Exploring a Dual Track Spent Nuclear Fuel and Radioactive Waste Disposal Policy for the Hashemite Kingdom of Jordan

Volume One

Main Report

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Abstract

Jordan is assessing options for the introduction of a nuclear power program. All nuclear power plants generate radioactive wastes that will eventually require deep geological disposal, although this would not be necessary in Jordan for at least fifty years. Nevertheless, the international best practice for new nuclear nations being followed by Jordan, along with prudent national planning, mean that options should be considered today for how to handle the eventual disposal needs.

Deep geological repositories (DGR) demand a high level of technical expertise and are expensive to develop and operate. However, it is not necessary for every country to have its own DGR and there are considerable technical, economic and political benefits to be gained from participating in a multinational repository (MNR), especially if implemented on a regional basis. Consequently, Jordan is considering this option in parallel with developing its own national DGR program. This *'dual track approach'* has the twin advantages that it develops Jordan's own expertise in geological disposal, allowing more effective participation in any MNR project, as well as addressing the contingency that no MNR solution becomes available.

The dual track approach does not require a decision on which track to follow for many years, but it does require an early commitment to active measures to explore the two options. However, none of the activities involved in a dual track approach requires significant additional resources beyond those that will, in any case, be necessary to develop a national nuclear power and radioactive waste management program.

This study, conducted by the Jordan Atomic Energy Commission (JAEC) in coordination with, and supported by, the United States Department of Energy (USDOE), examines the details of the dual track approach to radioactive waste management, reviewing international experience and activities and assessing the benefits and challenges involved. The study concludes that there are significant benefits for Jordan to become proactive in adopting the dual track approach in its national policy, which opens the door for exploring MNR solutions, in particular with regional MENA partners Egypt, Saudi Arabia and the UAE, and that the dual track approach is the optimal way forward for Jordan. It also suggests a range of specific activities to develop and enhance Jordan's involvement and capabilities in exploring DGR/MNR solutions.

Participants in this Study

This study was conducted by the Jordan Atomic Energy Commission (JAEC) in coordination with, and funded by, the United States Department of Energy (USDOE). The report was written by members of the project team, listed below, and compiled by the project Secretariat (comprising the Arius Association, with direction from USDOE and JAEC).

Hamdi Alaween	JAEC
Kamal J. Araj	JAEC
Ahmad H. Alsabbagh	JAEC
Alan Brownstein	Independent Consultant, USA
Neil Chapman	Arius Association, Switzerland
Leon Kegel	Independent Consultant, Slovenia
Charles McCombie	Arius Association, Switzerland
Paul Murphy	Murphy Energy & Infrastructure Consulting LLC, USA
Sean Tyson	USDOE, Office of Nuclear Energy
Tomaž Žagar	Independent Consultant, Slovenia

Executive Summary

Jordan is pursuing a national strategy for the introduction of nuclear power into its energy mix, using the IAEA Milestones Approach, which includes guidance on radioactive waste management (RWM) and the management of spent nuclear fuel (SNF). In its report to the IAEA Joint Convention[1] in 2018, Jordan stated that it currently considers three options for SNF disposition: return to the country of origin for final disposal; reprocess as a resource (nationally or internationally), with the ensuing High-Level Waste (HLW) to be disposed of in a national deep geological repository (DGR); dispose of SNF directly in a national DGR. This report examines the implications of parallel consideration of a fourth possible option: disposal in a multinational repository (MNR) in another country, should one become available. International cooperation in the field of RWM and nuclear fuel cycle management is already a significant and ongoing part of Jordan's nuclear program.

Since access to an MNR cannot be guaranteed, Jordan would need to continue work towards its own national DGR in parallel with exploring the MNR option. This is the so called **'dual track' approach**, which has been adopted by many countries involved in extensive worldwide studies of MNR solutions.

The objectives of this study are:

- to evaluate the potential benefits and challenges of adopting a dual track policy for the Jordanian nuclear power and radioactive waste management program;
- to provide information to decision-makers on the dual track approach and on the implications of involvement in an MNR solution that may result;
- to identify the actions that Jordan would need to take in order formally to adopt an effective dual track program.

The study has been conducted by the Jordan Atomic Energy Commission (JAEC) in coordination with, and supported by, the United States Department of Energy (USDOE).

This report is intended to guide decision-makers in Jordan in exploring whether to formally adopt a dual track policy.

Management of Jordan's nuclear power wastes

A responsible nuclear energy program must ensure the availability of a credible path to the disposal of SNF and higher-level RW. The internationally recognized solution is emplacement in a DGR, in geological formations that have been stable for millions of years. The IAEA Joint Convention makes clear that, while every country has the responsibility for preparing for safe disposal, the DGR need not be within the country generating the waste. Agreements between sovereign countries can lead to cooperation that might eventually lead to development of an MNR in a host country that accepts wastes from a number of other countries.

There are various ways in which the development of, or access to, an MNR can be approached, the principal options being sharing an MNR with other nuclear power programs or using a commercial MNR service. Most countries with an interest in an MNR solution are exploring the first option – a shared solution, generally on a regional basis. For this study, the principal dual-track option evaluated is thus the possibility of involvement in a **regional shared**

[1] The IAEA *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* is the first legal instrument to address the issue of spent fuel and radioactive waste management safety on a global scale. It does so by establishing fundamental safety principles and creating a peer review process. See: https://www.iaea.org/sites/default/files/infcirc546.pdf

MNR project, although the possibility of involvement in any appropriate MNR project is not excluded. Development of an MNR project would require an extensive phase of cooperative work between the countries adopting the dual track approach, and it would not be necessary for Jordan to decide, for many years, whether to participate in an MNR or implement a national DGR.

Current national RWM policy and MNR implications

JAEC, an independent governmental body reporting directly to the Prime Minister, leads the planning and implementation of the nuclear energy strategy and the nuclear energy program. The Energy and Minerals Regulatory Commission (EMRC) regulates and controls the use of nuclear energy and enforces the implementation of the national regulations on SNF and RW management.

The *National Policy for Radioactive Waste & Spent Nuclear Fuel* management, issued in 2015, covers all stages of safe management and disposal of SNF and RW. Decisions on the management of SNF generated by nuclear power reactors have not yet been taken. All but one of the options (take-back by the fuel supplier) require Jordan to have access to a DGR for SNF disposal. The current legislative framework does not currently cover the export of SNF for disposal in a country other than the fuel supplier; this issue must be addressed eventually if Jordan is ever in a position of deciding to make use of an MNR. Jordan's policy also currently prohibits the import of foreign RW. Accordingly, Jordan is not at present a potential host country for an MNR and its dual-track strategy would consider Jordan as a user country only, either of an MNR developed in a partnering arrangement with other countries, or of an MNR offered as a service by another country.

When assessing possible regional MNR solutions, coordination with other civilian nuclear nations (existing or soon-to-be), especially Egypt, Saudi Arabia and the United Arab Emirates, is to be expected. Regional cooperation extending beyond disposal planning to cover other aspects of the nuclear fuel cycle could also be considered.

Benefits of involvement in an MNR project

The study identifies a range of possible benefits that could apply to Jordan as a potential user/partner country, including:

Economic and financial: Sharing a repository with partners can considerably reduce the large expenditures necessary for siting, constructing and operating a national repository. Such savings are mainly due to economies of scale that result from sharing repository projects with high fixed costs – the ratio of fixed to variable costs for geological repositories is high for small inventories of waste. The study estimates that Jordan could save billions of USD by using an MNR, rather than having its own DGR – savings that could be passed on to electricity consumers.

Environmental: Globally, MNRs reduce the number of national DGRs required and the consequent (but limited) conventional environmental impacts of construction and operation associated with large engineered facilities. For those countries with no prospect of disposal for many decades, early access to an MNR could help avoid the environmental risks associated with under-funded, marginally funded or indefinitely extended national disposal programs.

Socio-political: MNRs can help increase global nuclear security by collecting and disposing wastes from several national programs in a central safe and secure location, thereby enhancing the credibility of nuclear power. Sharing can also help to assure that countries maintain consistent practices and standards on quality control, safeguards and monitoring, thus helping to build confidence between nations. These benefits would enhance Jordan's position internationally as a new nuclear power nation.

Technical: Scientific, educational and technical exchanges within an MNR project can improve and increase technical capacities for all partners. Jordan's parallel national DGR project would benefit from these interactions.

Institutional and legal: harmonizing legal and licensing systems of regional partner countries should aid Jordan in interfacing with these countries and further enhance the credibility of Jordan's NP program.

Framework requirements for a national DGR or MNR

The basic requirements for implementing a national DGR program and for participation in an MNR project are similar. A dual-track approach implies that an active, credible national program that could lead to geological disposal in Jordan is run in parallel with exploration of MNR options. In both cases, the responsible national organizations must have in-house expertise in the science and technology needed to implement a DGR. Even if a successful MNR project is offered to Jordan as a service, with no Jordanian involvement in its development, the responsible organizations in Jordan need to have the capability to act as an "intelligent customer": i.e., to assess and interact with the service providers on a fully informed, expert basis – technically, legally, commercially and financially. A national DGR program itself requires these skills and capabilities, so that a well-developed national program also forms a strong basis for involvement in multinational initiatives. Thus, while a dual track approach does not require any early commitment to one path or another, it does require diligent pursuit of both national and MNR options from the outset.

Involvement in an MNR project will require Jordan to extend its nuclear capabilities and competences at a pace allowing active participation. Jordan currently only deals with small quantities of medical, industrial and research wastes, and there is no expertise in managing fuel cycle back-end wastes. However, this is part of the Action Plan for implementation of the National RWM Strategy.

At present, Jordan is in the early stages of considering a national DGR and preliminary work has established that there could be potential for geological disposal in three regions, with formations in basalt, limestone and granite. Part of the future strategic planning work will be to consider scenarios for future waste arisings in Jordan and the routing of these wastes to the various types of disposal facility that will be needed.

For establishing either a national or a dual track program, it would be expected that there is an identified waste management organization (WMO) to implement the established national policy and strategy. Currently, among its other functions, JAEC acts as the WMO and is responsible for implementing the policy and the strategy. In due course, before NPPs begin operation, Jordan will consider establishing a dedicated WMO: a Jordanian Radioactive Waste Management Corporation (JRMC).

Economic aspects of involvement in an MNR project

Numerous published studies, together with data on the funds already invested by countries with most advanced disposal programs, indicate that a round-figure cost for geological disposal of SF is one million USD per tHM. Implementing and operating a DGR for even a small nuclear power program can thus be an undertaking requiring several billion USD, although these costs are only a minor part of total fuel cycle costs and can be covered by only a few percent of the expected revenue streams generated over a NPP lifetime. At average global prices for electricity and with typical high NPP efficiencies, the revenue generated by every tonne of fuel is around 40 million USD, making its disposal costs only a few percent of the revenue generated.

This study examines some of the cost analyses that have been carried out in various countries. Key conclusions include:

- Economies of scale favor MNR approaches, with the potential to save large percentages of disposal costs compared to a national DGR (i.e., 30% or more); these savings come not only from shared fixed infrastructure costs, but also from pooled RD&D and administration, and reduced financing costs.
- The main costs for disposing of SNF and RW (in either a national DGR or an MNR) will not arise for many decades, as a solution is not required for at least 40 or 50 years after NPPs become operational. Nevertheless, provision to meet these costs should be put in place at the start of Jordan's nuclear power program. Jordan should reserve RWM funds based on a small surcharge on nuclear electricity sales, based on the assumed cost of a national DGR.
- No significant additional funding is required for pursuing the dual track approach (compared to a purely national DGR approach) but, in the early program stages, the available funds will need to be used for exploring both DGR and MNR options.

Beyond the MNR evaluation phase, if a promising project emerges and is to be implemented, then the financing arrangements for participation will need to be agreed. This is not necessary at the present phase, but some of the key issues that would eventually be involved are noted in the report and expanded on in the Appendices volume.

Cooperation with other countries

International cooperation has played an important role in the field of RWM from the earliest days. Jordan's continued involvement with countries that have advanced nuclear power programs and are already experienced in pursuing a dual-track approach is highly recommended. Transfer of knowledge and practical experience is extremely valuable for Jordan. In parallel, initiatives to enhance regional cooperation should be promoted, initiated and pursued. This can be especially effective in encouraging not only information exchanges but also providing a framework for direct collaboration on projects. Many Arab countries are actively pursuing or have expressed an interest in a nuclear power program, with a range of prospects for possible co-operation on fuel cycle activities. Jordan could promote a regional collaborative project for common pre-disposal RW and SNF management activities that could eventually lead to a common MNR, for example with Egypt, Saudi Arabia and the UAE. The Arab Atomic Energy Agency (AAEA) could also be strengthened and restructured, to play a pivotal role in the interests of all Arab countries.

It is suggested that Jordan could take an active role in developing an Arab Regional Forum, initially with national representatives from Egypt, Saudi Arabia, and the United Arab Emirates constituting the core group.

Outline Program to Develop a National Dual Track Approach

Guidance on the practical steps that Jordan will have to take if it adopts a dual track policy can be obtained from examining how this has been implemented in other countries. The measures that several dual track countries have taken to implement the policy are described and the relatively modest impacts on their national RWM activities in the immediate future are noted. Suggestions by IFNEC on practical activities that countries with small nuclear power programs might initiate to progress a dual track policy are also considered. The legal, administrative and societal actions for Jordan that result from adoption and implementation of a dual track policy are discussed. An initial set of suggested actions is proposed that lays out a path towards adoption of a dual track policy and participation in cooperative efforts to advance the MNR concept.

The conclusions, recommendations and suggested actions are listed in Section 9 of this report. For the attention of Jordanian decision makers, the most important of these are summarized below.

Key Conclusions

- Implementation of a DGR does not necessarily have to take place in Jordan, provided MNR options become available elsewhere.
- A responsible and prudent approach to disposal planning is to adopt a 'dual track' policy and initiate associated activities in which national competencies are built up in parallel with cooperation with potential MNR partners.
- Creating a credible national DGR program and active involvement in promoting and seeking an MNR solution both require Jordan to extend its skills, resources and legal structures. Even though geological disposal will not be required for many decades, DGR/MNR programs take many years to develop and Jordan needs to begin developing capabilities and a sound knowledge base from the outset.
- There would be clear economic benefits to Jordan in using an MNR, with savings potentially of the order of 30% (in the order of billions of USD), depending on SNF or HLW inventory.
- The active nuclear power development programs in Jordan's MENA neighboring countries (Egypt, Saudi Arabia and the UAE) face similar challenges, and there could be significant technical and political benefits for Jordan in being proactive in promoting a shared, regional approach.
- Jordan has legal/policy constraints on the transboundary movement of SNF and RW that need to be addressed to make use of an MNR solution in a partner country, although this is not an urgent matter.

Key recommendations

- Jordan should include the dual track approach to geological disposal in its policy and strategy for the long-term, integrated management of all its radioactive wastes from all sources.
- Some RWM choices do not need to be made for many years, including commitment to any specific MNR implementation project, but an active national RWM and DGR program to sustain knowledge and capabilities is essential.
- To provide a firm foundation for a dual track policy, Jordan should explore all possibilities for involvement in existing or potential future MNR studies or projects; in particular, Jordan should initiate outreach to potential partner countries in the MENA region, taking a leadership role where appropriate.
- Jordan should consider societal outreach activities on RWM both in Jordan and in collaboration with MNR partner countries.
- The planned Jordanian Radioactive Waste Management Corporation (JRMC) should be established and be in place before any wastes are generated by the nuclear power program.

Initial actions demonstrating Jordan's commitment to a dual track policy

Actions resulting from the above conclusions and recommendations that would help Jordan to move forward with a dual track policy include.

- Carry out a detailed multi-attribute decision analysis exercise, along with a further, multi-stakeholder SWOT (Strengths, Weaknesses, Opportunities, Threats) exercise with decision-makers, to document the pros and cons of dual track transparently and inform decision-making.

