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PREPARING AMERICAN STAKEHOLDERS FOR THE SAUDI NUCLEAR PROGRAM

Prepared For:

Chris Williams
Booz Allen Hamilton

Prepared By:

Alejandro Lozano-Kramer

UNIVERSITY of VIRGINIA

FRANK BATTEN SCHOOL of LEADERSHIP and PUBLIC POLICY

Disclaimer:

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfilment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, Booz Allen Hamilton, Chris Williams or by any other agency.

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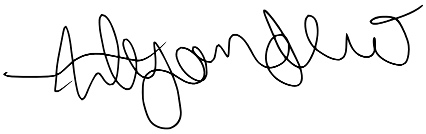
On my honor as a student, I have neither given nor received unauthorized aid on this assignment. All uses of AI were documented to the supervisor and complied to the University's policy.



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Executive Summary

Nuclear energy in the Middle East is not only an energy resource but also a geopolitical instrument. It shapes regional power dynamics and security considerations regarding the development of nuclear weapons. International concerns that civilian energy technology could be repurposed for the development of nuclear weapons programs stifles the adoption of civilian nuclear technology in the region.

In light of this challenge, the report, alongside the existing base of evidence on the issue, identifies three possible pathways the United States and Saudi Arabia can explore to engage in long-term cooperation within the nuclear domain:

1.) A traditional 123 agreement approach for the construction of conventional nuclear reactors.

2.) The transfer of emerging nuclear technology with non-proliferation guardrails.

3.) A strategic rapprochement of relations between both states that permits for an ARAMCO-style joint custody of nuclear installations; these would be capable of conducting all aspects of the nuclear fuel cycle (mining, enrichment, operation and waste disposal).

The United States does not hold a monopoly over civilian nuclear technology. In the Middle East, states such as France, South Korea and Russia have established themselves as competent energy partners. A failure by American stakeholders, such as Booz Allen Hamilton, to acknowledge the national-security dimensions of the Saudis vis a vis their nuclear program risks the Saudis vying for an alternative partner. A Saudi nuclear program developed without American involvement limits industrial opportunities for U.S. firms to expand operations in Saudi Arabia and the broader Middle East, placing American companies like BAH at a competitive disadvantage.

Saudi Arabia's desire to expand into nuclear energy falls within its wider attempt to diversify its economy under the Vision 2030 framework. This is a costly endeavor; the Kingdom is currently running its highest deficits and debt levels in its 92-year history. The report acknowledges Saudi financial priorities and evaluates these three alternatives on their economic effectiveness. This is achieved through an analysis on their power output (measured in GWh), capital cost, cost effectiveness and return on investment. The three pathways are also analyzed on their ability to generate support in the American and Saudi political landscapes. This political feasibility inclusion extends the report's relevance to diverse stakeholders across both countries. Previous attacks on Saudi energy infrastructure also designates physical security to nuclear installations as a key metric of success.

Applying these criteria, this report concludes that Alternative 3—an ARAMCO-style joint custody arrangement—offers the most mutually beneficial framework for Saudi Arabia, the United States, and U.S. private sector contractors such as BAH[*]. This model best reconciles Saudi concerns over energy sovereignty with U.S. non-proliferation priorities. While its costs are higher, Saudi Arabia could offset expenses by monetizing nuclear energy through electricity sales.

[*] As outlined and referenced in the paper, I do not claim to have coined the term nuclear ARAMCO. This is an established term in the Middle East nuclear energy landscape.

The main obstacle to implementation will be political feasibility in the United States Congress. Overcoming this hurdle would likely require Saudi Arabia to offer concessions, such as normalization with Israel and assurances of limited geopolitical alignment with China. This consideration falls outside of the scope of this report but will be a key step towards the implementation of the recommendation.

Introduction

For American firms to enhance their competitiveness in engagements with the Saudi government, they must first grasp the security, geopolitical, and economic dimensions of Saudi Arabia's nuclear program. A nuanced understanding of these factors will enable them to navigate the political landscape effectively and tailor their proposals accordingly.

This report provides a preliminary background on Saudi Arabia's nuclear ambitions, examines the program's unique challenges, and explores potential solutions. It concludes by outlining an implementation strategy for a nuclear ARAMCO that provides for the physical security of nuclear facilities and safeguards against proliferation risks. While previous analyses—such as those by Robert Einhorn—have detailed the concept of a "Nuclear ARAMCO," this report goes further by evaluating the costs of this model alongside alternative approaches, adding depth to the existing literature (Einhorn, 2018).

Client Overview

This analysis is conducted for Chris Williams, a senior consultant at Booz Allen Hamilton (referred to as BAH in the remainder of this document). As a military contracting firm, BAH is well positioned to view energy transformations/diversification through the prism of military and national security challenges. The Saudi civilian nuclear program presents a commercial opportunity for BAH. As discussed in the latter stages of this report, non-American firms from states such as China, France, South Korea and Russia are all vying to be the principal partners of the Saudi government in the nuclear domain. BAH is a US company and, in the case where the Saudis pursue a partnership with a geo-political adversary of the United States, principally Russia or China, export controls would prevent BAH from engaging in meaningful cooperation. Overall, A well-informed BAH, cognizant of the possible frameworks for a U.S.-Saudi nuclear partnership, would be positioned to optimize its involvement in a potential cooperation agreement.

Problem Statement

The perception that civilian nuclear energy initiatives in the Middle East are precursors to nuclear weapons development threatens Saudi Arabia's goal of energy diversification. Given this challenge, how can American stakeholders better understand the economic, national security, and political sensitivities of the Saudi Arabian government regarding its nuclear program and position themselves as a strategic partner in Saudi Arabia's nuclear journey, effectively outcompeting other nuclear energy providers.

Background

Nuclear Energy in the Middle East:

As demonstrated in figure 1, the Middle East possesses a comparatively underdeveloped nuclear energy landscape with only 4 active nuclear reactors, all located in the UAE. Although this trend can be attributed to the Middle East's vast fossil fuel reserves and the region's strong potential for alternative energy sources, particularly solar, states have shown a keen interest in acquiring nuclear technology since the early 2000s. However, this aspiration has yet to materialize—an issue this APP ultimately seeks to address (El Katiri, 2012).

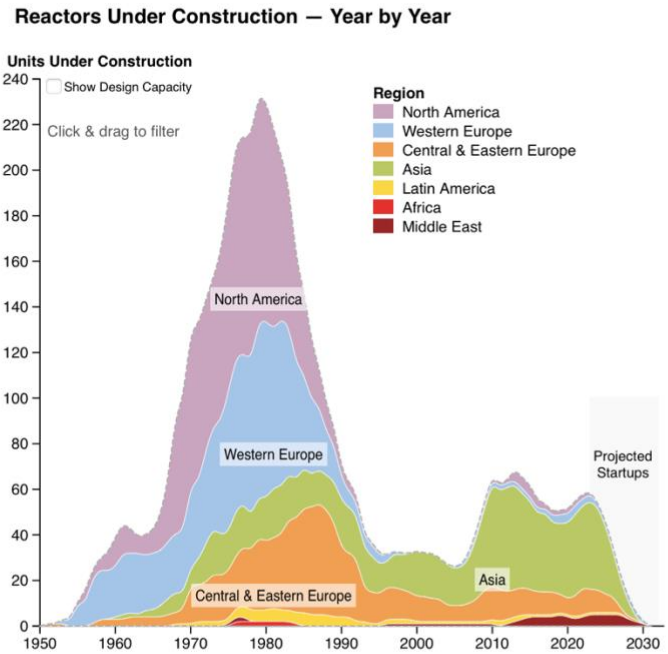

Figure 1: Demonstrating Construction of Nuclear Reactors by Geographic region.
(Friedemann, 2017).

Even in the singular case (the UAE) where a civilian nuclear program successfully entered operation, current deficiencies risk repelling further international investment. In a 2019 paper, analyzing the safety of the first operational nuclear in the region (located in the UAE), academic Dr. Paul Dorfman states that the plants reactor's design are inadequate to mitigate the impacts of a successful attack on the plant (Dorfman, 2019). Specifically, the lack of a *core catcher* [1] component would substantially increase the success rate of a sabotage attack (Dorfman, 2019).

This concern was similarly echoed by the Qatari foreign ministry in 2019. In a letter to the International Atomic Energy Agency (IAEA), Qatar mentioned the lack of safety measures as a threat to geo-political instability and the marine environment of the Gulf region (Al Jazeera, 2019). This complaint is subject to bias; in 2019, Qatar was embargoed by the UAE over a political dispute, providing an incentive for them to oppose the program as a form of retaliatory action. This limitation relates to the wider limitation of the literature. Although the UAE's development of an operational nuclear power plant is useful to the extent that it provides us with a region-specific case study, it remains only one instance of a nuclear development.

In so far as nuclear non-proliferation in the Middle East, historical instances point towards a concerted effort by numerous states in the region to develop nuclear weapons. This is principally because states in the region view the development of nuclear technology (whether it be civilian or military) as a means to ensure their survival and deter exogenous threats to their authority. This historical trend extends to Saudi Arabia. The country's de-factor ruler,

[1] A core catcher component permits the plant's operators to prevent the leak of radioactive material from the core in the case of a nuclear meltdown incident.

Mohammed Bin Salman, has stated on numerous occasions that should Iran develop a nuclear weapon, his country would follow suit.

As demonstrated by Figure 5, and by the fact that no states in the Middle East with the exception of the UAE are party to a 123 agreement with the United States, almost all nuclear programs in the Middle East are/were geared towards the construction of a nuclear warhead. Overall, regional geo-political instability and a failure by Middle East states to assure that their nuclear programs retain a civilian purpose have historically made the Middle East an infertile ground for the growth of nuclear energy. **Nuclear energy in the Middle East is therefore not only an energy resource but also a geopolitical instrument, shaping regional power dynamics and security considerations.**

Country	Result
Iran	Sanction nuclear program.
Iraq	Nuclear reactor destroyed by Israel.
Libya	Abandoned program after sanctions.
Syria	Nuclear reactor destroyed by Israel.
United Arab Emirates	Operational nuclear reactor with appropriate guardrails.

