# Jordan’s SMR RTA experience

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**Abstract**

The Jordan Atomic Energy Commission (JAEC), based on the updated electricity demand forecast study conducted on the Electricity Market in Jordan, initiated studies on the feasibility of deployment of Small Modular Reactors (SMRs) in Jordan. This paper discusses selecting and evaluating reactor vendors to align with Jordan’s nuclear power project requirements emphasizing the critical Energy and water state in Jordan, and justifying the need for such a program. It explains the rationale behind the requirements. The IAEA RTA methodology was used as a reference to build the process with some modifications to accommodate the special nature of the SMR technology. Throughout this framework, the paper navigates the process, it presents the results of the RTA offering insight into the SMR RTA experience and its implications for the country’s energy/water future.

## INTRODUCTION

Jordan is an 89,342 km2 country with an estimated population of 11.5 million with an electrification rate of 99.9%. Consisting mostly of an arid climate, and lacking large land water bodies, Jordan depends mostly on inconsistent seasonal rain as the primary water source. Jordan has a small shoreline in the Gulf of Aqaba, representing the only seaport for the country.

Currently, the only locally independent power source is the Attarat Power Company ‎[1] which consists of two 235 MW units. The plant is expected to meet up to 15% of the annual electricity demand. Jordan also has the Risha Gas field which produces 1.8% of the daily need for gas in Jordan. Jordan acquires its natural gas needs through an agreement that will end in 2031. This puts Jordan in a tight position and in a race against time to find alternative energy sources after 2030 to reconcile the expired natural gas supply agreement and the planned decommissioned conventional and renewable power stations.

The current annual freshwater share per capita in Jordan is 61m3, and the absolute water scarcity is 500 m3/capita/year, bearing in mind that the global median is 8,915 m3/capita/year‎[2]. The water sector consumed 16% of the total electricity produced in 2020‎[3], the challenges faced in the natural water sector consist of:

* High depth of groundwater;
* long distances from population centers;
* and low quantity of surface water.

The energy intensity of total supplied water is 3.4 kWh/m3, Energy demand is expected to increase due to the predicted increase in water desalination and the longer pumping distances by the National Conveyance Project to 9 kWh/m3 for freshwater delivered to Amman‎[4], which is 2.6 times higher than the current energy intensity.

Jordan, lacking local energy sources, depends highly on imported energy sources to cover its electricity and water generation needs. Having to decommission traditional fossil power plants around 2030 put Jordan in a race against time to come up with viably economically feasible replacements.

## Jordan nuclear power project

### Large Reactors

Sparking the need for a local independent power source, the Jordanian nuclear power project started in 2009 to build a large power reactor (LR) with a power of around 1000 MWe, during the process Jordan performed various technical studies:

* Water cooling studies;
* Electric/grid studies;
* Stakeholder involvement strategies;
* National infrastructure surveys and studies;
	+ - * Localization/national industry;
			* Transportation.
* Siting studies.
	+ - * Country Wide Survey (CWS) and site selection studies;
			* Full site characterization studies are still not performed;
			* Meteorological data collection at the selected site was started in 2017.

JAEC received expressions of interest from four vendors interested in providing Jordan with its first nuclear power plant. These four vendors offered JAEC seven different plant technologies for consideration, all Water-Cooled Reactors (Pressurized Light Water Reactor, and Pressurized Heavy Water Reactor). Except for one design, none of the technologies were constructed and placed into actual commercial operation by the time of JAEC’s evaluation in 2010. JAEC has elected to implement a competitive dialogue process with several technology providers and did not follow a typical procurement selection process.

A preliminary evaluation of the seven technologies was conducted to select two or three to carry forward into the competitive dialogue process. The assessment was based on a questionnaire on technical and preliminary financial information. The questions contained the essential details needed to evaluate various technologies for meeting JAEC’s expectations. The evaluation procedure was developed using an internationally recognized and accepted evaluation methodology based on the quantitative numerical evaluation method provided by the IAEA‎[5].

