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Preventing Proliferation: Tracking Uranium on the Blockchain

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ABSTRACT Advances in technology, the shifting sands of the global nuclear energy market, and the extant standards and practices surrounding the monitoring of radioactive materials raise important questions about the future of nuclear security. Technological advancements have enabled the retrieval of radioactive materials from unconventional sources and made fuel fabrication easier. The emergence of new players in the nuclear energy market also flags concerns about the ability of these nations to track and secure nuclear material within their borders. As nuclear terrorism becomes an increasingly real threat, newer measures must be introduced to securely monitor the movement of radioactive materials. This brief argues that a blockchain-based tracking system may help overcome current monitoring deficits in the trade of radioactive materials and help check proliferation in the process.

INTRODUCTION

Since the advent of Bitcoin, blockchain technology has gone from a financial novelty to an innovative phenomenon that is disrupting multiple industries including healthcare, public service, energy, manufacturing, and media and entertainment. Now, even the defence sector is looking to deploy blockchains to secure critical infrastructure and sensitive information. In this context, one particular area where blockchains would be invaluable is in monitoring the movement of radioactive materials and checking proliferation.

Advances in technology raise important questions about the future of nuclear security. Compounding the situation are the shifting sands of the global nuclear energy market,

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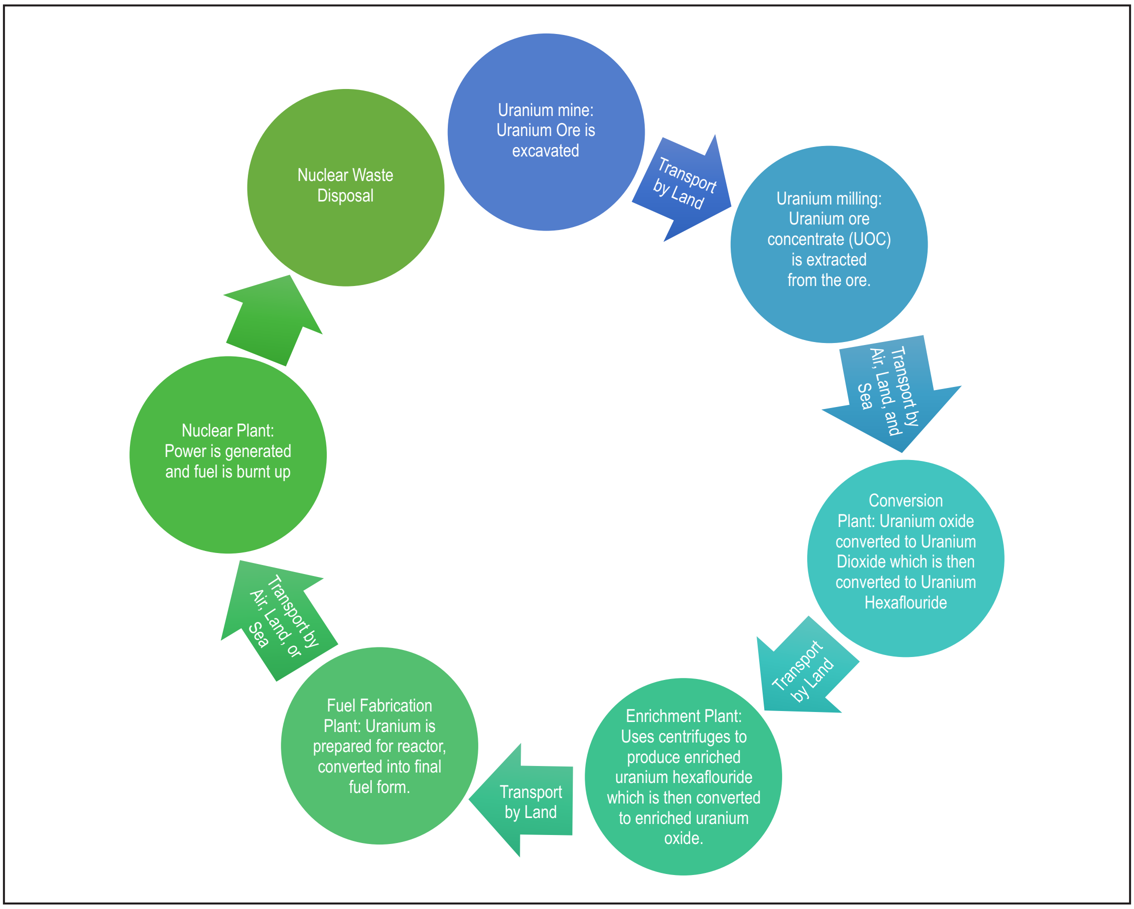
and the extant standards and practices surrounding the monitoring of radioactive materials. Technological advancements have enabled the retrieval of radioactive materials from unconventional sources and made fuel fabrication easier. The emergence of new players in the nuclear energy market also flags concerns about the ability of these states to track and secure nuclear material within their borders. This is exacerbated by the fact that the full extent of the International Atomic Energy Agency (IAEA) safeguards only apply to the back-end of the nuclear fuel cycle. Thus, globally, these materials are not closely tracked until they are shipped out of the conversion plant. Additionally, digital tracking systems are largely absent, making it difficult to monitor the movement of these materials from the mine to the plant/reactor and their final destination that is the disposal site.[1]