Figure 2: Outcomes of Nuclear Programs in the Middle East.

The issue of nuclear non-proliferation is further complicated by the Russian Federation's current willingness to bypass guardrails aimed at preventing civilian programs from acquiring nuclear weapons. This includes the Russian withdrawal from important non-proliferation treaties, such as the Nuclear Test Ban Treaty in 2023, with the United States (Starchak, 2023). Moreover, its engagement in military and technological cooperation with states sanctioned due to their development of illegal nuclear programs, such as North Korea and Iran, demonstrates a reduced desire by the Russia to propel a policy of global non-proliferation.

For Saudi interests, Russian technology could present a window of opportunity. Russia's nuclear energy company, Rosatom, has submitted various proposals to the Saudi government for the construction of a potential first nuclear reactor site (the latest in June 2023). The details of the proposal are not present in open-source forums. However, Russian concessions that enable the Saudis to possess sovereignty over the fuel cycle would be a major incentive to vie for Russian cooperation in the nuclear domain.

Outline on the current state of nuclear security in the literature:
Aside from the Middle East, the literature highlights clear deficiencies in the ability of governments to protect their nuclear facilities against attacks.

In "Nuclear Terrorism: countering the threat", researchers Volder and Sauer conduct an empirical study on 80 recorded attacks against nuclear installations over the past 60 years. Their findings uncovered that in 60% of the examined cases, the belligerents succeeded in their aims which included: sabotage, interrupting the operation of a nuclear facility and theft (Volden & Sauer, 2016). The majority of these attacks stemmed from unsophisticated attacks. For example, 17.5% of the examined cases pertain to anti-nuclear activists infiltrating nuclear sites (Volden & Sauer, 2016.). Within the context of the Middle East, where terrorist organizations such as the Houthis in Yemen and Hezbollah in Lebanon are in possession of sophisticated offensive capabilities, the lack of a robust protection system could result nuclear facilities being especially vulnerable. This is particularly pertinent considering the success of previous attacks on Saudi energy infrastructure: in September 2019, Houthi drones and missiles successfully struck ARAMCO refining facilities in the East of Saudi Arabia, severely disrupting ARAMCO's production output.

The issue of drone and aerial attacks is also salient in the literature. A 2014 article by journalist Arthur Nelsen reported that several French Nuclear Sites were the target of illegal drone flyovers (Nelsen, 2014). Similarly, and in the context of the current Ukraine War, energy watchdogs documented the Russian use of drones to strike the Zaporizhzhia nuclear power plants within Ukraine (Arms Control Association, 2024). Unlike Volder's and Sauer's study, which focuses on terrorist organizations, this instance provides a case study of a nation-state targeting another state's nuclear installations.

In sum, the literature identifies two key points 1.) Nuclear installations are the target of terrorist organizations and state-actors and 2.) Nuclear infrastructure is inadequately prepared to neutralize the offensive capabilities of modern belligerents.

Evidence On Potential Solutions

The literature review highlights short and long-term solutions for programs successfully to comply with their peaceful nuclear ambitions. These literature-based solutions: use of emerging nuclear technology, cyber security measures, international protocols, joint custody over nuclear installations and alternative nuclear fuel sources, will serve as the basis for a recommendation.

Utilizing SMRs (Small Modular Reactors) and Microreactors:

The literature points towards emerging nuclear technologies as a solution to the proliferation and safety concerns presented by large, conventional nuclear reactors.

SMRs are prefabricated components that are transported (as opposed to constructed) to their site. As a nascent technology, there is conflicting evidence as to their success in achieving cost-effectiveness. According to a study published by the National Academy of Science, SMRs produce more nuclear waste that their traditional counterparts by a scale factor of 2 to 30 times (Shwartz, 2022). Increased radioactive waste would erode monetary benefits produced by lower start-up costs, spur environmental concerns and endanger human life. Moreover, there is no evidence or research demonstrating this technology's capacity to provide electricity on a scale to meet the energy needs of a nation-state grid.

However, other components of the literature posit SMRs as cost-effective. A research paper published by Dr. Vegel and Dr. Quinn concludes that under the correct regulatory guidelines from the NRC (Nuclear Regulatory Commission), SMRs present numerous economic benefits over large reactors (Vegel & Quinn, 2017). The study examines the net present value (NPV) of SMRs in relation to costs including regulatory fees, construction and operational costs. This finding is supported by other studies, such as one supervised by the University of Bergen and another conducted by the University of Cambridge. Both demonstrate that SMRs, operating under a modularization model, decrease operating costs by 45% compared to their conventional counterparts (Lloyd, Roulstone, & Lyons, 2020; (Farstad, 2023). The external validly of these US-based studies translates to the energy environment of Saudi Arabia. SMRs, through their design, are transportable to overseas locations, making these studies a valuable framework for assessing the cost-effectiveness and viability of SMRs.

Despite disagreements over monetary benefits, there is widespread consensus, including on behalf of the world's leading nuclear regulatory authority, the UN's IAEA, that these components require less nuclear fuel to achieve operational status (Nam, Hong & Lee, 2020); (IAEA, 2024). This is primarily due to their more compact size, which allows for a resupply cycle of 3 to 7 years, compared to the annual refueling required by large conventional reactors (see Figure 6 below for a size comparison). This is a critical attribute. Decreased volumes of nuclear fuel would reduce the possibility of the Saudis possessing enough fissile material to repurpose for non-civilian use.

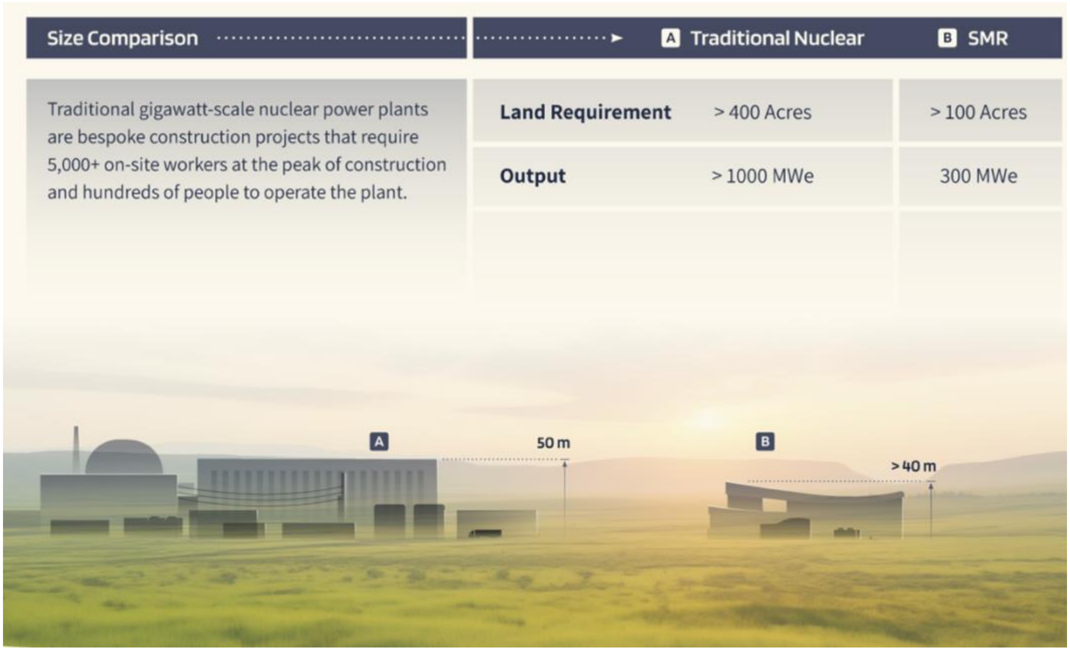

Figure 3: Size Comparison of Traditional Nuclear Plants and SMRs (Chabinsky, 2023).

The pre-fabrication aspect of the SMR permits the manufacturer to have considerable autonomy over nuclear waste. This is crucial for non-proliferation because it reduces the host country's access to sensitive nuclear materials that could be repurposed for weapons development. Under SMRs, the user is obligated to return the nuclear waste to the manufacturer for storage and disposal.

In comparison, the construction of traditional nuclear power plant involves the installation of adjacent sites to store radioactive waste (World Nuclear Organization, 2023). As demonstrated earlier by figure 1, this ultimately increases the control over the latter stages of the fuel cycle and increases the potential, particularly if no international protocols are in place, for the development of a nuclear weapon.

The potential for the additional security features of SMRs is acknowledged by a study published in the journal, *Progress in Nuclear Energy.* The authors highlight the ability of SMRs to provide an operational model where "the fuel remains sealed from factory fabrication to the fuel handling facility at the backend of the fuel cycle" (Prasad, Abdulla, Morgan & Azevedo, 2015).

Ultimately, the SMR's design provides two direct advantages in so far as reducing the risk of military repurposing:

1.) Decreasing the volumes of nuclear material that can be repurposed into weapons-grade fuel.

And

2.) Enabling the manufacturing custodian (US) of the component to control the end use (how nuclear infrastructure and related components are disposed) of the technology.

These attributes place SMRs as an important component of the future energy landscape. As stated by the United States Department of Energy assessment on the technology, SMRs possess a "distinctive advantage factoring in current safeguards and security requirements". (US Department of Energy, 2024). Several non-government studies such as ones conducted by Dr. Vladimir Kuzestov, Dr. Alhuzaymi or Cheng & Bari all identify SMRs as a key asset for developing countries due to their successful ability in limiting the repurposing of nuclear technology (Kuznetsov, 2007) (Al Huzaymi, 2023) (Cheng & Bari, 2020).