#### Large Reactors evaluation process

The evaluation procedure, matrix, and criteria (9 items + Economics) were developed before receipt of the vendors' responses to the questionnaire:

* General Design; Meeting international licensing requirements, areas of risk, vendor and owner responsibilities;
* Design; Design lifetime, efficiency;
* Operation and maintenance; Refueling outages, regular maintenance, staffing for operation and maintenance, etc.);
* Construction; design adaptation to Jordan’s environment and site characteristics, cooling, footprint, and plant layout;
* Reactor Performance: Availability, efficiency, load follow capability;
* Safety of the reactor design; Defence in depth, operational safety, internal and external hazards, passive safety features, grace period, CDF, LERF;
* Fuel Cycle and non-proliferation; Nuclear Fuel design and safety, SNF pool design and capacity, fuel handling system, Fuel supply and waste management and reduction;
* Licensing and operating experience; Proven design, compliance with IAEA safety standards, reference design;
* Vendor long-term commitment; vendor readiness, localization;
* Economics; Capex, O&M, LCOE.

Due to its sensitivity, the economic part of the evaluation will not be discussed in this paper. The evaluation was conducted using qualitative engineering judgment by technical personnel with extensive nuclear design, construction, and operations support experience.

The evaluation resulted in selecting the top three technologies for the competitive dialogue phase from the seven evaluated. The three technologies were evaluated concerning 15 key factors (KF):

* Overall Safety**;**
	+ - * KF-1 General safety design criteria;
			* KF-2 Exclusion zone;
			* KF-3 Seismic;
			* KF-4 Airplane crash;
			* KF-5 Fukushima Daiichi;
			* KF-6 Digital I&C systems;
			* KF-7 Licensing & Design Certification.
* Fuel Supply and RWM;
	+ - * KF-8 Fuel supply;
			* KF-9 Back end of the fuel cycle;
			* KF-11 Non-proliferation.
* Operation and Efficiency;
	+ - * KF-12 Performance Guarantees;
			* KF -13 Efficiency and Availability;
			* KF-14 Cooling water design;
			* KF-15 Vendor Long-term Sustainability.

TABLE 1 presents the terms used to evaluate bidder response for each of the 15 Key Factors:

TABLE 1 TERMS USED TO EVALUATE KEY FACTORS

|  |  |
| --- | --- |
| Term | Description |
| Compliant | The bidder has demonstrated that the BIS requirements for providing the requested information in the bid have been completely satisfied |
| Mostly Compliant | The bidder has demonstrated that the BIS requirements for providing the requested information in the bid have, for the most part, been submitted |
| Partly Compliant | The bidder has demonstrated that the BIS requirements for providing the requested information in the bid have not been submitted or are only partially satisfied |
| Not Compliant | The bidder has not demonstrated that the BIS requirements for providing the requested information |
| Open Items for Negotiation | Items that need to be resolved between the Owner and Bidder before contract signing |

Several issues were raised during the evaluation process:

* Technology licenseability;
	+ - * Technology licenseability posed a significant risk for designs without approval from their home country regulators, which is crucial for any final selections. Some designs were primarily created for foreign markets, lacking review by their home country's nuclear regulatory authority for construction licensing;
			* The evaluation was based on vendor statements, assuming a review level equivalent to that for home country construction, with the expectation of timely certification by home country regulators to avoid project schedule impacts.
* In some specific questions, some vendors did not respond, or their response was less detailed or informative compared to others, resulting in lower scores. Examples of such observations include:
	+ - * Not adequately addressing Jordan’s geotechnical or environmental requirements;
			* Insufficient information to confirm the 60-year plant design lifetime;
			* Lack of information for important SSCs lifetimes, such as the steam generator and steam turbine;
			* Lack of details in the whole waste management program;
			* Absence of a significant plan for optimizing in-country resources;
			* Lack of an identified worldwide supply chain;
			* Lack of any experience with back-end fuel;
			* Lack of details and information concerning fuel transport to a dry storage or casks system within Jordan.

