Jordan Atomic Energy Commission (JAEC)

"Considerations and Perceptions for Nuclear Fuel Cycle Back End Related to the SMRs under Consideration in Jordan"

Technical Meeting on Back End of the Fuel Cycle

Considerations for Small Modular Reactors

Vienna, Austria

20– 23 Sep 2022

Jordan’s Country Profile

- Total Area: 89,213 Km2
- Sea Port: Aqaba
- Coastline: 26 Km
- Population: 9.456 million (2016)*
  - 60% (15- 64)
  - 35% (below 15)
- Climate: Mediterranean & Arid Desert
- GDP: $38.65 billion (2016)*
- Per Capita: $4,087 (2016)*
- GDP Growth: 2.0% (2016)*
- GDP Growth: 2.6% f (2017-2019)*

* WORLD BANK

Jordan’s Energy Problem

- **Growing demand for energy**
  - Primary energy
  - Electricity
  - Desalination

- **Need for reliable and affordable base load power**

- **High dependency on imported fuels**
  - High and volatile prices
  - Insecurity of supply

- **Lack of indigenous conventional fuel options**

Jordan's Energy Options

Available energy options are limited:

- **Natural Gas:**
  - A short term option
  - Not a reliable energy source for medium and long terms
  - Cost is subject to market volatilities
- **Renewable Technologies:**
  - Limited utilization
  - Cannot be a base load option
- **Oil Shale:**
  - Only a limited medium-term option
  - Reserved for special uses
  - Not an environmentally friendly option
- **Nuclear Energy**

Jordan Nuclear Strategy

Large Nuclear Reactor	Small Modular Reactor
• Start direct negotiations with interested vendors on the feasibility of construction of 1000 MWe PWR on a BOT/BOOT basis.	• Continue technical & economic assessment to down-select to the most viable and suitable SMR options; • Conduct detailed feasibility studies on the short-listed SMRs.

SMRs Direction

- JAEC has been considering SMRs and their potential in Jordan in various capacities since 2011.

- Jordan strategy is considering the following aspects:

1. **Modularity**;
2. **CAPEX**
3. **Non-electrical applications**;
4. **EPZ**
5. **Grid Compatibility;**
6. **Construction time.**

- Yet, they come with a few challenges that affect deployment:

1. Maturity of the design;
2. Supply chain (lack of well-established supply chains);
3. Clarity of the construction cost.

- In deciding to proceed forth today, JAEC took into consideration many factors that are bespoke to SMRs.

Features of Interest for SMRs in Jordan

- Replace aging fossil plants
- Water desalination and hydrogen production
- Can be located close to population areas
- In-land away from water sources
- Mid to high seismicity
- Cogeneration of heat & electricity
- Water and air cooled condensers (ability for dry cooling)
- Island Mode and Load-Following capabilities
- Underground design with all safety systems underground

Project Schedule

	Project Timeline						
Milestone	**Y0**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**
BIS & Project Agreements	✓						
First Concrete		✓					
Construction		✓	✓	✓	✓	✓	
Commercial Operation Date							✓

National Policy for Spent Nuclear Fuel Management

- To store the spent nuclear fuel on an interim basis in pool storage at the nuclear power plant site until it decayed to sufficient levels to allow for safe storage;
- Establishing storage facilities near the nuclear power plant for further cooling;

Cont.……

- To decide on the possibility of returning the spent nuclear fuel to the country of its origin (to the supplier) for final disposal or interim storage or to remain in Jordan in interim storage for either of the two following options:
  - Considering the spent nuclear fuel as strategic resource that can be utilized through reprocessing (nationally or internationally) where the subsequent HLW will be sent for final disposal in a national waste disposal facility at The Hashemite Kingdom of Jordan.
  - Declare that the spent nuclear fuel as radioactive waste thereby allowing it to be disposed of directly to a national waste disposal facility.

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- Establishing the national facilities for disposal of low and intermediate level waste (LILW) in the Hashemite Kingdom of Jordan;
- To take relevant decisions for the disposal of spent nuclear fuel and high level waste (HLW).

National Strategy for Spent Nuclear Fuel Management

Safe interim storage option:

- Spent fuel discharged from the reactor will be safely stored in spent fuel storage pools until the decay heat generated from the spent fuel no longer requires water cooling.
- Sufficiently decayed spent fuel will be relocated to dry storage facilities built on the reactor site.

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After storage at the reactor, different technical options will be considered, as follows:

1. Return of the spent fuel to the country of origin for processing and final disposal (the take-back approach). This option is called "Return to Manufacturer".
2. Shipment of the spent fuel outside Jordan for reprocessing, and the HLW generated from reprocessing will be shipped back to Jordan for final disposal in a deep disposal facility. This option is called "Outside Jordan".
3. Spent fuel will be stored in Jordan to allow for its direct disposal at the national deep geological disposal facility in Jordan.

Both latest options require JAEC to construct and commission a Deep Geological Disposal facility and conditioning facility with associated infrastructure (facility to condition HLW and / or SNF before final disposal in Deep Geological Disposal).

The Bid Invitation Specifications (BIS)

The requirements for spent nuclear fuel management is both technology and country’s policies dependent.

The Bidder shall provide details of proposed solutions for the back end of the fuel cycle, such as fuel storage, reprocessing, etc.