In sum, literature research reveals that SMRs, although imperfect, could enable the United States to provide the Saudi authorities with a baseline level of nuclear technology.

Thorium as a Fuel Alternative:
There is research on the operation of nuclear reactors via an emerging nuclear fuel source that is inconducive to the production of a nuclear weapon: Thorium. Contrary to Uranium or Plutonium that contain fissile properties, Thorium is a fertile material that cannot sustain nuclear fission (a key characteristic in the manufacturing of nuclear weapons) (Rowinski, White & Zhao, 2015). The use of Thorium is an explored domain in nuclear science. For example, India is currently constructing its civilian nuclear program on a foundation that includes Thorium fuel (for context, India possesses the largest reserves of Thorium in the globe) (Patel, 2023).

However, there is no scientific or practical research as to the viability of a nuclear program that operates solely on a Thorium fuel source. According to the scientific consensus, Thorium cannot currently provide a unliteral source of fuel and instead depends on interactions with fissile materials such as Uranium to provide a nuclear chain reaction (World Nuclear Association, 2024). Even in the case of India, the use of Thorium is only incorporated in the latter stages of the fuel process alongside Uranium and Plutonium (Government of India, 2019). The potential of Thorium applies more to the operation of smaller scale reactors such as SMRs where Thorium can be transformed into a limited uranium source. Scientific studies demonstrating the ability of Thorium to act as the main source of fuel for smaller reactors are limited, with most research focused on Research and Development (Akbari, Nasr, D'Auria, Cammi, Maiorino, de Stefani, 2024).

Overall, Thorium, and its applicability in smaller reactors offers a potential gateway for Saudi Arabia to enjoy a form of nuclear technology (albeit limited) whilst avoiding accusations of offensive nuclear proliferation.

Guarding Against Cyber Threats:
Alongside aerial attacks, the literature identifies cyber-borne threats as a prominent feature in the securitization of nuclear installations. Sophisticated cyber-attacks have been successful in by-passing outdated safety regulations that centered on primitive cyber threats (Boltzer, 2019). As contented by the Nuclear Threat Initiative, the *"technical capacity to address the cyber threat is extremely limited"* (Stoutland, 2024).

Several research papers in the literature points towards the need for a unified framework to interpret the nature of cyber threats and create systems for rapid intervention (Van Dine, Assante & Stoutland, 2016 ;Pickering & Davies, 2021). Legal regulations scholar, Patricia Boltzer, provides more substantive recommendations and states that nuclear power plants should implement a regulatory framework that compels nuclear reactor operators to share cyberattack data, improve communication between technicians and IT experts, and ensure data integrity to protect against tampering (Boltzer, 2019).

Whilst the literature on countering cyber threats to nuclear infrastructure is limited, the literature describes attempts to standardize a model of cyber security. This includes the Department of Energy's C2M2 that enables operators of critical energy infrastructure to evaluate the resiliency of their technology against cyber threats (Curtis & Mehravari, 2015). It achieves this by providing energy infrastructure managers with: *"a self-evaluation methodology and tool to measure and improve its cybersecurity program"* (US Department of Energy, 2021). The model's presence is valuable as it demonstrates a concerted government effort to implement a plan of action to insulate critical infrastructure from cyber-attack. This is an aspect the Department of Energy can market to its Saudi counterparts to mitigate competition from French, Russian and Chinese nuclear suppliers.

The effectiveness of the C2M2 in mitigating cyber threats remains uncertain. The persistence of cyber-attacks on energy infrastructure—evidenced by a 70% increase in attacks on U.S. utilities in 2023—highlights ongoing resilience deficiencies.

International Agreement and Protocols (South Korea case study):
The literature around the securitization of the South Korean nuclear program is extensive and provides an important case study. Like Saudi Arabia, South Korea is in the immediate geographic proximity of a hostile state with developed nuclear weapon ambitions (referring to North Korea and Iran).

Senior officials in the current South Korean government have also expressed a desire to possess a nuclear weapon in order to deter the nuclear threat posed by the North. Despite this tense geo-political landscape, South Korea is the fifth largest generator of nuclear energy worldwide. Korean companies such as KEPCO are leading exporters of nuclear technology, including advanced reactors such as the APR-1400. The NTI's Nuclear Security and Safety Index scores South Korea 81/100 in its ability to protect facilities, this places it 15th worldwide and on level with countries such as the United States and Sweden (NTI, 2023). This is despite numerous attempts by North Korea to attack the country's nuclear energy infrastructure via cyber-attacks.

An article published by Chung Tae Park attributes the success of this program to the conclusion of a 123 agreement between the United States and South Korea in 1956 (Park, 1992); (Nuclear Business Platform, 2023). This foundation of trust facilitated the swift transfer of technology to a state with no prior nuclear energy expertise. Strong military ties between South Korea and the United States, including the presence of 28,500 U.S. troops, have also disincentivized physical attacks by North Korea. Saudi Arabia similarly maintains a robust military relationship with the U.S., and the South Korean success story suggests that a 123 Agreement—requiring Saudi Arabia to forgo enrichment capabilities—could serve as a foundation for the development of an indigenous nuclear technology.

Apart from South Korea, the impact of 123 agreements on nuclear development is positive. Of the 32 states that operate civilian nuclear reactors, only four states (Armenia, Pakistan, Iran and Belarus) have failed to ratify to a 123 agreement with the United States, with Armenia currently in negotiations to finalize an agreement (Statista, 2024); (US Department of Energy, 2024); (Benson, 2024). These isolated nuclear programs only yield 9 operational nuclear reactors out of the global total of 440 (Statista, 2024). In the case of states such as Iran and Pakistan, these civilian programs face sanction regimes by the United States which hinder their ability to readily attain nuclear fuel and upgrade their capacities (World Nuclear Association, 2024). This limits the programs expansion (evidenced by the low number of economic reactors) into a meaningful source of energy that provides economic and technological advantages to the host nation. In essence, the literature contends that a 123 agreement with the United States is a key determinant in the ability of a state to successfully integrate nuclear energy.

Joint Custody of Enrichment Facilities:
Another aspect of the literature proposes an organizational solution (Einhorn, 2018); (Solomon, 2023). Regional observers note that Saudi Arabia, in so far as their desire to conduct enrichment operations within their territory, could delegate such responsibilities to American contractors. The presence of enrichment facilities, although operated by American personnel, could nonetheless enable Saudi engineers to gain hands-on expertise.

Joint custody over energy infrastructure is not an unprecedented arrangement in Saudi Arabia and the wider Middle East. Saudi Arabia's national oil company ARAMCO (established in 1933), was initially managed, operated and owned by American petroleum companies. Over time, as the local Saudi local workforce accumulated expertise, the management of the company was entirely delegated to Saudi authorities with the company becoming fully nationalized in 1980 (ARAMCO, 2024).

Within the nuclear domain, a Nuclear ARAMCO model could be deployed whereby American control of sensitive facilities throughout the fuel cycle would be gradually devolved to Saudi authorities, enabling the latter to ensure the robustness of guardrails against the repurposing of the program whilst the former benefits from hands-on experience with nuclear energy (Einhorn, 2018). Decades of mutually beneficial cooperation between the United States and Saudi Arabia in oil infrastructure boost the external validity and credibility of a nuclear ARAMCO. This is because the Saudis consider the United States to be a competent, capable partner in the energy domain. ARAMCO today stands as the largest exporter of oil in the world and the world's 5th most valuable company (Finance Weekly, 2024).

The potential for a replication of joint custody agreement is recognized by Middle East observers such as Jay Solomon as well as Robert Einhorn who both contend that a Nuclear ARAMCO model would not only enable placate Saudi frustrations at a perceived loss in energy sovereignty but would also increase the likelihood of a negotiated 123 agreement (Einhorn, 2018); (Solomon, 2023). Einhorn specifically suggests including contingency clauses in a 123 Agreement. For instance, instead of a complete ban on Saudi indigenous enrichment, the Saudis and Americans could agree to renegotiate American operational control, allowing the Saudis to undergo *"enrichment and reprocessing activities"* after a case-by-case evaluation and under the basis of mutual consent (Einhorn, 2018).

Alternatives

Based on the literature review, this report proposes the following frameworks for a US- Saudi nuclear partnership:

Alternative 1: Pursue a 123 Agreement

Outline: Concentrating efforts on the passing of a traditional 123 resolution between the United States and Saudi Arabia. Under this alternative, the Saudis would construct conventional nuclear power plants in the Kingdom. This would be coupled with extensive American assistance in the domains including, but not limited to, cyber security, the physical security of nuclear installations and the operation of the reactors.

Alternative 2: Build Capability with Emerging Nuclear Technology

Outline: Persuading the Saudis to view their nuclear program as an experimental and research-based domain as opposed to a feasible path in their push towards energy diversification. This alternative would pivot around the use of SMRs and Thorium fuel sources. Under this proposal, the Saudis could start their journey towards the development of a skilled workforce in the nuclear domain albeit with no exposure to the enrichment and waste disposal aspects.

Alternative 3: Nuclear ARAMCO

Outline: This final alternative adopts a strategic solution: the United States develops and operates Saudi-based enrichment and disposal facilities. Derived from Robert Einhorn's description of his version of a nuclear ARAMCO, this arrangement would be temporary in nature and include an agreement to revisit American control over enrichment facilities (Einhorn, 2018). This alternative would rely on the formation of a join US-Saudi mutual defense pact which will serve two purposes: 1.) Deterring attacks (cyber, missile, sabotage etc.) against facilities and 2.) Reducing the incentive for Saudi Arabia to pursue nuclear weapons by providing a credible security guarantee.

Criteria

Criterion 1: Power Output.
This is measured per GWh annually.

