential for cyber-attacks to achieve significant impact. These all provide actionable insights for strengthening nuclear cybersecurity in Tunisia. Stuxnet was difficult to detect because it was a completely new malware, an emerging threat with no known signatures. In addition, Stuxnet exploited multiple unknown or unfixed software security flaws ('zero-day vulnerabilities'). This combination of factors created the perfect environment and opportunity for a cyber-attack.

Stuxnet set a precedent for the use of offensive cyber-weapons, potentially leading to an escalation of cyber warfare. This raises concerns about the ethical implications and potential consequences of using such tools. The covert development and deployment of Stuxnet affected Iran's nuclear operations, showcasing the need for heightened awareness and security measures in the international nuclear community, including Tunisia. Most notably, in 2021 Israel claimed that it had carried out another cyber attacks on Iran, damaging the electricity grid and halting the advanced centrifuges at the Natanz site.[98] The precedent makes it crucial for Tunisia to develop and implement defensive measures to protect its critical infrastructure, including nuclear facilities.

From the point of view of its creators, Stuxnet achieved its intended goal of sabotaging Iran's nuclear programme. Furthermore, the incident brought significant attention to the vulnerabilities of industrial control systems, leading to a greater emphasis on developing robust cybersecurity measures and best practices for protecting critical facilities. Consequently, the following lessons can be learned from this case:

- The Stuxnet case draws attention to the vulnerabilities of industrial control systems. Consequently, there has been a greater emphasis on developing robust cybersecurity measures and best practices. Tunisia can leverage these lessons to enhance the security of its own industrial control systems associated with nuclear facilities.

- The intricacy of the Stuxnet malware serves as a stark reminder of the ever-increasing complexity of cyber-weapons. The Stuxnet case underscores the need for continuous research and development efforts to proactively address and stay ahead of evolving cyber threats in the realm of nuclear facilities.

- Stuxnet's success in infiltrating highly protected industrial control systems highlights the vulnerability of such critical infrastructure to cyber-attacks. This underscores the importance of implementing rigorous security protocols, conducting regular assessments, and maintaining continuous monitoring to safeguard against potential threats.

- The incident highlighted the potential international repercussions of a cyber-attack on nuclear facilities, underlining the significance of international cooperation in establishing robust cybersecurity standards and protocols. The case serves as a catalyst for fostering collaboration to mitigate the global impact of cyber threats on nuclear infrastructure.

- Furthermore, recent incidents like the cyber-attack on Ukraine's power grid underscore the broader pattern of targeted cyber-attacks on critical infrastructure, reinforcing the urgency for collective global efforts to enhance cybersecurity across various sectors.

96 Reuters, 'Israel tested worm linked to Iran atom woes: report,' 16 January 2011. https://www.reuters.com/article/idUSTRE70F07N/

97 Mariusz Antoni Kamiński, 'Operation 'Olympic Games': Cyber-sabotage as a Tool of American Intelligence Aimed at Counteracting the Development of Iran's Nuclear Programme,' *Security and Defence Quarterly,* Vol. 29, No. 2, 2020: 63–71.

98 Martin Chulov, 'Israel appears to confirm it carried out cyberattack on Iran nuclear facility,' *The Guardian,* 11 April 2021. https://www.theguardian.com/world/2021/apr/11/israel-appears-confirm-cyberattack-iran-nuclear-facility

Key lessons for Tunisia

Today's rapid integration of digital technologies into various facets of daily life and industry increases vulnerability to cyber threats. Therefore, cyber resilience is crucial for nuclear security. The trend toward 'digitalisation' in nuclear facilities benefits operational efficiency but, at the same time, it expands the attack surface for cyber threat actors. Combining insights from recent developments in cybersecurity as well as nuclear security, the following recommendations can be considered:

- Pursue an integrated nuclear cybersecurity framework: leverage the recent developments in Tunisia's cybersecurity, particularly the 2023 legislation and the establishment of the national agency for cybersecurity (ANSC). Recognise how this can contribute to the formulation security governance policies to safeguard critical infrastructure, including facilities holding nuclear or radiological materials.

- Collaborative emergency response planning: encourage collaboration between the ANSC, public, and private sector to develop and implement a comprehensive national cyber emergency response plan which specifically includes a section addressing the unique challenges for facilities using, storing or transporting radiological materials. Adapt strategies in response to changing geopolitical situations and emerging cyber threats. In order to increase resilience, it is necessary to conduct regular risk assessments, and develop contingency plans to respond to incidents.

- Consider the establishment of a professional network.[99] Such networks play a crucial role in assisting and advancing isolated professionals, fostering resource sharing and knowledge transfer. Whether operating on a national, regional, or sub-regional scale, these networks contribute to exchanging experiences and distributing leadership roles across various domains. An example is the EYGN network, which supports those at the beginning of their professional careers.[100]

- Review international best practices: capitalise on collaborations with international organisations such as the IAEA and UN. Participate in training sessions, to reinforce and expand the knowledge of Tunisian officials regarding critical infrastructure security.

To enhance cybersecurity in Tunisia for facilities holding radiological materials (and potentially in the future nuclear materials), a comprehensive and coordinated approach is essential.

Conclusions

This case study highlights the 2010 Stuxnet cyber-attack on Iran's uranium enrichment facilities, emphasising the changing landscape of cybersecurity and its potential repercussions on critical infrastructure. The incident not only revealed the complexity of cyber-weapons but also highlighted vulnerabilities in industrial control systems, underscoring the imperative for global collaboration in cybersecurity efforts. Despite this, a decade later, few countries have clear nuclear cybersecurity policies. This gap is crucial for emerging nuclear energy countries like Tunisia. As demonstrated by incidents in Ukraine, Denmark and the UK, attacks remain both likely and possible. Despite positive advancements in Tunisia, it is crucial to acknowledge that designing a security regime capable of preventing an attack like Stuxnet remains a challenge. However, the key takeaway lies in the potential to fortify existing regimes, thereby enhancing protection for civilian nuclear infrastructure. For Tunisia, the need for primary legislation is essential to ensure coherence and consistency across cybersecurity regulations.

Suggested discussion points

1. How can emerging nuclear energy programmes effectively integrate robust cybersecurity measures in response to evolving cyber threats?
2. What are the potential benefits and challenges of fostering regional collaboration among North African countries to collectively address nuclear cybersecurity challenges?
3. In what ways can the 'digitalisation' of nuclear facilities enhance operational efficiency, and what challenges does it introduce in terms of cybersecurity?

99 Kanchan P Adhikari, Hielke Freerk Boersma, Roger Coates, Whitney Coulor, Eduardo Gallego, Latifa Ben Omrane, Rodolfo Cruz Suarez and Uranchimeg Tsegmed, 'Radiation protection infrastructure – challenges in developing countries,' *Journal of Radiological Protection,* Vol. 41, No. 3, 2021.

100 Egypt Young Generation Nuclear, 2023. https://www.eygn.org/

Lost and found part I: the Setif gamma radiography source, Algeria

By Anonymous

Overview

This case relates to a 25-curie (925GBq) iridium-192 source that was found 5 May 1978. During the transportation process, it accidentally fell off a truck. Two children later discovered this source and decided to keep it for several days. Eventually, they handed it over to their grandmother, who kept it in the kitchen of her home. After 38 days, radiation exposure was identified by medical personnel. As a result of exposure to the source, one person died and six people suffered life-threatening whole body injuries.

Background

The reason this incident is of high concern, is because a high activity radioactive source can be used to create a Radiological Dispersal Device (RDD) or Radiological Explosive Device (RED), also sometimes referred to as 'dirty bombs'. Iridium-192 has accounted for the majority of cases tracked by the US Nuclear Regulatory Commission in which radioactive materials have gone missing in quantities large enough to construct such a device.[101] RDDs and REDs can impact both health and environment due to the release of radioactive materials. Severe health consequences include radiation exposure leading to acute sickness, cancer risk and further long-term health effects, such as an increased risk of developing other diseases over time. Environmental consequences include contamination, clean-up challenges, ecosystem disruption, and water pollution.

Explosive RDDs cannot cause mass casualties on the scale of a nuclear explosion.[102] All or most fatalities or injuries would likely be due to the explosion itself or the release of radioactive materials. While large numbers of people residing in a densely populated area around the detonation of an RDD might become contaminated and require decontamination, few, if any, will suffer acute radiation syndrome and require medical treatment.[103] Local health authorities will have to assess the persons who were very close to the point of release for the need for medical intervention.[104] The sum of the cumulative exposures could result in an increased lifetime cancer risk, and some people may require mental health services.

The health and environmental consequences of RDDs, will depend on the following: 1) Device design, 2) Radioactive material type and quantity, and the 3) Dispersion pattern following release. RDDs may affect small, localised areas (eg, a street, single building, or a city block), but also larger areas, up to several square miles, depending on the nature of the dispersion and the amount and type of radioactive material. Other hazards may also be present, such as fire, smoke, shrapnel (from an explosion) or industrial chemicals. Radioactive decontamination of persons and areas affected may be required.[105, 106, 107]

101 Steve Coll, 'The Unthinkable,' *The New Yorker;* 4 March 2007. https://www.newyorker.com/magazine/2007/03/12/the-unthinkable-2
102 US Department of Health and Human Services, 'Radiological Dispersal Devices (RDDs),' Radiation Emergency Medical Management (REMM), 2023. https://remm.hhs.gov/rdd.htm
103 John Pike, 'Planning Scenarios, Executive Summaries: Radiological Attack – Radiological Dispersal Devices,' 2004. https://www.globalsecurity.org/security/library/report/2004/hsc-planning-scenarios-jul04_11.htm
104 US Department of Health and Human Services, 'Radiological Dispersal Devices (RDDs),' Radiation Emergency Medical Management (REMM), 2023. https://remm.hhs.gov/rdd.htm
105 Frederick T. Harper, Stephen V. Musolino & William B. Wente, 'Realistic radiological dispersal device hazard boundaries and ramifications for early consequence management decisions,' *Health Physics,* Vol. 93, No. 1, 2007.
106 James M. Smith, Armin Ansari & Frederick T. Harper, 'Hospital management of mass radiological casualties: reassessing exposures from contaminated victims of an exploded radiological dispersal device,' *Health Physics,* Vol. 89, No. 5, 2005.
107 Stephen V. Musolino & Frederick T. Harper, 'Emergency Response Guidance for the First 48 Hours after the Outdoor Detonation of an Explosive Radiological Device,' *Health Physics,* Vol. 90, No. 4, 2006.

Case summary

In May 1978, a 25-curie (925GBq) iridium-192 source used for industrial radiography fell from a truck during transportation between Algiers and Setif in Algeria. From openly available sources, it is currently not possible to verify which company was transporting the material or why. With that said, iridium is commonly used in industrial radiography as a gamma ray source and in radiotherapy as a radiation source (brachytherapy).

A few days later, two young boys, aged three and seven, discovered the source and handled it. Eventually, they brought it home, where it remained for 5–6 weeks, exposing the entire family to radiation. The specific conditions and levels of exposure varied depending on the family members' location and time spent in the kitchen, where the source was kept. Medical personnel only identified radiation exposure 38 days after the initial exposure, due to the health impact on the persons involved in the incident.

The boys' grandmother, aged 47 years, and four females, aged 14, 17, 19, and 20 years, who spent most of their time in the house, were exposed to varying doses of radiation. The two boys experienced severe skin lesions as a result of their exposure. Determining the exact doses for the five females was challenging due to several uncertainties, such as the daily exposure time, geometry, shielding, and distance from the source, over the 38-day period. Consequently, their treatment primarily focused on haematological presentations.

The grandmother suffered radiation injuries, including radiation burns and aplasia, and passed away in late June 1978. A pregnant 20-year-old woman experienced a miscarriage. Both boys required surgical intervention for their skin injuries, including amputation of fingers and skin grafts. One of the exposed females developed thyroid cancer in 1994, followed by breast cancer at a later date. However, all six survivors were still alive in 2000.

Consequences

Health consequences

As seen in this case, radiation exposure accidents involving orphan sources can have dire health implications. In Setif, the loss and delayed discovery of sources led to fatalities, severe whole-body exposures in young women, and localised overexposures in children. With that said, comparable incidents came both before and after. In China, in 1963, an abandoned source led to three deaths after it was taken home.[108] Similarly, a tragic case in Morocco, in 1984, resulted in the death of eight people from pulmonary haemorrhaging caused by overexposure to radiation from a lost iridium-192 source after a labourer at the Mohammedia power plant took it home.[109, 110]

These examples underscore the urgency of stringent source control, rapid detection, and intervention to prevent prolonged radiation exposure and its devastating health outcomes associated with orphaned radioactive sources. Put together, they also illustrate the need to enhance public awareness campaigns.