Between 1993 and 2012, there were 419 incidents involving illegal dealings in nuclear material that were reported to the IAEA's Incident and Trafficking Database (ITDB).[2] According to Rukhlo and Gadaric, there have been 91 incidents, between 1993 and 2007, involving the illegal trafficking of natural uranium.[3] As nuclear terrorism becomes an increasingly real threat, newer measures must be introduced to securely monitor the movement of radioactive materials. Inertia at this juncture would be catastrophic.

A blockchain-based tracking system may help overcome current monitoring deficits in the trade of radioactive materials. The blockchain is a technology protocol that enables a network of computers to store

Figure 1: Nuclear Fuel Cycle



information, complete transactions and manage a distributed ledger of these transactions. Building a blockchain-based tracking system can foster a more secure network for the transport and movement of these materials in the future.

RADIOACTIVE MATERIALS: THE CURRENT STATE OF SAFEGUARDS

The International Atomic Energy Agency is the watchdog for global nuclear safety and security.[4] It oversees the creation and application of safeguards to check the veracity of declarations that states make about their nuclear material stockpiles and ancillary activities. The IAEA safeguards are couched in legally enforceable treaties known as "safeguards agreements".[5] States accept these safeguards by entering into these agreements with the IAEA.[6] These safeguards are meant to apply to all nuclear material within each member nation as a whole.

Most IAEA safeguards have been captured under the IAEA statute and within the IAEA Information Circular, INFCIRC/153 of 1972 (INFCIRC/153). INFCIRC/153 indicates the point at which the full extent of IAEA

Table 1.

Type of Agreement	Scope and Mandate	Relevant IAEA Circular Document from which safeguards are derived	Parties
Comprehensive Safeguards Agreements	IAEA to ensure that nuclear material is not used to manufacture nuclear weapons or nuclear explosive devices[7]	INFCIRC/153 (Corrected)	Non-Nuclear Weapons States that have signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) + States that are parties to Nuclear Weapon Free Zone treaties[8]
Voluntary offer agreements	Selected facilities that carry out peaceful nuclear activities in the States concerned are made available to the IAEA for the application of safeguards[9]	INFCIRC/153	Nuclear Weapon States as classified under the NPT (China, France, Russia, United States of America, United Kingdom (UK))[10]
Item-specific safeguards agreements	Nuclear materials and facilities specified in these agreements may not be used to manufacture nuclear weapons or advance any martial purpose[11]	INFCIRC/66 (All versions)	Israel, Pakistan, India[12]
Additional Protocols	Expansion of the IAEA's obligation under the CSA. Shifts the focus from investigating and monitoring a State's known amounts of materials and declarations concerning nuclear activities to a system which aims at gathering intricate details about a nation's nuclear and nuclear – related activities, including imports and exports.[13]	INFCIRC/540 (Model Additional Protocol), INFCIRC/193	Countries that are parties to the NPT[14]