- Make dual track (using the phrase ‘dual track’) part of official Jordanian policy by including it in the next National Policy and National Strategy documents.
- Develop national competences by implementing a staged program of work that explores the technical siting feasibility of a national DGR and establish a work program to identify DGR concepts appropriate to the Jordanian inventory and geological environment.
- Continue and extend or initiate Jordanian participation in international organizations with interests in MNR developments: e.g., IAEA, AAEA, IFNEC and ERDO.
- Initiate an Arab Regional Forum on nuclear fuel cycle topics with national representatives initially from Jordan, Egypt, Saudi Arabia, and the United Arab Emirates.
- Establish a regional ‘club’ of waste management organizations and an equivalent ‘regulators club’, promoting knowledge transfer and information exchange. Use the regional ‘club’ to develop a roadmap of activities leading to a potential Arab region MNR. An eventual aim would be to establish an Arab Regional Waste Management Organization.
- Identify Jordan’s minimum requirements for the scale and nature of an MNR project that would meet its waste management needs, to set alongside similar information from other potential partner countries so as to make a first estimate of the type of facility that would be needed.

List of Acronyms

AAEA	Arab Atomic Energy Agency
ANNuR	Arab Network of Nuclear Regulators
CSF	Central storage & management facility
DBD	Deep borehole disposal
DGR	Deep geological repository
DKK	Danish kroner
DSRS	Disused sealed radioactive source
ECA	Export credit agency
EMRC	Energy and Minerals Regulatory Commission
ERDO	Association for European repository development
EU	European Union
EUR	Euro
FID	Final investment decision
GCC	Gulf Cooperation Council
GNEP	Global Nuclear Energy Partnership
HLW	High-level (radioactive) waste
HRD	Human resource development
HTGR	High-temperature gas reactor
IAEA	International Atomic Energy Agency
IFNEC	International Framework for Nuclear Energy Cooperation
ILW	Intermediate-level (radioactive) waste
ILW-LL	Intermediate-level (radioactive) waste: long-lived
ILW-SL	Intermediate-level (radioactive) waste: short-lived
JAEC	Jordan Atomic Energy Commission
JNRC	Jordan Nuclear and Radiation Regulatory Commission
JRMC	Jordanian Radioactive Waste Management Corporation
JRTR	Jordan research and training reactor
JSA	Jordan subcritical assembly
JUMCO	Jordanian Uranium Mining Company
JUST	Jordan University of Science and Technology
LLW	Low-level (radioactive) waste
LNPP	Large nuclear power plant
MENA	Middle East and North Africa
MNR	Multinational (geological) repository
NORM	Naturally occurring radioactive materials
NP	Nuclear power
NPP	Nuclear power plant
PWR	Pressurized water reactor
RD&D	Research, development and demonstration

RNFSWG	Reliable nuclear fuel services working group (of IFNEC)
RTF	Radioactive waste treatment facility
RW	Radioactive waste
RWM	Radioactive waste management
SMR	Small modular reactor
SNF	Spent nuclear fuel
SWOT	Strengths, weaknesses, opportunities and threats (analysis)
tHM	Tonnes of heavy metal
UAE	United Arab Emirates
USD	United States dollar
USDOE	United States Department of Energy
VLLW	Very low-level (radioactive) waste
WBS	Work breakdown structure
WMO	Waste management organization
WNA	World Nuclear Association

Contents

1 Introduction

Jordan is pursuing a national strategy for the introduction of nuclear power into its energy mix, with plans to install nuclear power plants (NPP) for electricity production and for water desalination, to help secure water supply in the country. Jordan is considering two parallel paths: Small Modular Reactors (SMR) and conventional large nuclear power plants (LNPP), with a current priority being given to SMR deployment.

For the introduction of a nuclear power program, Jordan is using the IAEA Milestones Approach[2], a phased and comprehensive method to assist countries that are considering or planning their first nuclear power plant. This includes guidance on radioactive waste management (RWM) and the management of spent nuclear fuel (SNF). In its report to the IAEA Joint Convention in 2018, Jordan stated that it currently considers three options for SNF disposition:

- return to the country of origin for final disposal;
- reprocess as a resource (nationally or internationally), with the ensuing High-Level Waste (HLW) to be disposed of in a deep geological repository (DGR) in Jordan;
- dispose of SNF directly in a national DGR.

Another possible option is disposal in a multinational repository (MNR).

For small and newcomer nuclear power countries such as Jordan, there has been increasing interest over the past two decades in the merits of adopting a **"dual track" disposal policy** that involves developing a national disposal program in parallel with promoting and evaluating, in cooperation with like-minded countries, the potential for a multinational disposal solution. An MNR would provide a disposal solution for spent fuel and radioactive wastes from a number of countries. This report on the management and eventual disposal of Jordan's current and future arisings of RW considers whether it might be beneficial to dispose of some wastes in another country, as part of a multinational project, and to adopt a dual track approach to RWM.

1.1 Jordan's radioactive wastes

Currently, RW in Jordan originates from medicine, education and research and training centers, from industry and agriculture, and from uranium mining. Jordan's first Research and Training Reactor (JRTR) received its operational license in November 2017 and, in addition to Jordan Subcritical Assembly (JSA), is currently the only source of SNF. However, Jordan is considering the introduction of civilian nuclear power into its energy mix, with the goal to generate 20% of its electricity by nuclear power by the year 2035. This will generate significant additional quantities of radioactive wastes and SNF over many decades into the future.

As one of the 19 infrastructure development issues to be addressed in the IAEA Milestones approach, Jordan is planning its radioactive waste management program. Leading up to Milestone 1 (Ready to make a knowledgeable commitment to a nuclear power program), it is recommended that countries "*consider technological options and research on the ultimate disposal of spent fuel and HLW from reprocessing"*. Leading up to Milestone 2 (Ready to invite bids/negotiate a contract for the first nuclear power plant), the national planning for radioactive waste disposal should "*consider the extent to which geological conditions exist in the country to allow disposal of all types of radioactive waste and/or the potential for contracting for waste disposal with other countries"*. This study is a key contribution to achieving both Milestones.

[2] IAEA Nuclear Energy Series NG-G-3.1 Rev.1

In addition to following the IAEA Milestones Approach, Jordan is a signatory to the IAEA Joint Convention on the management of SNF and RW[3], which requires firm commitments from countries on how to manage these materials safely throughout all activities, including final disposal. The reason that the Convention treats SNF and RW separately is because SNF is not necessarily to be regarded as waste material. As stated in its first national report to the 7th Joint Convention meeting[4], Jordan's current SNF Management Policy includes the option of direct disposal in a deep geological repository (DGR) and the alternative option of considering it a strategic resource that can be recycled through reprocessing to produce fresh fuels, with the subsequent High-Level Waste (HLW) being routed to geological disposal.

The focus for this study is to recognize that there are also options for where SNF or HLW might be disposed: in a DGR in Jordan, or in an MNR in another country.

1.2 Background and objectives of this study

International cooperation is a significant and ongoing part of Jordan's nuclear program. Formal arrangements include direct agreements with the IAEA and signing of major international treaties, including the Joint Convention. Jordan has signed Nuclear Cooperation Agreements with many countries to provide support in nuclear project management, research reactor utilization, nuclear power systems, reactor safety, nuclear waste management, and nuclear fuel cycle management. Jordan has also been an active participant in the Global Nuclear Energy Partnership (GNEP) and the International Framework for Nuclear Energy Cooperation (IFNEC), and, in recent years, JAEC representatives have played leading roles in the work of IFNEC on reactor systems and in discussions organized by IFNEC's Reliable Nuclear Fuel Services Working Group (RNFSWG) on disposal options for spent fuel and radioactive wastes.

The current study has been carried out by Jordan, in coordination with, and supported by, the U.S. Department of Energy (USDOE).

The aims of the study are:

- to evaluate the potential benefits and challenges to the Jordanian nuclear program of adopting a dual track approach to disposal planning;
- to provide information to decision-makers on the implications of involvement in a multinational disposal solution that might result from following a dual track policy;
- to identify the actions that Jordan would need to take to adopt and implement an effective dual track policy and work program.

Based on its conclusions and recommendations, the study identifies further activities that would provide input to national policy decisions, anchor the dual track approach in the Jordanian strategy and facilitate establishment of an operational national RWM program.

The principal intended readership of this report is decision-makers in Jordan. It may also be of interest to those in other countries and to the nuclear technical community.

[3] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997), www-ns.iaea.org/conventions/waste-jointconvention.asp

[4] Jordan's First National Report for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Vienna, 2017.

1.3 Structure of the report

This study report is presented in two volumes:

- **Volume 1:** The main study findings and recommendations (this volume), presented at three levels – a brief abstract highlighting the most important conclusions, an extended Executive Summary and the main text.

  In the main text, Section 2 provides a brief introduction to the concept of the "dual track" approach to radioactive waste planning, followed in Section 3 by an overview of the current policies and strategies in Jordan. Section 4 goes into more detail about the benefits and challenges associated with adopting a dual track approach and illustrates how it is currently being implemented in some national RWM programs. In Section 5, the specific implications for Jordan of this approach are examined. A central issue concerns the cost implications, both in the immediate future and longer term, should an implementable MNR project be developed in cooperation with other countries; these are covered in Section 6. Jordan already has multiple cooperation activities and these, together with indications of potential future expansion, are covered in Section 7. The specific steps that countries, in particular Jordan, might take towards adopting and implementing a dual track policy are covered in Section 8. Section 9 then summarizes conclusions and recommendations.

- **Volume 2:** Appendices containing more detailed results covering specific aspects of the study.

  These are structured into three categories. Appendix 1 gives further details on the current Jordanian policy, strategy, organizational arrangements and activities related to radioactive waste management. Appendix 2 assembles information on past and current initiatives on MNR development and gives more insight into how other national RWM programs are implementing or considering a dual track approach. The prime goal of this report is to examine the implications of Jordan retaining flexibility over the coming years by including use of an MNR as a back-end option. Future participation in an implementable project involves consideration of many further questions related to project development, financing, contracting, etc. Although these need not be answered definitively at the present time, Appendix 3 addresses at a broad level the issues that would be involved.

2 Introducing the Dual Track Approach

There is a wide consensus that every country has a responsibility for ensuring safe and environmentally acceptable disposal of its wastes. The only recognized practicable solution for the long-lived and highly active types of waste is isolation and containment in deep geological formations that have been stable for millions of years. This solution does not require the development of fundamentally new technologies or the emergence of new scientific approaches.

As described in Section 6, implementation of deep disposal in a mined deep geological repository (DGR) is expensive; national cost estimates range from a few to many billions of US dollars. For a nuclear power program of significant size, these high disposal costs are a relatively minor part (a few percent) of the full nuclear fuel cycle costs – and, importantly, the necessary funds can be accumulated by a small surcharge on the electricity produced. For example, the USA established a fee of 0.1 cents (0.001 USD) per kWh generated and sold. The European Commission has recently estimated an average overall cost of radioactive waste management of EUR 3.2 per MWh generated (equivalent to about 0.004 USD/kWh)[5]. For small nuclear power programs with only one or a few nuclear reactors, meeting DGR costs can be a formidable challenge and could render small nuclear programs uneconomic. For small SNF inventories and for some specific waste streams in large and diverse waste inventories, geological disposal in deep boreholes (rather than excavated caverns and tunnels) is being studied as a possible alternative approach, although it cannot be used for large waste packages. A mined repository is today the most widely accepted solution for geological disposal, as it can accept all types and quantities of waste. Fortunately, as recognized in documents such as the IAEA Joint Convention or European Commission Waste Directive 2011/70/Euratom [6], the international consensus is clearly that, while every country has the responsibility for preparing for disposal, the actual facility need not be within the country generating the waste. As described below, agreements between sovereign states can lead to cooperation that might eventually lead to development of a multinational repository (MNR).

2.1 Geological disposal options for newcomer countries[7]

The back-end options open to any country that has, or which plans to introduce, nuclear energy into its national energy strategy all involve geological disposal (a DGR) for SNF or HLW, and other long-lived wastes. The broad approaches available have been documented in a number of IAEA technical documents, as summarized below:

Option 1: Work towards development of a national geological disposal facility

The large financial outlays associated with a DGR do not arise until decades after nuclear power is introduced. SNF emerging from a power reactor needs to have an extended cooling period before it can be emplaced in a deep underground facility, so the earliest that a DGR could be required would be 40 or 50 years after initial nuclear power production. Nevertheless, typical times to progress from initial choice of disposal concept, through facility design, site

[5] European Commission (2017). Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC) {COM(2017) 237 final}. Available at:

https://ec.europa.eu/energy/sites/ener/files/documents/pinc_staff_working_document_.pdf

[6] European Commission, Council Directive 2011/70/Euratom of 19 July 2011 Establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, OJ L 199 (2 August 2011), http://ec.europa.eu/energy/nuclear/waste_management/waste_management_en.htm

[7] Adapted from C. McCombie input to ECE Expert Group on Resource Management report on The Role of Nuclear Energy in Sustainable Development: Entry Pathways, https://unece.org/sustainable-energy/publications/nuclear-entry-pathways

selection and characterization, to repository construction and operation are more than 20 years, so establishing a disposal policy and strategy should begin in parallel with the establishment of a nuclear power program. In numerous national nuclear power programs, failure to develop and transparently document a long-term strategy has led to weakening of public trust and confidence. Building the necessary technical competences, establishing an effective regulatory system, formulating a DGR siting methodology and program, and accumulation of the funds required for later construction and operation of the DGR, are all critical activities that should have commenced by the time a nuclear power program starts or, in the case of accumulating funds, begins to generate revenues. In a typical DGR spend profile, costs remain modest in the planning phase, rise significantly when comprehensive site characterization tasks are undertaken, peak during the construction phase and continue at a lower, but nevertheless still high level through the operational phase, which can last for several decades.

Option 2: Examine possibilities for a more cost-effective national solution

For countries that opt for purely national disposal but have small nuclear programs and correspondingly small radioactive waste inventories, there will be considerable interest in developing an approach that promises to be more cost efficient than implementation of a mined DGR with tunnels and caverns at depths of hundreds of meters. A potentially practicable, but much less developed alternative is deep borehole disposal (DBD), involving disposal of highly active wastes in boreholes drilled to depths of a few kilometers. Today, it appears that DBD is more appropriate for countries with small nuclear power programs or countries that do not use nuclear power but have small quantities of RW from other nuclear applications (such as research reactors) that also require geological disposal[8]. Depending on the national inventory, DBD might not be suitable for all wastes that eventually require geological disposal (e.g., owing to waste-form or waste package dimensions) but might be a cost-effective constituent of an overall RWM program that still requires a DGR. Jordan has been an active participant in RNFSWG discussions on the DBD concept. However, as it is not clear at present how this less mature technology might best be deployed with respect to the Jordan's uncertain future waste inventory, it is not given specific consideration in this report.

Option 3: Explore multinational/regional approaches to disposal

A key characteristic of a DGR program is that the fixed costs (i.e., all steps leading up through siting to construction of access shafts or tunnels) constitute a relatively large part of the total costs. The variable costs that are proportional to inventory are those for excavation of disposal tunnels or caverns, encapsulation of wastes and waste emplacement operations. By sharing the fixed costs between several partners whose combined waste inventories justify a DGR, significant savings can result for all participants. The development of the required multinational repository can be approached in various ways:

- **Option 3a: Sharing with other programs**. This approach has been extensively studied over the last 20 years, with key reports produced by the IAEA, the Arius Association and the ERDO Working Group. IAEA TECDOC 141[9] provides an extended summary of work done up to 2004 and identifies potential mechanisms for realization of an MNR. Subsequent IAEA publications look in more detail at the associated challenges and at the project risks[10].