As a result of these studies, it was concluded that Jordan would not pursue LRs, and the project was put on hold, due to:

* Financial burden and capital investment;
* Water cooling requirements;
* Grid compatibility.

In 2018 Jordan shifted its eyes to SMRs as a replacement for LRs as the technology of choice used in the Jordanian nuclear power program.

### Small Modular Reactors

Looking into SMRs, Jordan found that they agreed with the project requirement:

* Low capital costs and initial investment;
* Low cooling water requirements;
* Compatible with the small electricity grid;
* Scalable to match the gradual increase in electricity;
* Deployable post-2030.

Due to the nature and number of SMR designs emerging into the market, JAEC set some general exclusion topics to initially down-select the number of studied reactors:

* Deployment time: by 2030-2032 operational in Jordan (Nth of a kind);
* Mature technology and vendor: only LWRs and HTGRs;
* Size: micro-reactors are excluded, less than 50 MWe;
* Only land-based reactors: FNPP and submerged are excluded.

### Evaluation Process

This evaluation process is designed to be fully transparent, and self-explanatory, allowing quantification and integration of all essential Jordanian requirements.

The evaluation process was performed by a technical and economic team from JAEC (with review and input from IAEA experts). The evaluation process is designed to capture the differences between the available SMR technologies. The evaluation methodology utilizes the following criteria:

* Technical;
	+ - * Exclusionary Topics (mentioned earlier);
			* Evaluation Matrix (EM);
			* Key Factors (KF);
			* Best-In-Class (BIC).
* Economic.

Based on the SMRs exclusionary, JAEC has selected 6 SMR technologies for detailed assessment. Due to confidentiality, the reactor technologies will not be named in this paper.

#### Evaluation Matrix (EM)

The six selected SMRs were assessed using the EM to down-select to the top design. JAEC consultants developed the original EM during the LR phase. However, the original EM was revised by the JAEC team for application to SMR technologies with Nuclear Reactor Technology Assessment for Near Term Deployment- NP-T-1.10 as a reference. This resulted in 109 items divided into 10 categories as follows:

* General.
	+ - * meeting current international license-ability requirements, areas of risks, vendor and owner responsibilities, etc.
* Design.
	+ - * lifetime, efficiency, design adaptation to Jordan’s environment and site characteristics, cooling, footprint, plant layout, etc.
* Operation and maintenance.
	+ - * refueling outages, regular maintenance, staffing for operation and maintenance, etc.;
			* No experience; maintenance and staffing are still under development (Setback).
* Construction.
	+ - * Construction period, the approach of modular construction and assembly, manufacturing capabilities, transportation of heavy equipment, etc…;
			* No experience or reference plant (at the time).
* Reactor performance.
	+ - * Availability, efficiency, load following capability, etc.
* Nuclear Safety.
	+ - * Defense in depth, operational safety, internal and external hazards, passive safety features, grace period, CDF, LERF, etc…;
			* Experience with Non-water-cooled reactors (Setback);
			* Safety Classifications (Setback).
* Fuel cycle, waste management, and non-proliferation.
	+ - * Nuclear Fuel design and safety, SNF pool design and capacity, fuel handling system to deal with failed fuel elements, experience in fuel supply, experience in waste management and reduction of waste, etc…;
			* Sustainable Fuel Supply (Setback);
			* Manufacturing experience (Setback).
* Licensing and operating experience.
	+ - * proven design, compliance with IAEA safety standards, reference design, etc….
* Vendor long-term commitment.
	+ - * Some vendors were small newcomer companies that couldn’t prove long-term commitment (Setback).

Some reactors either did not have the information ready (design phase), or the information requested did not apply to the technology such as:

* Safety Systems: a vendor claimed that there was no need for safety systems and that a system was just classified as such for licensing needs;
* Licensing: almost all reactors were not licensed (at the time); didn’t apply for safety reviews by any regulatory bodies, or were still in the design phase;
* Confidentiality.