Suspected malicious use

Radioactive sources can fall into the wrong hands, potentially exploited by ideological or cult groups to create RDDs or REDs, triggering public harm and panic with a primary objective of maximising fear.[111] These malicious acts, distinct from accidents, hold significance when they result in immediate health impacts due to radiation exposure.

A prominent example of such malicious use is the UK case of Alexander Litvinenko in November 2006, involving the fatal poisoning of a Russian national with 210-Po.[112] Although the Litvinenko incident garnered substantial media attention, thorough monitoring revealed no adverse radiological health effects in public spaces. Over 700 individuals in the UK were tested for 210-Po contamination, with more than 100 displaying traces of exposure. Fortunately, fewer than 20 individuals received radiation doses surpassing the critical 6mSv safety threshold, underscoring the importance of maintaining radiological safety standards even in cases of suspected malicious use.

108 Jean-Claude Nénot, 'Les accidents d'irradiation, 1950-2000 leçons du passé,' *Journal of Radiological Protection,* Vol. 36, No. 4, 2009.
109 Eliot Marshall, 'Morocco reports lethal radiation accident,' *Science,* Vol. 225, No. 4660, 1984.
110 United States Nuclear Regulatory Commission (US NRC), 'Information Notice No. 85-57: Lost Iridium-192 Source Resulting in the Death of Eight Persons in Morocco, Jul 16, 1985.' https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1985/in85057.html
111 United Nations Scientific Committee on the Effects of Atomic Radiation, 'Sources and Effects of Ionizing Radiation, Volume II, Annex C: Radiation exposures in accidents.' https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2008_Annex-C-CORR.pdf
112 Ibid.

Environmental impact

Radioactive materials released into the environment can contaminate air, water, surfaces, soil, plants, buildings, and living organisms.[113] During radiological emergencies, these substances can contaminate plants through air deposition and soil uptake via roots, enter the food chain through ingestion by animals, and affect marine life via water and marine plants, becoming diluted in seawater over time.[114]

Regulation for transport

The orphan source incident in Algeria is consistent with a 1962 Mexico case, where a family suffered fatal exposure due to improper disposal of a radiological source.[115] It is critical to have effective regulations and rules in place for the management, use and transport of radiological materials. There are millions of packages of radioactive materials being transported worldwide, and there are potential risks to public safety and the environment.[116] These materials are often moved through urban areas, increasing the likelihood of accidents that could result in local releases and dispersion. However, the reassuring aspect is that, despite accidents occurring occasionally, adherence to rigorous regulatory controls as well as safety features within the packages has generally limited the consequences.

In Algeria, the regulation of activities related to the research, production, and peaceful use of nuclear energy is now governed by law number 19–05, enacted on 17 July 2019.[117] The law's core objectives include safeguarding human health, preserving the environment, and protecting future generations from potential detrimental effects associated with ionising radiation, all while adhering to the fundamental principles of radiation protection and nuclear safety.

To achieve these objectives, the law empowers regulatory bodies to establish specific measures for operators, importers, transporters, and holders of radioactive materials. These measures encompass exposure limits, accident prevention protocols, and systems for facility access control and the prevention of illicit trafficking in nuclear materials.

Communication and training

The Setif incident further holds similarities to a 1977 case from South Africa, highlighting a need for immediate reporting. In South Africa, a worker stored a radiological source in his shirt pocket.[118, 119] Storing the source in his pocket for an extended period of time resulted in the amputation of two fingers.

Training, connecting different levels of relevant personnel, will reduce the time to retrieve these sources under regulatory control. It will also reduce RDD and RED impact on health and environment. The occurrences of radiation accidents are frequently attributed to factors such as human error, lapses in caution, deviations from prescribed procedures and safety protocols, equipment defects or substandard repairs, insufficient training, instances of control loss, source abandonment, and various other circumstances.

Lessons learned

By incorporating knowledge from the Setif case, and other similar orphan source cases from Morocco, Mexico and South Africa, this case study has sought to provide a comprehensive approach to enhancing the security, movement, and transport of radiological sources in the North African context and beyond. The lessons learned from this case are as follows:

- Public awareness campaigns: this case, in addition to others, underscores the importance of educating the public about the dangers of handling unknown objects. There is a clear need to implement comprehensive public awareness campaigns, in both urban and rural areas, highlighting the dangers of radiological sources, especially orphan sources, and what people should (not) do if they come across one.

- Transportation protocols: this case emphasises the need for stricter transportation protocols and secure storage to prevent accidental loss. Governments and regulatory bodies must enforce strict regulations governing radiological source use, transportation, and disposal to prevent unauthorised access and mishandling.

113 Centers for Disease Control and Prevention, 'Contamination vs. Exposure,' 2022. https://www.cdc.gov/nceh/radiation/emergencies/contamination.htm
114 Bundesamt für Strahlenschutz, 'Environmental consequences of a radiological emergency,' 2023. https://www.bfs.de/EN/topics/ion/accident-management/consequences/environment/environment_node.html
115 P. Ortiz, M. Oresegun & J. Wheatley, 'Lessons from Major Radiation Accidents,' Paper presented at IRPA 10, Hiroshima, May 2000. https://www.irpa.net/irpa10/cdrom/00140.pdf
116 United Nations Scientific Committee on the Effects of Atomic Radiation, 'Sources and Effects of Ionizing Radiation, Volume II, Annex C: Radiation exposures in accidents.' https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2008_Annex-C-CORR.pdf
117 Richard Mugni, Fabien Hecquet and Keltoum Boudribila, 'Algeria – Law on nuclear activities,' Baker McKenzie, Lexology, 30 September 2019. https://www.lexology.com/library/detail.aspx?g=6f580112-e62d-4410-b1c1-456593169de1
118 United Nations Scientific Committee on the Effects of Atomic Radiation, 'Sources and Effects of Ionizing Radiation, Volume I, Annex E: Occupational radiation exposures.' http://www.unscear.org/docs/reports/annexe.pdf
119 Jean-Claude Nénot, 'Les accidents d'irradiation, 1950-2000 leçons du passé,' *Journal of Radiological Protection,* Vol. 36, No. 4, 2009.

- Immediate reporting: in addition to the above, this Algeria case highlights the need for immediate reporting of lost radiological sources to authorities. In any authorities-led public awareness campaign, the authorities should encourage quick reporting of lost radiological sources to authorities to prevent prolonged exposure to the public. Delays in reporting can lead to severe consequences.

- Prompt medical attention: the delay in recognising radiation exposure in the Setif case serves as a reminder of the importance of rapid identification, immediate medical attention and better protocols in detecting the radiation dosage in exposed individuals.

- Safe storage: lost source incidents emphasise the importance of secure storage.[120] Radiological sources should never be kept in homes, kitchens, or other improper locations.

- Need for improved EPR: effective security for controlling orphaned radiological sources needs comprehensive training and an improved emergency response that includes coordination among regulatory, health, and environmental authorities, as well as HAZMAT (hazardous material) teams. This should include detailed contingency plans and regular drills.

- Protection of children and women: in addition to the above, it is important to pay special attention to protecting vulnerable populations, such as children who may come across an orphan source playing or outside, from accidental exposure to radiological sources. Similarly, the source was kept in the kitchen, which is where the women of this family spent more time, and as such, increased their radiological exposure.

- Regional lessons: lessons from this case stress the significance of international collaboration and information sharing to prevent future accidents, demonstrating the need for a global approach to radiological source safety. Co-operation can improve public awareness, and should include sharing best practices, and pooling resources to collectively enhance the security, and handling of radiological materials. Furthermore, since it is common for sources to be transported across borders, a collaborative approach would ensure a safer environment across the region.[121]

Conclusion

This case study of an orphan radiological source in Setif, Algeria, shows how radiological security could be improved both nationally and regionally. This case underscores the need for comprehensive public awareness campaigns and risk communication that target both urban and rural areas, to educate the public on the potential health consequences of handling radiological sources. Strict transportation and storage regulation is essential to prevent accidental loss of sources and subsequent mishandling. Additionally, timely reporting of lost sources to authorities is crucial, as delays can lead to severe consequences and a delayed emergency response. Prompt medical attention and improved EPR protocols are therefore necessary for managing radiation exposure effectively. Radiological sources should be securely stored, not in homes or kitchens. Additionally, international collaboration and information sharing will ensure a more secure environment in transportation across borders.

Suggested discussion points

1. How can the transport and movement of radiological sources be made more secure and less susceptible to accidental loss or theft?
2. How can we enhance public awareness and understanding of radiological sources, particularly orphan sources, to prevent their accidental discovery and handling by members of the public?
3. What measures can be taken to prevent malicious actors from obtaining and misusing radioactive substances?

120 Ibid.
121 United Nations Scientific Committee on the Effects of Atomic Radiation, 'Sources and Effects of Ionizing Radiation, Volume II, Annex C: Radiation exposures in accidents.' https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2008_Annex-C-CORR.pdf

Lost and found part II: the Meet Halfa gamma radiography source, Egypt

By Wafaa Mohamed Moustafa

Overview

This case study will discuss the loss of an industrial gamma radiography source at Meet Halfa, Egypt, in 2000. Workers failed to report the absence of four sources used for checking pipes, and a family unknowingly took one source home.[122] This lead to the death of a nine-year-old from radiation sickness. Subsequent hospitalisations and fatalities occurred in the family, with additional neighbours experiencing symptoms. Authorities initiated radiation surveys, recovering the source and arresting individuals linked to the incident.

The incident was an important lesson for the Egyptian government in terms of nuclear safety and security culture. It influenced the development of nuclear infrastructure and legislation, which is particularly significant now that Egypt is about to begin generating nuclear power.

The lessons from this historical case study have broader significance as well: on the African continent many countries are currently considering adding new nuclear power technologies to their energy mix. As illustrated by the previous case study, incidents involving lost sources are still frequent in the region – which means it is important to understand their impact, consequences, and solutions.

Case summary

Meet Halfa is in the Al Qalyubia Governorate, north of Cairo, Egypt. In late April 2000, four sources used for checking pipes were lost in the Abu Rawash area. Workers at the site searched for them, but they were unsuccessful and did not report the loss to authorities.

On 5 May 2000, a local farmer from Meet Halfa village found one of the sources.[123] Unaware of the unusual metal object's nature, the man (aged 60) took the source home. He lived together with his wife (50), sister (65), two sons (22 and 9) and two daughters (17 and 13). All seven members of the family were fascinated by the object and firmly believed it was a precious metal.

During the weeks that followed, the source was handled by the family members with varying frequencies and durations. It was placed in different locations within the home for various periods, but primarily it was housed in a cardboard box on top of a closet in the utility room. The family members experienced varied and prolonged radiation exposures.

On 5 June, nearly a month later, the Ministry of Health in Cairo's Infectious Disease office received a message from Qalyubia's Public Health Department. It reported the death of a nine-year-old child from Meet Halfa village. The clinical condition prior to death was that of marked bone marrow failure and extensive inflammatory skin lesions. There was, however, no precise diagnosis.

122 Robert Johnston, 'Meet Halfa orphaned source, 2000,' Database of radiological incidents and related events, 17 August 2005. https://www.johnstonsarchive.net/nuclear/radevents/2000EGY1.html

123 M. H. Shabbon, 'Health Effects Sequence of Meet Halfa Radiological Accident After Twelve Years,' Proceedings of the Eleventh Radiation Physics and Protection Conference, 2013.

On 10 June, a fact-finding mission from the Ministry of Health discovered four cases with similar signs and symptoms among family members of the deceased boy. Medical professionals diagnosed inflammatory or viral cutaneous lesion associated with bone marrow depression. All family members were admitted to Imbaba Fever hospital for observation. On 16 June, the father died from bone marrow failure associated with extensive inflammatory skin lesions. The rest of the family was transferred to Abassiah. All laboratory investigations related to inflammatory or viral conditions of the skin proved negative.