Source: IAEA, "IAEA Safeguards: Serving Nuclear Non-Proliferation" (IAEA, June 2015), https://www.iaea.org/sites/default/files/safeguards_web_june_2015_1.pdf.

accountancy and monitoring measures begin to apply to a particular stock of radioactive material. Paragraph 34 (c) of the document provides that the full measure of safeguards within the agreements only apply to nuclear material that is ready to be fabricated or enriched.[15] Thus, the application of these safeguards begins only when the material leaves the conversion plant.

Uranium at the front-end of the nuclear fuel cycle, i.e., Uranium ore that is mined and the Uranium Ore Concentrate (UOC) or yellowcake that is extracted from the ore—is quite low-risk as only a small percentage of it is fissile. As such, both are exempt from full material accountancy and control as it is presumed that these materials are easily secured using existing best practices.

The IAEA has included limited provisions for reporting the trading of UOC. Under these provisions, a State is obligated to report to the IAEA if it has imported or exported any radioactive material, unless it has done so for non-nuclear purposes. Reporting and recording is mandatory if any source material is traded for use in a nuclear reactor. This system of reporting is the only safeguard that is in place for radioactive source materials. It must be noted that no safeguards apply to Uranium ore.

In 1997, the IAEA passed the Model Additional Protocol (INFCIRC/540), to bolster existing safeguards and reporting stipulations. INFCIRC/540 provides that States must furnish an annual report of total uranium and thorium holdings. States must also report the import and export of radioactive source materials for non-nuclear purposes.[16]

The Risk

The systems currently in place to control the illegal use of nuclear material consist of a smorgasbord of disjointed international treaties and documents, unofficial measures, and national regulatory frameworks. Unsurprisingly, there are significant disparities in the domestic implementation and enforcement of these systems, making it difficult to thwart proliferation. These deficits, along with the changing face of the global nuclear market, have made it easier for unverified intermediaries to enter the network and create paths that illegal procurement rings can exploit.

Deficits in the Implementation of IAEA Safeguards[17]

The IAEA annually publishes a Safeguards Implementation Report (SIR) that it submits to its Board of Governors. The SIR provides data to member nations about the obstacles faced by the Department of Safeguards when fulfilling its obligations to ensure the integrity and comprehensiveness of a member State's declarations about its nuclear activities and material. In 2013, a copy of the 2012 SIR that was leaked to the media brought disturbing details to light. The report revealed that 22 States which had Additional Protocols in force failed to adhere to the declaration requirements under these protocols. Additionally, significant delays were noted in report submissions for States that had executed CSAs with the IAEA. Many States also actively thwarted IAEA inspections by hindering access to nuclear facilities or the areas around them and prohibiting the collection of environmental samples. Finally, the report found that States were yet to establish national protocols for material accountancy and safety.

Although larger supplier countries report the trading of radioactive source material on a regular basis, the 2012 SIR revealed that there was considerable inconsistency in the reporting activities of other member States.

NUCLEAR MATERIALS: ACCOUNTING FOR INVENTORY[18]

Industrial nuclear entities in most countries follow a standardised process to account for material inventory. Unique identification (UID) numbers are allotted to each drum. Producers can trace a particular drum to a specific batch of product as UID numbers are linked to the production lot number. Labels contain information about the purity and weight of the material. The information on these labels is usually filled in by felt pen. Drums are weighed and then shipped to the fabrication or conversion plants in batches of 50 and upwards. At the fabrication or conversion plant, the drums are weighed once again. If any discrepancies arise in the weight of the product that was shipped and that which was received, independent auditors are called in to review the shipment. Incongruities are then reported to the regulatory authorities.