Criterion 2: Cost.
This report assumes that the government of Saudi Arabia would not finance these nuclear infrastructure projects through public debt financing or sovereign borrowing from international banks. The justification for this is that Saudi Arabia does not typically borrow from

international lenders (such as the IMF and or other states). Instead, it primarily funds infrastructure projects, particularly those related to national security, through national reserves generated from the sale of oil. This is evidenced by its level of debt which as of 2023, stands at 26% of GDP - ranking 94th out of 131 countries where data is available (IMF, 2023). When it does need to borrow, it does so through the issuance of Islamic-compliant sukuk bonds, and in some cases the privatization of state assets (Reuters, 2025); (Fitch Ratings). Due to Islamic finance laws, Sukuk bonds do not carry interest, with the investor instead receiving the parr value of the bond at maturity.

Funding for the alternatives would therefore come entirely from the Saudi government, resulting in the absence of any interest rates on the payment structure.

For cost calculations, the report utilizes the annuity formula that enables the report to analyze the value of future cash flows.

Annuity Formula (performed automatically on excel).

$$PV = c\left(\frac{1}{r} - \frac{1}{r(1+r)^n}\right)$$

PV= Present Value
C= Cash Flow
R= Discount Rate (8% in this report).

Criterion 3: Cost Efficiency.
Indication of how much capital (in USD) is needed to generate 1GWh.

Criterion 4: Return on Investment.
The Saudis will generate revenues from the sale of electricity and other commodities through this nuclear program. Unlike cost efficiency, which only computes electricity output, this criterion weights financial returns against costs.

Return on Investment= Net Return/ Cost of Investment

For comparability, criteria 1 through 4 are scaled to a singular nuclear reactor. To calculate the total costs, power output etc. of 2+ reactors, the reader of this paper can multiply the values by the number of reactors in the program.

Criteria 5: Saudi Political Feasibility
The ability of the alternatives to inspire positive responses from Saudi stakeholders.

Criterion 6: US Political Feasibility.
Level of political opposition (or support) for the current regulatory landscape to change in order to facilitate Saudi access to nuclear technology. As cited in the evidence review, nuclear non-proliferation guardrails will be a key determinant to American political support.

Criterion 7: Resilience to external Security Threats.
Analyzes the ability to defend against hostile attacks targeting nuclear infrastructure in Saudi Arabia.

All aspect of the analysis highlighted in **Yellow** are the outcomes presented in the matrix.

Findings and Evaluation

Alternative 1: Pursue a 123 Agreement

Criterion 1: Power Output.
Assuming that the Saudi government opts for Westinghouse's AP1000 (the only American nuclear reactor company to develop an international reactor in the past 15 years), each reactor would be capable of generating 10,000 GWh of energy (US Department of Energy, 2023). Accounting for maintenance interruptions, the generators will operate at full capacity for 93% of the year. This means that the plants will generate 9,3000 of energy annually (0.93*10,000).

Criterion 2: Cost.
Under this alternative, other aspects of the nuclear cycle, i.e.: mining, enrichment and disposal, would be delegated to American companies in the United States. The US already possesses an extensive supply chain network of Uranium ore and has domestically located enrichment plants. There would be no costs for the development of facilities except for the import costs of Uranium fuel already factored in the AP1000's operational expenditures. The economics would entail the following (these figures are per AP1000 reactor):

(Discount Rate and Payment Period Provided by client).

Given		**Assumptions**	
Cap Ex	$6.8 billion [2]	Lifespan	80 years [3]
Annual Op Ex	$ 128 million [4]	Discount Rate	8%
Construction	8 years [5]	Payment period	15 years
Power	9,300 GWh		

Cost of Financing Infrastructure: The present value, when considering the 15-year payment plan, of the costs associated with one AP1000 would equal approximately USD 3.87 billion for every AP1000 nuclear reactor built.

In terms of the operational costs, the AP1000's annual maintenance costs amount to a present value of USD 862.6 million.

Taking these two figures together, the total cost of per nuclear reactor would amount to 3.87 billion + 862.6 million= approximately **USD 4.74 billion per nuclear reactor**.

Criterion 3: Cost and benefit Analysis.
Over each reactor's lifetime, they will generate an annual energy output of 9,300 GWh hours. Over an 80 period, this will total 744,000 GWh.

[2] Clifford. C. (2023). "Westinghouse announces a new small modular reactor". *CNBC.*
[3] Shirvan. K. (2022). "Overnight Capital Cost of the next AP1000". *Center for Advanced Nuclear Energy Systems*.
[4] Ibid.
[5] Oettingen. M. (2021). "Costs and timeframes of construction of nuclear power plants carried out by potential nuclear technology suppliers for Poland". *Casimir Pulaski Foundation*

This means that throughout the lifetime of one AP1000, it will cost a present value of **USD 6,371.02 generate one GWh.**

Criterion 4: Return on Investment.
The monetary benefits from this program would come from the Saudi government selling this electricity domestically, enabling them to increase their exports of oil and gas internationally at competitive prices.

- For Electricity: According to governmental statistics, the average price for electricity in Saudi Arabia currently stands at USD 0.05 per KWh, this converts to USD 50,000 per GWh (Statistica, 2024). If we assume that Saudi Arabia maintains current electricity subsidies, nuclear power could expect to generate the following in revenue:

Revenue Per Reactor: 9300 GWh* USD 50,000= USD 465 million.

Additional Revenues from Increased Energy exports:
The influx of nuclear energy for domestic consumption will enable Saudi Arabia to increase gas and oil exports, that unlike electricity in the Kingdom, are sold at international prices (i.e.: higher than the subsidized rate in Saudi Arabia). For context, in 2023, the total electricity consumption of Saudi Arabia was approximately 300,000 GWh (CEIC, 2022). If we assume that the growth rate for electricity demand increases as the country's population grows at 8% (average increase over past 10 years), this means that when the reactors become operational in 2032/2033, the country's consumption will equate to approximately (300,000*1.08ˆ8) = 555,279 GWh (CEIC, 2022). Referring back to the 9300 GWh figure this means that every AP1000 could generate approximately 1.7% of the country's 2032 anticipated electricity demand.

Currently Saudi Arabia's energy mix consists of 67% oil and 33% gas (IEA, 2022). For every nuclear reactor Saudi builds, it could now export (0.67*9300) = 6,231 GWh of oil and 3,069 GWh of gas to international markets. This would lead to the following export revenues:

- For Oil**:** 80,000 gallons of oil produces 1GWh of electricity (0.08 gallons produces 1 KWh, converting to GWh gives you 80,000 gallons) (US Energy Information Administration, 2025). This means Saudi Arabia would save (80,000*6,231) = 498 million gallons of oil yearly. This can be converted to approximately (498 million/42) 11.9 million barrels of oil yearly. For context, Saudi Arabia exported 4 billion barrels of oil in 2023. The price of oil is volatile, and it is unlikely that the Saudis would export it all, as flooding the markets would lower the price, hurting their bottom line. However, assuming that the Kingdom's unofficial target of USD 75 per barrel is maintained through the sales of 40% of these new exports we calculate a revenue of:

Revenue per reactor: USD 75* (0.4*11.9 million) = USD 356 million starting in 2032 (Reuters, 2024).

- For Gas: 7.4 cubic feet of natural gas is required to produce 1kWh of electricity. Converting to GWh, this is 7.4 million cubic feet per GWh (US Energy Information Administration, 2025). This means the Saudi government could now export an additional quantity of (7.4. million*3,069) approximately 22.7 billion cubic feet of natural gas. A cubic feet of natural gas costs on average USD 6.7 per thousand cubic feet (US Energy Information Administration, 2025). Alike, oil, the Saudi government is unlikely to export all this gas in order maintain price stability. If we assume it exports 40% of this new gas, and LNG prices remain at present levels, this will give the Saudi Government approximately:

Revenue per reactor: USD 6.7*(0.4*90.8 billion/1000) = USD 60.9 million starting in 2032

These revenues, alongside the sale of electricity, would enable the Saudi government to generate approximately USD 881 million annually per reactor. Over, the nuclear reactor's 80-year operation as well as the industry standard 8% discount rate would stand at a PV of USD 5.9 billion in revenues. **This leads to an ROI of 25%.**

Criteria 5: Saudi Political Feasibility

Key: ***1 No control***
2 Partial Control
3 Full Control

Sub-Criteria	Score for Alt 1.
Mining Control	2
Enrichment Control	1
Reactor Operation and Maintenance	3
Waste Disposal Control	2
Independently Access Sites	2
Control over sale of electricity	3
Sovereignty Score	**13/18 (High)**

This alternative paves the way for Saudi Arabia to follow the United Arab Emirates in acquiring civilian nuclear technology. Alike the UAE's 123 agreement with the United States, it would prohibit the Kingdom from undergoing any enrichment operations. Although this alternative does not encompass domestic mining, the door could be left open for Saudi Arabia to complete further geological surveys on its Uranium deposits and potentially mine ore on a small scale. This would enable the Saudis to at least develop expertise in the initial stage of the fuel cycle. The AP1000's design (alike the AP300) contains an internal interim waste disposal system (NRC, 2010). The Saudis would be prohibited from relocating spent fuel, however, the presence of some elements of the final stages of the fuel cycle will provide them with exposure to fuel management, developing their expertise.

Aside from its commercial benefits that would be entirely directed to the Saudi government, the UAEs success in integrating Emirati professionals to the operations of their reactors sets a precedent (FANR, 2022). Given their neighbor's achievements, the Saudis may perceive the mere presence of the AP1000 on their soil as the essential, albeit imperfect, first step in developing their currently non-existing nuclear capabilities.