On 25 June, a Ministry of Public Health task group visited Meet Halfa on a fact-finding mission. The mission findings revealed high radiation levels around the farmer's family house. The task group immediately notified the responsible authorities. The following day, experts from the Division of Chemical Warfare (armed forces) and from the EAEA carried out a detailed radiological survey of the family house and its surroundings in Meet Halfa. A radiological industrial source was eventually found. It was controlled, retrieved, and contained in a suitable lead container, before being transported under protective guidance to the EAEA laboratories at Inchas. There, it was placed in a hot cell.

Exact determination of the nature, magnitude, extent and duration of the radiation exposure involved is difficult to achieve. However, exposure to the source resulted in two fatalities, clinical forms of bone marrow depression, and several skin burns of different severities. The farmer's sister died in 2007, aged 72, old with senility and no specific disease. The farmer's three surviving children married and had healthy children. This means that there were no hereditary stochastic effects. All three children had to have fingers amputated between 2001 and 2009 however, as a result of the exposure. The elder son further had to receive treatment for a burn in the lower right quadrant of the abdomen and suffered a severe abdominal hernia due to necroses in the abdominal muscles.

The local authorities arrested four people for involvement in the incident, and found the remaining three cylinders on 3 July in a warehouse.

Lessons learned

The incident in Meet Halfa, Egypt, revealed several lessons and had a notable impact on the response to radiological incidents in the country, as well as on nuclear security.

Oversight of radiological source import and transport

The incident in Meet Halfa revealed a significant lapse in the monitoring and tracking of radiological source materials in Egypt. The gamma radiography source had been lost sometime before 5 May by an operator working for a pipe welding testing company. The source, identified as iridium-192 with a half-life of 74 days, had therefore been missing for an unspecified duration before it was discovered. The lack of information about the operator or the company involved also raises questions about how such an incident could occur unnoticed.

This case underscores the need for more stringent measures in monitoring and tracking radiological materials in transit to prevent unauthorised access or loss.

Egypt's response to radiological incidents

Once identified, the incident elicited a swift response from Egypt, with visits by the Ministry of Public Health and the Division of Chemical Warfare to Meet Halfa in 2000. Significant improvements have since also been made in Egypt's radiological material security framework. The introduction of the Law Regulating Nuclear and Radiological Activities in 2010 (law number 7) was a pivotal step.[124] This law establishes a comprehensive legal framework to regulate all nuclear and radioactive activities in Egypt, prioritising the safety and protection of human lives, property, and the environment against radioactive hazards.

Under Article 12 of the 2nd chapter, ENRRA was granted various responsibilities, including the development of regulatory requirements and rules, licensing processes, safety document review, regulatory inspections, safeguard inspections, transportation control of radioactive materials, EPR coordination, collaboration with government and non-governmental entities, and the regular issuance of public reports. This legal framework represents a substantial enhancement in Egypt's efforts to secure radiological materials and protect its citizens and surroundings.

124 Mohamed Gaheen, 'Infrastructure for Licensing and oversight the NPP in Egypt,' presented at the IAEA workshop Promoting Effective Interaction Among Nuclear Industry and Regulatory Body in Countries Introducing Nuclear Power Programmes, 30–31 May 2022. https://www.afcone.org/wp-content/uploads/2022/06/12-GAHEEN-Mohamed-ENRRA-FINAL-REVIEWED.pdf

Emergency response and healthcare preparedness

On 26 June, it became evident that the death of the younger son and the father, and the clinical conditions of the remaining members of the family, were caused by the radiation exposures they received during the time they lived in possession of the source.[125] The event revealed that the Egyptian healthcare system was challenged when it came to diagnosing and treating the radiation-related illnesses effectively. As a result, this underscores the need for enhanced medical preparedness to handle such situations. This includes the development of comprehensive EPR protocols that can be swiftly activated to address radiological incidents. The incident's treatment protocols, while essentially similar for the affected patients, highlighted the importance of tailoring medical care to specific patient needs.

Key aspects of medical management in the treatment protocol for the five patients included patient isolation in a laminar airflow tent, excellent hygiene practices of daily baths, high quality nursing-mouth and respiratory care, controlling infection portals, ensuring balanced nutrition and hydration, maintaining electrolyte balance, and administering medication like Granulocyte Colony Stimulating Factor, antibiotics, and platelet transfusions. This highlights the significance of readiness and precise medical intervention in the face of radiological emergencies.

Psychological impact

The Meet Halfa incident had psychological repercussions on those affected, including on the family members themselves and other villagers. The primary drivers of the psychological effects included the absence of precise and credible information about the accident, a lack of understanding about radiation's nature, and uncertainties surrounding recovery prospects and exposure consequences, including delayed effects. These psychological patterns mainly impacted the surviving family members, with concerns extending to several village residents who were apprehensive about potential radioactive pollution and contagion.

Significantly, these psychological implications may have been overlooked during the initial phases of the incident. These psychological effects highlight the importance of addressing the emotional and mental aspects of radiological incidents, as they can significantly impact the well-being of those involved and the broader community.

International response and public perception

Finally, it is relevant here to compare the Meet Halfa case to the radioactive contamination accident that took place in Goiânia, Brazil, in 1987.[126] An unsecured radiotherapy source from an abandoned hospital site was handled by a number of people, resulting in four deaths – and, notably, the examination of more than a hundred thousand people for radioactive contamination.

The Goiânia incident was characterised by its global reach and extensive media coverage, both nationally and internationally. The reporting and widespread contamination in Goiânia led to profound public fear and stigma. As a result, mass evacuations were conducted, and thousands of residents were relocated from affected areas. This extensive response drew considerable attention from the public and the international community, ultimately prompting a substantial global response. The incident was marked by a profound psychological impact on individuals and communities affected, leading to anxiety about contamination and interactions with those from affected areas.

Yet, while the narrative is comparable (a lost source handled by unknown members of the public) the knowledge and impact of this event did not stretch to Meet Halfa a decade later. In Meet Halfa, the incident unfolded on a more localised scale, impacting a smaller number of individuals, with a confined geographical extent. This incident received less media attention and international focus compared to Goiânia. The public response was inherently influenced by Egypt's unique sociocultural context, namely more limited information dissemination and public awareness practices. As a result, the Meet Halfa incident had a more contained and comparatively smaller public response. This is negative in the sense that the population of Meet Halfa had not heard of Goiânia, and could not compare their situation and therefore prevent contamination. However, it was positive in the sense that no public panic broke out in Egypt.

125 M. H. Shabbon, 'Health Effects Sequence of Meet Halfa Radiological Accident After Twelve Years,' Proceedings of the Eleventh Radiation Physics and Protection Conference, 2013.

126 IAEA, 'The Radiological Accident in Goiânia,' 1988. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub815_web.pdf

Conclusion

In summary, the radiological incident in Meet Halfa underscored the need for stricter monitoring and improved public awareness to prevent unauthorised handling and access to radiological materials. Egypt's legal framework, especially law number 7 in 2010, gave priority to safety and environmental protection, with a central role assigned to ENNRA. Public education emerged as a critical element in averting unauthorised handling of radioactive materials. The challenges in diagnosing and treating radiation-related illnesses stressed the importance of enhanced medical readiness and clear EPR procedures. Additionally, the psychological impact of both Meet Halfa and Goiânia highlighted the necessity of addressing the emotional and mental aspects of radiological incidents.

Suggested discussion points

1. How strong is Egypt's regulatory framework for nuclear security and radiation source handling, and what enhancements can be implemented to prevent unauthorised access to such sources?
2. What measures are in place to educate the public about the potential risks associated with radiation sources, and how can these be improved to prevent future incidents like the one in Meet Halfa?
3. What measures can be taken to ensure that the healthcare system is sufficiently prepared to diagnose and treat radiation-related illnesses effectively?

Lost and found part III: the Sabha uranium barrels, Libya

By Fawzi A Ikraiam

Overview

According to the IAEA Incident and Trafficking Database, 36 countries reported 189 cases of 'unauthorised activities' such as theft and trafficking of nuclear and radiological material in 2019 alone.[127] This case study explores how this has affected Libya, focusing on IAEA guidance for materials outside of regulatory control.[128] In March 2023, a total of 2.5 tons of natural uranium in the form of uranium ore concentrate (UOC) went missing from a storage site near Sabha city in the south of Libya. The barrels were recovered a few days later at a distance of about 5 km from the storage site. The incident was reported by the UN Nuclear Watchdog of the IAEA following a series of verification activities carried out by UN inspectors.[129] This presented significant concerns regarding Libya in relation to nuclear security measures and proliferation on various levels. Although the IAEA declared that the missing uranium emits low levels of radioactivity and posed little radiation hazard as well as there was no immediate radiological risk at the location, this incident holds serious significance in terms of radiological security and nuclear terrorism.[130]

Case summary

The uranium barrels were stored in a guarded warehouse in southern Libya, at site near Sabha city, during the rule period of Gaddafi (who ruled Libya 1969–2011), most probably between 1978–1981.[131] Sabha is located some 660km southeast of the capital Tripoli.

On 17 March 2023 a Libyan National Army (LNA) spokesman confirmed that the barrels were found after a search that lasted a few days close to the storage site, at a distance of about 5km. He added that a barrel-sized hole was found cut open in the side of the storage warehouse. He also added that the site guards were positioned a safe distance away from the materials due to concerns about radioactivity.[132] The outcomes of the investigation were not publicly revealed and to consolidate his statements, the LNA spokesman posted a video showing a man wearing a hazmat suit vocally counting 18 blue barrels that supposedly contain the missing natural uranium. However, the authenticity of this video was questioned by international media.[133]

The IAEA asserted that ten barrels were missing from the warehouse.[134] An IAEA spokesman in turn claimed that Chadian separatist fighters, who operate heavily in the region, might have been responsible for theft of the barrels after confusing them for arms and ammunitions. He added that they would have dumped the barrels after not exactly knowing what was inside. However,

127 IAEA, 'Incident and Trafficking Database,' Fact Sheet, 2020. https://www.iaea.org/sites/default/files/20/02/itdb-factsheet-2020.pdf

128 IAEA, 'Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control', *Nuclear Security Series,* No. 15, 2011. https://www.iaea.org/publications/8622/nuclear-security-recommendations-on-nuclear-and-other-radioactive-material-out-of-regulatory-control/

129 Francois Murphy, 'Tons of uranium missing from Libyan site,' Reuters, 16 March 2023. https://www.reuters.com/markets/commodities/tons-uranium-missing-libyan-site-iaea-tells-member-states-2023-03-15/

130 IAEA, 'Nuclear Security Culture: Implementing Guide', *Nuclear Security Series,* No. 7, 2008. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1347_web.pdf

131 CNN, 'Libya military site yields possible radioactive material,' 22 September 2011. http://edition.cnn.com/2011/WORLD/africa/09/22/libya.war/index.html

132 CNN, 'Libyan armed group says barrels of missing natural uranium recovered,' 17 March 17 2023. https://edition.cnn.com/2023/03/17/africa/libya-missing-uranium-intl/index.html

133 Francois Murphy, 'Tons of uranium missing from Libyan site,' *Reuters,* 16 March 2023. https://www.reuters.com/markets/commodities/tons-uranium-missing-libyan-site-iaea-tells-member-states-2023-03-15/

134 CNN, 'Libyan armed group says barrels of missing natural uranium recovered,' 17 March 2023. https://edition.cnn.com/2023/03/17/africa/libya-missing-uranium-intl/index.html

no evidence was presented to back this claim. The spokesman also added that forces were assigned to guard the storage site after a visit by an IAEA team in 2020, when the barrels were marked as containing uranium.[135]

It is nearly impossible to verify the Libyan accounts and statements and the LNA itself does not control all of the southern regions in Libya. The narrative of the missing uranium is confusing and complicated, but also hard to verify. This is compounded by the lack of access to the site and lack of transparency in the Libyan accounts of the incident. Prior to the LNA statement, the IAEA had already stated that the loss of knowledge about the present location of nuclear material may present a radiological risk as well as nuclear security concerns. However, UN inspectors visited the area in March 2021 and saw the material being transferred to the storage site and reporting that a small amount of UOC remained unaccounted for. Their statement said investigations were still underway on the matter, including reconciling the quantities of natural uranium at the site with those previously verified by the IAEA. The IAEA said that its director-general informed member states about the findings of the visit.[136]

The substance contained in the barrels is commonly known as 'yellowcake', a powder containing about 80 per cent uranium oxide which can be utilised in the preparation of nuclear fuel for reactors and for energy production. Significantly, this natural substance can also be enriched for use in nuclear weapons. This enrichment process normally involves converting the metal into a gas. The enriched uranium, which is an essential component in atomic reactors or weapons, is produced in centrifuges spinning uranium hexafluoride gas (UF6) at high speeds to reach the required levels. The UF6 is obtained from this yellowcake, the concentrate from mined UOC.[137, 138] Radiological hazards and exposures from this material are limited but cannot be overlooked. But each ton of natural uranium, if obtained by a group with the technological means and resources, can be refined to 5.6kg of weapons-grade material over time.[139]

Background

The fact that Libya might have radioactive material is not a surprise. The existence of these uranium barrels dates to the rule of late Muammar Gaddafi when thousands of barrels of the yellowcake uranium were imported by Libya. According to a 2008 IAEA report, Libya imported 2,263 tonnes of UOC between 1978 and 1981, which was being stored at Sabha. It was intended for a uranium ore concentration and conversion facility to be built in that area by mid 1990s as part of Libya's secret weapons programme. This facility was never fulfilled. Libya declared its previously secret nuclear programme in December 2003 and confirmed the storage of yellowcake in Sabha. From 2003, Gaddafi's government stated its intent to dismantle its nuclear programme.[140] The Libyan authorities also cooperated with verification efforts by the IAEA. The storage site, not far from Sabha, has two warehouses containing thousands of blue barrels marked with 'radioactive' tape and plastic bags of yellow powder sealed with the same type of tape. The region, where the Sabha incident occurred is notably characterised by lawless groups positioned in the southern spreads of the Sahara Desert.