[8] Chapman, N. A. (2019). Who might be interested in a deep borehole disposal facility for their radioactive waste? Energies, 12, 1542; doi:10.3390/en12081542

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Developing Multinational Radioactive Waste Repositories: Infrastructural Framework and Scenarios of Cooperation, IAEA-TECDOC-1413, IAEA, Vienna (2004).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Viability of Sharing Facilities for the Disposal of Spent Fuel and Nuclear Waste, IAEA-TECDOC-1658, IAEA, Vienna (2011)

- **Option 3b: Using or offering a commercial disposal service**, run by a private developer or a government. There have been fewer in-depth studies of this approach since the comprehensive Pangea project that ran in Australia from 1998 to 2001[11]. More recently, the South Australian state government established a Royal Commission that re-examined the possibility of hosting a commercial MNR[12]. Despite the clear financial benefits that both these projects show to be attainable for the host, neither could achieve the necessary political and public support. The IFNEC project has also recently examined the service provider option and has studied possible financing mechanisms[13]. There are thus mixed experiences from initiatives that have tried to develop a commercial MNR and these are outlined in more detail in Appendix 2.2.
- **Option 3c: Take-back or take-away by a large add-on program**. A logical solution to the SNF disposal challenge of small or new nuclear programs would be that the supplier of the fuel takes back the SNF elements and manages them along with its own much larger inventory. Whether the management option chosen by the supplier involves reprocessing or direct disposal of SNF is not a matter of concern for the fuel user. This option might also take the form of a leasing arrangement in which ownership of the fuel stays with the supplier. The take-back option was offered in the past by countries selling reprocessing services: i.e., SNF could be sent back and no HLW was returned to a customer. Unfortunately, political and public opposition to this approach resulted in the UK and France retracting this offer. Under special conditions, it may still be an option for countries using Russian reactors and/or fuel.
- **Option 3d: A supranational solution**. The concept of a supranational DGR controlled by an international organization such as the IAEA and offering disposal services to countries around the globe was included in the seminal IAEA report on MNRs, TECDOC 1413[14]. However, no serious attempts have been made to further this option.

Option 3a is clearly an approach that could be attractive on a regional basis to a group of adjacent or nearby countries, especially if these countries have similar plans for nuclear power development or similar RW management requirements. A powerful argument for a region where several countries are contemplating initiating nuclear power programs is enhanced regional security. The international non-proliferation community is likely to be supportive of the idea of consolidating sensitive nuclear fuel-cycle facilities, including repositories, in fewer locations. An MNR could also be used by regional neighbors that have no NPP wastes but do have small quantities of other RW that require geological disposal, such as SNF from research reactors.

On a regional basis, the concept of sharing an MNR might also be linked to other sharing possibilities (e.g., in technical co-operation), including sharing all or part of the electrical output of a NPP (or even the plant itself) with neighboring countries, such as the Krško plant in

INTERNATIONAL ATOMIC ENERGY AGENCY, Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programs, IAEA Nuclear Energy Series NW-T-1.24 (2013)

INTERNATIONAL ATOMIC ENERGY AGENCY, Framework and Challenges for Initiating Multinational Cooperation for the Development of Radioactive Waste Repositories, IAEA Nuclear Energy Series report, 2016

[11] McCombie C., Butler G., Kurzeme M., Pentz D., Voss J., Winter P., The Pangea International Repository: a Technical Overview, WM99 "HL W , LL W, Mixed Wastes and Environmental Restoration -Working Towards a Cleaner Environment", 28 February - 4 March 1999, Tucson, USA

[12] NUCLEAR FUEL CYCLE ROYAL COMMISSION REPORT MAY 2016ttps://s3-ap-southeast-2.amazonaws.com/assets.yoursay.sa.gov.au/production/2017/11/09/03/09/17/3923630b-087f-424b-a039-ac6c12d33211/NFCRC_Final_Report_Web.pdf

[13] Žagar T., Tyson S., Mussler R., Development of the Multinational Repository Concept: Exploring Alternative Approaches Financing a Multinational Repository, IAEA Spent Fuel Conference (2019)

[14] Developing Multinational Radioactive Waste Repositories: Infrastructural Framework and Scenarios of Cooperation IAEA, Vienna, 2004. IAEA-TECDOC-1413

Slovenia, shared with neighboring Croatia. This has led to a common understanding (documented in a bilateral agreement) on sharing NPP decommissioning and waste management responsibility and later to bilateral discussions and decisions on sharing repositories for low and intermediate level radioactive waste (LLW/ILW), HLW and SNF. In 2019 it was decided that joint disposal for LLW/ILW will not take place but planning of HLW and SNF disposal will continue as a joint project between both countries.

It should be noted that for a newcomer nuclear country, the options listed above are not mutually exclusive. The long development time for a disposal solution implies that choices need not be made early in the program planning cycle. In particular, it has been emphasized by international bodies that countries should not rely on hopes that one of the options in the multinational category will definitely be available. A national program that could lead to a DGR, including competence building and funding accrual, should be commenced in any case. Implementing a national program along with keeping multinational options open and evaluating them regularly is the definition of the dual track strategy.

2.2 Countries with a dual track policy

The evidence of global interest in considering involvement in a multinational repository is clear from the number of countries that have been involved in relevant studies, initiatives, and proposals over many years. According to data from the IAEA[15], more than half of the 30 or so countries with nuclear power have small programs and, therefore, have relatively small inventories of spent fuel requiring disposal. Based on data from the World Nuclear Association[16], about 30 countries are considering, planning or starting nuclear power programs, and a further 20 or so countries have at some point expressed an interest. Thus, the number of countries with relatively small inventories of spent fuel is expected to grow significantly over the coming decades.

A publication by the IAEA, *Framework and challenges for initiating multinational cooperation for the development of a radioactive waste repository*[17], presented the positions as of 2016 of 24 countries on the question of disposal policy and transboundary movements of radioactive waste. Of the 24 countries, 12 did not allow the import of wastes for disposal, while 11 others permitted it, but only under certain conditions. Only one of the states surveyed prohibited the export of waste to another country. Two states did not have a position on waste exports, while the other 21 permitted it subject to conditions. Ten states mentioned having a “Dual Track” policy of pursuing the possibility of having either a national repository or participating in an international one. Nine other states noted their intention to construct national repositories, while four have no stated position. The remaining country has an agreement to return its research reactor fuel to the United States.

The results of the IAEA publication on countries’ positions on the question of disposal policy and transboundary movements of radioactive waste were supported in 2019 by a study prepared by Belgian waste management organization, ONDRAF[18]. The findings are presented in Appendix 2.5.

The dual-track approach with regional or multinational option for disposal is included formally in a number of countries in Europe and is mentioned in their disposal options also by some

[15] Status and trends in spent fuel and radioactive waste management / International Atomic Energy Agency, IAEA Nuclear Energy Series No. NW-T-1.14, 2018, Section 6.

[16] https://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

[17] “Framework and Challenges for Initiating Multinational Cooperation for the Development of a Radioactive Waste Repository”, IAEA nuclear energy series no. NW-T-1.5, 2016, Section 2.

[18] Monitoring international developments regarding shared geological repositories for high-level and/or long-lived waste: status as of March 2019, Ondraf/ Niras, NIROND-TR 2019-07 E, June 2019.

others (see Appendix 2.5). Detailed case studies of four leading dual track countries are presented in Appendix 2.3 (Slovenia, the Netherlands, Denmark and Norway). Some smaller EU countries (such as Cyprus, Greece, Latvia, Portugal, and Malta) have no operating nuclear power plants or research reactors, but also consider sharing of disposal facilities for small RW inventories from medicine, industry and research.

The dual track approach is not limited to Europe. For example, the United Arab Emirates, as one of the recent countries that started a major nuclear energy program, is also committed to a dual track approach[19].

2.3 When are decisions on the preferred disposal route required?

There is certainly no urgency to decide which avenue of dual track to pursue – national DGR or MNR. Indeed, it is not possible for Jordan, or any other country, to make such decisions at present, as there are no MNR solutions currently available. It is recognized by those countries with a dual track approach that, given the extended timescales of their own national DGR programs and the likelihood that MNR projects will need equivalent lengths of time to develop to an operational status, it may take some decades for either option to become a concrete possibility. Consequently, these countries anticipate that their dual track approaches may remain open for many years and it will be a future generation of decision-makers that decides which is the optimal route to take.

This does not mean, however, that a dual track country has a passive attitude to the MNR option. As with their own national DGR programs, it takes many years to engage with stakeholders, assess opinions and possibilities, initiate and foster partnerships, and identify and explore possible solutions. All of this must take place before it is possible to engage actively in an implementable MNR project. These preliminary stages do not require a significant extension of resources, either in personnel or funding, and are, indeed, best carried out by those who are also developing the national DGR program. Nevertheless, allowance needs to be made for the additional legal, commercial and financial skillsets that will be needed later to interact effectively with potential MNR partners.

Thus, while adopting a dual track policy does not require any early commitment to one route or another, it does require energetic pursuit of both national and MNR options from the outset.

[19] UAE weighs options for nuclear waste disposal | The National (thenationalnews.com)

3 National Policy, Regulation and Strategic Decisions

This Section outlines the current national policy and strategy of Jordan for the management of radioactive wastes and spent nuclear fuel in light of the current national plans for the development of nuclear power and identifies the organizations that have responsibilities in these areas. A more detailed description is provided in Appendix 1.

3.1 Overall organizational framework

The **Jordan Atomic Energy Commission (JAEC)** was established in 2007 according to Nuclear Energy Law No. 42 and subsequent amendment, empowering JAEC to lead the development and implementation of nuclear energy strategy and to manage the nuclear energy program. JAEC is an independent governmental body, reporting directly to the Prime Minister, and mandated to articulate a vision, strategy and roadmap to develop the use of nuclear energy for research, nuclear applications in medicine and industry, generating electricity and water desalination.

JAEC acts as the effective Nuclear Energy Program Implementing Organization and is supervised by a Council of Commissioners. JAEC's primary responsibilities are the development and eventual deployment of commercially viable nuclear power plants for energy generation in Jordan, and it is currently evaluating small modular reactors (SMRs) as a viable option for medium term deployment, recognizing the potential advantages that these possess (suitability for small grid, smaller upfront investment, flexibility in deployment, etc.). JAEC is concentrating on the technical and economic evaluation of SMR technologies that could meet Jordan's requirements and be deployed in the 2030s.

The legally, financially and administratively independent entity, **Jordan Nuclear and Radiation Regulatory Commission (JNRC)**, established in 2007, was directly linked to the Prime Minister. Its mission was to regulate and control the use of nuclear energy and ionizing radiation, protect the environment, human health, and property from hazards of contamination and exposure to ionizing radiation, and to ensure the fulfilment of requirements of public safety, radiation protection and nuclear safety and security. In 2014, the **Energy and Minerals Regulatory Commission (EMRC)** was established, merging the JNRC with the Electricity Sector Regulatory Authority, which includes within its organizational structure the Commission responsible for regulation of the peaceful uses of nuclear energy.

3.2 National Policy: Goals, Roles and Responsibilities

The current **National Policy for Radioactive Waste & Spent Nuclear Fuel Management**, revision 1 (hereafter, the 'National Policy'), was issued in 2015. This policy demonstrates the national commitment to address the management of SNF and RW in a coordinated and cooperative manner with all related national organizations and entities. The policy covers all specific steps and stages related to the safe management of SNF and RW, from generation through to disposal. It documents the nuclear safety and security provisions that aim to protect human health and the environment against radiological and nuclear contamination, currently and in the future, and without imposing undue burden on future generations.

An important aim of the National Policy is to support the nuclear energy program, thereby converting the country from energy importer to exporter, while maximizing the exploitation of local resources available for energy. The management of SNF and RW is a national responsibility that has been assigned to JAEC through Nuclear Energy Law No. 42 and its 2007 amendments.

The National Policy of Jordan aims to set up the generic legal framework, arrangements, measures and actions as well as all necessary requirements needed to achieve the goals of

the safe management of SNF and RW, and also to harmonize and develop technical, legislative and control concepts. Developing local resources (human and technical) is taken into consideration, as well as cooperation with private sector entities that generate radioactive waste, to ensure that these entities bear all financial costs for their management. The internationally accepted principles used in the National Policy include intergenerational equality and the 'polluter pays' principles. Other principles relate to public participation, transparency and openness, international and regional cooperation and many other issues that guarantee a sound decision-making process. Also addressed are the requirements to meet safeguards and nuclear security requirements during the management of SNF and RW in Jordan.

Jordan signed the IAEA Joint Convention in 2015 and has submitted its national reports in 2017 and 2020. This required the Government to develop and upgrade its national legislation, technical capabilities, and institutional structures and to construct the necessary facilities for the implementation of the Joint Convention and the National Policy. The National Policy will be used as a basis for the preparation and review of national legislation that ensures that Jordan is in line with its international commitments on environmental protection and nuclear and radiation safety and security.

Within the National Policy, responsibilities for management of SNF and RW are distributed among the following parties:

- **Government:** ensures that the human, financial and technical resources to implement the National Policy and the associated **National Strategy for Radioactive Waste and Spent Nuclear Fuel Management** [20] are available and are maintained. To do this, it has tasked JAEC and EMRC with the following responsibilities:
    - ***JAEC:*** is responsible for the long-term management of RW and SNF, including the administrative and generic management activities related to the control, coordination, preparation and implementation of plans, efforts and approaches by which the comprehensive process of managing SNF and RW, including disposal, would be practically and effectively completed.
    - ***EMRC:*** ensures the implementation of the National Policy and its inclusion in national legislation issued in cooperation with other regulatory bodies such as the Ministries of Environment and Health, and other relevant national entities. The EMRC regulates and controls use of nuclear energy and enforces implementation of national regulations on SNF and RW management. It grants licenses, ensures fulfillment of requirements for public safety, radiation protection of workers, and nuclear safety and security. EMRC is also responsible for preparation of a national registry of radiation sources and radioactive materials that are in use, exported or imported[21].
- **Generators and Operators:** Generators of SNF and RW or operators/managers of RW storage and treatment facilities are responsible for the technical, financial and administrative short-term management of wastes within their facilities. They are also responsible for development and updating of SNF and RW management plans within their facilities based on the National Strategy. Other responsibilities include minimizing generation of RW and keeping records on the SNF and RW inventory.

[20] In October 2020, the Nuclear Fuel Cycle Commission at JAEC completed the final draft for the National Strategy for Radioactive Waste and Spent Nuclear Fuel Management after review and discussion by EU and IAEA experts. Currently, JAEC staff are working with international experts to develop the strategy action plan to be presented to the Board of Commissioners at JAEC for final official approval and endorsement.

[21] JAEC, *The Hashemite Kingdom of Jordan National Policy for Radioactive Waste & Spent Nuclear Fuel Management: 2015, Rev.1*.

3.3 The National Strategy

The **National Strategy for Radioactive Waste and Spent Nuclear Fuel Management** mentioned above includes an Action Plan for implementation, prepared by JAEC. The Strategy defines the technical options for management of SNF irradiated in research reactors, subcritical assemblies and future NPPs in order to accomplish the management goals outlined in the National Policy. All technical options include safe storage at the site of a nuclear installation, and the Action Plan for management of SNF up to final disposal defines the following three phases.

- Phase I: Improvement of the national RWM framework (duration: 4 years);
- Phase II: Improvement of technical capacities, investigation of options and preparation of the decisions for disposal of all RW (duration: 10 years);
- Phase III: Creation of routes for disposal of current and committed future RW, disposal of all classes of RW requiring disposal and continued predisposal management and disposal of newly generated RW, avoiding the creation of burdens (duration: 10 years).

Implementation of the Strategy commenced in 2021, with a currently expected implementation period up to 2045.

3.4 Policy on Spent Nuclear Fuel

SNF management is a specific issue to be dealt with in National Policy and Strategy, as it might not be regarded as a waste material. Current policy states that, after storage at the reactor, different technical options will be considered for managing SNF:

1. Return to the country of origin (the 'take-back' approach). This option is called *"Return to its origin (Manufacturer)"*; it allows the supplier to choose its own subsequent fuel management strategy – direct disposal or reprocessing, with no return of HLW to Jordan.
2. Shipment outside Jordan for reprocessing, with the HLW generated from reprocessing shipped back to Jordan for disposal in a DGR. This option is called *"HLW disposal in Jordan after SNF reprocessing outside Jordan"*.
3. Storage in Jordan for subsequent direct disposal at the national DGR. This option is called *"Direct disposal in Jordan"*.

A fourth option, to dispose of SNF and/or HLW in a multinational facility in another country, is not currently part of policy, but is the topic of the current report. This fourth option would eventually need to be entered into National Policy if Jordan decides to adopt the dual track approach.

The multinational approach would then be pursued in parallel to the national approach included in options 2 and 3, which both require JAEC to construct and commission a DGR and associated infrastructure[22].