Criterion 6: US Political Feasibility

Assuming that negotiations produce an agreement, this alternative encompasses what the United States labels as the Gold Standard of nuclear safety (Glinsky & Sokolski, 2019). Even prominent opponents of Saudi Arabia's civilian nuclear program in Congress, such as Massachusetts Senator Ed Markey, co-chair of the nuclear weapons and Arms Control Working Group (and author of the Saudi WMD Act discussed in alternative 3), concede that they would not obstruct a Gold Standard 123 agreement with Saudi Arabia (Ed Markey, 2024). This is in addition to the inefficient mobilization of lawmakers in Congress against Saudi interests (see figure in alternative 3). Saudi-sceptic advocacy groups, such as the Arms Control Association, also base their opposition to the Saudi nuclear program on the basis of enrichment control. A traditional 123 agreement would address these concerns. Additionally, the US Congress has never issued a resolution of disapproval for a 123 agreement. This is despite the US signing this agreement with geo-political adversaries such as China and Russia in the past 20 years (US Department of Energy, 2023).

The ability to mobilize congressional majorities is important under this alternative as the US Congress plays a specific role in a 123 framework. If it passes a join resolution of disapproval within 60 days of the of the President's signature, it will stall the implementation of the agreement. If this resolution becomes law, the agreement is void (Blanchard & Kerr, 2024). The presence of multiple political stakeholders, encompassing both the Democratic and Republican parties, increases the possibility of political resistance. However, the 123 internal safeguards and track-record of success in the UAE program will decrease incentives for opposition, primarily from the Democratic party.

The political feasibility for this alternative is therefore high.

Overall Political feasibility: High

Criterion 7: Resilience to external Security Threats.

The United States would provide nuclear technology without security guarantees under this alternative. Iran and its proxies, particularly the Houthis in Yemen, successfully targeted Saudi energy infrastructure without repercussions. For example, in 2019, Houthi rebels successfully used drones to target oil processing facilities in the East of the country, causing 4 fatalities and significant supply shocks in oil markets. This was despite the presence of an on-site PATRIOT air defense system (Safi & Borger, 2019). In so far as the current air defenses of the Kingdom, the Ukraine war demonstrates the cost-inefficiency of the PATRIOT against one-way Iranian drones. According to a study by CSIS on the use of such systems in the Ukraine theater, a PATRIOT NASAMS munition costs USD 1 million compared to the USD 35,000 price tag of a Shaheed drone that can be effectively deployed in swarm warfare, as occurred in the 2019 attack. For every Iranian drone downed by NASAMS, the Saudi government incurs a cost of USD 600,000 (Hollenbeck, Altaf, Avila, Ramirez, Sharma & Jensen, 2025). This asymmetry, between the cost of the drone and the cost of interception decreases the resilience of the Saudi military to effectively defend against swarm tactics.

In sum, the Saudis therefore do not a credible deterrent against Iran and its proxies. This is important as the Houthis have drones and ballistic missiles capable of striking any target in Saudi Arabia. In 2019, the Houthis stated that they had targeted the UAE's nuclear power plants (Al Jazeera, 2017). This suggests that they consider large-scale nuclear installations as legitimate targets.

Saudi-Iran relations improved in March 2023 when both countries re-normalized relations. On the Yemen front, the last drone attack against Saudi soil occurred in late 2023, indicating a calming of tensions (Al Jazeera, 2023). However, the Trump administration's decision to relabel the Houthis as a terrorist organization and reports that Russia is seeking to supply the group with advanced weapons could re-incentivize Saudi Arabia to resume military operations (BBC, 2025). This would increase the probability of retaliatory attacks by the Houthis.

The probability of a regional war between Israel and Iran also presents a threat to these installations. Israeli political stakeholders manifest a clear desire to target Iranian nuclear installations. In the case of an Israeli operation, an American aligned Saudi Arabia, operating American-made reactors, could be the target of Iranian retaliatory attacks. In sum, without a cost-efficient and effective upgrade in aerial defenses, nuclear installations, as well as the broader energy infrastructure in Saudi Arabia, will be exposed to aerial borne threats from the Houthis and vulnerable in a regional war scenario between Israel and Iran.

Overall Risk Assessment: Highly Vulnerable.

Alternative 2: Build Capability with SMRs and Microreactors

As cited in the alternatives section, Westinghouse is the only American company that possesses SMRs and microreactors that are advanced for commercial deployment. The company provides two options, the eVinci microreactor and the AP300 SMR.

Criterion 1: Power Output (Microreactor)
The eVinci microreactor produces 48.3 GWh annually. Accounting for a 93% operation rate, it will generate 45 GWh annually.

Economic Parameters:
(Discount Rate and Payment Period Provided by client).

Given		**Assumptions.**	
Cap Ex	$ 80 million [6]	Lifespan	8 years [7]
Annual Op Ex	$ N/A [8]	Discount Rate	8%
Construction	40 Days [9]	Payment period	5 years
Annual Power	45 GWh [10]		

Criterion 2: Associated Costs
The total cost of 1 eVinci SMR amounts to a present value of **USD 63.8 million.**

Criterion 3: Cost and Benefit
Throughout the microreactor's lifetime, it will produce approximately 360 GWh of electricity. The costs per GWh throughout the microreactor's lifetime would amount to 63.8 million/ 360= **USD 177,453 per GWh**.

Criterion 4*:* Return on Investment.
This alternative is not designed to supplement the Saudi grid with large quantities of energy. The revenue from increased exports, if any, would be negligible. Revenue would therefore be derived from the sales of electricity exclusively.

[6] Westinghouse. (2023). "First Canadian eVinci Microreactor Targeted for Saskatchewan".
[7] Westinghouse. (2025). "eVinci™ Microreactor Clean Energy Solution for Mining".
[8] Operational expenses accounted for in USD 80 million price.
[9] Westinghouse-Bruce Power. (2021). "Executive Summary of the eVinciTM Micro-Reactor".
[10] Ibid.

Alike alternative 1, the Saudis could generate electricity and sell it domestically. Retaining the assumption that 1 GWh in Saudi Arabia has a market price of USD 50,000. Using these two numbers, (45 GWh at a USD 50,000 price), the Saudis could expect to generate a present value of USD 13 million over 8 years.

This results in an ROI of -80% per eVinci reactor.

The negative return on investment highlights the experimental nature of this technology. As mentioned in the literature review, unlike conventional reactors, SMRs and microreactors lack the economies of scale to produce cost efficient quantities of electricity. Under a commercial lens, microreactors cannot currently operate profitably.

AP300:

Criterion 1: Power Output (SMR). The AP300 is essentially a miniaturized version of the AP1000 mentioned in alternative 1. It utilizes the same technology; its more compact further reduces construction time and the land area occupation. Its power output, when accounting for a 93% operation rate, is approximately 2,700 GWh (Westinghouse, 2025).

Criterion 2: Cost.
Economic Parameters:

Given		**Assumptions**	
Cap Ex	$1 billion [11]	Lifespan	80 years [12]
Annual Op Ex	$100 million [13]	Discount Rate	8%
Construction	3 years [14]	Payment period	10 years
Annual Power	2,700 GWh		

Associated costs: The total construction cost of the AP300, paid over 10 years at an 8% discount rate, would represent a present value cost of USD 671 million. Unlike the eVinci microreactor, the AP300 entails operational costs. Assuming that these costs remain constant, they will amount to a PV of USD 990 million.

In total, every AP300 cost would cost the Saudis approximately USD 1.66 billion.

Criterion 3: Cost and Benefit.
The reactors will generate 2,700*80= 216,000 GWh throughout their lifetime. When accounting for their cost 1.66 billion, this results in a cost of **USD 7,690.7 per GWh.**

Criterion 4: Return on Investment.
Once they come online in 2028, the reactors will generate 2,700 GWh of electricity annually. Over the 80 years, the Saudis will generate approximately USD 1.33 billion.

The ROI of the AP300 would be = -20%

The ROI of the AP300 is low, but 60 percentage points higher than the eVinci microreactor.

[11] Clifford. C. (2023). "Westinghouse announces a new small modular reactor". *CNBC.*
[12] Westinghouse. (2025). "AP300 SMR"
[13] Provided by Client.
[14] World Nuclear News. (2023). "Westinghouse unveils AP300 small modular reactor".

This negative value is not indicative of the AP300's inefficient technology and is more the result of highly subsidized electricity prices in Saudi Arabia. As shown on the excel spreadsheet, adjusting subsidies to increase the price of electricity from USD 0.05 to USD 0.065 per KWh would enable the Saudis to operate one AP300 with a positive ROI.

Criterion 4: Saudi Political Feasibility (for both microreactor and SMR).

Sub-Criteria	Score for Alt 2.
Mining Control	1
Enrichment Control	1
Reactor Operation and Maintenance	3
Waste Disposal Control	1
Independently Access Sites	2
Control over sale of electricity	3
Total Score	**11/18 (Medium)**

Alternative 2 ranks similarly, albeit lower, to Alternative 1. It provides the same restrictions on mining, enrichment and disposal which will frustrate Saudi Arabia's plans to acquire their home-grown nuclear technology. Moreover, instead of acquiring established technology with a track record of large-scale deployment as alternative 1, the Saudis would adopt experimental nuclear technology. From a commercial standpoint, the Saudis would consider this alternative to be a temporary arrangement whilst they negotiate the transfer of more conventional nuclear technology with the United States or another foreign partner.

Nonetheless, this alternative would provide the Saudis with direct access to cutting edge nuclear energy. Under a practical perspective, control and hands-on experience over smaller scale nuclear infrastructure (as opposed to a conventional reactor) provides an ideal training ground for Saudi engineers to familiarize themselves with fuel management, reactor operations and safety protocols. Saudi workforce participation in this program would garner support in the political leadership of the country which aims to reduce dependence on foreign labor for high-level STEM expertise (Babineau, 2023).