Challenges

This analysis focuses on the availability of relevant information in open sources, with reference to similar cases and experiences in other states. The importance of crisis management of this nuclear security incident is examined and lessons that can be learnt from it are highlighted. Since the 2011 NATO-backed uprising against Gaddafi (who was killed on 20 October 2011), Libya lost its remnants of peace and stability and the country descended into civil war. As a result, the south of Libya has not been ruled by a unified government or army. Since then, the country has been divided between two competing administrations and military factions in the east and the west, forming opposing alliances backed by foreign powers, each backed in turn by armed groups. Neither is in complete control of the south, where the uranium barrels were taken from. Up to now, the oil-rich country is largely lawless and has the potential to be, as previously described by UN experts, an 'arms bazaar' – with weapons trafficking fuelling conflicts in other parts of Africa and the Middle East.[141]

135 AP News, 'UN nuclear watchdog says missing Libya uranium found,' 25 March 2023. https://apnews.com/article/libya-missing-uranium-gadhafi-nuclear-program-23fbfa686ea465d091f6c5590ed117ce
136 Ibid.
137 NRC, 'Uranium enrichment,' 2020. https://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html
138 Tanzila Younas et al., 'Enrichment of Uranium,' 5th International Conference on Engineering Technologies and Applied Sciences (ICETAS), November 2018.
139 Reuters, 'Libya arms fuelling conflicts in Syria, Mali and beyond: U.N. experts,' 9 April 2013. https://www.reuters.com/article/us-libya-arms-un-idUSBRE93814Y20130409
140 CNN, 'Libya military site yields possible radioactive material,' 22 September 2011. http://edition.cnn.com/2011/WORLD/africa/09/22/libya.war/index.html
141 Reuters, 'Libya arms fuelling conflicts in Syria, Mali and beyond: U.N. experts,' 9 April 2013. https://www.reuters.com/article/us-libya-arms-un-idUSBRE93814Y20130409

Materials outside of regulatory control

Incidents as the one described in this case study clearly jeopardise nuclear and radiological security – not only in Libya, but the entire region. Since 2011, the IAEA said that the site, where the uranium was stored, was not in government-controlled territory. The IAEA said that it is unclear when the uranium barrels went missing or who could have taken them. As mentioned, an IAEA spokesman claimed that Chadian separatist might be responsible for this theft. These fighters were obliged to leave their old bases and ultimately driven from the country into exiles, Libya been one of them, after the end of the Chadian Civil War (2005–2010). They moved into south of Libya, along the Chadian-Libyan border, taking advantage of the unrest and the instability in Libya. Some of these Chadian separatist groups subsequently became mercenaries in service of various Libyan rival factions, in return for money and weaponry to prepare for their return to Chad.[142]

According to NTI, 'If you're removing this material from that location, you must really want it'.[143] The quantity that appears to have been taken is 'approximately one tenth of the amount of material' stored at the facility 'so you would absolutely see it missing'. In the form of yellowcake, the material cannot be made into a nuclear weapon – although it may be used as 'feedstock', the raw material required for production of nuclear weapons. Fears of radiation are minimal since 'yellowcake doesn't really have any radiation in its current form' and consequently it had been stored in some 'pretty rudimentary drums'. The IAEA explained that reaching the site had been difficulty. For example, UN inspectors had wanted to visit the location in 2011, but the trip had to be suspended due fighting between rival Libyan militias.[144]

The IAEA encourages its member states to increase control, accounting and security of radioactive sources to prevent their malicious use and the associated potential consequences. However, this cannot be fully implemented and monitored in countries such as Libya. Due to this limited regulatory government control, terrorist groups have been able to prosper and flourish as well as take advantage of the political vacuum. These conditions, combined with degraded security at these storage sites and the interest expressed by terrorist organisations in obtaining nuclear weapons intensified concerns of nuclear and radiological material trafficking[145] and making so-called 'dirty bombs'.[146]

Nuclear legacy

Under King Idris (ruler of Libya from 1954 to 1969), Libya signed the Nuclear Non-Proliferation Treaty (NPT) in 1968 (ratified by Gaddafi in 1975) and agreed to a safeguards agreement with the IAEA in 1980. However, Libya, as a member of the IAEA, ranks relatively low on the NTI Index for Nuclear Security. The NTI index stresses the significance of societal factors. These may be the presence of terrorist groups seeking to have control of nuclear materials or weak governments that cannot apply security requirements.[147] Hence, Libya faces several crucial challenges and changes, whether political, military or social.

According to the IAEA, the Libyan stockpile is estimated at some 1,000 metric tons of yellowcake uranium under Gaddafi's rule, who revealed his nuclear weapons programme to the world in 2003 after the US-led invasion of Iraq. Following secret meetings with the United States and United Kingdom, Libya publicly renounced its programme and gave up its nuclear, biological and chemical weapon programmes. Libya officially dismantled its programme in late 2003 after reaching an agreement with the UK and the USA. Libya agreed to restrict itself to the possession of ballistic missiles with a maximum range of 300km. At this time, the Libyan nuclear weapons programme was in the very initial stages of development and made little progress. By this agreement Gaddafi wanted to settle Libya's nuclear crises with the US in the intent of lifting the sanctions against Libya. In exchange, Libya also returned to the international community and saved some of its resources due to it giving up its nuclear weapons programme.[148]

Commitment to nuclear security

Nuclear security has become increasingly important in the protection of nuclear and radiological materials due to turmoil in different parts of the world. Threats of terrorism are a real and serious concern. Moreover, cases of nuclear theft and mishandling of sensitive nuclear assets have been ascribed to weaknesses in personnel

142 Declan Walsh, 'Where Did Chad Rebels Prepare for Their Own War? In Libya,' New York Times, 22 April 2021. https://www.nytimes.com/2021/04/22/world/africa/chad-rebels.html?searchResultPosition=1
143 Bethany Bell, 'Libya uranium: Tonnes gone missing, UN says,' BBC, 15 March 2023. https://bbc.com/news/world-africa-64972945
144 BBC News, 'Libya uranium: Tonnes gone missing, UN says,' 16 March 2023. https://www.bbc.com/news/world-africa-64972945
145 Farhad Rezaei, 'Shopping for Armageddon: Islamist Groups and Nuclear Terror', *Middle East Policy,* Vol.23, No.3, 2016.
146 Charles Streeper, 'Preventing Dirty Bombs: Addressing the Threat at the Source,' *The Nonproliferation Review*, Vol.17, No.3, 2010.
147 NTI, 'Nuclear Security Index', 2022. https://www.ntiindex.org/
148 Målfrid Braut-Hegghammer, 'Giving Up on the Bomb: Revisiting Libya's Decision to Dismantle its Nuclear Program,' Wilson Center, 23 October 2017. https://www.wilsoncenter.org/blog-post/giving-the-bomb-revisiting-libyas-decision-to-dismantle-its-nuclear-program

behaviour.[149, 150] Disasters like Chernobyl and Fukushima have been linked to human factors.[151, 152, 153] Due to its fragile political situation, lack of regulatory control, and the presence of militant groups, Libya faces significant challenges. These challenges extend beyond weaknesses in personnel behaviour and have contributed to the occurrence of the missing uranium barrels case.

However, the lack of cohesive Libyan commitment to nuclear security poses a challenge. This is required in order to increase control and accountability procedures of nuclear materials to enhance nuclear security considerations. Nuclear crisis response and disaster management in Libya remain largely dependent on existing non-unified army forces which may lack knowledge of handling nuclear materials, proper communication and urgent response, as demonstrated during the Sabha incident. IAEA regulations state several measures to increase safety and security of nuclear facilities and materials according to the measures implemented globally.[154] Yet, the authorities in Libya, like those in other states with similar circumstances, faced challenges in implementing these measures countrywide. One particular challenge was the formation and maintenance of consistent and clear communication and consultation means among the different parties involved – such as security officers, the army and nuclear authorities. As for the case at hand, the absence of publicly available information and lack of transparency about the Sabha incident makes it difficult to assess the incident in greater detail.

Public perception

Another dimension to this analysis, particularly in comparison to other countries, is that the Libyan population, in general, does not pay enough attention to nuclear threats. Despite growing international recognition of their importance, this lack of attention poses a distinct aspect for consideration. For example, there are almost no anti-nuclear activists in Libya, while in other countries NPPs have been closed due to public pressure, and security measures around nuclear facilities and storage places have been increased.[155] Public perception about mishandling of nuclear materials in Libya is limited, and nuclear security measures are not a key issue, even in the region where these barrels are stored.[156]

Lessons learned

The Sabha incident is an example of nuclear security as well as safety failure, insufficient governmental(s) coordination, and general lack of guidance. This case illustrates the gaps in nuclear security programmes – an issue which can be linked to weak security in Libya in general, and the division in the country. The loss of these nuclear barrels is a primary nuclear security concern and a wakeup call for Libya to address nuclear security concerns. This incident could have led to possible radiological exposure, or, even worse, the falling of nuclear materials in the wrong hands where these barrels of uranium could have found their way to the black market, and potentially used for non-peaceful purposes. While the barrels could not have been sold easily, potential buyers and interested groups do exist. Thus, the present case offers valuable lessons for nuclear security and indicates the urgent need for safety and security means and practices. There are certain key lessons to be drawn from this incident that are directly transferable to nuclear security:

- The need for more transparency (without compromising the principles of security) with regards to the processes, procedures and measures taken by Libyan nuclear authorities. Transparency not only builds trust, but also generates a state in which nuclear security can be criticised and enhanced.
- The requirement for improved nuclear control systems.
- The identification of possible risks in the nuclear security programmes in Libya, the appropriate authorities should encourage and adopt increased

149 Christopher Hobbs & Matthew Moran, 'Exploring the human dimension of nuclear security: the history, theory, and practice of security culture,' *The Nonproliferation Review,* Vol. 27, No. 5/6, 2020.
150 The International News, 'Over 200kg uranium theft in India poses threats of nuclear terrorism', 5 September 2021. https://www.thenews.com.pk/print/888297-over200kg-uranium-theft-in-india-poses-threats-of-nuclear-terrorism
151 IAEA, 'Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident,' *Safety Series,* No.75-INSAG-1, Report by the International Nuclear Safety Advisory Group, Vienna, 1986. https://www.iaea.org/publications/3598/summary-report-on-the-post-accident-review-meeting-on-the-chernobyl-accident
152 National Academy of Sciences, 'Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of U.S. Nuclear Plants.' Washington (DC): National Academies Press (US); 29 October 2014. https://www.ncbi.nlm.nih.gov/books/NBK253947/
153 IAEA, 'Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident,' *Safety Series,* No.75-INSAG-1, Report by the International Nuclear Safety Advisory Group, Vienna, 1986. https://www.iaea.org/publications/3598/summary-report-on-the-post-accident-review-meeting-on-the-chernobyl-accident
154 IAEA, 'Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities,' *Nuclear Security Series,* No. 13 (INFCIRC/225/Revision 5), 2011. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1481_web.pdf
155 Aljazeera, 'Germany ends nuclear energy era as last reactors power down,' 15 April 2023. https://www.aljazeera.com/news/2023/4/15/germany-ends-nuclear-energy-era-as-last-reactors-power-down
156 George Bunn, 'Raising International Standards for Protecting Nuclear Materials from Theft and Sabotage', *The Nonproliferation Review,* 2000.

awareness and shared accountability that will lead to the establishment of nuclear security programmes in nuclear storages and facilities.