This subsequently affected both the assessment of the technology and the progress of the assessment process overall for the decision-making, this was fixed by periodically asking the vendors for progress and design updates to rectify the assessment. In addition, there were challenges related to the nature of SMRs as shown in TABLE 2:

TABLE 2. SMR TECHNOLOGY RELATED CHALLENGES

|  |  |
| --- | --- |
| Topic | Challenge |
| core damage (CDF) | This issue is inapplicable to some designs. |
| Large Release Frequency (LRF) | This issue is inapplicable for some pebble fuel due to the claim that core melt is impossible. |
| SNF Storage Methods | Different Designs for spent fuel storage (Wet, Dry). |
| Plant Lifetime | The graphite lifetime is a major issue to discuss between these two different lines of technologies (HTGR/PWR), verification that graphite could last for the whole plant lifetime isn’t backed with abundant data and enough practical experience. Handling the replacement of this graphite (if found needed) is a major challenge. |
| Plant Outages | Some reactors focus on the feature of online refueling, which might be misleading since planned outages can be aligned with refueling |
| Fuel Supply | The lack of fuel supply chains is a major concern. Fuel design and proof for commercial-scale production are a setback for some designs. |
| Safety Systems | The difference in the safety systems design (function/ number) is rather big. Due to Design philosophy, inherent safety features |

The assessment result is shown in TABLE 3. Top management decided the weights of the categories reflecting prime importance for the nuclear power project. Reactors A, B, C, D, and E scored the highest and were moved into the KF step for further assessment.

TABLE 3. EM RESULTS

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Category | Weight | A | B | C | D | E | F |
| General  | 5  | 4.0 | 2.7 | 4.2 | 4.1 | 3.2 | 4.4 |
| Design  | 7  | 5.4 | 5.2 | 4.2 | 4.4 | 4.8 | 4.4 |
| Operation and Maintenance  | 11.5  | 9.5 | 10.1 | 5.6 | 8.9 | 10.5 | 8.7 |
| Construction  | 9  | 6.5 | 6.0 | 3.0 | 5.9 | 6.5 | 6.2 |
| Reactor Performance  | 7  | 6.1 | 6.0 | 3.8 | 5.2 | 5.9 | 4.1 |
| Safety of the Reactor Design  | 16.5  | 16.2 | 16.0 | 13.0 | 12.2 | 14.8 | 12.5 |
| Fuel Cycle, WM, Non-Proliferation  | 10.5  | 7.7 | 6.7 | 7.8 | 7.3 | 7.9 | 6.6 |
| Licensing and Operating Experience  | 14  | 10.7 | 7.4 | 10.6 | 7.5 | 9.9 | 6.9 |
| Vendor Long-Term Commitment  | 11  | 9.1 | 8.2 | 9.5 | 9.0 | 8.2 | 4.9 |
| Site and Infrastructure  | 8.5  | 5.8 | 6.4 | 5.6 | 6.1 | 6.2 | 5.3 |
| **Total**  | **100**  | **81.0** | **74.8** | **67.2** | **70.6** | **77.9** | **63.9** |

#### Key Factors (KF)

To confirm the EM rankings of the 4 down-selected SMRs, Key Factors (KFs) evaluation and Best-In-Class (BIC) approaches were followed to compare with rankings in the EM. For KF evaluation, JAEC identified 14 factors of prime importance based on established guidelines extracted from the EM approach. KFs were equally weighted and graded out of 3 each (42 for 14 KFs). The results for the final KF evaluations are presented in TABLE 4