Despite this positive potential, the Saudis would express frustration over their inability to complement this project with the development of their Uranium mining sector. An aspect which Alternatives 1 and 3 both provide. Essentially, Alternative 2 is the most similar to the status quo in which the Saudis are unable to develop an independent nuclear fuel cycle and hope to achieve more substantial transfers of nuclear technology in future negotiations.

Criterion 5: US Political Feasibility (for both SMR and Microreactor).
This agreement would proceed with unilateral action from the executive branch (via the issuance of 810 authorizations) (Blanchard & Kerr, 2024). Congress's absence reduces the quantity of opponents to the policy, increasing its political feasibility as well as the time frame of the technology transfer. Even if certain lawmakers contemplate a non-binding resolution of disapproval to the authorizations, the design safeguards of SMRs and Microreactors (as well as previous examples of failure discussed further in alternative 3), make it unlikely for these legislative efforts to materialize.

Overall Political feasibility: High

Criterion 6: The ability to dissuade and defend against hostile attacks targeting nuclear infrastructure in Saudi Arabia (for both SMR and Microreactor).

Without American security guarantees, the facilities could still be exposed to swarm drone attacks. However, the design of SMRs and Microreactors provide guardrails. Their compact size reduces their vulnerability to long-range missile attacks. Iranian forces and their proxies lack missiles with the accuracy to target infrastructure as small as the dimensions of a microreactor and an SMR (Gambrell, 2024). Moreover, the Saudis could choose to not reveal the location of their nuclear installations. In the case where these locations were compromised, the design of a microreactor will enable them to relocate their facilities (Westinghouse, 2025). Microreactors are also able to operate in remote areas, including the vast Saudi Rub Al-Khali desert in southeastern Saudi Arabia (Westinghouse, 2025). This minimizes the environmental and economic impact of a potential strike on a microreactor. The deployment of these assets in inaccessible sites will also mitigate the risk of a ground-based sabotage effort.

As mentioned in the evidence review, SMRs and Microreactors would not enable the Saudis to develop nuclear weapons, reducing their perception as a legitimate target by hostile actors. The research-focused aspect of these components would also put pressure on Iran and its proxies to not target them as doing so would damage their international standing and incentivize retaliatory attacks against their own nuclear facilities, which states such as Israel already contemplate.

Overall risk assessment: Moderately Vulnerable.

Alternative 3: Nuclear ARAMCO

Criterion 1: Power Output.
This alternative employs AP1000s, as elaborated in Alternative 1, they generate 9,300 GWh of electricity annually (accounting for maintenance interruptions).

Criterion 2: Costs.
The Saudi government would pay American companies to develop a domestic Uranium mining industry. The reactor calculations of Alternative 1 apply to this alternative, the AP1000 reactors will still cost USD 4.76 billion individually. However, the costs associated with the construction of mining, enrichment and disposal facilities must be incorporated.

Uranium Mine Cost:
These numbers are taken from a comparable Uranium mining project in Canada.

Given		**Assumptions**	
Cap Ex	$400 million[15]	Lifespan	10 years [16]
Annual Op Ex	$33 million [17]	Discount Rate	8%

[15] Eninson Mines. (2023). “Wheeler River Project”.
[16] Ibid.
[17] Ibid.

Construction	10 years [18]	Payment period	5 years

In the long term, the Saudis could aim to develop their mining industry and establish them as a major global supplier of Uranium. However, under this alternative all mined Uranium would be used for domestic consumption. Accounting for the financing plan and discount rate, the costs of Uranium mining are approximately USD 422 million.

As of February 2025, it is impossible to fully calculate revenue streams from the domestic sale of Uranium. Geological surveys on the country's reserves are inconclusive. Initial findings revealed that Saudi Arabia has an inferred capacity to produce 90,000 tons of Uranium (Harrison. G. & Kirchgaessner, 2020). However, according to a 2023 Bloomberg, these reserves have so far proven to be "uneconomical to mine" compared to imports from established exporters. (Tirone, 2023).

Enrichment facilities:

Given		**Assumptions**	
Cap Ex	$3.9 billion [19]	Lifespan	10 years
Annual Op Ex	$100 million [20]	Discount Rate	8%
Construction	5 years [21]	Payment period	10 years

When taking into the discount rate and financing plan, the enrichment facility would cost the Saudis USD 2.6 billion to bring online. The operational costs, starting in year 5 would cost USD 456.7 million in total. In total, enrichment capabilities would amount to approximately USD 3.07 billion.

Waste Disposal:

As part of their efforts to have full sovereignty over the fuel cycle, the Saudis would also contract American companies to dispose the spent fuel within the Kingdom's borders. According to research conducted at the University of Michigan and Stanford, the costs associated with a long-term disposal of the spent Uranium would equal the following:

Expenses	
Annual Waste Per Reactor (Tons)	27 [22]
Cost per Ton (USD)	350,000 [23]
Total Annually (USD)	**9.45 million**

[18] Ibid.
[19] Norman. R. (2023). "How Much Does It Cost to Develop New Nuclear Fuel Capacity?". *Third Way.*
[20] Jensen. R. , O'Dean. J. & Sullivan. A. (1982). "Economic Perspective for Uranium Enrichment". *Los Alamos Science Vol 3*.
[21] Norman. R. (2023). "How Much Does It Cost to Develop New Nuclear Fuel Capacity?". *Third Way.*
[22] Center for Sustainable Systems, University of Michigan. (2024). "Nuclear Energy Factsheet."
[23] Cranmer. C. (2024). "Cost of Nuclear Management in the US". *Stanford University.*

These annual payments would start when the plants become online after 8 years and the first waste is disposed of the subsequent year, bringing the total price of disposal to a present value of USD 58.8 million to dispose of waste throughout an AP1000's lifetime.

Total Cost:
The costs of mining, enrichment, and waste disposal would be distributed across four reactors, as these sites provide the necessary materials to support their operation. The present value of the AP1000s, alongside their construction and operation costs calculated in alternative 1, amounts to **USD 5.6 billion per reactor**.

Criterion 3: Cost Benefit Analysis.
The cost to GWh would not stand at= **USD 7,565.43 per GWh**.

Criterion 4: Return on Investment.
The Trump's administration policy towards the Ukraine conflict, as well as German and South Korean security arrangements, where mineral revenue concessions could be exchanged for potential security guarantees, makes it likely that the US will demand financial compensation for the deployment of US troops (Gregory, 2025).

As calculated in alternative 1, the Saudis can expect to generate USD 5.9 billion in revenue (from electricity sales and the increased export of oil and gas) throughout the lifetime of one AP1000 reactor. Although this remains speculative, the Saudis could finance American troop presence on the ground through revenue sharing agreements with the United States. This could be done through one of two ways: 1.) The Saudis export at a discount the surplus oil they no long utilize to meet domestic demand to the US or 2.) The Saudis directly split revenues from the sale of oil with the United States. Although different in concept, they will both result in the Saudi bottom line decreasing.

The profit split in the second option is speculative. However, based on historical benchmarks, we can calculate an approximation. Saudi Arabia paid the United States USD 38 billion (in 2025 USD) for the deployment of 500,000 US troops during operation Desert Shield between 1990 and 1991 (GAO, 1991). The protection of Saudi Arabia's nuclear sites would require fewer personnel, with a number comparable to South Korea, which faces a similar geopolitical environment. South Korea hosts approximately 25,000 American military personnel. Given that 40,000 U.S. troops are already stationed in the Middle East as a deterrent to hostile actors, an additional 12,500 personnel would be needed for Saudi Arabia's nuclear security. Based on the cost proportions of Operation Desert Storm, deploying these 12,500 personnel would incur an annual expense of approximately USD 950 million. This estimate aligns with claims made by the Trump administration in 2019, which stated that Saudi Arabia was paying the United States an annual fee of USD 1 billion for protection against Iranian threats.

Over an 80-year period, this annuity of USD 950 million would amount to approximately USD 11.6 billion, exceeding the estimated reactor revenues of USD 10.1 billion. However, this financial burden would not necessarily fall on Saudi Arabia's nuclear program alone but could instead be absorbed by the Ministry of Defense, which operates with an annual budget of USD 75 billion—the fifth largest in the world. Assuming that only operational and maintenance costs (including those of mining, enrichment and waste disposal operations) are covered by Saudi

ARAMCO and that defense partnership expenses are allocated to the Ministry of Defense, the revised return on investment (ROI) calculation would be:

ROI stands at: 6%

Criterion 5: Saudi Political Feasibility:

Sub-Criteria	Score for Alt 3.
Mining Control	2
Enrichment Control	2
Reactor Operation and Maintenance	3
Waste Disposal Control	2
Independently Access Sites	2
Control over sale of electricity	3
Total Sovereignty Score	**14/18 (High).**

High degrees of sovereignty over the nuclear program are central to Saudi support. As the table demonstrates, this alternative rates high for Saudi stakeholders. Although American personnel would conduct the mining, enrichment and disposal phases of the fuel cycle, they would be present on Saudi soil. The insertion of a clause to, after 15 years, annually review the operation of enrichment facilities would also equip the Saudis with a pathway to develop expertise and an indigenous nuclear technology. In the short term, there would be no restrictions on the employment of Saudi personnel in the operations and management aspects of the operation, enabling for immediate access to sophisticated nuclear technology. As stated on several occasions by senior Saudi stakeholders, such as Crown Prince Mohammed bin Salman and Minister of Energy Abul Aziz bin Salman, this is a feature that the Saudis consider to be an integral part of their self-dependence policy (Reuters, 2025).

Moreover, the development of mines in the countrywould enable the Saudis to explore the possibility of entering the Uranium export market and establishing themselves as the leading provider of Uranium in the GCC (Gulf Cooperation Council) region. Although this is also a feature of Alternative 1, the American guarantee of developing mines would inspire greater support. All six states in the group express a desire to invest in nuclear energy. Unlike Saudi Arabia, these states lack the Uranium deposits to establish a domestic mining industry. The Saudis could therefore leverage high levels of regional trade integration to market their Uranium against that of, for example, the traditional supplier.