- Increase of access and action authorisation controls must be established to exclude any unauthorised operation or the misuse of nuclear materials or facilities.
- Nuclear security training programmes are urgently needed for Libyan organisations related to nuclear materials and sites which require detailed implementation procedures to enhance nuclear security measures.
- Libyan nuclear authorities should encourage nuclear employees to report any weaknesses and vulnerabilities so that corrective procedures can be implemented.

In realising these measures, the acute economic situation of the country has to be taken into account. Employees might be aware of illegal activities, but they would not report them in the hope that may gain financial rewards. Cooperative communication can be generated over time but is also hindered by the interference of external elements. In the case of Libya, major political decisions and actions may not be entirely in Libyan hands due to the country's political instability. Increased involvement by the IAEA and other international experts could lead to cooperation, security improvements, funding, and generally building common interests with other countries. Since the security of radioactive materials and associated facilities is an international responsibility, the IAEA started its Nuclear Security Series in 2006. Especially relevant to the Sabha case is a 2021 update of the Implementing Guide for Computer Security for Nuclear Security where a guiding document that complements the existing international regime on nuclear and radiological security is presented.[157] In light of this IAEA guidance, a review of existing nuclear security procedures in Libya and recommendations for further improvements are required.

Conclusions

The threat of terrorism remains a vital concern for Libya due to its vulnerable and fragile situation. While there is no one-stop solution, Libya needs to seriously consider adopting IAEA reforms and guidelines to enhance its nuclear security culture. The Sabha incident, where 2.5 tons of natural uranium were lost and found, illustrates crucial gaps in Libya's ability to safeguard nuclear materials, revealing broader security and safety conditions that require urgent attention. The incident particularly highlights the risk for those who do not recognise the nuclear materials, while presenting an opportunity to those who do. As such, his case prompts questions about the existing situation in Libya – which may lead to nuclear security encroachments including theft and sabotage.

Recognising potential threats should motivate decision-makers to take appropriate and urgently needed actions. In the Libyan case, building awareness and ensuring a quick response are crucial requirements to enhance resilience within nuclear facilities and storage sites. These conclusions might be easy to state, but the suggested measures are hard to implement in real life situations in Libya. Everyday challenges include lack of security in the country, spread of uncontrolled arms, and presence of militia. It is now up to the rival Libyan governments and main stakeholders to promote a change in public perception on nuclear materials to achieve a strong nuclear security culture.

Suggested discussion points

1. What lessons can be learned from the Sabha incident in developing a nuclear security culture? And what role does the IAEA have in helping Libya to achieve its nuclear and radiological security ambitions?
2. What does the Sabha incident tell us about the importance of clarity and transparency in organisational and personnel responsibilities for nuclear security and security culture?
3. Who should be responsible for nuclear safety concerns at nuclear facilities? How can operators, regulators and government ensure there are clear roles and responsibilities in this area?

157 IAEA, 'Computer Security for Nuclear Security', *Nuclear Security Series,* No. 42-G, Vienna, 2021. https://www.iaea.org/publications/13629/computer-security-for-nuclear-security

Industrial radiology vulnerabilities in North Africa

By Marwa Feraig

Overview

Understanding and mitigating potential risks is of paramount importance in the commercial world, particularly in sectors dealing with so-called 'Category 2' sources such as industrial gamma radiography.[158] When conducted safely, industrial radiography work carries minimal risk. However, as explained in the previous three case studies, historical incidents related to radioactive industrial radiography sources have led to significant exposure doses for workers, resulting in severe health effects such as radiation burns and, in rare cases, fatalities.[159] Moreover, there have been documented cases where the general public were exposed to excessive radiation due to insufficient control and regulation of radioactive sources. Consequently, the sector has encountered numerous challenges in both safety and security that necessitate effective control measures.

This case study will draw attention to the gaps in control strategies where human-machine errors can lead to accidents. Identifying these gaps allows for reflection on the development of more robust and effective safety and security strategies. It is crucial to be aware of the potential consequences associated with incidents related to radioactive sources. Understanding the direct causes of such incidents enables us to address both immediate concerns and establish long-term preventive measures.

Background

The Naval Research Laboratory in the United States established gamma radiography in the 1920s.[160] Since then, it has rapidly expanded globally. Industrial radiography now plays a vital role in inspecting manufactured goods for large-scale projects such as power plants, submarines, and spaceships. Three essential elements contribute to the success of industrial radiography: competent radiographers, modern equipment, and oversight by authoritative bodies. Any issues with these components can lead to events of varying severity, ranging from minor incidents to catastrophes that impact both the economy and the environment.

The simplicity and accessibility of materials make the development of radiological weapons relatively straightforward compared to other options. Consequently, these sources are an intriguing target for terrorist groups with limited resources, so there is always a risk of unauthorised acquisition of radiography sources.

By analysing the records documenting radiation overexposure events from the past thirty years, it is possible to identify the primary factors influencing accidents in industrial radiography in Africa. The literature reveals that accidents involving the artificial source Ir-192 were most prevalent across various African cities, followed by Co-60 and Cs-137.[161] The IAEA

158 IAEA, 'Categorization of Radiation Sources,' TECDOC-1191, 200. https://www.iaea.org/publications/6180/categorization-of-radiation-sources

159 P. Ortiz, M. Oresegun & J. Wheatley, 'Lessons from Major Radiation Accidents,' Paper presented at IRPA 10, Hiroshima, May 2000. https://www.irpa.net/irpa10/cdrom/00140.pdf

160 Don J. DeYoung, 'The Naval Research Laboratory and its Mission of a Century,' US Naval Research Laboratory, 2023. https://apps.dtic.mil/sti/trecms/pdf/AD1209080.pdf

161 This finding was corroborated by the annual report for 2016 by the James Martin Centre for Nonproliferation Studies (CNS), which highlighted the resolution of four incidents involving Iridium-192 sources intended for industrial use.

prioritises the recovery of the most dangerous radioactive sources and has a track record of successful retrieval efforts. A recent example is the case of missing uranium in Libya (see page 33).

Furthermore, the record of cases shows that if defence-in-depth (DiD) principles are not applied to both safety and security components, the likelihood of an accident increases dramatically.[162] Consequently, the layers necessary to mitigate and prevent the occurrence of accidents include the control of human error and machine defects, as well as regulatory authorisation and training.

How accidents happen

Industrial radiography procedures are often conducted in remote environments, such as construction sites, where reliance on procedural controls rather than security measures is prevalent. Additionally, time constraints in completing projects can lead radiographers to finish their tasks in haste. Under such circumstances, radiographers may inadvertently or intentionally lose control of the radiation source. Inadvertent loss of control can occur due to equipment failure, loss during transportation, or misrouting. On the other hand, intentional loss of control may stem from theft for monetary gain (such as scrapping the source), inappropriate disposal, or malicious intent. These factors highlight the potential risks and vulnerabilities in industrial radiography practices, where the combination of challenging work environments, time pressures, and reliance on procedural controls can contribute to incidents.

Maintaining a delicate balance between security and safety is crucial when dealing with radioactive sources throughout their life cycle, from acquisition to disposal. This includes activities such as licensing, importing, possessing, using, and disposing of radioactive materials. By prioritising security and safety throughout the life cycle of radioactive sources, organisations can effectively manage the risks associated with these materials and contribute to a safer working environment and community. To accomplish this, it is necessary to establish robust protocols, adhere to regulatory guidelines, and provide continuous training and awareness programmes.

It is necessary to draw lessons from the initial events, contributing factors, and outcomes of accidents in order to prevent or mitigate their reoccurrence. Human error is the leading cause of exposure incidents in radiography, followed by equipment malfunctions and loss of authority control. The primary cause of human error is noncompliance with set rules; after hundreds of radiography shots, the radiographer feels confident conducting their work without adhering to procedures. For instance, the radiographer does not determine whether the radiation source is exposed or shielded. Another example of human error is incorrect interpretation; some radiographers interpret the radiation survey meter reading incorrectly and do not react appropriately. On other occasions, the radiographer is aware of the issue but does not respond appropriately. Wilful transgression is a type of human error that occurs when employees are influenced by economic factors. In the workplace, human error is more complex than other errors because it is unpredictable. In addition, it is an inevitable aspect of our life.

Equipment failure is the leading cause of accidents. For example, where the radiographer has no choice but to use a radiological survey meter to confirm that the source is in a secure location. Due to poor survey meter maintenance, radiographers frequently fail to monitor the radiation after exposure. Any fundamental or auxiliary component breakdown may result in an accident, for example the failure of the guide tube or the gear teeth of the hand.

An indirect cause that may result in an accident is loss of control by the competent authority. Inadequate communication between registrants, licensees, and competent authorities may have an impact on the management system used by the authority body to control and investigate the process. On the other hand, ambiguous policies or unclearly written regulations will hinder compliance with regulatory requirements. Regulators must ensure that licensees comprehend their roles, how their performance will be evaluated, and how they will be held accountable. Moreover, they are fully conscious of the possibility of an accident and its repercussions.

Embarking on a journey to build trust and positive relationships is a challenging task. Identifying the paths that the authoritative body could take for guidance and supervision and establishing the responsibilities and accountability of registrants during normal operations or in the event of incidents or accidents requires significant effort.

162 Olivier Grégoire, 'The application of Defence-in-Depth in nuclear security,' presented at the Canadian Nuclear Society annual conference, June 2023.

Lessons learned

It is particularly challenging for workers to determine when they are receiving a dangerous dose of radiation, because radioactivity does not provide any typical cues that indicate the existence of a hazard (eg, light, sound, heat, smoke, or smell). A radiographer can only prevent exposure to this hazard by meticulously adhering to the instructions provided for the task. In order to complete industrial radiography in a safe and efficient manner, it is essential to hire qualified and skilled personnel. Radiography companies should provide radiography professionals with ongoing training to keep their knowledge and skills current.

The operator's second line of defence against radioactive hazards involves selecting the appropriate device according to international standards and consistently maintaining and calibrating it. Additionally, it is crucial to maintain a positive relationship through effective communication between regulatory authorities and licensees, demonstrating openness and willingness to discuss issues and potential solutions promptly. A strong partnership includes regular discussion meetings and the dissemination of information and updated regulations through electronic bulletins, providing opportunities for exchanging information, sharing best practices, and fostering cooperation. This approach helps prevent radioactive sources from becoming uncontrolled – whether accidental or on purpose.

Conclusions

The previous three case studies highlighted lost and found incident in Algeria, Egypt and Libya. Accordingly, this piece has tried to put together broad lessons for North Africa – and beyond. Given current international conflicts and political tensions, there is a need for effective management and collaboration to mitigate the risk of illicit trafficking attempts by adversaries or rivals. In the context of industrial radiography, enhancing the process involves the initial selection of a skilled and trained radiographer, followed by emphasising the importance of choosing the right equipment and maintaining it in optimal condition. As a third step to ensure compliance with regulatory requirements, the governing body can enhance the process by establishing open communication channels with registrants for the exchange of best practices. Furthermore, sustaining nuclear development requires international cooperation through the establishment of an effective nuclear security regime.

Suggested discussion points

1. How can the industrial radiography sector ensure security without compromising efficiency in challenging environments with time constraints?
2. How can national regulatory bodies and industry stakeholders collaborate more effectively to establish comprehensive control measures?
3. How can cooperation in North Africa be strengthened to prevent unauthorised acquisition and misuse of radioactive sources?

Tools to enhance nuclear security in North Africa

By Mohammed Allam

Overview

In the evolving landscape of nuclear security, North Africa occupies a pivotal position. The region is witnessing a burgeoning interest in nuclear technology and energy. This heightened interest corresponds with an escalating demand for nuclear and radioactive materials essential for applications ranging from electricity production to medicine, agriculture, industry, and research – contributing to the improvement of daily life worldwide. However, this increasing demand brings forth distinctive challenges, notably the potential risk of these materials falling into unauthorised hands. This underscores the necessity for a comprehensive approach to enhance nuclear security. Accordingly, this case study explores the diverse tools and strategies implemented in North Africa to fortify nuclear security, taking into account the region's unique geopolitical and technological dynamics.