TABLE 4. GENERAL KEY FACTORS EVALUATION

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Key Factor | A | E | B | D |
| General Safety Design Criteria  | 2.8 | 2.5 | 2.8 | 2.1 |
| Exclusion Zone  | 2.4 | 3.0 | 2.6 | 2.6 |
| Seismicity  | 2.4 | 3.0 | 2.4 | 2.4 |
| Aircraft Crash  | 2.5 | 3.0 | 2.9 | 2.9 |
| Construction and Transportation  | 1.6 | 2.3 | 2.7 | 2.7 |
| Licensing and Design Certification  | 2.7 | 2.2 | 1.2 | 2.0 |
| Fuel Supply  | 2.3 | 2.5 | 2.2 | 2.6 |
| Back End of the Fuel Cycle  | 2.1 | 2.3 | 2.2 | 2.2 |
| Radioactive Waste Management  | 2.4 | 2.6 | 2.5 | 2.3 |
| Non-proliferation  | 2.8 | 2.5 | 2.6 | 2.4 |
| Thermal Efficiency  | 3.0 | 2.1 | 2.7 | 2.2 |
| Operability & Maintainability  | 2.2 | 2.7 | 2.7 | 2.7 |
| Cooling Water Design  | 3.0 | 2.8 | 3.0 | 2.7 |
| Vendor Long-Term Sustainability  | 2.7 | 2.1 | 2.2 | 2.5 |
| Total (%)  | 82.9 | 84.5 | 82.5 | 81.4 |

#### Best-in-Class

The BIC is intended to complement the EM approach. Specifically, for the 150 EM items, each of the 4 selected SMR technologies was assessed item by item following a simple rule: the best technology for that specific item is assigned a gold medal, and the second a silver medal. If the scores were equal, the designs were assigned the same medal.

This process intends to form a complementary understanding of the proposed technology by not considering the weighting factors included in the EM methodology. The results of the BIC are illustrated in TABLE 5:

TABLE 5. BEST IN CLASS EVALUATION

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Category | A | E | B | D |
| Medal | Gold | Silver | Gold | Silver | Gold | Silver | Gold | Silver |
| General  | 4 | 2 | 0 | 5 | 0 | 2 | 6 | 1 |
| Design  | 8 | 4 | 4 | 6 | 8 | 3 | 3 | 8 |
| Operations and Maintenance  | 7 | 3 | 11 | 3 | 7 | 6 | 5 | 4 |
| Construction  | 6 | 4 | 7 | 3 | 6 | 1 | 5 | 3 |
| Reactor Performance  | 6 | 2 | 5 | 2 | 6 | 3 | 4 | 4 |
| Safety of the Reactor Design  | 26 | 0 | 9 | 16 | 24 | 2 | 5 | 6 |
| Fuel Cycle, WM, and Non-Proliferation  | 8 | 4 | 4  | 8 | 5 | 4 | 5 | 4 |
| International Licensing & Operating Experience  | 6 | 5 | 6 | 5 | 4 | 2 | 8 | 1 |
| Vendor Long-Term Commitment  | 13 | 1 | 9 | 4 | 8 | 5 | 12 | 2 |
| Site and Infrastructure  | 10 | 3 | 10 | 3 | 12 | 2 | 10 | 3 |
| Total (out of 150)  | 94 | 28 | 65 | 55 | 80 | 30 | 63 | 36 |

#### Evaluation Summary

TABLE 6 summarizes the three evaluation methodologies’ results and the overall technology ranking.

TABLE 6. TECHNICAL EVALUATION RESULTS

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Evaluation Methodology  | A | E | B | D |
| Evaluation Matrix  | 81 | 78 | 75 | 71 |
| Key Factors  | 83 | 85 | 83 | 81 |
| Best-In-Class  | 81 | 80 | 73 | 66 |
| Average  | **82** | **81** | **77** | **73** |
| Rank  | **1** | **2** | **3** | **4** |

## ConClusion

* Jordan has completed the evaluation of 6 reactors and as a result has a clear understanding of the challenges and obstacles coming ahead;
* Using SMR for both power and non-power applications would help Jordan to have energy and water security while having a domestic alternative to imported sources;
* Although not discussed in this paper, the economic evaluation plays a major role in the technology assessment and, when combined with the technical assessment, would change the ranking results;
* The evaluation process is not final and is open to additional reactor technologies if merit is shown.

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