Although major private players have deployed control systems within their supply chains and most nations maintain databases to capture the stock of nuclear materials within their borders, these mechanisms remain fragmented and the information exists *in silos*.

It takes private entities from one to 30 days to detect the loss or theft of material at the mills, mines, or during transit. Although drum inventory management processes are automated at most facilities, information about drums and their contents are recorded by hand on paper, leaving room for transcription errors. Moreover, hardly any digital barcoding systems exist for the tracking of material that exit the mines or enter conversion facilities.

Inventory issues are the most pronounced at conversion facilities. Globally, the output of most uranium mines is handled by five conversion plants – Canada, Russia, United States, France, and China. These facilities accumulate huge volumes of material in their storage spaces, which leads to an immense backlog and issues with efficiency.

NUCLEAR SOURCE MATERIALS: THE THREAT OF COMPLACENCY[19]

Overall, it is difficult to steal uranium ores without being detected as the requisite quantities for most applications are quite large. One would have to divert at least ten trucks worth of material to make the venture worthwhile. This has not, however, dissuaded attempts to misappropriate uranium ore. In 2004, authorities confiscated 600 kilograms of ore from a vehicle near the Caetite mine in Brazil. In 2011, 324 kilograms of uranium ore were stolen from the Trekkopje mine in Namibia.

Research has shown that UOC also needs additional safeguards to mitigate the risks involved. The most prominent risk is the pilfering of UOC from the mine, the mill, or during the transport phase by either individuals working within the system or outside it, or both working as cohorts. This was demonstrated in 2009 when personnel at the Rossing Uranium mine in Namibia were caught in a covert police operation attempting to sell 170 Kg of UOC. Materials are also at risk of being diverted from sanctioned routes and end-users once they have been exported from a supplier country. A notorious instance was the "Plumbat Affair" in 1968. Some 200 tonnes of UOC were redirected in Antwerp from its original destination in Italy to Haifa, Israel and onward to Dimona. The incident occurred before the NPT was incepted, though Euratom safeguards were in place at the time. As UOC is currently exempt from full material accountancy and control, there is also a danger that parties could store it and sell it in the black market to a nation that has the capability to process and convert it into reactor fuel or weapon-grade fissile material. This threat increases in the face of inadequate tracking and monitoring measures.

The Changing Face of the Global Nuclear Market

Over the last few years, there have been paradigmatic shifts in the demand and consumption of nuclear resources across the globe. Illustratively, traditional consumers of nuclear energy such as Germany, the US and Japan have scaled back and shut down nuclear power operations.[20] This can be attributed to concerns about both safety and economic competitiveness arising in the aftermath of the Fukushima Daiichi accident in 2011.

The fallout from the Fukushima Daiichi incident spurred a chilling effect across Japan about the safety of nuclear power. Immediately after the incident, Japan shut down 48 of its nuclear reactors.[21] Till date, it has only restarted operations at five of them.[22] Fukushima was an inflection point for the nuclear energy discourse in Germany as well. The events that transpired at the ill-fated nuclear reactor prompted the pro-nuclear Merkel government to initiate a plan to shut down nuclear reactors within Germany by 2022.[23] The rising expenditure associated with the increased emphasis on safety, combined with the dropping costs of fossil fuels and renewables, has made nuclear power a commercially unattractive resource. This is especially true for the US where the rapid increase in shale production has dramatically decreased the price of natural gas.[24]

At the same time, China and several other rapidly developing nations are turning to nuclear power to satisfy a greater proportion of their energy requirements.[25] Of the 60 new reactors currently being constructed around the world, 39 are in developing nations in Asia.[26] Since the turn of the 21st century, 85 of the 105 nuclear reactors that have begun construction are in this region.[27] This relocation can be ascribed to two key factors. The first is economic: Most developing nations are energy and resource deficient[28] and need viable, cost-effective sources of energy to meet their growing needs.[29] Although nuclear power is capital intensive at the outset, its operations are relatively low cost.[30]