Criterion 6: US Political Feasibility.
This alternative would require a substantial recalibration of relations between the United States and Saudi Arabia. American military personnel would be stationed in Saudi Arabia with the mission to defend the territory against any hostile activity. Such an agreement could only be concluded via a treaty framework, necessitating ratification by the United States Senate. This is evidenced by the fact that all US mutual defense treaties exist in the medium of a Senate ratified treaty (US Department of State, 2017).

According to February 2024 Gallup poll data, 38% of the American public views Saudi Arabia favorably, with 53% viewing the Kingdom unfavorably (Gallup Ratings, 2024). These approval ratings are comparable to the public's perception of countries such as Turkey and Cuba (Gallup Ratings, 2024). The table below demonstrates that low public approval ratings do not necessarily materialize into long-term policy changes by the United States towards Saudi Arabia. If anything, relations over the past 25 years expanded to include Saudi involvement in American institutions such as the PGA (Professional Golf Association) and Saudi commitments, as of April 2025, to invest USD 600 billion, over four years, in the United States economy (Gambrell, 2025).

Outcome of Major US-Saudi legislation/ executive action in previous 10 years:

Bill/Action and Purpose	Year	Outcome
S. Res.105: Seeking to ban proposed sale of weapons to Saudi Arabia. [24]	2024	Failed to receive vote on Senate floor.
S. 1146: Saudi WMD Act, implementation of arms sales bans if Saudi Arabia does not relinquish aim of obtaining nuclear weapons. [25]	2021	Failed to receive vote on Senate and House floor.
Executive Action by Biden administration freezing arms sales to Saudi Arabia. [26]	2021	Freeze reversed in 2024 by Biden administration.
S.J.Res.38: Banning of certain arms to Saudi Arabia over humans' rights abuses (related to Khashoggi incident). [27]	2019	Initially passed Senate, vetoed by President trump. Failed to obtain majority on second reading.
S.J.Res.32: Limitation of weapons munitions sold to Saudi Arabia. [28]	2016	Failed to received vote on Senate floor.
S.0240: Justice against Sponsors of Terrorism Act, enabling 9/11 families to sue Saudi government [29].	2016	Became federal law, although bill never mentioned Saudi Arabia by name.

Whilst these policy initiatives provide an indication of how the American political system perceives the US-Saudi relationship, this potential treaty, would be different in so far as they would put American lives at stake for the defense of a foreign territory. Current US defense commitments exclusively include democratic countries (eg: NATO, Japan and South Korea) (US Department of State, 2017). Although there is precedent for the United States defending a Middle Eastern country from a hostile actor (US intervention in Kuwait in 1990/1991), it is complicated to gauge the potential support, or lack thereof, for a mutual defense treaty with a nation that lacks democratic commonalities with the United States.

The current dynamic of the American political system is also important. As of 2025, the Republicans control both houses of Congress. However, this does not translate into a Saudi-

[24] Congress.gov. (2024). "S.Res.105".
[25] Congress.gov. (2024). "S.1146".
[26] Reuters. (2024). "US expected to lift ban on sale of offensive weapons to Saudi Arabia, FT reports".
[27] Congress.gov. (2024). "S.Res.38".
[28] Congress.gov. (2024). "S.Res.32".
[29] Congress.gov. (2024). "S.0240".

US treaty being a fait accompli. As highlighted in the table, in Trumps first term, a Republican controlled Senate passed a resolution of disapproval against Saudi arms transfers.

In addition, the current Trump administration would certainly face accusations of influence pedaling. This is evidenced by Democratic Party calls, including from the ranking member of the Senate Finance Committee, Senator Wyden, for investigations into the business dealings of Jared Kushner (Trump's son in law) with Saudi Arabia. For context, Kushner received a USD 2 billion contribution from the Kingdom to initiate a regional equity fund (US Senate Committee on Finance, 2024). Additionally, although the Republican Party is more pro-Saudi than its Democrat counterpart, several Senators could plausibly vote against a mutual defense pact. In a Senate with a Republican majority of 3, this could prove pivotal. Below is a table outlining the Republican members most likely to oppose a treaty in 2025.

Senator	Action	Date
Rand Paul (KY)	Sponsor of S.J.Res.53, a bill seeking to block arms sale to Saudi Arabia. [30]	11/2023.
Mike Lee (UT)	Co-sponsor of S.J.Res.53 and introduced bi-partisan bill to require USG to report annually on state of human rights in Saudi Arabia. [31]	03/2023 and 11/2023.
Bill Cassidy (LA)	Introduced bill to bill to withdraw American troops and impose oil tariffs on Saudi Arabia due to oil market manipulation. [32]	04/2020.

In the current Senate, if these three individuals vote no (presuming all democrats oppose the deal), the vote would be a tiebreaker. Vice President Vance would presumably vote with the administration, leading to the enactment of the treaty.

More importantly, Congress is unlikely to approve a recalibration of relations without immediate Saudi concessions. The Kingdom's pledges to not repurpose American technology for the construction of a nuclear weapon is a start, but aspects such as normalization with Israel and a quasi-severance of geo-political ties with China will be pre-requisites for a nuclear ARAMCO. The latter of these appears to be more plausible. Aside from the precedent set by the Abraham Accords in 2021, MBS stated in an October 2023 Fox News interview that relations with Israel were *"getting closer every day"* but that normalization still depended on the creation of a sovereign Palestinian state (Fox News, 2023). Saudi-Israel normalization stalled after the 2023 Hamas attacks and is unlikely to resume before the installation of a permanent ceasefire between Israel and Hamas in Gaza. Regarding China, the United States

[30] Congress.gov. (2024). "S.Res.32".
[31] Ibid.
[32] Bill Cassidy. (2020). "In Response to Saudi Aggression, Cassidy to Introduce Bill to Withdraw American Troops, Impose Oil Tariffs".

can leverage new security guarantees as a countermeasure to limit Sino-Saudi geopolitical ties, but it cannot halt their expanding commercial relationship.

Overall, on the condition that a Nuclear ARAMCO is enacted as part of a wider geo-political rapprochement of the United States and Saudi Arabia, emblemized through aspects such as Saudi-Israeli diplomatic normalization, the political feasibility for this alternative is medium.

Overall Political feasibility: Medium

Criterion 7: The ability to dissuade and defend against hostile attacks targeting nuclear infrastructure in Saudi Arabia.

This alternative provides Saudi Arabia with an American defense pact. For this arrangement to be effective, this security guarantee would need to deter Iranian proxies, as well as Iran itself. According to strategist David Lonsdale, a credible extended deterrence needs three attributes: commitment, capability and communication (Lonsdale, 2022). As shown in the table below, the United States military is able, or will be able, to meet all three in the Arabian Peninsula.

Table Substantiating American Deterrence in Middle East.

Attribute	US Military Strength.
Capability	The US maintains a robust military presence in the Peninsula through CENTCOM. This includes advanced missile defense systems, naval forces in the Fifth Fleet, air bases and a total 40,000 servicemembers.[33] The United States can ensure rapid mobilization to potential threats with forces adapted to the region's terrain.
Commitment	The US has a track record of security commitments in the region, including military interventions in Kuwait, Iraq, the Red Sea and the Persian Gulf. A formal, legally-binding, defense treaty will institutionalize this commitment, reinforcing credibility.
Communication	The US does not have any explicit red lines that would trigger an armed response in the Arabian Peninsula.[34] A treaty that outlines obligations would remove this ambiguity and signal to adversaries that the United States is not engaging in a regional withdrawal, thereby strengthening deterrence.

As mentioned in the table, a treaty is an ideal medium for the United States to establish a credible deterrence over Saudi territory. Assuming that this alternative is activated, the risk of an attack on a Nuclear ARAMCO is low. This is important as unlike Alternative 1 and 2, it

[33] Masters. J. & Merrow. W. (2024). "U.S. Troops in the Middle East: Mapping the Military Presence. *Council on Foreign Relations.*

[34] Roule. N. (2024). "American and the Middle East in 2025: Old Challenges, Broken Myths, New Opportunities". *Hoover Institution*.

provides for the development of enrichment facilities and nuclear waste disposal that can be interpreted by the Iranians as a step towards offensive nuclearization.

Overall Risk Assessment: Secure

Recommendation

Outcomes Matrix:

	Criteria	Power (Annually/ Reactor)	Cost (USD)	Cost Effectiveness (USD/ GWh)	ROI (%)	US Political Feasibility	Saudi Political Feasibility (Score)	Security Resilience
Alternatives	**Alternative 1 (123 Agreement)**	9,300 GWh	4.74 billion	6,371	25	High	High	Highly Vulnerable
	Alternative 2a (Microreactor)	45 GWh	0.063 billion	177,453	-80	High	Medium	Moderately Vulnerable
	Alternative 2b (SMR)	2,700 GWh	1.66 billion	7,690.7	-20	High	Medium	Moderately Vulnerable
	Alternative 3 (Nuclear ARAMCO)	9,300 GWh	5.6 billion	7,565.4	6	Medium	High	Secure

**All monetary values in Present Value (2025 USD)*

Trade Offs:
The outcomes matrix summarizes the performance of every alternative vis a vis the criteria; there is no alternative that supersedes the other in every category. However, the following is clear:

Despite support in the American political landscape and integrated safety-design features of emerging nuclear technology, both versions of Alternative 2 do not provide commercially viable volumes of power to the Saudis. They should therefore not be perused as the centerpiece of the civilian nuclear program.

Alternatives 1 and 3 provide identical levels of power to the Saudis, albeit at different financial costs. Alternative 1's nuclear infrastructure, which only consists of a reactor, coupled with the lack of direct compensation to the United States government, makes it with a more cost-effective option with a more attractive ROI.