Recognising the gravity of potential threats, this case presents the available cooperative measures, regional policies, and international initiatives adopted to minimise risks. Access to essential tools for all stakeholders involved is indispensable, aligning with aims to implement effective national policies and ensuring a secure and sustainable future for nuclear development in North Africa.

Regional and international platforms to enhance nuclear security

There are many international as well as regional organisations that play an effective role in strengthening nuclear security and increase cooperation among countries.[163] The most important of these for North Africa are as follows:

International Atomic Energy Agency (IAEA)

The IAEA's mandate and functions in nuclear security are derived from its establishment in both legally binding and non-binding instruments. Universal adherence to these instruments and harmonized national legal and regulatory frameworks can make a major contribution towards strengthening nuclear security. The IAEA informs and advises States about the relevant international legal standards and encourages them to adhere to and implement them. The main international legal instruments adopted under the IAEA's auspices are the CPPNM and its 2005 amendment, as well as the *Code of Conduct for the Safety and Security of Radioactive Sources* with its supplementary guidance.[164] In terms of non-binding rules, there is the *Code of Conduct on the Safety and Security of Radioactive Sources* along with supplementary guidance on the import and export of radioactive sources and on the management of disused sources, as well as a body of technical guidance on establishing and maintaining a national nuclear security regime (Nuclear Security Series).[165]

163 A paper on tools relevant for the Middle East is available here: Nilsu Goren, 'Regional Tools to Strenghten Nuclear Security: The Middle East,' NTI Global Dialogue on Nuclear Security Priorities, 2019. https://media.nti.org/documents/6_NTI_Global_Dialogue_November_2019_Discussion_Paper_Middle_East_FINAL.pdf

164 IAEA, 'Nuclear security conventions.' https://www.iaea.org/topics/nuclear-security-conventions

165 J. Herbach, 'Relationship Between Legally Binding and Non-Binding Instruments in the International Legal Framework for Nuclear Security,' *Nuclear Law Institute: A Collective View on a Decade of Capacity Building and Development in Nuclear Law,* 2022.

The International Atomic Energy Agency holds training courses, workshops and technical meetings with the authorities concerned with nuclear security issues in North Africa. It also provides financial and technical support for the modernisation and establishment of physical protection systems for nuclear installations and related facilities. Specifically, the International Physical Protection Advisory Service (IPPAS), created by the IAEA in 1995, provides peer advice on implementing international instruments and Agency guidance on the protection of nuclear and other radioactive material, associated facilities and associated activities. An IPPAS mission compares a State's existing practices against relevant international instruments and IAEA nuclear security publications. It also includes an exchange of experience and good international practices aimed at strengthening the State's nuclear security regime. IPPAS missions comprise a national level review of the legal and regulatory framework. Depending on a State's request, they may also include a review of security systems and measures at facilities and during the transport of nuclear and other radioactive material. IPPAS missions also can cover computer security.

The IAEA also offers nuclear security e-learning, with free online learning modules in nuclear security. Each module is based on the Nuclear Security Series and other guidance documents with an estimated to take one to four hours to complete. The modules target a wide range of professionals with nuclear security responsibilities and others interested. Modules can be accessed by visiting the IAEA's e-learning platform. Furthermore, an international master's degree programme in Nuclear Security started at the beginning of January 2016 with the active support of the IAEA and the Bulgarian government. This programme is intended to prepare highly qualified managerial staff for the nuclear security sector, and it has hosted students from Jordan, Egypt, Sudan, Yemen, Lebanon, Iraq, Algeria, Libya, Mauritania, and Morocco.[166]

Furthermore, the INSEN is a partnership established under the auspices of the IAEA. INSEN was founded in 2010 during an IAEA nuclear security workshop on nuclear security education, in which representatives from almost 30 academic institutions and other stakeholders took part. The network aims to enhance global nuclear security by developing, sharing and promoting excellence in nuclear security education. INSEN members collaborate in the following areas:

- Development of peer-reviewed textbooks, instructional material, computer-based teaching tools, and exercises and materials for laboratory work.
- Faculty development in the different areas of nuclear security through courses, exchanges, and joint development and implementation of nuclear security education programmes or courses.
- Joint research and development activities to share scientific knowledge and infrastructure;
- Student exchange programmes to foster international cooperation and exchange of information.
- Implementation of degree programmes and courses in nuclear security education.
- Quality assurance, namely consistency with IAEA defined terminology set out in the IAEA Nuclear Security guidance documents.
- Academic theses supervision and evaluation.
- and performance of surveys on the effectiveness of nuclear security education among students and faculty.[167]

The IAEA also works with States to establish national Nuclear Security Support Centers (NSSCs) to strengthen the sustainability of nuclear security and facilitates cooperation among NSSCs. NSSCs contribute to sustaining the national nuclear security regime by supporting competent authorities, authorised persons, and other organizations with nuclear security responsibilities. Main NSSC functions are:

- Human resource development, specifically through the provision of a national nuclear security training programme.
- Technical support services for nuclear security equipment lifecycle management.
- and scientific support services for provision of expertise, analysis, and research and development for nuclear security.[168]

166 University of National and World Economy, 'International Master's Programme in Nuclear Security,' 2023. https://www.unwe.bg/nuclear-security/en
167 IAEA, 'International Nuclear Security Education Network.' https://www.iaea.org/services/networks/insen
168 IAEA, 'Arab Network of Nuclear Regulators,' 2022. https://gnssn.iaea.org/main/ANNuR/Pages/default.aspx

The Arab Atomic Energy Agency (AAEA)

AAEA works within the framework of the League of Arab States to coordinate the scientific efforts of Arab countries in the field of peaceful uses of atomic energy.[169] It also contributes to the transfer of knowledge and peaceful nuclear technologies. Its main objectives are:

- To coordinate activities in the peaceful applications of atomic energy to improve overall economic development.
- Assist in capacity building and transfer of scientific information.
- Focus on training and supporting Arab scientists to attend conferences related to the peaceful uses of atomic energy.
- Establishing harmonised regulations on radiation protection, nuclear safety and security, and the safe handling of radioactive materials.
- Development of an EPR system.
- Coordination of scientific and technical activities with relevant regional and international organisations.
- Organising and sponsoring relevant regional conferences.
- And creating scientific and technical awareness towards nuclear sciences by publishing scientific documents and translating relevant rules and regulations. [170]

The actual work of the Arab Atomic Energy Authority began on 15 February 1989. Its permanent official headquarters is located in Tunis, the Republic of Tunisia. There are 14 member states in the Commission: Jordan, Bahrain, Tunisia, Saudi Arabia, Sudan, Syria, Iraq, Palestine, Kuwait, Lebanon, Libya, Egypt, Mauritania, and Yemen – and the AAEA welcomes the joining of further Arab countries.[171] Notable AAEA activities include representation at the IAEA General Conference[172] and Arab Conference on Peaceful Uses of Atomic Energy.[173]

The Arab Network of Nuclear Regulators (ANNuR)

The ANNuR was created in 2010 with the purpose of strengthening and harmonising the regulatory infrastructure in Arab countries as well as exchanging regulatory knowledge and experiences with other international and regional networks under the IAEA Global Nuclear Safety and Security Network (GNSSN). The IAEA and the ANNuR signed practical arrangements in April 2014 that constitute a clear framework for the increased cooperation between the two organisations. For example, ANNuR delegates have participated in IAEA workshops on Nuclear Safety and Security[174] as well as Small Modular Reactors (SMR).[175]

At the time of writing, ANNuR has 22 members, of which 19 have IAEA approved Integrated Nuclear Security Support Plans (INSSPs). Network members provide each other with information on the implementation of their national INSSPs, such as activities related to the legislative and regulatory framework for nuclear security; national threat and risk assessments; physical protection regimes; and the detection of criminal and unauthorised acts involving nuclear or other radioactive material out of regulatory control.[176]

Initiatives based in the Middle East

The Arab Institute for Security Studies (known by the acronym ACSIS) is a regional organisation located in Amman (Jordan). Established in 1995, the Institute carries out its activities in association with a number of local, and international agencies, including the United Nations, League of Arab States and other bodies. The institute operates under royal patronage with an international board.

ACSIS is dedicated to upholding global peace, fostering peaceful relations among people worldwide, and preserving global security. The institute addresses

169 D. Mosbah & S. Takriti, 'The Research Reactors in Arab Countries: characteristics and utilizations,' presented at the International Conference on Research Reactors: Safe Management and Effective Utilization 14–18 November 2011, Rabat, Morocco.

170 AAEA, 'الخطط التنفيذية التفصيلية لمشاريع الإستراتيجية العربية للاستخدامات السلمية للطاقة الذرية,' 2020. http://www.aaea.org.tn/?page_id=697

171 Mohamed I. Shaker, 'Nuclear power in the Arab world & the regionalization of the nuclear fuel cycle: an Egyptian perspective,' *Daedalus*, Vol. 139, No. 1, 2010.

172 Nayana Jayarajan, 'IAEA and Countries Collaborate to Strengthen Nuclear and Radiological Emergency Response,' IAEA News, 16 October 2023. https://www.iaea.org/newscenter/news/iaea-and-countries-collaborate-to-strengthen-nuclear-and-radiological-emergency-response

173 Joint Institute for Nuclear Research, 'Arab Atomic Energy Agency strengthens ties with JINR,' 5 March 2021. http://www.jinr.ru/posts/arab-atomic-energy-agency-strengthens-ties-with-jinr/

174 Arab News, 'Jordan hosts regional workshop on nuclear safety, security,' 4 October 2022. https://www.arabnews.com/node/2175031/middle-east

175 World Nuclear News, 'IAEA holds first SMR workshop,' 10 March 2016. https://world-nuclear-news.org/Articles/IAEA-holds-first-SMR-workshop

176 Vasiliki Tafili, 'Arabic Speaking Countries Discuss Nuclear Security Plans,' IAEA News, 9 March 2023. https://www.iaea.org/newscenter/news/arabic-speaking-countries-discuss-nuclear-security-plans

conditions essential for promoting peace and stability both regionally and internationally, aligning with the principles of the United Nations. It aims to offer precise and effective analyses of the security landscape and provide recommendations for addressing pressing issues.[177] For example, ACSIS has been able to bring together representatives from Saudi Arabia and Iran – advocating that dialogue between the parties is the only way forward.[178]

The Gulf Nuclear Energy Infrastructure Institute (GNEII) seeks to develop expertise among future leaders of Gulf region nuclear power programmes in global standards, norms and best practices in nuclear energy programmes. More specifically, the institute aims to contribute to the enhancement of nuclear security, safety, and safeguards by providing an avenue for regional nuclear interaction, technical collaboration, lessons learned discussions, and best-practices sharing. It is a multidisciplinary human capacity development institute offering education, research and technical services to support responsible nuclear energy programmes in the Gulf and Middle East regions.[179]

Naif Arab University for Security Sciences (NAUSS) was established in 1978 as an Arab institution specialised in security sciences to fulfil the needs of the Arab law enforcement agencies for an academic institution that promotes research in security sciences, offers graduate education programmes and conduct short-term training courses, which should contribute to the prevention and control of crimes in the Arab world. NAUSS is a regional organisation providing education and training in all security disciplines to students from 22 Arab countries. NAUSS is operated by board of directors reporting directly to the Council of Arab Ministers of Interiors.