The second reason is environmental: Climate change, pollution, and other ecological exigencies are prompting several developing nations to turn to cleaner sources of energy to meet their power needs.[31] Emissions associated with nuclear energy are decidedly lower than fossil fuel-backed resources and comparable to those of wind and biomass.[32] Further, the generation of most renewable sources is intermittent, dependent as it is on environmental vagaries.[33] In contrast, nuclear reactors produce a steady stream of power, making nuclear energy an attractive option for many developing nations.

Although the uptake of nuclear power within developing regions is a positive development, concerns about armed nuclear proliferation and safety loom large. Many developing nations are characterised by political volatility, high rates of terror activity, and a general air of complacency about nuclear safety and security. In Malaysia, for example, proliferation was not a primary policy concern for authorities until recently,[34] when it was discovered that a Malaysian company had been producing centrifuges for the Abdul Qadeer Khan nuclear network.[35] Malaysia then introduced strong measures to prevent the re-occurrence of such activities.[36]

The complacency mentioned earlier may be attributed to the resource and capacity constraints faced by most developing nations. When these countries put their national priorities in order of urgency, nuclear security takes a back seat to much more pressing concerns such as widespread poverty, overpopulation, and food security. As such, they are unable to keep a close check on nuclear activities within their borders, in turn creating opportunities for nefarious actors.

In Africa,[37] for instance, where illegal uranium mining and milling activities are rampant, there is a high risk of uranium smuggling. Between 1994 and 2005, a total of 24 incidents involving the theft of uranium ore have occurred within the continent. Experts suggest that the deteriorating security around the Shinkolobwe mine in the Democratic Republic of the Congo (DRC) presents the most urgent security concern in Africa. In 2010, a UN report revealed that a band of Hutu rebels from Rwanda had attempted to sell six drums of UOC that were produced in the Shinkolobwe mine when the DRC was a Belgian colony. The rebels, however, could not find a buyer and abandoned the venture after a year.

The list of security concerns in Africa includes a lack of transparency in the way in which nuclear materials are transported to and within African nations. There are, for example, around 6,400 containers of UOC currently stored in a facility in Libya. In 2004, Libya confessed to the IAEA that it had imported uranium from Niger from 1978 to 1981. At the time, it was not incumbent upon Libya to report the imported ore as it did not have a safeguards agreement with the IAEA. Muammar Qadafi had acquired the material to build a nuclear arsenal. In 2004, an inspection conducted by the IAEA revealed that the amount of nuclear material in Libya was consistent with the country's declaration. And though the last bit of Libya's enriched uranium was taken away in 2009, stocks of ore still remain. Given the high rate of terror activity in the region, there exists a credible risk of a terror organisation attempting to seize this material.

As there is a strong likelihood of diversion, theft, or misuse of nuclear material in developing nations, there is a serious need for the introduction of a modern, digitised system of controls and safeguards.

Stakeholders in the global nuclear value and governance chains have a duty to create and implement a mechanism that will assist them in tracking radioactive materials. A blockchain-based global nuclear inventory management system may be the answer.

BLOCKCHAINS: A CONCEPTUAL OVERVIEW

Blockchains first gained notoriety as the technology underpinning Bitcoin – a decentralised cryptocurrency application that allowed users to safely transact over an untrusted medium like the internet without the oversight of a "trusted" central intermediary such as a bank. The trusted intermediary was supplanted by the blockchain. Resultantly, blockchain technology is often referred to as the "trustless protocol"[38]— as it has an in-built mechanism that helps overcome a tricky computer science puzzle known as the "Byzantine Generals Problem". First described by Lamport et al. in 1982, the Byzantine Generals Problem is an allegory for the redundancy or trust deficits in computer systems.[39]

In a blockchain, the mechanisms that secure trust between the nodes on the network are the following:

1. A Consensus Protocol: This ensures ledger consistency across the network and decreases the risk of fraudulent transactions because, any interference, if it is to be effective, would have to occur synchronously on more than 51 percent of the network.