There are currently legal restrictions on waste movement in or out of Jordan that would need to be updated via established legal and political processes if a viable multinational disposal solution were to be developed in conjunction with partner countries. Law no. 43 (2007) lays the foundation for limiting the import (currently prohibited, except for returned materials) and export of RW and SNF across Jordanian borders. Although export is not currently prohibited,

[22] JAEC, *The Hashemite Kingdom of Jordan National Policy for Radioactive Waste & Spent Nuclear Fuel Management*.

a license is required. The National Policy recognizes the potential for export and states[23] that Jordan will pursue international and regional solutions.

The current legislative framework does not cover the transfer of ownership of SNF and HLW in an international framework, and this issue must be addressed, along with international liability and insurance requirements, in any developments towards the adoption of a dual track approach to cover specific issues related to an MNR.

3.5 Jordan's current position on the dual track approach

The National Policy expresses Jordan's interest in investigating all disposal options for SNF and RW, including regional and international solutions, but the only foreign options clearly stated involve transfers to and from the country supplying the reactor fuel or to another country for reprocessing. However, the policy of Jordan is meant to be reviewed and updated periodically, and, for a full dual track approach, updates would have to extend the current option of returning SNF to its supplier for disposal to include shipment to any third country that operates an MNR.

Jordan recognizes that multinational repositories can offer numerous economic, human resources, expertise and nonproliferation benefits for both the host and for Jordan. With its relatively small planned nuclear program, Jordan also realizes that providing the financial and human resources required for the construction and operation of a national geological disposal facility could be challenging. Adopting the dual-track approach could help to develop these necessary resources, allowing Jordan to develop its national plans in collaboration with other countries in the region having nuclear power programs.

[23] EMRC, 'Instructions on Decommissioning Nuclear Facilities'.

4 Benefits and Challenges of Involvement in an MNR

Decision-makers considering adoption of dual track need to consider the implications of such an approach, in terms of the potential benefits and challenges associated with involvement in an MNR. This Section presents an overview of potential benefits, opportunities and challenges in areas related to economics, environment, safety and security, technical aspects, socio political, ethical, and institutional aspects, non-proliferation, and public engagement and support for adopting the MNR option. If Jordan adopts a dual track policy, it will likely become involved with regional partner countries in exploring the MNR option, either specifically or as part of broader multilateral fuel cycle collaboration. The potential for broader multilateral fuel cycle arrangements is discussed in Appendix A1.7.

An MNR project has the potential to benefit the host and partner countries or the disposal service provider and user in many ways. It also presents them with potential risks and requires them to address the associated challenges of successfully responding to those risks. The benefits and the risks have both been addressed in a series of studies produced by international organizations. Sharing repositories or using a MNR disposal service can provide a viable alternative for countries that may, due to political, social, geological, economic or other concerns, face difficulties in domestic siting of such facilities. For an MNR host country there are considerable macro-economic and regional/global political benefits that compensate for the increased technical work required and the need to manage the extended sociopolitical issues associated with any disposal facility – challenges that the user countries are able to minimize or avoid. For a multinational disposal solution to be successful, the benefits for all stakeholders involved must be sufficiently attractive to outweigh challenges and any perceived or real disadvantages. Key initial criteria that an MNR must satisfy are those concerning safety, security and safeguards. Any proposed MNR must meet internationally accepted high standards for RW disposal in order to be implemented.

4.1 Economic and financial issues

Economic and financial benefits

The economic impacts of adopting a dual track policy are insignificant for the phases before a decision on project implementation is required. Minor additional costs due to participation in collaboration on MNR activities can be offset by savings resulting from access to a wider pool of expertise. Financial aspects become important, however, should an MNR move to the implementation phase.

DGRs involve high levels of fixed costs, such as site characterization, underground and surface facility design and construction, infrastructure construction, procurement of capital equipment and materials, and licensing / regulatory matters that are, to a degree, independent of the quantity of waste to be emplaced. Fixed operating expenses such as administration, security and maintenance of facilities and equipment occur even in the case of a small radioactive waste inventory. For a single DGR, the total costs are typically of the order of billions of USD (see Section 6). In any country, provisions to manage these liabilities need to be made by the generators of RW, and these provisions need to account for fiscal and program uncertainties that can make long term financial planning challenging. Nevertheless, as much of the cost outlay for a DGR lies many decades into the future, it has been demonstrated that adequate provision can be accrued over the long operating lifetime of an NPP by the inclusion of a small surcharge on the unit price of the electricity delivered to customers.

A key attraction of using an MNR is that the financial provisions required can be significantly reduced. Sharing the repository with a few partners can dramatically reduce expenditure on fixed costs for all those involved, compared to the fixed costs of one national repository. These cost savings can be passed on to the countries participating in the MNR: for example, it might be possible for the surcharge on electricity that funds the disposal program to be lower.

Savings can also occur at the project development level that precedes construction, eliminating site investigation, design, procurement, regulatory, and stakeholder engagement costs that would otherwise be incurred by each country individually. In addition to country-specific project savings, savings on financing costs would also be achieved, as interest during construction is avoided on every country-specific repository that no longer needs to be constructed. Moreover, the local economic benefits delivered to the MNR host communities will only be incurred in one location, rather than many, for multiple national solutions. In addition, participating member states can use state-of-the-art planning and execution approaches, drawing from differing skills sets from the respective participants (and, in cases where the MNR is an "add on" to an existing effort in a particular country, take advantage of advanced work of the host country), as opposed to each country having to replicate such skills sets for each individual program.

It is in large part due to these economic advantages that countries, especially those with smaller or no NPP programs, such as Jordan, favor the idea of shared MNRs. For a smaller host (co-operation scenario), the main advantage might be in achieving a cost-sharing arrangement that allows it to take care of its own wastes in a manner that might otherwise be economically infeasible. Such a cooperation example of cost reduction for Slovenia and Croatia is described in Appendix 2.3. It is estimated that in the case of 5 partner countries, unit costs for the Republic of Slovenia and the Republic of Croatia for the disposal of their entire HLW and SNF inventory decrease from 1.25 million USD/tHM to 0.66 million USD/tHM – a saving of 50% on the national DGR option.

A service provider that establishes a multinational disposal service stands to benefit from the direct receipt of disposal fee revenues. The MNR will also benefit a wider range of stakeholders in the host country because of the economic growth that results from increased expenditures in the region, including the sourcing of local content during construction. Increased tax and royalty revenue; direct, indirect, and induced employment; and opportunities for increased investment in related and unrelated industries are potentially significant benefits to communities and governments at the local, regional, and national levels. Furthermore, incentive and community advancement programs could provide direct benefits to the local community, as has been already demonstrated with various types of radioactive waste repositories[24]. Additionally, if existing and future country-based assessments (from participating member states) are pooled and invested, the savings (through unused funds) and investment income could serve as a dividend to the shareholders / country participants of the MNR[25].

Economic and financial challenges

For a national repository, especially for smaller countries such as Jordan, transport costs represent only a small part of total costs. In using an MNR, potential added costs could arise from the more complex modes of transport that might involve different combinations of sea, road and rail transport through host, partner or other countries. Additional administrative costs could be incurred as a result of the legal, regulatory and financial systems and arrangements needed for the project. Transportation of nuclear materials, however, is not a technical problem and has been practiced safely for many years. About 20 million consignments of radioactive material take place around the world each year. Since 1961, when the IAEA's safe

[24] See Table 7.1 of : *Work Package 3: Economic Aspects of Regional Repositories* (SAPIERR II – Strategic Action Plan for Implementation of European Regional Repositories: Stage 2)

[25] *Considerations on the Financing of a Multinational Repository* (IFNEC Workshop on Approaches to Financing an Multinational Repository – Challenges and Alternate Approaches (Paris, 11 December 2018) – Paul Murphy, Edward Kee, Xavier Rollat, and Timothy A. Frazier.

transport regulations were first issued, around a billion consignments have been safely completed[26].

MNR implementation and estimated expenditures are, as in the case of national repositories, sensitive to significant delays, siting issues or even failure of the project, inflation changes, management of accumulated funds with yield changes, increased regulatory requirements, etc. Mutually agreed approaches should be developed to reduce the overall economic risks for all involved countries and for allocating the economic risks among the countries in the project. Commercial arrangements should then be developed based on agreed risk allocation arrangements.

Another significant financing issue (which is applicable to both national and multinational repository projects) is the occurrence of major project development costs well before any financial closure to the main construction effort. The development period that precedes commencement of construction will be much longer than for a large NPP. These costs will be a particular challenge, as they are far removed from any "return on investment". Financing arrangements will have to be agreed early on, so that it can be determined whether there is a critical mass of participants to make an MNR viable.

4.2 Safety, security and nuclear safeguards

An MNR project can expand the available range of geological options available, if several countries participate. Simple geological environments that are more readily suited to repository development might not be available in small countries with complex geological environments, which might be an issue for Jordan. A larger choice of geological formations that might be available across a group of MNR participant countries can also help to optimize repository design solutions to the waste inventories involved. Moreover, the wider range of expertise involved and the probable requirement to satisfy the specific radiological safety requirements of each user country will help ensure that the highest levels of operational and long-term safety are met by the MNR.

Another key benefit of an MNR is enhanced global nuclear security, as the number of facilities that need to be protected against terrorist and other potential threats is reduced.

In addition, nuclear safeguards control for the prevention of misuse of nuclear materials is simpler at a single site than at many scattered storage or disposal sites, especially since an MNR might be realized sooner through cooperation, thus helping prevent selection of a perpetual storage policy by some countries. The earlier emplacement of wastes deep underground inside a facility that is monitored, with numerous engineered and administrative controls, can enhance both physical security and safeguards relative to most surface storage facilities. Earlier disposal in an MNR will also increase passive safety features comparing to long-term storage.

4.3 Environmental issues

Many countries generating RW, including those with nuclear programs, have implemented a strategy of medium or long-term storage and are not planning to develop a repository for many decades. An MNR approach offers the potential for them to dispose more quickly of the RW and SNF, both that held currently and that to be generated in future and held in surface storage. For those countries with no prospect of disposal for many decades, early access to an MNR could help avoid the environmental risks associated with under-funded or marginally funded national disposal programs. In addition, a multinational repository approach has the potential to reduce globally the total number of future repository sites that would otherwise be

[26] https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/transport-of-nuclear-materials/transport-of-radioactive-materials.aspx

needed. This creates the potential to avoid much of the conventional environmental impact associated with any large infrastructure project, which would be incurred as a result of the construction and operation of the numerous repositories that would be needed in the absence of a multinational approach. Implementing a single repository instead of multiple facilities will result in consolidation of waste storage and disposal activities at one location, in the need for fewer resources and reduced land disturbance.

4.4 Societal and political issues

Societal and political benefits

Siting of a geological repository in a consensual process has proven to be a major challenge in almost all national disposal programs. Users of an MNR in another country will to some extent be spared the often-contentious public debate arising from the siting process, although a responsible waste exporter country will still have to be convinced of the safety of the facility. Undeniably, in the host country, public dialogue during the siting process may be more challenging. For success, the MNR developer will have to develop a comprehensive and transparent public engagement process that demonstrates clearly to the host country, region and community that the benefits of hosting the facility far outweigh any real or perceived drawbacks.

Even at an early phase, partners in an MNR project may benefit from enhanced societal acceptance of their nuclear activities. Some will have no realistic national disposal solution in sight or only vague and unrealistic time schedules. Public trust may be enhanced by the demonstration that attention is being paid to the long-term disposal problems – especially if the MNR option is combined with a modest national program in the dual track approach.

Sharing repositories may help to assure that all countries maintain consistent practices and quality control standards in working with nuclear materials, as well as consistent levels of safeguards, monitoring and verification in nuclear fuel cycle activities, helping to build confidence among nations. Harmonizing political decisions on involvement in an MNR project can lead to consistency in practices and regulations, which can also be helpful in building trust and confidence among participant countries.

Successful implementation of an MNR will enhance the credibility of nuclear power by showing that there are potential RWM closure solutions for all nations that are not dependent on each nation, on its own, having to overcome the multiple challenges of developing a DGR.

Societal and political challenges

It is generally accepted and part of international conventions that countries have a direct responsibility for the safe long-term management of their radioactive wastes. This does not imply that the wastes must necessarily be disposed of in the country in question. However, there is some public perception that countries that have the benefits of nuclear power generation should bear the burden of storing and disposing of their RW. This argument raises ethical and fairness issues when discussing the concept of an MNR. Accordingly, to obtain public and political support, it is imperative that an arrangement for an MNR should be based on a fair, transparent and equitable sharing of benefits and risks among a repository host and other participating countries.

Public support for multinational repositories will be difficult to achieve for the same reasons that apply to national repositories. In addition, host country public support will need to be sufficiently motivated to accept larger inventories and different types of foreign wastes and SNF. A sufficient level of public acceptance is necessary in both the host and partner countries. Throughout the MNR project, public acceptance and support can vary and, at some point, sustained public support for the MNR project could be reduced or even lost. An MNR is also a politically sensitive project, so strong and continued political support is essential. Any necessary changes in laws or regulations that will enable the realization of the MNR, either in

host or participating countries, are endangered without sufficient political support. Effective majority support nationally and a high level of support in the local community, combined with stable government policy, are also essential, given the long-term siting, construction and operation times of the repositories and the need for certainty for potential cooperating or client nations.

4.5 Technical issues

At present, Jordan has not decided on either the NPP technology to be adopted for its nuclear power program or the generating capacity to be installed. It is thus too early to specify the detailed technical requirements for a DGR or an MNR for the wastes that will be generated. However, in keeping with international best practice, a national DGR in Jordan would certainly be constructed at a depth of several hundred meters, depending on the geological environment selected, and would use the multi-barrier concept of engineered and natural barriers to contain and isolate RW/SNF safely.

Technical benefits

From a technical perspective, the same requirements apply to an MNR as to national DGR, and the same technical principles should be followed in designing, constructing and operating the repository. The fact that the technical challenges associated with repository implementation can be overcome is demonstrated by the successful national repository programs in progress today. In particular, the Finnish waste management organization is close to commencing operation of the first deep geological disposal facility for SNF.

In the multinational case, technical advantages may result from collaborating on repository implementation. Scientific, educational, and technical exchanges resulting from collaborating on repository implementation can generate advantages and increased technical capacity on disposal issues to help to assure that countries have a common understanding and knowledge base in pursuit of the common goal of MNR implementation. For an MNR project more expertise is available, and more funding can be made available for developing robust engineered systems and a wider choice of siting in a larger choice of geological formations may be possible with enabling analysis of different disposal design concepts.

Technical challenges

One potential technical challenge arising from the larger scale of an MNR is that there may be a greater variety of waste sources and types/streams. In this context, the waste acceptance criteria might be more complex due to differences in the nationally employed conditioning technologies and waste packaging, and a greater variety of waste handling equipment might be required. Furthermore, the safety case to present evidence that an MNR provides a high level of safety could be more complex, owing to a wider variety of RW streams/inventories.

A specific issue is quality assurance of the waste packages to be disposed of in an MNR. Usually, the waste generators are involved to a great extent in the quality assurance of the waste packages. If they follow different national systems, it might be difficult to maintain compatibility. The situation may become more difficult if historic waste is involved, since this may not be adequately documented and, in some cases, reconditioning and/or repackaging of waste might be needed. However, for new nuclear power programs such as those of Jordan and its MENA counterparts, where systems have yet to be developed and historic waste is not present, agreeing compatible WAC should not present particular problems if considered early in their RWM programs.

Possible Jordan-specific technical challenges can be industrial bottlenecks and the very limited access to the sea (a coastline of only 26 km), which can be an issue restricting transportation of RW to the port and should be considered at an early stage of the program. For construction of a national DGR, it is important to note that, although Jordan has developed

extensive experience in near-surface mining and drilling, it lacks experience from a deep geological drilling and mining industry.

4.6 Institutional and legal challenges

Involvement in an MNR project with other countries requires a range of institutional issues to be addressed that go beyond those encountered in a national DGR project.

Relevant aspects of the national legal and licensing regimes of countries should be harmonized in relation to multinational projects. The exact nature of the harmonization would require considerable discussion, but it is likely to cover issues such as common terminology and definitions, and equivalent safety standards and criteria for geological disposal. Compatibility among the respective national licensing and RW classification systems should be achieved. This task can be completed only when the host country is finally selected, but the participating countries in the MNR should begin an in-depth comparison of the relevant national legal waste management frameworks before then.