NAUSS has developed a one-year nuclear security programme which serves the medical, military, and industrial sectors by preparing – through critical thinking and discussion – skilled specialists to support nuclear security at the national level.[180] The programme also supports the Arab cadre in developing a nuclear security system that can effectively prevent and detect unauthorized access to physical facilities. The curriculum of the current higher-diploma programme at NAUSS provides students with a fundamental understanding of nuclear security.[181]

Other relevant global organisations

The World Institute for Nuclear Security (WINS) is a professional institute and international non-governmental membership organisation based in Vienna, Austria. Its mission is to be a leader in knowledge exchange, professional development and certification for nuclear security management. In this capacity, WINS focuses on the operational level of license holders, regulators and other similar stakeholders rather than on the country level (which is the purview of the IAEA). They have contributed to training many workers in the field of nuclear security in Arab countries.[182]

The National Nuclear Security Administration (NNSA), created by US Congress in 2000, is a semi-autonomous agency within the US Department of Energy responsible for enhancing national security through the military application of nuclear science. It responds to nuclear and radiological emergencies in the United States and abroad and also supports many Arab countries with training programmes in the field of nuclear security.[183]

Lessons learned

After the establishment and expansion of nuclear programmes across North Africa, an urgent need to strengthen nuclear security became evident. Specifically, the need to improve local expertise in the field of nuclear security culture. There is no doubt that all of the above organisations have played and will play a major role in strengthening nuclear security in North Africa and the Middle East, and that they enhance cooperation between Arab countries in the field of nuclear security. Relevant countries must cooperate among themselves in order to:

- Establish a permanent regional centre for radiological and nuclear security that brings together national delegations regularly to discuss issues that concern their interests.

177 Arab Institute for Security Studies, 'Who We Are.' https://acsis.org/about.php
178 Angus Kingsley-Anderson, 'A meeting of Saudi Arabian and Iranian minds in Amman,' Middle East Monitor, 21 August 2023. https://www.middleeastmonitor.com/20230821-a-meeting-of-saudi-arabian-and-iranian-minds-in-amman/
179 Adam D. Williams, Alexander Andreevich Solodov, Amir H. Mohagheghi, Philip A. Beeley & Saeed Al-Ameri, 'The Gulf Nuclear Energy Infrastructure Institute (GNEII): Origins, Objectives, and Operations – A Joint Report. No. SAND-2019-14857,' Sandia National Lab, Albuquerque, NM (United States) and Khalifa University of Science and Technology, Abu Dhabi (United Arab Emirates), 2019.
180 Fataftah Amjad, 'Nuclear security education and training at Naif Arab University for Security Science,' 2009. https://inis.iaea.org/collection/NCLCollectionStore/_Public/41/011/41011712.pdf
181 Ahmed Alanazi, Ahmed M. Alqasimi & Mostafa Kofi, 'Adapting Nuclear Security Education Programs in Arab Countries,' *International Journal of Nuclear Security,* Vol. 8, No. 1, 2023
182 WINS, 'About Us,' 2023. https://www.wins.org/about-us/
183 US Department of Energy, 'About NNSA.' https://www.energy.gov/nnsa/about-nnsa

- Establish a regional expert group on nuclear security, with support from international networks such as INSEN.

- Facilitate procedures for establishing cooperative protocols with international organisations, centres and institutes concerned with the field of nuclear security to benefit from their expertise and support nuclear security systems in North Africa.

- Take practical measures to address the technical necessities for implementing nuclear security measures and consider the organisational aspects of the institutions that will accommodate these efforts.

These action points are especially relevant given the ongoing wars and the complexity of conflicts and terrorist activities. Focusing on nuclear security will allow governments to effectively cooperate in combating nuclear security threats in the region. This focus will also contribute to monitoring nuclear materials, reducing internal threats, taking the necessary measures to eliminate the risks of unintended access to current and upcoming nuclear materials and facilities in the region, exchanging experiences, and building professional cadres in the field of nuclear security.

Conclusions

In conclusion, the proliferation of nuclear technology across North Africa has raised concerns about the potential risks of these materials falling into the wrong hands. Recognising the critical importance of enhancing nuclear security, international and regional organisations have taken significant strides to establish frameworks, guidelines, and training programmes aimed at bolstering security measures.

Notably, the IAEA has played a central role in providing technical assistance, training, and educational programmes to strengthen nuclear security in the region. Furthermore, the establishment of ANNuR and the AAEA has facilitated increased collaboration and knowledge sharing among Arab countries. These initiatives have led to the development of harmonised regulations and the coordination of scientific efforts to ensure the safe handling of radioactive materials.

Moving forward, the establishment of a permanent regional centre for radiological and nuclear security, the formation of a regional expert group on nuclear security, and the facilitation of cooperative protocols with international organisations will be instrumental in addressing the evolving threats in the region. By prioritising these measures, governments in North Africa can strengthen their collaborative efforts and ensure the effective implementation of nuclear security measures, thus mitigating the risks posed by unauthorised access to nuclear materials and facilities. This concerted focus on nuclear security is vital not only for regional stability but also for global efforts to combat nuclear security threats and ensure the safe use of nuclear technology for the betterment of society.

Suggested discussion points

1. What are the key challenges that North African countries face in implementing and maintaining effective nuclear security measure?
2. How can international and regional organisations collaborate to establish a comprehensive framework for nuclear security in North Africa?
3. What specific initiatives or strategies can be developed to address the unique challenges in the region?

Scenario: radioactive source security during civil unrest

By Mostafa Kofi and Lamiaa Fiala

Overview

This scenario addresses the critical issue of securing radioactive sources during civil unrest and times of war. It is set in a fictional country, Gamastane. Radioactive sources, often used for medical and industrial purposes, pose a significant risk if mishandled or misappropriated during times of instability. This hypothetical case aims to highlight the relevance of this topic to nuclear and radiological security, emphasising increased complexities and vulnerabilities during political upheaval.

Key issues that this case will cover are the impact of conflicts and civil unrest on radioactive source security; management of sources during turbulent times; instances of source theft or loss during these situations; and anticipating and preparing for such scenarios.

Scenario summary

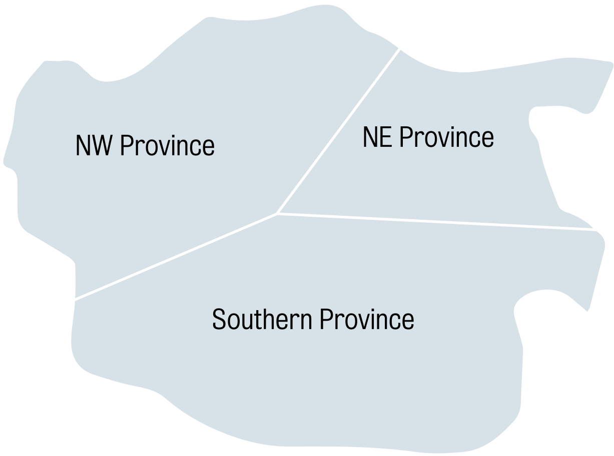
In the fictional country of Gamastane (made up of a North-West, North-East and Southern Province), the use of radioactive sources is integral to the functioning of three prominent hospitals and eight industrial facilities.[184, 185] These sources, including cesium-137 and cobalt-60, play a vital role in critical medical procedures such as cancer treatments and advanced radiography within the hospitals. Furthermore, barium-133 is utilised for precise quality control processes and density measurements across various industries, ensuring the maintenance of high standards in manufacturing and construction practices. The regulatory agency oversees these radioactive sources, evaluating their approval, usage, and disposal while enforcing stringent safety and security protocols across all facilities.

Gamastane recently found itself embroiled in a wave of civil unrest, triggered initially by peaceful strikes and demonstrations organised by discontented workers and citizens, advocating for improved living standards and labour rights. However, as political tensions flared, the situation swiftly escalated into violent clashes and widespread riots, stretching the capabilities of the local law enforcement. The authorities encountered numerous challenges, including the geographical distribution of the radioactive sources across the various provinces, breakdowns in communication channels, and shortages of essential resources – hindering their ability to mount an effective response to the intensifying crisis.

Amid the chaos, concerns mounted over the potential misuse of radioactive sources during the unrest. Fears were compounded by apprehensions that these materials could be seized by nefarious actors, potentially leading to the development of devastating RDDs or REDs, commonly known as 'dirty bombs.' While the security of the radioactive sources remained intact throughout the period of turmoil, stringent preventive measures were promptly instituted.[186] Additional security personnel were deployed to bolster the safeguarding of critical facilities housing radioactive sources. Enhanced surveillance systems and stringent access controls were implemented to fortify security and prevent any unauthorised access to areas where radioactive materials were stored.

184 IAEA, 'Identification of Radioactive Sources and Devices,' *Nuclear Security Series,* No. 5 (Technical Guidance), 2007. https://www.iaea.org/publications/7567/identification-of-radioactive-sources-and-devices
185 WINS, 'Peaceful Uses of Radioactive Material: Nuclear Security Considerations,' 2023. https://www.wins.org/document/peaceful-uses-of-radioactive-material/
186 IAEA, 'Security of Radioactive Sources,' *Nuclear Security Series,* No. 11 (Implementing Guide), 2009. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1387_web.pdf

Figure i: Gamastane country profile for radioactive sources



Recognising the gravity of the situation, the regulatory agency collaborated closely with law enforcement agencies and relevant government bodies to formulate a unified response strategy. Emphasising the importance of upholding the integrity and security of radioactive sources during the turbulent period, the collective efforts of all stakeholders were focused on ensuring the protection of these critical materials. In tandem with these efforts, emergency communication channels were established to expedite the dissemination of critical information and real-time updates regarding the status of radioactive source security to all relevant stakeholders, fostering a coordinated and well-informed approach to crisis management. In the end, no sources were reported missing or stolen.

Scope of the problem

The scope of the problem extends beyond the immediate impact of civil unrest, significantly hindering the effective management and security of radioactive sources. This unrest, characterised by its unpredictability, disrupts societal and governmental systems, posing complex challenges. While these emergencies may not directly result from radioactive sources, their influence can profoundly affect the security and stability of these critical materials.

During civil unrest, the regulatory agency overseeing radioactive sources faces strain as law enforcement resources are redirected from routine duties, potentially compromising monitoring and oversight processes. This diversion can create vulnerabilities, exposing materials to potential security breaches and unauthorised access. Disruption in the supply chain during civil unrest can lead to delayed delivery of crucial security equipment, leaving facilities vulnerable to external threats like theft or misuse by malicious actors taking advantage of the chaotic environment. Moreover, a lack of preparedness to manage challenges posed by civil unrest further complicates source security. Without well-defined contingency plans tailored for these scenarios, the agency's ability to respond effectively is hindered, leaving facilities and communities susceptible to radiological hazards.

Design Basis Threat (DBT)[187]

Relevant here is DBT: a statement of the intentions and capabilities of an adversary or adversaries that could be considered a 'worst-case credible threat' to a facility that contains nuclear or radiological materials.[188] During civil unrest this can include insider theft attempts, both

Table 1: Types of radioactive sources used in Gamastane

	Number	Type	Uses
NE Province	3	Cesium-137	Medical
	2	Cobalt-60	Medical
	9	Barium-133	Industrial
NW Province	1	Cesium-137	Medical
	3	Cobalt-60	Medical
	8	Barium-133	Industrial
Southern Province	6	Cesium-137	Medical
	7	Cobalt-60	Medical
	9	Barium-133	Industrial

187 With thanks to George Foster for valuable insight on DBT in this scenario.
188 International Atomic Energy Agency, 'Design Basis Threat (DBT),' 2023. https://www.iaea.org/topics/security-of-nuclear-and-other-radioactive-material/design-basis-threat

non-violent and violent, as well as sabotage attempts with unacceptable radiological consequences. Potential adversaries could be individuals, groups, or organisations with malevolent intentions, such as terrorist groups or even hostile governments seeking to acquire nuclear materials or sabotage nuclear facilities.

The concept of DBT is crucial in the design and implementation of security measures for nuclear facilities. It helps in establishing a set of criteria that the facility's security systems and protocols must be able to withstand. By considering various realistic threat scenarios and their potential impacts, security professionals can develop appropriate security strategies, protocols and preventative measures.

The DBT typically takes into account factors such motivation, intent, and capability – including enabling support. Information is derived from National Intelligence Agencies, and then analysed to facilitate the implementation of security measures that are commensurate with the potential consequences of the realised risks. The DBT is continuously reviewed and updated to ensure that security measures remain effective against evolving threats and potential changes in the security landscape. Regular assessments and evaluations are conducted to identify any gaps in security and to implement necessary upgrades to counter new and emerging threats.

In responding to the current situation in Gamastane, it is necessary to understand the origins and specific characteristics of the civil unrest, including changes in societal conditions and the validity of existing assumptions. Authorities have to identify relevant organisations, and discuss what licensees need to do to for secure their radioactive sources. They should engage with regulators, operators, academia, and other stakeholders to develop short- and long-term plans for securing radioactive sources.