2. Cryptographic Hashing: Hashes are functions that convert any informational input into a string of arbitrary letters and numbers of a defined length. Any amount of information can be hashed and the same data input will give you the same hash output every time. However, if a single character in the data input is different, the hashing function will churn out a completely different hash output. Thus, hashing precludes the alteration of transaction inputs on the blockchain.

3. Digital Signature: A mathematical method that is deployed to validate the authenticity, integrity, and validity of transaction participants.

4. Public-key cryptography: Encrypts transaction information with a public key that may only be decrypted with a corresponding private key.

The combination of these components gives users an immutable, chronological record of transactions that cannot be altered or reversed.

Although blockchains were originally classified as financial breakthrough, their use potential now extends well beyond the realm of banking. For one, the blockchain technology protocol can be leveraged to operate "Smart Contracts", which are lines of code that execute autonomously once certain contingencies are met. They can be used to execute business logic and legal agreements automatically, and store records and underpin decentralised applications.

More significantly for the subject of this brief, blockchains can be used to track the provenance of any physical asset across a system. It could revolutionise the logistical workings of any industrial ecosystem.

There are currently three varieties of blockchains. The first are public blockchains that are open for anyone to join. Participants are not scrutinised and everyone on the network may read and write data. The public blockchain network is driven by a direct economic incentive such as a cryptocurrency. The Bitcoin and Ethereum networks are examples of public blockchains. The second is a consortium blockchain, a semi-restricted network where only verified stakeholders are allowed to participate. Transactions generally go through quicker on this type of blockchain as the consensus modality does not involve mining. The third is a private blockchain, a permissioned ledger or controlled environment designed for rapid application, immediate deployment, and intra-corporational usage. Accountability on such networks is incentivised and preserved primarily through reputational risk, as all participants are known to each other.

Private and consortium blockchains were conceived to overcome certain issues with public blockchains such as the requirement for large amounts for computational power, limited transactional output, and the limited privacy for more sensitive transactions.[40] Private and consortium blockchains have been envisioned as secure databases for intra- and inter-corporation transactions, but the possibilities are not restricted to these cases alone.[41] Both these types of blockchains can be used to securely track and monitor the global migration of nuclear material.

A GLOBAL DECENTRALISED LEDGER FOR NUCLEAR MATERIAL

A consortium blockchain can be used to capture the movement of the global uranium supply through the nuclear fuel cycle. This solution should ideally be deployed in two parts. The first part can track the movement of nuclear material through the front-end of the nuclear cycle, i.e., from the time the ore is loaded into a drum at the mine up to when it reaches the conversion facility. The second part may follow the converted uranium from the conversion facility until its final destination. The IAEA may also consider recommending that importers of uranium supplement this global tracking system with a blockchain-based monitoring mechanism that tracks the movement of uranium within the importing nation's borders.

How would it work?

Once uranium ore is loaded into a drum at the mine, the container can be secured with a tamper-evident sealing device that has a Near Field Communication (NFC) or Radio Frequency Identification (RFID)-enabled microchip.[42] The microchip acts like an immutable identifier that creates a digital identity for the drum.[43] It would contain important identifying information about the drum such as the type of material, its UN Number and shipping name, weight, the quantum of radioactivity, the point of origin, the destination, the date for which the activity is estimated, and the names of the individuals handling the container at each point. This digital identification, along with other logistical information, is then uploaded to the blockchain. Inlays can be used to provide real-time location tracking as well.[44] Additionally, motion sensor boards can be embedded into the seals to notify parties about any aberrant movements.