A wide range of contracting matters will need to be discussed and resolved, including the legal nature of any entity that might be established to manage the MNR, the structure of participation models for each partner, organizational responsibilities, financing arrangements and the allocation of risks in the case of any default by partners.

New and specific questions might also arise in the context of transboundary movement of the waste, associated with transfer of title. Particularly in case of the execution of a retrievability option for the MNR and in case of intervention measures that involve waste retrieval, the question of waste ownership should be clearly addressed.

One of the challenges in implementing an MNR is associated with bringing together and working within the different institutional frameworks in the partner countries, which might have varying environmental regulations, regulatory entities, processes for establishing funding, technical and legal infrastructure, and different approaches to organizational responsibilities and public participation.

4.7 Conclusions on the potential benefits of an MNR

Despite the challenges associated with an MNR presented in this section the benefits are manifest, and some overarching conclusions can be drawn based on international consensus[27]:

- Multinational repositories can enhance global safety, security and safeguards by making timely disposal options available to a wider range of countries. For some countries, multinational repositories are a necessity, if safe and secure final disposal of long-lived RW is to replace indefinite storage in surface facilities, when viable national options are not available. Moreover, developing a viable solution for multiple countries, particularly newcomer countries, will counter assertions from the anti-nuclear community that nuclear power has not adequately addressed legacy issues.
- The global economic, strategic and political advantages of multinational repositories are clear, and the benefits can be significant for all parties, if they are equitably shared. For individual countries, the appropriate national decision-making bodies must weigh the balance of benefits and risks resulting from participation in an MNR project.
- The high ratio of fixed to variable costs for any repository ensures that considerable economies of scale will apply in implementing an MNR, which can then be monetized for the benefit of the participating countries and the host country. Moreover, these

[27] IAEA (2011): Viability of Sharing Facilities for the Disposal of Spent Fuel and Nuclear Waste, TECDOC-1658

economies of scale, by creating savings for each participant, should enable funds to be deployed (in each participating country) for other social and infrastructure issues.

- Transport of nuclear material is a safe, secure and well-established international practice. The additional distances involved in using an MNR will not have any impact on public health and environment, nor will the incremental costs for transportation be determinative in the decision of a potential participant.
- The challenges accompanying the establishment and implementation of an MNR presented in this Section are extensively and methodically addressed through possible mitigation measures in several reference documents[28].

4.8 Examples of functioning dual track programs

Numerous countries have expressed interest in the possibility of utilizing a multinational repository. Relatively few, however, have formally introduced it into their national policies and initiated practical steps to progress this approach. Some examples of European countries with relatively modest waste inventories that have fully committed to the dual track approach are summarized below and described in more detail in Appendix 2.3.

4.8.1 Slovenia

Slovenia has a very small nuclear program: it co-owns one nuclear power plant with Croatia with a 50:50 share. In 2016, Slovenia revised the national waste management strategy to implement the concept of shared facilities and regional cooperation in waste management, including the dual-track approach. For long-term SNF management, a dual-track (national DGR or MNR) policy has been adopted as a reasonable solution in the present situation. The main reason put forward for cooperation and integration in this area was that Slovenia's extremely small-scale nuclear program indicates that, by participation in joint RW programs, it can achieve significant positive economic effects. Slovenia was a founding member of the ERDO Working Group, which has brought together a group of EU countries to consider a model for the development of joint disposal solutions.

The national waste management organization, Agency for Radwaste Management (ARAO), monitors international developments in SNF and HLW management permanently and will conduct planning and carry out development-related activities for the continuation of SNF dry storage after the cessation of Krško NPP operation and for ensuring the final disposal of the SNF.

In 2019, a new disposal reference scenario was developed for a DGR in hard rock[29]. Cost estimates were made for activities in both a national and a multinational approach: e.g., encapsulation in a regional encapsulation plant and disposal in an MNR, for which two concepts were analyzed. The service concept assumes a service provider country develops an MNR that accepts SNF from customer countries (e.g., the proposed South Australia approach), while the cooperation concept is based on collaboration between partner countries

[28] Developing multinational radioactive waste repositories: Infrastructural framework and scenarios of cooperation IAEA TE 1413,

IAEA Framework and challenges for initiating multinational cooperation for the development of a radioactive waste repository

INPRO Cooperative Approaches to the Back End of the Nuclear Fuel Cycle: Drivers and Institutional, Economic and Legal Impediments,

[29] Third Revision of the Krško NPP RW and SF Disposal Program, ARAO, Fond NEK, 2019

in a joint venture project for development and construction of an MNR. In Slovenia, the export of SNF and HLW is an acceptable societal solution[30].

4.8.2 Netherlands

In the Netherlands, there is one NPP in operation and one that was shut down in 1997. The Dutch policy on RW management is stable and for more than thirty years has assumed SNF reprocessing and the above-ground storage of the RW for a period of at least 100 years, after which geological disposal is envisaged around 2130. The relatively long period of above ground storage will provide time to learn from experiences in other countries, to carry out research and to accumulate knowledge and sufficient funding. In this way, sufficient money can also be set aside to make eventual disposal possible.

The dual track disposal strategy is being followed: a national route towards disposal will be elaborated while at the same time the possibility of collaborating with other European Member States in establishing a disposal location will not be excluded. In this dual track strategy, intensive international collaboration has been promoted through the ERDO working group. In 2021, a formal ERDO Association was established, based at the headquarters of the national waste management organization, COVRA. The Dutch national program for the management of RW and SNF[31] recognizes that creating a multinational disposal facility offers clear advantages. These include lower costs for creating the disposal facility, more choice of possible suitable locations, the combining of technical capacity and supranational supervision.

4.8.3 Denmark[32]

Nuclear energy is not part of the Danish energy mix and the bulk of RW in Denmark originates from the decommissioning of the former research reactors and supporting facilities at Risø. Danish Decommissioning is responsible for management of SNF and RW arising from decommissioning and the research, industrial and medical sectors. In 2018, the Danish parliament specified long term storage for up to 50 years of all SNF and RW, followed by geological disposal, no later than 2073, and a new national policy and work program is to be established. In the medium term, geological studies should be performed in order to identify possible sites for a deep geological disposal facility in Denmark, while the Government can continue to explore possibilities for an international solution – the dual track approach. Danish Decommissioning participates in cooperation on any joint European solution under the auspices of the ERDO Association.

4.8.4 Norway[33]

Norway has no nuclear power program but has had four research reactors that are permanently shut down. In 2018, the Norwegian Nuclear Decommissioning (NND) was established as a state agency to take over responsibility for decommissioning the research reactors and other nuclear infrastructure and for management, storage and disposal of RW. Technical assessments from 2018 indicated that it is likely that packaging and other disposal system features could be designed, and a disposal site found in Norway, suitable to allow safe

[30] Resolution on the National Program for Managing Radioactive Waste and Spent Fuel for the Period 2016–2025 (Official Gazette RS, No. 31/16),

[31] The national program for the management of radioactive waste and spent fuel: The Netherlands, June 2016 https://english.autoriteitnvs.nl/binaries/anvs-en/documents/report/2016/08/09/the-national-program-for-the-management-of-radioactive-waste-and-spent-fuel/the-national-program-for-the-management-of-radioactive-waste-and-spent-fuel.pdf

[32] Parliamentary resolution on a long-term solution for Denmark's radioactive waste, https://ufm.dk/en/newsroom/issues/radio-active-waste/english-material, Council Directive 2011/70/Euratom for the Responsible and Safe Management of Spent Fuel and Radioactive Waste: Second Report from Denmark, 2018 (sst.dk)

[33] National Report of the Kingdom of Norway to the seventh Review Meeting, October 2020

direct disposal for the relatively small amounts of SNF concerned. Norway keeps open the option of using an MNR and is a Member of the recently established ERDO Association.

4.8.5 Implications of co-existing national and multinational repository development programs

There has been a significant debate on how the concurrent existence of national and multinational programs might impact on the probability of success of either program[34,35]. Tables A2-1 and A2-2 in Appendix 2.4 summarize the positive and negative implications of co-existing national and MNR programs.

The conclusions drawn are that no conflicts need exist and that symbiosis is in fact possible and could provide added value to the national DGR program. This is supported by the examples of functioning dual track programs presented above. They propose common messages that can be espoused by proponents of either approach. The most important of these in the current context are as follows:

- To ensure high levels of nuclear security and environmental safety, every country needs a disposal solution for all its radioactive wastes. For countries with long-lived radioactive waste, this requires access to a DGR.
- For a global solution, this will require a mix of both national and shared multinational projects, and it is essential that each country is actively involved today in one of these options, or in a dual track combination of both.
- Countries that opt for a dual track approach should clearly communicate their policy, program and timing to their national publics and to the global nuclear community.
- Multinational repositories can only be sited in willing communities and nations, and in host countries that are able to provide the technical and regulatory framework that is necessary to ensure safety and security.

Based on analysis of all aspects of the proposed NP program in Jordan, this report provides a set of recommendations and measures that can help avoid any potential negative interactions and implications of a dual track disposal program. Moreover, it emphasizes the positive safety, security, environmental, technical and economic implications of adopting a dual track approach.

[34] McCombie c., Verhoef E., Chapman N., 2015. Towards A European Regional Geological Repository, WM2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA14620

[35] Chapman N.A., McCombie C. and Verhoef E. (2011). Implications of Co-Existing National And Multinational Geological Repository Development Programs In Europe. In: Proceedings of 14th International Conference on Environmental Remediation and Radioactive Waste Management, ICEM2011, September 25th – 29th, 2011, Reims, France. ICEM2011-59118

5 Framework Requirements for National DGR or MNR

Irrespective of whether Jordan adopts a dual track approach for disposal of SNF and its higher activity wastes or remains with a purely national disposal program, there are similar requirements in terms of organizational aspects, data inputs and technical activities. These form the framework needed for both a dual track and a national disposal program and are described in this Section:

- Robust RWM policy, well-defined strategy and an active national program leading to disposal.
- Defined current and future inventory of waste arisings.
- National DGR siting and development program.
- Transport infrastructure framework.
- RWM capabilities and competences.

5.1 Robust RWM policy, strategy and an active national program

In either a purely national or a dual-track option, Jordan has a national commitment to maintain its policy and legal basis for safe management of SNF and RW in full conformance with the recommendations of international best practice and IAEA standards[36]. This commitment is represented by Jordan's adherence to the Joint Convention, backed up by the organizational basis to implement this policy effectively and with clear definition of roles and responsibilities. Both the policy basis and the organizational basis described previously are considered robust, but certain aspects would need to be updated to clarify the role of a possible MNR in the dual track approach. It is thus proposed by JAEC that, to meet international standards, a new law on RWM will need to be established, along with a new waste management organization (WMO). This **Jordanian Radioactive Waste Management Corporation (JRMC)** could have a broad spectrum of national missions:

- Acceptance, transport, storage, treatment, conditioning and disposal of all types of radioactive wastes.
- Site selection, planning and preparation for construction, construction, operation, and monitoring of disposal facilities.
- RD&D and technical support to waste generators.
- Information management, international cooperation and external engagement.
- Operation of a **Radioactive Waste Management Fund**, which is not yet established.

A fundamental requirement is that Jordan must have an active and credible national program that could lead to geological disposal of all Jordanian wastes within Jordan. This is important, because a multinational solution that meets Jordan's requirements might not be found. A national solution must remain an option up to the point where an implementable multinational solution has been developed. At the very least, the responsible national organizations must have the in-house expertise to act as an 'intelligent customer' for either the specialist contractors commissioned to assist in implementation of a national DGR siting program, or to

[36] The National Policy states: The Jordan Atomic energy Commission is keen to apply the basic safety standards for spent nuclear fuel and radioactive waste management and will ensure that the methods applied in The Hashemite Kingdom of Jordan are in full conformance with the recommendations of the international best practice and the IAEA standards.

take an active part in a potential MNR project. For example, Jordan must be able to define its own technical requirements[37] that must be met by any MNR that it might use.

Even if a multinational project emerges that is simply offered to Jordan as a service (i.e., is not co-developed as a partnering enterprise with Jordan), the responsible organizations in Jordan need to have the capability to assess and interact with the service providers on a fully informed and expert basis and need to prepare clear advice for responsible decision makers on whether such an option is acceptable and feasible for Jordan. A national DGR program will itself require the establishment of these skills and capabilities, so a well-developed national program also forms a strong basis for involvement in any multinational initiatives. The national DGR program serves as a basis for comparison and analysis for Jordan to decide to join either as a partner in an MNR or a user of an MNR disposal service.

Meeting all the above organizational and capability requirements will result in the development of national competence that will be essential if Jordan were to become a partner in an MNR project and would also enhance the possibility of a regional leadership role. Similarly, any country offering to host such a facility must have competence and security credentials that are acknowledged and accepted not only by Jordan, as a potential user country, but also by the broader international community.

5.2 Current and future SNF and RW inventory considerations

JAEC has established two RWM facilities; the **Central Storage & management Facility (CSF)**, located at JAEC headquarters, for the management of Disused Sealed Radioactive Sources (DSRS) and Sealed Radioactive Sources (SRS) arising from medical, industrial, and agricultural nuclear applications, as well as research and training centers, and the **Radioactive Waste Treatment Facility (RTF)** located at JRTR premises. JAEC also manages an old legacy RW storage facility at Sewaqa in southern Jordan.[38]

With respect to evaluation of the dual track option, the main inventory consideration concerns the SNF and HLW that would be routed to a national DGR or an MNR. Other long-lived wastes generated by future decommissioning and possibly some of the materials already in store at JAEC would also require geological disposal but have not yet been evaluated. Also, as no decisions are yet required on the possible use of reprocessing, there are no estimates available of potential HLW arisings. Thus, the only inventory factor taken into account at the moment is the amount of SNF that might be generated in Jordan.

5.2.1 Potential future SNF inventory

Jordan currently has two nuclear facilities in operation that generate SNF: the **Jordan Research and Training Reactor (JRTR)** and the **Jordan Subcritical Assembly (JSA)**. The main generator of SNF will be the future nuclear power program. SNF assemblies generated in the JSA are stored in a long-term storage pool. SNF will then be managed in parallel with the SNF from JRTR and the future NPP. SNF assemblies from the JRTR are stored in the service pool for decay heat removal, with the capacity of the pool being sufficient to contain SNF for the lifetime of JRTR. It is expected that 300 SNF units will be generated by the JRTR by the end of its lifetime. A similar storage approach will be used for the SNF from the future nuclear power program, but with SNF eventually being transferred from pool to dry storage.

[37] The *systems engineering approach* (using a *requirements management system*) is widely adopted by waste management organisations and is included in recent IAEA guidance. If it is established early, it can provide considerable clarity to the identification and evaluation of options and a sound basis for the decisions that need to be made. Requirements will arise externally to the implementing organisation, from international agreements, national policy, safety and environmental regulations, budgetary constraints and, in the case of a potential multinational DGR, from the external users. They will also arise internally, as requirements developed specifically for, or placed on the DGR system, the site and the repository components.

[38] JAEC, National Strategy for Radioactive Waste and Spent Nuclear Fuel Management. Amman, 2019.

Jordan is evaluating available NPP options in order to decide the appropriate technology mix to be deployed. SNF and HLW generated volumes depend on the reactor technology being utilized. Estimates of SNF arising from the NPP project assume four scenarios for the mix of NPP types: small modular PWRs (PWR SMR), small modular HTGRs and large conventional PWRs (LNPP). For more information on the estimation of SNF arisings, see Appendix 1.5.

Table 1 shows the total amounts of SNF (as metric tonnes of heavy metal: tHM) assumed to be generated for the four scenarios, each with 4000 MWe total power operating over 60 years. The design of a repository is normally dictated by the heat load, and then by the volume. However, options for SNF disposal packaging, engineered barrier systems and repository design concepts have not been evaluated as part of the current project. The largest mass of SNF generated annually is expected for Scenario 2 (2000 MWe LNPP and 2000 MWe PWR SMR), which excludes the HTGR technologies. This is mainly because all of the power generation is from PWR fuel elements, which generate more heavy metal content than HTGR pebble bed fuel types. The smallest SNF volume generated is for Scenarios 1 and 3, which include a 50% HTGR contribution to the total share of the assumed installed capacity. HTGR power plants in all scenarios are expected to generate only 10.6 tHM of SNF annually. On the other hand, HTGRs generate large volumes of spherical SNF elements (0.172 m^3/MWe per year), which could significantly impact the size of the DGR. Currently, laboratory-scale technologies have been developed to separate fuel kernels from their graphite matrix, which would provide the capability to reduce the SNF volume designated for final disposal. The reduced requirements for HTGR SNF handling, storage containers and facilities (compared with PWR SNF), make HTGRs a potentially attractive option. Further evaluation of NPP scenarios will need to take into account economic impacts and associated requirements.