With that said, the licensee is not going to play out these complicated social scenarios; to do so would confer too great a responsibility. It would likely encourage and generate inconsistency and would cause operational confusion, probably, with parallel State level bodies.

Key points that can be addressed are the evaluation of threats in the face of political violence; coordination with stakeholders and defining roles and responsibilities, including leadership and management; international and regional communication, as well as public engagement strategies; flexibility of EPR plans; and any required training.

The goal of these plans is to ensure public health and safety, including staff safety. They can also be used to anticipate and mitigate risks; identify possible liabilities and losses; protect radioactive assets; facilitate collaboration amongst relevant parties; ensure sensitive information is shared securely; coordinate with relevant external organisations; and generally maintaining situational awareness in order to act swiftly.

Designing a DBT for Gamastane

Given the situation in the Gamastane scenario, a standard DBT would include the following considerations:

- Local security infrastructure: evaluate the effectiveness of the existing security infrastructure in Gamastane, including the capabilities of local law enforcement agencies, emergency response protocols, and the integration of security measures within the hospitals and industrial facilities.

- Historical precedents and global threats: consider past incidents involving the theft or misuse of radioactive sources in similar geopolitical environments. Analyse regional trends and threats related to the illicit trafficking of radioactive materials and the proliferation of radiological weapons.

- Adversary profiles: identify potential adversaries, such as organised criminal groups, extremist factions, or terrorist organisations, which could attempt to exploit the civil unrest to obtain radioactive sources for malicious purposes.

- Motivations and capabilities: Assess the potential motivations of adversaries, including their desire to cause harm, instil fear, or disrupt the country's stability. Evaluate their capabilities in terms of accessing and utilising radioactive materials, as well as their knowledge of constructing RDD or RED.

- Vulnerabilities and points of entry: analyse the vulnerabilities within the hospitals and industrial facilities that could be exploited by adversaries to gain access to radioactive sources. Identify potential points of entry, such as lax security protocols or inadequate surveillance.

- Risk assessment: assess the potential consequences of a security breach, considering the scale of impact on public health, the environment, and the country's socio-economic stability. Determine the likelihood of adversaries successfully acquiring and utilising radioactive sources for malicious intent.

Civil unrest in Gamastane

The above DBT would aid in fortifying the security of radioactive sources and mitigating the risk of unauthorised access or misuse during the civil unrest as described. With that said, there are a few specific points that should be addressed:

- Increased vulnerability during unrest: during civil unrest and protests, the focus of security forces might shift towards maintaining public order, leading to potential security gaps in critical facilities, including those handling radioactive sources. For instance, post-Arab spring protests in Tunisia lead to increased security concerns – creating opportunities for illicit activities including theft and vandalism.[189]

- Potential infiltration by extremist groups: assess the likelihood of extremist groups exploiting the chaos during civil unrest to infiltrate facilities with radioactive sources. The case of Libya after the fall of Gaddafi's regime serves as an example, where extremist groups exploited the security vacuum to gain access to various types of weapons and materials.[190]

- Impact on regulatory oversight: evaluate the possible impact of civil unrest on the functioning of regulatory agencies overseeing the use of radioactive materials. For instance, political instability in Algeria has affected regulatory oversight of various industries – creating opportunities for security breaches.[191]

- Threat of insider complicity: consider the risk of insiders within facilities being sympathetic to or influenced by protest movements, potentially aiding adversaries in accessing radioactive sources.[192] Instances of insider involvement in security breaches during the 2011–2012 Egyptian revolution illustrate this risk.[193]

- Social disruption and public panic: analyse the potential consequences of public panic or misinformation during civil unrest, which may lead to further security challenges and impediments to effective crisis management. The spread of 'fake news' during protests following a military coup in Sudan serves as an example of such ramifications.[194]

Lessons learned

What went right

- The radio-regulatory agency in Gamastane was functional and maintained control over radioactive sources.

- Despite widespread civil unrest, no radioactive sources were lost, demonstrating effective initial security measures.

- Stakeholder engagement and collaboration were recognised as crucial for planning and executing security measures.

What went wrong

- The escalation of civil unrest highlighted vulnerabilities in the security of radioactive sources, demanding improved preparedness.

- Lack of detailed contingency plans for civil unrest scenarios led to uncertainties in response.

- The compromise of supply chains hindered efforts to support source security.

Proposed improvements

- Develop comprehensive contingency plans tailored to civil unrest scenarios, outlining roles, responsibilities, and communication protocols.

- Enhance international and regional cooperation to share best practices and intelligence.

- Conduct regular training and drills to prepare staff for crisis situations.

- Invest in robust supply chain security measures to prevent source compromise during unrest.

- Foster public awareness campaigns about the importance of radioactive source security.

189 Monica Marks, 'Plagued by Insecurities,' Carnegie Endowment for International Peace, 5 March 2013. https://carnegieendowment.org/sada/51117
190 Crisis Group, 'Exploiting Disorder: al-Qaeda and the Islamic State,' 14 March 2016. https://www.crisisgroup.org/global/exploiting-disorder-al-qaeda-and-islamic-state
191 Freedom House, 'Algeria – Freedom in the World 2020'. https://freedomhouse.org/country/algeria/freedom-world/2020
192 IAEA, 'Preventive and Protective Measures against Insider Threats,' *Nuclear Security Series,* No. 8 (Implementing Guide), 2008. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1359_web.pdf
193 Yasmine Saleh, 'Restive Egypt workers pose economic, political threats,' *Reuters,* 6 October 2011. https://www.reuters.com/article/uk-egypt-workers-unrest-idUKTRE7951EI20111006
194 Flora Carmichael and Owen Pinnell, 'How fake news from Sudan's regime backfired,' *BBC News,* 25 April 2019. https://www.bbc.com/news/blogs-trending-47899076

Conclusions

The case study of securing radioactive sources during civil unrest in Gamastane highlights the critical importance of preparedness and coordination in maintaining nuclear and radiological security during turbulent times. Lessons learned from this scenario emphasise the need for tailored contingency plans, stakeholder engagement, and international cooperation to ensure the protection of radioactive sources. As civil unrest and conflicts continue to pose threats to nuclear security worldwide, this scenario serves as a reminder of the ongoing challenges and the necessity of adapting security measures to evolving circumstances.

Suggested discussion points

1. How do conflicts and violent civil unrest impact radioactive source security? Does the vulnerability of radioactive sources increase; are regular security measures affected; are usual activities such as transport affected?
2. What changes to security occur when countries are experiencing civil unrest? How do security measures differ depending on the event?
3. Can we anticipate civil unrest and prepare for it? How can we improve the security of radioactive sources during unplanned or unexpected conditions?

III: Conclusion


RADIOACTIVE II
CONTENTS
ACTIVITY
TRANSPORT INDEX

This handbook has presented regional case studies from North Africa, written by authors from North Africa. Put together, several key conclusions can be drawn regarding challenges, implications, and lessons related to nuclear and radiological security. The cases cover the need for robust security strategies in industries dealing with nuclear and radiological sources, and demonstrate the leaps Morocco, Algeria, Tunisia, Libya and Egypt have made to create practical policies. They highlight the role of international cooperation and information sharing. In particular, many of the case studies underline the importance of comprehensive public awareness campaigns to educate people about the risks associated with handling nuclear or radiological sources. In a region where this is especially relevant, the cases stress the importance of tailored contingency plans and stakeholder engagement to ensure the protection of hazardous materials during times of civil unrest and conflicts. Together, the case studies underscore the significance of implementing comprehensive strategies that account for evolving threats and they reveal unique opportunities for cooperation and knowledge exchange between countries with similar challenges.

Navigating nuclear and radiological security in North Africa

The reason this handbook focussed on North Africa as a region, is because the neighbouring countries share in certain challenges when it comes to nuclear security. Namely:

Historical legacy and colonial influence: the historical impact of colonialism is evident in the nuclear security landscape of North Africa. Colonial powers' interventions and actions have left a lasting imprint on the region's nuclear security dynamics, with both positive and negative repercussions.

Nuclear energy goals: despite the current absence of operational NPP, there is growing interest among several North African countries in developing civil nuclear sectors. This interest is primarily driven by the aim to diversify energy sources and bolster national development, although progress in this area has been hindered by various factors such as political instability, financial constraints, and international scrutiny.

Nuclear security infrastructures and international relations: all countries in the region are actively striving to establish and strengthen nuclear security infrastructures and regulatory frameworks. Efforts to adhere to international conventions and standards for nuclear security and cooperation with international organisations such as the IAEA reflect a commitment to enhancing nuclear security measures. North African countries' engagement in international forums and agreements, such as the NSS, highlights their commitment to global nuclear security initiatives and their willingness to cooperate with the international community to address shared security concerns.

Socioeconomic disparities and resource constraints: socioeconomic disparities and resource constraints within North African countries have posed significant challenges to the effective management of nuclear facilities, as well as the enforcement of safety standards and protocols. These constraints have resulted in fragmented governance and limited financial resources, which have, in turn, affected nuclear security measures in the region. Accordingly, all North African countries are actively engaging in partnerships and collaborations with foreign entities and international organisations to leverage expertise and resources for the advancement of their nuclear capabilities and infrastructures. These partnerships aim to bolster technical expertise, institutional capacities, and overall nuclear security practices in the region.

Societal and political contexts: the socio-political contexts of the North African countries play a significant role in shaping their nuclear security approaches. Factors such as regional power dynamics, national defence aspirations, and societal perceptions of nuclear security contribute to the varying strategies and priorities adopted by these nations. Furthermore, the presence of protracted conflicts and political unrest in the region has created significant challenges for ensuring robust nuclear security measures. The potential loss of control over military arsenals and the proliferation of weapons in conflict zones pose risks to the security of nuclear materials and facilities.

These factors underscore the complex interplay between historical legacies, regional conflicts, national development goals, and international cooperation in shaping the current state of nuclear security in North Africa.

Looking beyond North Africa

Lessons for North Africa have relevance beyond the region itself. Conducting thorough post-incident analyses and implementing necessary corrective actions contribute to the ongoing evolution and strengthening of nuclear security protocols around the world.

Comparable security contexts: similarities in socio-political settings make the lessons learned in North Africa highly applicable to the challenges faced by other countries in their pursuit of robust nuclear security measures. For example, in the Middle East, conflict in Yemen, Afghanistan and Lebanon has highlighted the risk of weapons proliferation, technology transfer, and the diversion of nuclear materials. In particular, concerns have been put forward about extremist groups acquiring nuclear or radiological materials. What is more, nuclear energy aspirations in both North Africa and the Middle East are often hindered by challenges such as international scrutiny and financial constraints.

Shared platforms: there are many organisations that exist uniting Arab nations across continents, and productive knowledge sharing has already resulted in increased cooperation and opportunities. Gathering additional regional case studies that elaborate on local insights will enable national regulators, policymakers, operators, and other professionals in the nuclear and radiological fields to access examples that are relevant to their context, fostering productive knowledge exchange. Establishing effective communication channels, sharing best practices, and coordinating response mechanisms are important components of a robust approach to nuclear and radiological security.

Transnational nature of nuclear security culture: underlined particularly by the three lost and found cases, it is imperative that countries across the world cultivate awareness of nuclear security culture amongst both personnel and the public. Crucially, national and regional culture influence the way in which nuclear security measures are developed and implemented. For example, countries may share cultural characteristics in terms of leadership, approval processes, and personnel behaviour. By sharing best practices, it is possible to understand how to achieve active engagement in particular organisational contexts. The goal is not only to encourage staff to regularly participate in exercises – but also to understand how to motivate them to commit. Furthermore, public awareness campaigns and comprehensive education programmes play a critical role in promoting individual responsibility – and their effectiveness is influenced by the way in which they are presented and received.

In conclusion, as North Africa strives for sustainable development, energy security, and progress across various sectors, addressing critical concerns in nuclear and radiological security is imperative in order to achieve resiliency going forward. This handbook, featuring comprehensive case studies, not only illuminates historical incidents but also offers insights to avert future incidents. Beyond serving as a knowledge repository, nuclear security educators can leverage this handbook to streamline the creation and execution of impactful training courses and events. Delving into past events makes it possible to enhance awareness and to contribute to capacity building in the region, empowering North Africa to successfully navigate the intricacies of nuclear and radiological security.

Centre for Science & Security Studies
Department of War Studies
King's College London
Strand
London WC2R 2LS
United Kingdom

www.kcl.ac.uk/csss
@KCL_CSSS