This system would allow all stakeholders in the global nuclear supply chain such as State entities, private companies and auditing entities to verify the origins of the ore and track its movements as well as the identities of the individuals handling it. Feedback would be received in real-time, rather than the one to thirty-day window industry players currently require. This would help the IAEA be more efficient with inspection planning and declaration analysis.[45] Additionally, if an incident were to take place, the response can be immediate.

Information and records would no longer be produced in silos. Each stakeholder on the network would have data on the entire history of a particular drum's movements and where it is on the globe. A blockchain-based monitoring mechanism can also be integrated with legacy recording systems that may be in place across different facilities.

As stated earlier, a majority of the world's conversion activities take place in just five countries. As a result, these facilities amass huge volumes of material that remains at storage lots for years. The implementation of a blockchain-based tracking system would help alleviate the problems with backlog and inventory maintenance faced by these facilities. The use of blockchains would also safeguard the shipments from cyberattacks which can be used to create dummy lots of material and wipe out information.

ISSUES FOR CONSIDERATION AND THE WAY FORWARD

Global material monitoring systems like the one proposed in this brief have already been established in the diamond industry, where each stone is given a digital identity and tracked from mine to store, to thwart the use of "conflict diamonds"[46]. There would, however, be significant impediments to the actualisation of such a system when dealing with a politically sensitive material like uranium.

First, the implementation of such a monitoring system will require a reimagining of the existing policy landscape surrounding nuclear safeguards. Most of the protocols in place exist in the form of guidelines and reporting standards – many of which are voluntary in nature. A blockchain-based monitoring mechanism would render most of these policy frameworks redundant. Second, determining which stakeholders should form the nodes on the network would be a political minefield. While the on-boarding of private actors, the IAEA, and the exporter states seems intuitive, importers would have to form a part of the system as well. This might lead to an impasse, as the platform could be used as a pretext by members of the NPT to get countries like India, Israel and Pakistan to sign the treaty. Third, most proliferation occurs surreptitiously and is more dependent on technological aspects than material availability.[47] A prime example of this is the workings of the notorious Abdul Qadeer Khan network, which originated as a result of Abdul Qadeer Khan stealing important technical papers from Germany to help Pakistan develop a nuclear arsenal. The availability of material was inconsequential to Pakistan as the country had rich, natural stores of Uranium.[48] What was more important was developing the technological infrastructure that would help make the material fissile.

The AQ Khan network then went on to assist countries such as North Korea and Iran in developing their own nuclear capabilities.[49] It is alleged that this took place under the watch of American and European stakeholders.[50] Thus, a blockchain-based monitoring system can never be a panacea and must be bolstered by added measures and efforts to ensure such activities do not take place in the future.

Despite the significant obstacles to implementing a blockchain-based monitoring system for nuclear material, the IAEA and the Nuclear Suppliers Group (NSG) must work together and seriously consider how such a mechanism could be incorporated into the current uranium governance framework. A possible first step could be piloting the technology at the low-enriched Uranium (LEU) bank in Kazakhstan. The bank is owned and controlled by the IAEA, and was established as a supplier of last resort for countries that encounter a disruption of their regular nuclear fuel supply chains. This poses a relatively low-risk environment to help test the efficacy of the blockchain in securing the transport of materials. Additionally, it will help in garnering a better understanding of how the dynamics of the different actors within the system could work. It would also help establish guidance on how assurances, transfers, and end-user licensing systems could be carried out in the midst of implementation. Thus, it would serve as an effective microcosm for a global system.

The full-scale realisation of such a scheme may be a distant dream for now. Yet it is becoming increasingly evident that blockchains must form an integral part of the global nuclear monitoring system in the foreseeable future.

ABOUT THE AUTHOR

Meghna Bal is a Junior Fellow at Observer Research Foundation.

ENDNOTES

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    1. Loyalists can reach an agreement on a reasonable course of action;

    2. Traitors must not be able to derail the adoption of a reasonable plan and replace it with an unsuitable option.

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