The design of spent nuclear fuel storage facility offered by Bidder shall be able to fulfill number of requirements such as:

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- Determine the overall strategy of spent fuel, all stages of spent fuel management and the options available;
- Provide a storage capacity enough for 20 years at least (if applicable);and determine the capability to expand the spent nuclear fuel storage facility at SMR site, in which the spent fuel can be safely stored in dry casks for at least 60 years or longer according to the owner's requirements (if applicable);
- Provide a technical description of the spent fuel storage containers, which will be used for interim and long-term storage;
- Provide an adequate storage capacity for the failed fuel elements;

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- Provide a systematic identification of hazards and scenarios associated with operational states and accident conditions and external events of spent fuel storage facilities (e.g. fires, handling accidents and seismic events);
- Transportation insurance of spent fuel to interim or permanent storage or transfer casks within Jordan;

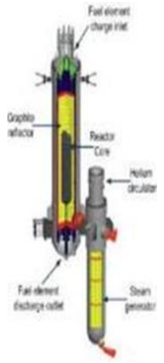
SMRs under Consideration

ACP-100

Chinese iPWR

- 125 MWe (Gross) / module
- 112.5 MWe (net) /module
- 0.3 g seismicity
- 2 passive safety trains
- 24 months refueling cycle

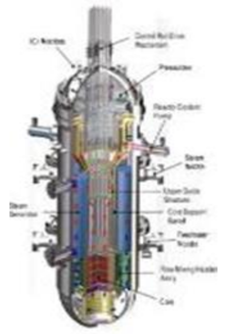
HTR-PM



Chinese HTR

- 110.5 MWe (Gross) / module
- 103 MWe (net) / module
- 0.3 g seismicity
- 2 Passive safety trains
- Online refueling

SMART



South Korean iPWR

- 123 MWe (Gross) / module
- 103 MWe (net)/ module
- 0.3 g seismicity
- 4 passive safety trains
- 30-36 months refueling cycle

RITM-200

Russian iPWR

- 57 MWe (Gross) / module
- 52.5 MWe (net)/ module
- 0.3 g seismicity
- 4 safety trains (2 active and 2 passive)
- 48-72 months refueling cycle

NuScale

American iPWR

- 77 MWe (Gross) / module
- 74 MWe (net)/ module
- 0.5 g seismicity
- 2 passive safety trains (baked up by active systems)
- 24 months refueling cycle

Xe-100

American HTR

- 81.5 MWe (Gross) / module
- 75 MWe (net) / module
- 0.3 g seismicity
- 2 passive (inherent) safety trains
- Online refueling

The Back End for the SMRs under Consideration in Jordan

Spent fuel storage type:

- HTR-PM and Xe-100: The fuel design eliminates the requirements for spent fuel wet storage They use the dry storage.
- RITM, NuScale, ACP-100: the reactor plants are designed to store spent fuel onsite in spent fuel storage racks in a spent fuel storage pool for a short time and then transfer it for interim or permanent storage, or processing.

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Reprocessing and Recycling activities:

- NuScale: will rely on Orano experience for spent fuel transportation and recycling activities.
- HTR-PM and Xe-100: reprocessing spent TRISO fuel particles is complicated, difficult and too expensive process due to the high mechanical resistance of SiC coatings (Attempts to develop a method for crushing TRISO particles and recovering uranium were investigated by the Oak Ridge National Laboratory in US with non satisfactory results due to the high mechanical resistance of SiC coatings).

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- However, there are some researches in China on reprocessing the TRSIO fuel particles and they succeed to develop a technology for crushing TRISO particles and recovering uranium).

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- Spent fuel transfer process to a licensed dry storage or transfer cask within Jordan:

For all designs: a standalone onsite interim dry storage facility is anticipated for 60 years.

Technology Assessment

- Preliminary Assessment of different SMR technologies is being conducted and in two main phases.

  – The first phase will be the generic assessment phase with the aim of down-selecting the most advanced and competitive technologies that are deployable and viable in Jordan.

  – The next phase will be the preparation of a Feasibility Studies (FS) based on the short-listed technologies or issuance of BIS.

Fuel Cycle - Back End Related to the SMRs in Jordan

- Until now we have no final decision on the SNF treatment as it will be based on the selected technology.
- The shortlisted SMRs (based on matrix evaluation criteria) as an examples for the Back End are:
  - HTR-PM China/ CNEC
  - NuScale USA/NuScale Power
  - RITM Russia/ Afrikantov OKBM

Spent Fuel Management in HTR-PM

- The fission products in the spent fuel are all contained in the spherical fuel element.
- The spent fuel elements are filled in the designed storage tank, the capacity of which is 40 000 pebbles.
- The filled storage tanks will be placed in shielded concrete compartments in the spent fuel intermediate storage, capacity of which is 20 years and expandable upon owner's requirement.
- Critical safety, residual heat cooling, seismic and radiation protection, etc., are considered in the design of the storage and tanks to ensure the safety of spent fuel elements during intermediate storage.

Spent Fuel Management in NuScale

- The NuScale Used fuel pool provides storage for up to 10 years of Used fuel storage, plus temporary storage for new fuel assemblies. The pool water volume provides approximately 150 days of passive cooling of the Used fuel assemblies following a loss of all electrical power without the need for additional water.

- After removal from the reactor core, Used fuel assemblies are placed in dedicated Used fuel storage racks in the below ground Used fuel pool, which contains four times more water volume for cooling per fuel assembly than current designs.

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- After cooling in the spent fuel pool, spent fuel is placed into certified casks, steel containers with concrete shells, on site of the plant.

- The facility is designed for ease of Used fuel transfer to a dry cask storage system. Within approximately 5 years, the thermal load of the Used fuel assemblies is reduced significantly, and can be moved to a secure dry storage area.

Spent Fuel Management in RITM

- Firstly, the spent fuel follows to a wet storage, where leak-tight tanks are used, and where decay heat removal is performed. In total, there are three independent wet storage tanks, capacity of each one is enough to store in there spent FA's of one reactor. Afterwards, fuel transferred to a dry storage, where leak-tight canisters are used.
- RAOS propose an option of shipping SNF from Jordan to the Russian Federation for reprocessing.

Thank you