Table 1: Total amounts of SNF assumed to be generated for four nuclear power scenarios.

Scenario	Description	SNF/ year [tHM]			SNF / 60 Years Lifetime [tHM]			Total Expected SNF [tHM]
S.1	2000 MWe HTGR 2000 MWe LNPP	***HTGR***		***LNPP***	***HTGR***		***LNPP***	**3036**
		10.6**		40*	636		2400	
S.2	2000 MWe PWR SMR 2000 MWe LNPP	***PWR SMR***		***LNPP***	***PWR SMR***		***LNPP***	**4800**
		40		40	2400		2400	
S.3	2000 MWe HTGR 2000 MWe PWR SMR	***HTGR***		***PWR SMR***	***HTGR***		***PWR SMR***	**3036**
		10.6		40	636		2400	
S.4	1000 MWe HTGR 1000 MWe PWR SMR 2000 MWe LNPP	***HTGR***	***PWR SMR***	***LNPP***	***HTGR***	***PWR SMR***	***LNPP***	**3918**
		5.3	20	40	318	1200	2400	

*1 GWe generated from a PWR produces 20 tHM annually, assuming 90% capacity and 50 GWd/tHM[39].

**: Since TRISO fuels are HALEU and have high burnup levels, an assumption was made of 95% TRISO SNF content as heavy metal, based on 7 g initial content in each kernel[40].

[39] International Panel on Fissile Materials (IPFM), Managing Spent Fuel from Nuclear Power Reactors - Experience and Lessons from Around the World, 2011

[40] Treatment and recycling of spent nuclear fuel Actinide partitioning – Application to waste management, CEA Saclay and Groupe Moniteur (Éditions du Moniteur), Paris, 2008

5.3 MENA regional SNF inventory

Several countries in the Middle East and North Africa region have expressed their interest in aspects of the fuel cycle. As a regional prospective, a potential initial contact group of the four Arab nuclear power countries with advanced plans (Jordan, Egypt, Saudi Arabia, and the UAE) could be initiated to consider their common HLW and SNF disposal issues. These countries are commissioning, constructing or have announced their NPP plans for the foreseen future. Based on the plans announced, the total amount of SNF could exceed 36,000 tHM, as outlined in Table 2. If these countries were to share in an MNR for disposal of their SNF, then Jordan would use around 12% of the capacity of the repository.

Table 2: Potential amounts of SNF that could be generated in selected MENA countries

Country	Committed / Projected [GWe]	Potential SNF [tHM]**
Jordan	4	3036 - 4800
UAE	5.6*	6720
Egypt	4.8* [41]	5760
Saudi Arabia	4 to 17*** [42]	20400

*Potential for future expansion based on operational experience

**Would depend on many factors that are currently uncertain

***The larger number was in early plans: currently (see Section 7.2), scenarios from 4 to 8 reactors of varying types are being evaluated; the SNF figure shown is for the early plans

5.4 Siting a deep geological repository

The principles of selecting and characterizing a suitable site for a DGR are the same for either a national DGR or a multinational DGR. These principles are based on demonstrating that the site has properties that assure both operational (pre-closure) and long-term post closure safety by *containing* and *isolating* the waste.

It is recognized that there are other important factors in the siting process, regarding both safety and non-safety issues, such as nuclear security considerations, technology, economics, regulatory, logistics, land use planning, non-radiological environmental impacts and socioeconomic impacts, among them the opinion of interested parties, including the public. Typically, as a siting process progresses, candidate sites are screened out. For the few potential sites that remain, safety considerations will become more pronounced.

The way in which safety principles are applied to geological disposal is elaborated in two key IAEA publications:

- Safety Standards series SSR-5 (2011): Disposal of radioactive waste.
- Specific Safety Guide SSG-14 (2011): Geological disposal facilities for radioactive waste.

These standards and guidance documents provide recommendations on how to meet the safety requirements for the disposal of radioactive waste and are themselves based on the

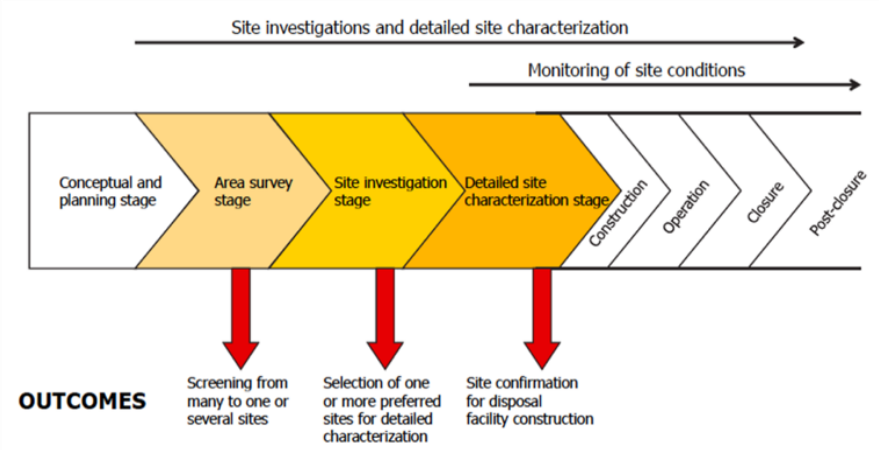
[41] D A Cauich-López et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 337 012081

[42] Nuclear Power in Saudi Arabia, WNA, 2021.

high-level safety principles set out in the IAEA Safety Fundamentals[43] – principles that also form the ethical and conceptual basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Appendix 1 of SSG-14 provides a description of the staged approach to siting a DGR that is the basis of the IAEA guidance. Figure 1 shows the stages envisaged.

Figure 1: Stages in siting a DGR (IAEA SSG-14)



The detailed guidance provided by the IAEA is not reiterated here, but has been adopted by most countries, adapted as necessary to their own national situations. It will be expected by the international community that either a purely national DGR program, or involvement in an MNR project in a partner country, would follow this guidance and be described in Jordan's regular reporting under the Joint Convention.

5.4.1 Siting a national DGR in Jordan

Consideration of national siting options is a requirement of the national program but should also be included in the dual track approach. Jordan is in the early stages of considering the eventual deployment of geological disposal, which will be one aspect of policy considerations on the future development of nuclear power and nuclear research. The 2018 report to the 6th Review Meeting of the Joint Convention notes, for example, that no decision has yet been taken on how to manage SNF, which would be a key component of the inventory of a DGR.

Nevertheless, some very preliminary work has been carried out recently to identify geological formations that might be suitable for a DGR[44]. This work has established that there could be potential for geological disposal in Jordan: three regions, with formations in basalt, limestone and granite having been suggested. If this work is to be extended into a formal DGR siting project, then there is significant experience available internationally on which to base the program – for example in approaches to site evaluation and characterization, the use of multi-attribute options analysis, and approaches for dealing with seismic hazard, an issue that Jordan will need to address when considering the potential use of regional siting exclusion criteria.

[43] European Atomic Energy Community, Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, International Maritime Organization, OECD Nuclear Energy Agency, Pan American Health Organization, United Nations Environment Program, World Health Organization. Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[44] Dweirj, M., Tarawneh, K., Titi, A. and Malkawi, S. (2016). Toward Site Selection of Permanent Geological Disposal for High-Level Nuclear Waste in Jordan. Journal of Environment and Earth Science, v.6, No.9, 206-216.

Jordan also has good experience in NPP siting, where phase one of siting has been successfully completed. Following IAEA guidance, a preferred site that passes a set of exclusion criteria published by the EMRC has been identified for construction of the first NPP in Jordan.

There is some overlap in the technical siting requirements for a DGR and those for a NPP (e.g., in respect of land stability), but a DGR has many specific requirements that are not relevant to NPP siting (e.g., deep rock properties). While there are clearly some benefits in considering siting of both facilities at the same time (e.g., the same teams could assess technical criteria in a uniform manner; proximity of NPP to DGR could reduce transport requirements and allow optimized use of technical staff; local community engagement and approval could be higher, as they will already host a nuclear facility, etc.), there might be only limited value in attempts to co-locate the facilities.

The inventory to be managed has a major role in determining the DGR concepts to be assessed. One of the main tasks of the DGR program will be to consider how an appropriate DGR concept (multibarrier system and safety concept, based upon a set of safety functions) can be matched closely to the potential geological environment(s) in which the DGR could be constructed – the main constraint on choice of concept being the host rock and surrounding rock formation properties. Solutions can be found that meet requirements in different ways for different environments, as there are various ways to build an integrated multibarrier system using different combinations of the barrier functions. Thus, identifying the approach to *concept selection* is directly linked with the approach adopted to DGR siting and needs to be considered at the outset of the program. A recent IAEA document[45] provides further guidance on this topic.

Once roles and responsibilities have been established, an early requirement on a DGR siting program will be for the implementor to agree the siting approach and the siting requirements with the regulatory authority. This should be based upon IAEA guidance but, within this framework, specific requirements will need to be developed to address the particular geographical, geological and environmental characteristics of the country. For example, one topic would be whether to use exclusion criteria to remove certain parts of the country from consideration on technical, societal or land-use planning grounds (e.g., based on seismicity, specific ground stability factors, population, resources, environment, etc.). Another topic might be whether to require detailed evaluation of more than one site. To reach an agreed siting approach, it will be important to have wide-ranging discussions with relevant organizations in Jordan and to consider alternative methodologies. Once agreed, the approach can be laid out in a regulatory policy document, against which the siting program can be audited.

5.4.2 Involvement in MNR siting in a partner country

A further aspect of DGR siting to be considered concerns ‘multinational siting’ – the selection of a site for an MNR from a range of options across a group of collaborating countries. It is recognized that Jordan would not be a potential host country under its current policy, but it could, nevertheless, be involved in multinational siting as a partner.

The technical requirements for designing and siting a DGR identified in this scenario are in principle no different from those discussed in the previous section. The technical characteristics of the site (suitability of geological environment, location with respect to access routes, etc.) and the means of selecting a DGR concept and design, and demonstrating safety, will be the same. The difference lies in the approach to identifying the eventual host country. There may be considerable variations in the way in which partner countries deal with their

[45] Design principles and approaches for radioactive waste repositories. IAEA Nuclear Energy Series NW-T-1.27 (2020).

national organizational inputs, the roles of governments and regulators, and their approaches to public engagement and involvement in the siting process. A major question is whether a shared project of this nature would be managed and implemented by a multinational organization formed specifically for the purpose (effectively, a multinational waste management organization - WMO) or by a national organization in the host country (subject to agreements with user countries). A critical question is how decisions on siting are eventually made and how they achieve legal and political legitimacy within the countries concerned, especially the host country.

Clearly there are many issues that need to be discussed and resolved among participating governments at the outset of such a shared project. In essence, each government needs to decide at some stage whether they would be willing to participate in a multinational siting project where the end result, based on comparison of potential options between countries, might be a long-term project with the outcome not decided for many years. This is a substantially different scenario than a government deciding unilaterally to offer itself as a host country for an MNR, provided it has the appropriate conditions. There is a range of possible permutations of how and when to make decisions in both scenarios.

To address some of these issues, one possible route to multinational siting was suggested some years ago[46], based on a European case study carried out prior to the formation of the ERDO Working Group. The approach is based on the application of consensual staged and adaptive siting, with appropriate public engagement programs in each of the participating nations. A key aspect of the suggested approach is that it is driven by the interests of communities in hosting a repository. National governments must agree that acting as host is not forbidden and, ideally, would provide the framework for discussions to take place (perhaps facilitated by a multinational WMO formed by the partner countries) but they need not drive the process once this agreement has been reached. In the approach suggested, having established intergovernmental agreements to proceed with a shared siting program, each national government would need to take only a secondary role in the early stage of the siting process until concrete possibilities emerge and, of course, national governments will retain the ultimate right of approval. Effectively, the communities themselves take a much more proactive role in the international arena, with a range of benefits consequently accruing to them. The essence of the model approach is that it takes the burden of leadership of a highly sensitive project off national governments that may not wish to be in the vanguard of such a program. This, of course, is just one approach that might be considered – the more promising approach would be for the national governments of potential host countries to act as champions and proponents.

The alternative to the MNR sharing scenario discussed above, in which partners are involved in siting, is the use of a facility developed independently in a provider country. This might be developed specifically as an MNR from the outset (as was the proposal in South Australia) or be an ‘add-on’ service provided by a DGR initially developed only for national purposes. In the former case, while the developer country might carry out all the work itself, it is also possible that it might wish to identify, consult and possibly involve user countries at the time at which it is assessing siting and repository design options. In any case, it is likely that MNR users or regulators in user countries will have to be satisfied that the site chosen by the host country fulfills all necessary requirements.

5.5 Transport infrastructure framework

As an MNR user, Jordan would require the infrastructure to manage the export of SNF and RW. This would include segregated areas of port facilities and secure road or rail transport routes and systems. Jordan only has one port facility (Port of Aqaba), which could restrict

[46] Chapman, N. A. and McCombie, C. (2008). An Adaptive, Staged, Siting Strategy for a Multinational Repository. *Nuclear Engineering International*, **53**, 26-33.

waste transport unless a regional initiative for multinational disposal were to be established with one or more neighboring countries, possibly allowing the use of other Red Sea facilities. Integration of waste transport plans into the ambitious program of rail network development planned in Jordan could also be considered and might provide additional transport possibilities. Generally, waste transport to a host country by sea rather than by land across one or more neighboring countries would be expected to provide more robust flexibility and security and is likely to be preferred by potential users.

The National Strategy (described in Section 3) that is currently being drafted by the RWM team at JAEC presents the national infrastructure that will be required for present and future RW and SNF management activities, including SNF/HLW transportation. Current arrangements are that the EMRC issues instructions on nuclear security for nuclear facilities, nuclear materials and related activities which cover nuclear materials (including SNF) transport security requirements and conditions associated with the movement of nuclear material. The EMRC regulation on radioactive materials transport deals with the transport of radioactive materials and SNF/HLW from one storage location to another, or to a central storage location.

5.6 National nuclear competences

Jordan has existing competences relevant to a national RWM program or to involvement in an MNR program as part of a dual-track approach. These are located in various organizations and there are also plans to maintain and extend competences, as described below:

Nuclear laboratories and centers

Jordan utilizes radioactive materials through medical and industrial applications, research and training centers, and the operation of research reactors, accelerators, and nuclear laboratories. The JSA at the Jordan University of Science and Technology (JUST) is the first nuclear facility to be constructed in Jordan for the purposes of education, training and experimental research. It is mainly being utilized for Nuclear Reactor Physics Laboratory training for nuclear engineering students at JUST. The JRTR is a cornerstone for R&D and Human Resource Development (HRD) in the fields of nuclear science and technology in Jordan. It provides a basic training platform for nuclear engineering students, other nuclear scientists, engineers, and technicians on the fields of nuclear reactor operation and is used to produce radioisotopes to support nuclear applications in medicine, agriculture, and industry at national and regional level.

Jordan has drafted a national strategy for the front-end of the nuclear fuel cycle to secure the long-term fuel supply for its first NPP. The basic human resources required for implementing this strategy include:[47]

- Technical and commercial experts in the international fuel market.
- Experts in international laws, and conventions related to nuclear fuel.
- Expert consultant advice as required.

It is recognized that, for involvement in an MNR project, similar but more broadly based (than only fuel supply) skills would also be required, in particular in issues related to negotiating and financing major multinational projects.

The strategy outlines the approach to securing nuclear fuel while maintaining nuclear safety through strict adherence to international standards and quality assurance practices.

[47] IAEA, TECDOC-1513, Basic infrastructure for a nuclear power project. Vienna, 2006.