However, the problem statement of this report does not exclusively address economic costs but also values the security dimensions. As mentioned in the evidence and findings section, the threats to energy infrastructure are a relevant risk in the Arabian Peninsula. A successful attack against a conventional nuclear reactor, leading to substantial environmental and economic repercussions, could erode the benefits of alternative 1. Moreover, alternative 1 does not fully satisfy the Saudi ambitions for the program and, in their eyes, would render them observers as opposed to equal partners.

In the security domain, Alternative 3 outperforms Alternative 1 in its ability to protect nuclear installations from an attack. It also placates Saudi desires to develop an indigenous civilian nuclear technology whilst consolidating US policy of non-proliferation through a joint ownership and operational model. The strength of alternative 3 in the domains of security and Saudi political feasibility renders the increased cost an acceptable financial tradeoff for the Saudis. Numerically speaking, the trade-off would not amount to a substantial cost change: for an additional USD 1.04 billion per reactor, the Saudis could construct an entire nuclear ecosystem that could pay future dividends and further compliment their aim of economic diversification (i.e.: establishing a domestic mining industry). Although payments to the American government would erode ROI vis a vis alternative 1, alternative 3 still provides a positive rate of return to the Saudis, enabling them to reinvest revenues into the development and future upgrade of their fuel cycle infrastructure.

The only hurdle for this alternative would be its feasibility in the American political system, a criterion where it significantly underperforms its two counterparts. Financial compensation to the United States government could encourage law makers in the Senate to green-light the deal, particularly the three Republican Senators cited in the report as well as some Democratic Senators. In addition, the Kingdom's pledge to invest USD 600 billion in the US economy could increase their standing and position them as an invaluable economic partner whose alignment with other nuclear providers (such as China and Russia) could harm US interests.

The US could leverage security guarantees with Saudi Arabia to curtail growing Chinese influence in the region and restrict Beijing's oil supply chains in the Middle East. According to open-source information, China obtains 10.7% of its oil supplies from the Kingdom (WTP, 2023). However, as mentioned above, Saudi concessions would need to extend into guarantees to the United States on minimal geo-political alignment with Chinese and Russian interests in the Middle East.

Final Recommendation:
As outlined in the matrix and justified in the preceding section, **this report encourages BAH to view the establishment of a Saudi ARAMCO as the most favorable framework for a US-Saudi nuclear partnership.**

Additionally, if the Saudis decide that the ability to conduct research is a monetary valuable tradeoff, they could also deploy the AP3000 in a research-capacity role, as well as in the application of small-scale energy generation.

Implementation:

The diagram below demonstrates the implementation sequence.

Phase 1: Enaction

(Current to Year 1)

- Saudi selects US as partner in nuclear program.
- Conclusion of negotiations between Saudi Arabia and US.
- Completion of Department of Energy authorizations for transfer of specific nuclear technology.
- Ratification of treaty by US Senate.
- Commencement of payment plans.

Phase 2: Execution

(Year 2 to Year 10)

- Construction of enrichment, mining and waste disposal systems.
- All payment plans completed by Y10.
- Saudi peronsel integrated into reactor operator teams.
- Reactors, mining, enrichment and waste Disposal all online by Y10.
- Profit distribution transferred to the American government.
- Deployment of US military assets and contractors in the country.
- Establishment of Joint Nuclear Commission and negotiation framework for future transfers.

Phase 3 :Transition

(Year 11 to Year 15)

- Commission meets to discuss possible transfers of operational control over enrichment facilities in Y15.
- American military presence and contractors remain.

Phase 4: Transfer

(Year 16 to Year 80.

- Comission meets anually after Y15.
- If negotiations succesful and US deems that risk of repurposing is managed, training of Saudi personnel in enrichment and waste disposal facilities begins.
- Transfer of facilitiec continues but American personel remain and Saudi complies with IAEA inspections.
- Reactors reach life-cycle end at Y80 and negotiations resume for renovation of program.

Lobbying efforts in Phase 1, within the US Senate and Administration, can begin immediately. In phase 2, once the infrastructure is completed, Saudi elements would be incorporated in the aspects relating to the operation of the nuclear reactor. Moreover, as per the desire of the Saudis to maintain their energy sovereignty, American mining companies could aid the Saudis in developing their domestic uranium mining industry. Throughout phase 2, BAH should recommend to Saudi and American stakeholders to form a joint nuclear commission (in addition to involvement by the IAEA) to oversee compliance with international safeguards and facilitate future technology transfers. The United States already employs this commission framework with Japan through the US-Japan Nuclear Security Working Group.

As demonstrated on the graphic, Phase 3 and 4 pivot around the agreement to revisit shared custody after a period of 15 years with the objective of civilian-focused Saudi take-over.

Risk Assessment of Implementation

Saudi Public Opposition: The Saudi public is mostly unfavorable towards the United States. According to polls conducted in December 2022, only 41% of Saudis believe that good ties with the United States are important, this is 16 percentage points lower than their perception of China and 12 of Russia (Pollock, 2022). This poll was taken before the onset of the Gaza conflict. The US involvement in an overwhelmingly unpopular war in the Arab world had likely led to the further diminishing of this favorability rating. Saudi Arabia is not a democratic country, and it is therefore very unlikely that the government would be swayed by the public sentiment represented in these numbers. As demonstrated by open-source information, the government of MBS successfully in stifles political opposition to socio-political changes in the country (Martinez, 2023). It is therefore unlikely to impact development in Phase 1.

However, Operation Desert Shield provides a case study to analyze the impact of a substantial American troop presence on Saudi society. Although this intervention was a success, i.e.: Saddam Hussein did not attack Saudi Arabia, it fueled a rise in Saudi-based terrorism. Osama Bin-Laden frequently labelled the entry of 500,000 American troops in the Kingdom throughout 1990/1991 as a betrayal of the Saudi royal family to the Islamic faith, justifying terrorist acts (Jehl, 2001). Within Saudi Arabia, Al Qaeda committed several attacks against American personnel, including the 2003 Riyadh Compound bombings which killed 9 Americans. In the United States, the organization was responsible for the largest terrorist attack on American soil in 2001. Although as of 2025, Al Qaeda has not posed a serious threat to the political establishment and stability of the country, BAH should be aware that such an extension of ties could trigger waves of radicalization within the country (Thomas, 2024). This could in turn increase security threats to American military personnel and contractors in the Kingdom throughout Phases 2, 3 and 4. However, a boosted American military presence could enable the US to coordinate with Saudi authorities to rapidly identify and neutralize such threats.

Undeterred Iran and Iranian Proxies: Iran could also consider the implementation of ARAMCO as a direct threat to its national security. As opposed to providing a deterrent, the presence of American troops would provide an incentive to launch a pre-emptive missile strike on Saudi-based enrichment facilities in Phases 2, 3 and 4. Iranian proxies killed American military personnel as recent as January 2024 when an Iran backed militia killed three American servicemembers in Jordan. Despite this, Iran has never directly targeted American troops in the Persian Gulf. This is in addition to the US willingness to assert dominance over Iran in the region as evidenced by operation Praying Mantis in 1988 as well as the assassination of Qassem Soleimani in 2019.

Following its recent conflict with Israel, Iran is in a weakened position. An October 2024 Israeli operation destroyed their Air Defense systems, reducing their ability to defend against an American counterstrike (Staff, 2024). In sum, an Iranian attack on American-operated nuclear facilities is unlikely.

Presence of other Stakeholders:
South Korea, in particular, would be a robust challenger. Saudi stakeholders will take note of its involvement in the UAE program, which was delivered without major delays and employs a more cost-efficient reactor than the AP1000, the APR1400 (Oettinge, 2021). Unlike, the United States, South Korea has a demonstrable, proven ability to operate in the Middle Eastern nuclear energy landscape. Under the Trump administration and in the context of Phase 1, the US could leverage its security relationship with South Korea (as well as France through EDF) to pressure the latter into annulling its bid. However, this tactic would not be applicable to Chinese and Russian competitors. Furthermore, although South Korea, France, China and Russia have track records of successfully developing international nuclear programs, none of these countries could attach their assistance to the provision of security guarantees.

Additional Implementation Challenges:
The greatest obstacles to the implementation of the recommendation are present in Phase 1 and Phase 4. Other concerns, notably construction delays and budget overruns will be present throughout all stages.

In Phase 1, the US Senate's refusal to ratify a mutual defense treaty as well as the possibility of Saudi Arabia vying for another nuclear partner would make an American-led nuclear ARAMCO impossible. However, the evidence discussed above demonstrates that once Phase 1 is complete, the US and Saudi Arabia can ensure the treaty's elements not only materialize, but that the project's infrastructure and personnel is also protected from Iranian security threats. In Phase 4, a refusal or delay by the United States to transfer control of enrichment sites to Saudi Arabia after Year 15 could heighten tensions between the two nations. However, as noted earlier in this report, the sustained presence of American troops in Saudi Arabia would reduce the Kingdom's incentive to develop its own deterrent against a potentially nuclear-armed Iran.

Concluding Remarks

The report concludes that Nuclear ARAMCO presents a profitable and widely supported proposal within Saudi Arabia. The immediate next step is for the United States and Saudi Arabia to recalibrate their relations, with key aspects such as Israeli-Saudi normalization and a strategic distancing from China and Russia playing a crucial role in addressing skepticism within both the Republican and Democratic Parties.

In anticipation of an agreement, BAH should identify areas where its expertise can add value across the nuclear ARAMCO ecosystem that will include mining, enrichment, reactor operations, waste disposal, and facility security. The longevity of modern nuclear reactors, which operate for 80+ years, will incentivize continued partnership between both states. If successful, a nuclear ARAMCO will encourage other GCC states interested in nuclear energy to engage in similar proposals, strengthening the US position in the Middle East.

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