Jordanian Uranium Project

There are significant deposits of uranium ore in several parts of Jordan. Established in 2013, the Jordanian Uranium Mining Company (JUMCO) serves as the commercial arm of JAEC to develop the Central Jordan Uranium Project. JUMCO has produced yellow cake from a semi-continuous industrial system. It is also working to establish a pilot plant at Sewaqa. Uranium exploration continues in accordance with international guidelines. The uranium mining project allows development of technical expertise across scientific and engineering fields at the national level. This expertise will filter into the local industrial sector. JUMCO recruits qualified Jordanian geologists and engineers who utilize and implement international standards.

Back End Nuclear Fuel Cycle

The National Policy makes the Government of Jordan responsible for taking appropriate steps to ensure the availability of qualified staff for RW and SNF management, by recruitment of human resources and allocation of funds for training and qualification of personnel. [48] In a draft document (*National Strategy for Radioactive Waste and Spent Nuclear Fuel Management*), JAEC, among others, has envisaged adequacy of funds and availability of human resources for RWM.[49] A comprehensive syllabus for a training program on RWM was recently developed. JAEC has many employees who are licensed by the EMRC to work in the field of RWM at both RWM facilities: the CSF and the RTF. The number of RWM staff will be increased in the future once the Government decides to deploy an NPP in the country. The EMRC regulations on the SNF management state that the personnel of SNF management facilities shall be professionally qualified and licensed by EMRC. Selection, training and maintaining the qualification of the personnel shall ensure safe operation of nuclear facilities.[50]

However, as no national RW disposal facility exists in Jordan for any type of RW, hands-on RW disposal expertise is not currently available.

Education & Training

Jordan has a well-developed academic infrastructure, providing a strong foundation in disciplines required for nuclear applications. The safe operations of the nuclear facilities need and require implementing an HRD plan to identify the capabilities needed to support the Jordanian nuclear power program, assess the ability of the current market to provide those capabilities, and develop the required skills and abilities within the country in order to have the required skilled local workforce available when implementing the nuclear power program and to build the human capacity to support the radiation and nuclear industry in Jordan through a long-term national education and training program. This program includes formal education in universities and community colleges, facility-specific training provided by the vendor of the nuclear facilities, in addition to a national or international specific training on different topics.

JUST offers a five-year bachelor's degree in Nuclear Engineering; the department was founded in early 2007 and graduates approximately 25 students every year. JAEC assisted JUST in developing its capabilities and JAEC's training and education efforts include scholarship support for international education and training programs. JAEC is committed to its training and education efforts to create a local well qualified trained and knowledgeable workforce that can take over and train others in a way to sustain the process of capacity building of the country. JAEC is also requiring external consultants and contracting nuclear technology providers to provide training as part of their activities.

[48] JAEC, National Policy for Radioactive Waste and Spent Nuclear Fuel Management Rev. (1). Amman, 2015.

[49] JAEC, National Strategy for Radioactive Waste and Spent Nuclear Fuel Management. Amman, 2019.

[50] EMRC, Instruction on the Spent Nuclear Fuel Management. Amman, 2015.

When Jordan signs a contract with any provider of nuclear facilities or technology transfer, it emphasizes that a training component, local involvement and technology transfer are included from design, through construction, commissioning, operation and maintenance.

6 Economics of a Dual Track Approach

The potential cost savings in using an MNR option are one of the principal drivers in considering whether to adopt a dual track approach. Thus, it is important to outline the possible scale of these savings.

The first part of this Section deals with the costs associated with developing and operating a national DGR and comparison with the possible costs of being involved in and utilizing an MNR. Jordan is at the early, strategic level of considering whether to adopt a dual track policy, and only broad estimates are currently required of the basic costs and of the potential savings of participation in an MNR. The second part of the Section looks at the issue of financing arrangements for involvement in an MNR, which are also a key consideration in deciding whether to choose the dual track approach. Only later are more in-depth analyses of financing approaches, contracting methods and project structuring needed, and a more detailed introduction to some of these aspects is included as Appendix 3.

At the current early phase of Jordan's disposal considerations, it should be emphasized that the costs discussed below are for implementation of a repository project rather than for further study of the costs of keeping the MNR option open. The former costs will only become significant relatively far into the future (depending on how funds are set aside and when the NPP goes into operation) when Jordan starts implementation of a national DGR or joins an MNR project. The later costs for advancing the MNR concept in collaboration with like-minded partner countries (based on experience from such countries) are relatively modest and do not increase significantly the early costs of operating only a national DGR program.

6.1 Cost estimates for national DGR and MNR options

Many studies have estimated the costs of national DGRs; fewer have produced estimates for MNR options. This section discusses principally the costs of disposal of SNF, as this is the central issue for consideration with respect to the dual track approach and, should SNF direct disposal be the chosen route in Jordan, it will be the main back-end cost element to be managed.

The economic advantages of shared disposal arise because there are large fixed costs for a DGR that can be divided among participants. The implication is that, for a purely national DGR, these fixed costs are inevitable and make up a large fraction of the total costs when the eventual disposal inventory is small. Unit disposal cost estimates from national programs thus tend to reflect the size of their national inventory.

It is not essential in the current study to look at the details of national cost estimates and how they have been constructed, especially as they use different approaches and make different assumptions, but it is valuable to look at the overall outcomes and trends.

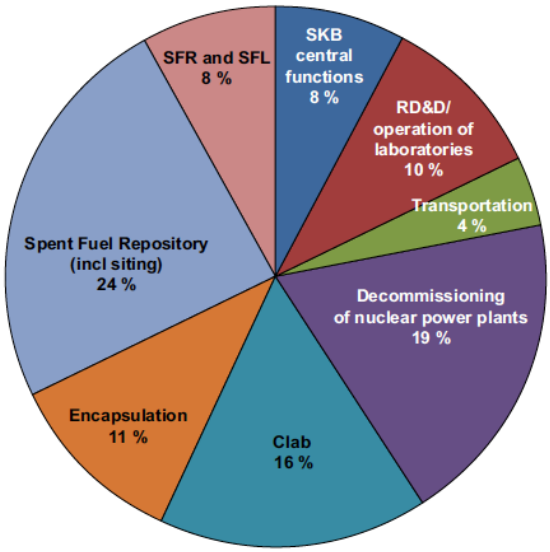
In the early, generic stages of a national or multinational program, it has been found useful to use analogous national programs as models of overall costs. Only later, when the Jordanian program becomes more developed, will it be necessary to perform more detailed cost modelling using Work Breakdown Structures (a bottom-up engineering approach) or parametric models.

A recent exercise to assemble analogue cost estimates and consider them within the framework of multinational disposal was carried out in the South Australian study[51] and a

[51] Cook, D., McCombie, C., Chapman, N., Sullivan, N., Zauner, R. and Johnson, T. (2016). Radioactive Waste Storage and Disposal facilities in South Australia. Quantitative Cost Analysis and Business Case. Report to the South Australian Nuclear Fuel Cycle Royal Commission. Jacobs-MCM report, 227 pages.

subsequent summary of current SNF disposal costs was reported in 2018[52]. From the latter, the Swedish program can be identified as a useful analogue of a relatively small national nuclear power program with a well-established costing framework. Figure 2 shows a breakdown of the 2019 Swedish estimates of total (past and future) national RWM program and decommissioning costs (equivalent to around 16 billion USD); it can be seen that SNF disposal in a DGR, including encapsulation for disposal, amounts to 35% of the total program costs (or approaching 50%, if management and RD&D costs for the DGR are included). The total costs of the DGR program for SNF disposal is thus about 8 billion USD, excluding SNF storage (the 'Clab' facility indicated in Figure 2) and transport costs. The additional costs of disposing of LILW in underground repositories (SFR and SFL in Figure 2) is about 8% of the total – a further billion USD.

Figure 2: Breakdown of 2019 estimates of total past and future national RWM program and decommissioning costs in Sweden (SKB[53]).



An example of the fixed to variable cost ratio that makes MNR so economically attractive, is provided by the 2013 cost estimates from the Yucca Mountain project in the USA[54]. The fixed cost component (which would be shared in an MNR project) amounted to over 40% of the total repository costs, even for this very large SNF inventory and even without accounting for the large precursor R&D costs. In 2008, the SAPIERR 2[55] project carried out an economic study of a hypothetical scenario where 14 European countries with relatively small nuclear power programs shared an MNR. It was estimated that, separately, each country would be spending between 1.3 and 3.7 billion EUR on a DGR (*n.b.* 2006 costs), totaling around 38 billion EUR, but together they would spend only about 10 billion EUR, resulting in a saving of over 25 billion EUR, shared among them.

Typical cost estimates for a DGR for SNF and/or reprocessed HLW range from a few billion USD for small inventory countries (as in the case of the EU countries considered in the SAPIERR project) up to tens of billions for larger programs. For example, a DGR in Belgium

[52] Chapman, N. A. (2018). The Costs of Geological Disposal. IFNEC-RNFSWG Workshop on Approaches to Financing a Multinational Repository – Challenges and Alternate Approaches. Paris, 11th December 2018

[53] SKB (2019). Plan 2019. Costs from and including 2021 for the radioactive residual products from nuclear power. Basis for fees and guarantees for the period 2021–2023. SKB Report TR-19-26, SKB Stockholm.

[54] Chapman (2018): op.cit.

[55] *Work Package 3: Economic Aspects of Regional Repositories* (SAPIERR II – Strategic Action Plan for Implementation of European Regional Repositories: Stage 2)

is estimated to cost 6 billion USD and a new DGR in Germany 9.4 billion USD[56], while the DGR for SNF in Finland is estimated to cost between about 6.2 and 7.4 billion USD over its c.100-year lifetime (undiscounted), up to and including closure[57]. These figures can be compared with projected costs of new, large conventional NPPs, which are typically of the order of 5 - 10 billion USD or more. For a DGR, however, the costs are spread over a much longer period than for a NPP, where the principal costs are concentrated over a few years. For example, the Finnish DGR costs will be spread over an operational lifetime of around 100 years.

A Jordanian national DGR would be analogous in scale to one of these smaller programs and thus likely to lie in the range of a few billion USD, noting again that, for a relatively small NP program, DGR costs are a significant fraction of overall RWM program costs.

The typical costs of disposal of SNF from LWRs have been used to derive a round-figure value of 1 million USD/tHM, although the range can be wide, depending on how the cost estimates are made and what they include[58]. For example, the 2019 figures presented above for Sweden (for disposal of about 11,300 tHM of SNF) indicate a figure of about 0.71 million USD/tHM. and those for Finland (for disposal of about 6500 tHM of SNF) indicate a figure of between about 0.95 and 1.14 million USD/tHM, while some of the largest national programs (such as the Yucca Mountain project in the USA) have produced estimates of well over 1 million USD/tHM. It might, however, be expected that, because the most advanced national DGR cost estimates mentioned cover substantial 'first-of-a-kind' concept development work and costly RD&D programs that ran over several decades, future DGR projects might be able to save costs in this area.

A round-figure disposal cost of 1 million USD/tHM should be viewed in the context of the much greater revenue that is generated by the electricity produced by the fuel. Electricity prices in Jordan are currently 0.10 USD/kWh for households and 0.12 USD/kWh for business; the global averages for these prices are respectively 0.14 and 0.125 USD/kWh. Typical nuclear fuel at 50 GWd/tHM (thermal) burn up with 30% efficiency produces around 360 million kWh/tHM of electricity. At an average price of 0.11 USD/kWh, this would generate a revenue of around 40 million USD, making the disposal costs only about 2.5% of the revenue generated.

Based on this round-figure value of 1 million USD/tHM, a rough estimate of disposal costs can be made for at least part of the Jordanian SNF inventory. For example, three of the four reactor mix scenarios described in Section 5.2 generate half the total power using conventional large PWRs, which are estimated to discharge about 2400 tHM SNF over a 60-year lifetime. This results in an estimated disposal cost of around 2.4 billion USD for the SNF from half the power program.

Unfortunately, there are no comparable cost estimates for disposal of SMR fuel assemblies – the other half of the power generation in the Jordanian scenarios. As noted in Section 5.2, HTGRs generate large volumes of SNF assemblies and the packaging for disposal and consequent costs have not been optimized in any detail. However, the total mass (tHM) of SMR fuel discharged can be much smaller than for the large PWR component of the program. If disposal costs were to be similar to conventional LWR fuel, then the Jordanian DGR program could cost between about 3 to 5 billion USD at current monetary values, although it is emphasized that this is a very rough estimate, given the uncertainties outlined above.

[56] European Commission (2019): Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects: {COM(2019) 632 final} - {SWD(2019) 435 final}.

[57] Mika Pohjonen: IFNEC workshop on approaches to financing a multinational repository, Paris, December 2018. Available at: https://www.ifnec.org/ifnec/upload/docs/application/pdf/2019-10/74820

[58] Chapman (2018) op.cit.

Largely based on the results of the SAPIERR study, it was suggested[59] that for a small disposal program, sharing in a multi-partner MNR project could save between 30 – 50% of the stand-alone cost of a national DGR. According to its current planning, Jordan is likely to be at the larger inventory end of these "small disposal programs" and thus, on this basis, might save in the order of 30%: around 1 to 2 billion USD. However, the savings depend heavily on the number of participating countries (in SAPIERR, 14 countries – some with very small SNF inventories – were assumed to share), so this figure should be treated with caution.

Slovenia is one of the few countries that have compared the costs of using a commercial service MNR concept with those of developing and using a shared multi-partner MNR. A commercial model for pricing SNF disposal services that can be used for such comparisons was developed by the South Australia Nuclear Fuel Cycle Royal Commission project[60]. A baseline 'willingness to pay' figure of 1.5 million USD/tHM was derived by the study. Taking account of the costs that a user would bear themselves in preparing and delivering the SNF to Australia for disposal, this was reduced slightly to produce a baseline 'price to charge' for disposal of 1.35 million USD/tHM. For Slovenia, the cooperative option, estimated to cost around 0.66 million USD/tHM for five partners countries, could clearly be more favorable than using a full commercial service provider.

If a commercial disposal service in an MNR were to be offered to Jordan (e.g., as was being considered by South Australia), then the savings would not be expected to be as large as in a partnering project. Indeed, it might be that there would be no major savings if the provider added a large profit margin to actual disposal costs. In this case, the benefits would largely be those of early availability of a disposal option, without the necessity of a potentially controversial public siting debate. There might also be some savings in terms of being able to scale-down the national program if a viable service were to emerge at an early stage of the new Jordanian power program.

While all of these estimates are approximations, they provide some indication of the cost considerations underlying any decision on seeking a dual track partnering solution.

Several other general points emerge from past international studies of the costs of DGR and MNR implementation:

- Repository cost can be impacted by the type of host rock and geological environment, but this does not result in widely varying cost estimates. MNR cost will vary, depending on the country in which the project is located: as a function of geological, infrastructure, labor cost and productivity factors, and regulatory, licensing and permitting arrangements.
- Transportation costs should not be determinative in the viability of using an MNR. Most of the cost of transport is involved in mobilization, rather than the movement itself, so moving SNF to a regional repository does not cost significantly more than transports to national facilities[61].
- Involvement in a dual track approach should not cost significantly more than pursuing a purely national DGR: in the early stages, both are largely strategic evaluations and the only point at which additional funds might be required is if simultaneous national DGR and shared MNR site investigations are being carried out (and the latter would, in any case, be shared).

[59] Chapman (2028) op.cit.

[60] Jacobs-MCM report to Australian Fuel Cycle Royal Commission (April 2016). Radioactive Waste Storage and Disposal Facilities in South Australia. Quantitative Cost Analysis and Business Case. Available at: http://nuclearrc.sa.gov.au/app/uploads/2016/03/Jacobs-MCM.pdf

[61] *Work Package 3: Economic Aspects of Regional Repositories* (SAPIERR II – Strategic Action Plan for Implementation of European Regional Repositories: Stage 2)

- The cost of capital (financing) will have a significant impact on the economic assessment of the MNR under consideration.
- Benefits packages for participating local communities should be considered (and for the host country, in the case of an MNR).
- Development costs will be significant, and there will be a long lead time between when development and construction costs are incurred and when waste can be accepted for disposal. For an MNR, this mismatch of costs and usage creates particular financing challenges.
- Significant savings in an MNR come from pooled research and development, and administration, highlighting the particular significance of development "soft" costs (as compared to the direct costs of construction and operation).
- Significant savings would be achieved by co-locating a shared encapsulation plant with the repository, to avoid multiple transports.
- Cooling time before SNF can easily be disposed of in a geological repository is between 30-50 years, which means that participants cannot avoid interim fuel storage options.
- Amalgamation of national nuclear waste management funds could provide significant financing support to the project, particularly if current funds are pooled and invested. With the pooling of funds, any national contributions that were ultimately unused could be returned to the participants over time, provided adequate completion support funding is assigned. Pooled funds could also serve as collateral against loans, if debt financing is favorable.

6.2 Financing Jordanian involvement in an MNR

The major costs associated with geological disposal, whether in a national DGR or an MNR, will arise some decades after NPPs start to operate. However, ensuring that any disposal program, national or MNR, can be funded through to its completion is essential. This is recognized in the Joint Convention, which states that *"Each Contracting Party shall take the appropriate steps to ensure that…adequate financial resources are available to support the safety of facilities for spent fuel and radioactive waste management during their operating lifetime and for decommissioning"*. The most common funding sources are the waste generators and the State. Selecting the most suitable funding mechanism depends on many factors, such as the national nuclear policy and strategy, the disposal option, the legislative and regulatory background and the institutional framework.

In the following discussion it is assumed that a dual track program eventually offers Jordan the opportunity to participate in a shared MNR project (rather than being simply a user of a commercial MNR). In this regard, there is little difference between establishing and ensuring funding mechanisms for an MNR or a purely national DGR and, as noted in the previous section, the costs to be financed will not be significantly different. Appendix 3 discusses financing arrangements and mechanisms for funding RWM that will need to be settled in more detail only when specific projects are being developed. Nevertheless, when deciding whether or not to follow a dual track approach, it is worthwhile to consider some important financial issues that will be faced later:

- Will participants in an MNR take *pro rata* ownership interests in the project, with the corresponding obligation to support the project with development funds? If so, the sharing arrangements and management of funds (e.g., as a shared trust fund) are key issues for ensuring overall financial provision at each stage of MNR development.

- An MNR consortium that includes SNF/HLW from existing operating nuclear fleets might access already existing funds, which could significantly reduce financing costs and improve overall project economics. For the right combination of core countries, the pooling of such funds could eliminate the need for external financing. However, for a purely regional initiative among MENA countries, this situation would not currently arise.
- The ability to source existing funds could enhance returns to those members contributing such funds, as it could enable further scaling of the project to support newcomer countries. Such second-stage participants might benefit from a more favorable fee structure, as the reduced impact of interest during construction should be reflected in the fees assessed.
- The ability to have up-front contributions from partners, and thus minimize the need for debt, serves to reduce the cost of financing, principally in respect of the accumulation of interest during construction, noting the long construction periods that are envisioned for a DGR.
- Any financing structure will need to have a creditworthy completion support facility. This could come from the host government (under sole ownership structure) or collectively from all co-owners (under a multi-owner model), especially if existing funds are pooled.
- Any debt finance could be sourced from export credit agencies (ECA), based on the relative national contributions that support the facility, plus the ability to finance local content under OECD Rules.[62]. The multiphase nature of the project implies staged financing requirements. After initial project development, backed by creditworthy partners with guaranteed revenue streams[63], it should be possible to interest commercial banks in further financing, especially if existing funds set aside for DGRs are pooled. To the extent that external debt is needed, consideration could be given to linking procurement decisions with assessments of the availability of accompanying ECA financing, particularly direct loans.
- An open question for project developers will be whether all customers should pay the same fees. Under an equitable treatment analysis, it is easiest and most logical to assume that the fees are the same for all customers of the facility. Nevertheless, if the goal of the facility is to maximize usage in order to collect revenue from as many sources as the facility's capacity will allow, there is an argument to be made that pricing should adjust for national situations. Also, a large customer of the facility, or an earlier customer of the facility, might be offered discounts by virtue of volume or of earlier collection of revenues from usage. One model is that initial investment costs are shared roughly equally, while operating costs are scaled to the inventories delivered.
- As with any DGR, significant expenditures will be needed prior to a Final Investment Decision (FID), as well as before Financial Close on the main financing. These include regulatory development and alignment, stakeholder engagement, site investigations, and the inherent complexities associated with bringing together sovereign participants. Such pre-FID expenditures are the highest risk[64] undertakings in the project's lifecycle, but in an MNR project they would be shared among participants.
- Ultimately, a decision must be made as to whether an MNR is developed as a "for profit" endeavor for the founding participants. As investors, they would expect to be

[62] The Arrangement on Officially Supported Export Credits; see: https://www.oecd.org/trade/topics/export-credits/arrangement-and-sector-understandings/.

[63] From the fees charged to users of the MNR, based on binding contractual obligations.

[64] An initial outline of project risks associated with an MNR project is presented in Appendix 20.

using the facility at cost. Non-participant users would be customers and would expect to pay a premium that contributes to a profit for the project. Even under an “at cost” approach, the host country will need to capture tangible benefits in order to justify being the host, which relate more to stakeholder incentives (which would be factored into the financial model) and economic impact. If a profit aspect is a desired element in the project’s structuring, then pricing for late-comer users (i.e., those not participating in an initial shared venture) will need to consider facility size, utilization, and a price that provides the right incentive level for countries to participate (e.g., pricing could be at the same level as what a participant would otherwise see in a national DGR).

6.3 Decisive cost and financing factors in a dual track decision

With a focus only on financing and project economics, Jordan, which would fall into the “user” category and not the “host” category, should evaluate the implications of an MNR in the dual track approach in terms of:

- Cost of participation and spending profile.
- Type of participation (participant, co-owner, user, etc.).
- Timing of commitment of funds.
- Potential requirement for an intergovernmental agreement to support Jordan’s commitment.
- Overall financial model for the project.

7 Opportunities for International Cooperation

The dual track approach is an advanced and ambitious form of international cooperation in the field of nuclear power development.

International cooperation has played an important role in RWM, from the earliest days. In fact, the entire nuclear fuel cycle is today highly international, with a relatively small number of countries providing uranium, enrichment services, fuel fabrication, reprocessing, and other services to a wide range of customer countries. International cooperation has been essential in building up and maintaining competence. This cooperation entails direct cooperation with sister organizations and using experts trained in other programs, as well as participation in the work of international organizations such as the IAEA, IFNEC and the OECD/NEA.

As proper management of the back end of the fuel cycle – in particular disposal of SNF and HLW – became increasingly acknowledged to be a difficult issue, cooperation was expanded. Although the responsibility for proper waste management rests with each country that generates it, there are clear opportunities for cooperation, including in disposal, among countries. The IAEA Joint Convention explicitly supports international cooperation and acknowledges that shared facilities, including MNRs, can be beneficial.

Many scientific and technical concepts and also challenges are common to different countries, as are societal attitudes and concerns. However, problems will not always be weighted equally in different countries, challenges will not be assigned identical priorities, and solutions might not be directly transferable. Nevertheless, the international character of RWM must be recognized and taken advantage of in developing national concepts and strategies. Regional cooperation can be especially effective in encouraging not only information exchanges but also providing a framework for direct collaboration on specific projects. Appendix 2.1 outlines some of the major international co-operation projects in the field of RWM that have taken place over the past decades.

7.1 Jordanian participation in multinational initiatives

Jordan, as a Member State in the IAEA and through technical cooperation has hosted specialized training courses and workshops, fellowship programs, on-the-job training, scientific visits, national consultant visits and expert missions to qualify and train JAEC's staff in all topics related to nuclear energy. Jordan has also received support and assistance in developing and strengthening national capabilities and improving practices in RW and SNF management through technical projects funded by the Europe Union.

Jordan is a member of several international networks and has signed Nuclear Cooperation Agreements with many countries to provide support in nuclear project management, research reactor utilization, nuclear power systems, reactor safety, nuclear waste management and nuclear fuel cycle management. As one of the key goals related to improvement of the safety of RW and SNF management, JAEC intends to establish strong cooperation with international community in the field of RW and SNF management.

This strong background experience and contact/project network places Jordan in a good position to initiate a dual track approach to RWM and to explore and participate in potential MNR developments. Although there are no geographical limits on location of cooperation partners, the most obvious opportunities could be participation in regional multinational projects, as discussed below.

7.2 Background to dual track in the Arab region

Nuclear power in the Middle East has appeared poised for dramatic growth for more than a decade. Several Arab countries are pursuing or have expressed an interest in a nuclear power

program. An outline or regional fuel cycle activities is provided in Appendix 1.7, and Table 3 summarizes the current NPP situation, along with national positions on RW and SNF import and export.

Table 3: National Policies in selected Arab Region countries on HLW/SNF disposal and export and import regulations. Current affiliations of relevant international organizations or groupings are also shown.

Country	Power Reactors (PR)[65], Research Reactors (RR)[66]	National Disposal Policy for HLW/SNF	Export permitted	Import for disposal	Affiliations**
Jordan	No PR yet 1 RR	Considering dual track: priority not defined yet	Yes (under certain conditions)	No	IAEA member AAEA member IFNEC member ANNuR member Arab League member
Egypt	4 PR* 2 RR	NA	Yes (under certain conditions)	No	IAEA member AAEA member IFNEC observer ANNuR member Arab League member
Saudi Arabia	No PR yet 1 RR	NA	Yes (under certain conditions)	No	IAEA member AAEA member IFNEC observer ANNuR member GCC member Arab League member
UAE	4 PR No RR.	Dual track: priority on national solution	Yes (under certain conditions)	No	IAEA member IFNEC member ANNuR member GCC member Arab League member

**planned or under construction*

***AAEA: Arab Atomic Energy Agency; ANNuR: Arab Network of Nuclear Regulators; GCC: Gulf Cooperation Council*

In 2007, the UAE decided to build a 4-unit NPP, and the Barakah nuclear power plant started producing electricity in August 2020[67]. This is the first NPP in the Arab world. The UAE has declared itself open to multinational cooperation in the field of SNF management and disposal.

In 2015, Egypt signed an intergovernmental agreement with Russia to build and operate four VVER-1200 reactors, and in April 2019, the Nuclear Power Plant Authority (NPPA) received site approval permit for the El Dabaa site from the Egyptian Nuclear Regulation and Radiological Authority (ENRRA)[68]. In July 2021, NPPA submitted licensing documentation to ENRRA to receive a permit for construction of the first two units at the El Dabaa nuclear

[65] https://pris.iaea.org/PRIS/home.aspx, included power reactors under construction.

[66] https://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?filter=0

[67] World Nuclear Association (November 2020) Nuclear Power in the United Arab Emirates, Available at: https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx.

[68] World Nuclear Association (January 2021) Nuclear Power in Egypt, Available at: https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/egypt.aspx.

station[69]. Egypt has participated in working meetings arranged by the IAEA, the AAEA and the Arius Association on the topic of MNRs.

Saudi Arabia is interested in building two large reactors and two small modular reactors, although no financing, contractual or technical model is envisioned yet. The Kingdom is also carrying out feasibility studies with Korea's KAERI for two or more 100 MWe SMART reactors, for desalination. Saudi representatives in a coordinating group of the GCC have received briefings on the potential benefits of MNR cooperation.

Other countries in the broad region that have expressed an interest in nuclear power include Algeria, Sudan and Tunisia, but none of these has taken concrete steps towards implementation. However, in these and many other countries in the region, there are small inventories of radioactive wastes from medicine, research and industry that need to be disposed of in a DGR. Ten years ago, representatives of these and other MENA countries took part in regional workshops discussing regional cooperation on RWM issues.

The storage and long-term disposal of SNF and RW is recognized to be a potential barrier to large-scale nuclear growth in the Middle East, so disposal projects that are open to and managed by a regional grouping of states would clearly be beneficial to all.

7.3 First steps towards Arab regional co-operation

While there are various ways in which Jordan might make use of an MNR if one becomes available internationally, an obvious objective of a dual track policy is the possibility of sharing in an Arab region MNR. As has been demonstrated by the European ERDO Association[70], this could be regarded as a long-term ambition, with many steps that serve progressively to develop and enhance co-operation, while, at the same time, facilitating an eventual shared disposal solution. The early steps could include:

- Collaboration on predisposal activities: standardized waste characterization methods and recording, common inventory structures, storage planning, shared mobile facilities, etc.
- Establishing a regional 'club' of waste management organizations and an equivalent 'regulators club', promoting knowledge transfer and information exchange.
- Cooperation in disposal planning: DGR generic design development and comparisons, common waste acceptance criteria for generic disposal facilities, definition of common disposability assessments, generic RWM costing, shared DGR siting guidelines and characterization techniques for arid regions, RD&D planning, etc.
- Exploration of all the implications of and possible MNR models for a regional dual track approach adoption and synergies.

To begin, Jordan could initiate a "contact group" with national representatives from interested countries to investigate which of the above steps might be attractive. The four nuclear power aspirants in the Middle East (Jordan, Egypt, Saudi Arabia and the UAE), although they are at different levels of commitment and progress towards establishing their civilian nuclear power programs, could constitute a core group.

Regional cooperation could also be structured more broadly around fuel cycle cooperation. Most of these countries have expressed interest in one or more aspects of the fuel cycle and, considering the sensitivity of some of these facilities, a regional approach to the back end could be a good beginning.

[69]https://www.nucnet.org/news/licensing-documentation-submitted-to-regulator-for-el-dabaa-units-1-and-2-7-5-2021

[70] https://www.covra.nl/app/uploads/2021/01/ERDO_brochure.pdf

JAEC could approach the atomic energy commissions of UAE, Saudi Arabia and Egypt, suggesting the nomination of an expert group that would develop the agenda for the first meeting of the countries and serve as the convening authority. The expert group could develop a policy paper to establish a ‘Regional Organization for Fuel Cycle’ with clear objectives.

It is expected that multiple meetings would be needed, with the appropriate level of preparation in advance. These meetings would be working meetings with a sufficiently high level of representatives from each country, such that meaningful discussions could be conducted. Each meeting would be preceded and followed with intervening work, such that the meetings can make clear and significant progress. The work leading up to the formation of the European ERDO Association could form a useful model and contacts with this group would be beneficial.

8 An Outline Program to Develop a Dual Track Approach

The key requirement to demonstrate the credibility of a dual track RWM program is that there is a credible route to achieve the MNR alternative to a national DGR. Waiting for an MNR solution to emerge somewhere in the world is not sufficient for credibility. Thus, in choosing dual track, Jordan must take active steps to promote activities that could lead to an MNR. As was discussed in the previous Section, the most promising scenario would likely be a regional shared solution.

The objective of this Section is to identify the practical steps that Jordan will have to take if it elects to adopt a dual track policy and to develop an initial program of activities demonstrating its commitment to this policy, with a focus on the potential for a regional solution. Guidance can be obtained from examining how this has been done in other countries: e.g., Slovenia or the Netherlands, countries with small nuclear programs, which have been particularly structured in their approach to dual track and details of the steps they have taken are provided as case studies in Appendix 2.3.

8.1 Practical steps to advance a regional MNR solution

Some of the practical steps that could be taken by countries with a dual track policy were identified in a 2016 report published by the IFNEC forum.[71] This section is developed further from the IFNEC report, with a focus on activities to promote a regional solution. It looks first at the steps that Jordan and other potential participant countries that have, or are considering, a dual track policy might take individually, and then at actions that these countries could take together.

8.1.1 Individual actions for Jordan and potential participant countries

For Jordan and other countries exploring the potential for regional MNR solutions, important steps that each could take individually are:

- Make a dual track strategy part of official national policy, if this is not already the case.
- Review the national laws, international agreements, or commercial contracts, related to the import or export of SNF and HLW: for example, amendments on import regulations would be necessary for many MENA countries to be an MNR host.
- Review their national ownership, liability, and insurance requirements for the storage, transport, and disposal of SNF and HLW.
- To meet their international commitments and to ensure final disposal, countries with a dual track policy should maintain an active parallel national DGR program operated in a synergetic and complementary manner with the work on MNR shared solutions.
- In order to advance their knowledge and also to signal transparently the dual track nature of their policy, potential participant countries should participate in ongoing initiatives, studies and events on multinational options.
- Assess their own expectations for the minimum technical requirements and host country conditions to be met by an MNR (e.g., types of waste to be accepted; when the MNR must be able to accept wastes) in order to assist in scoping projects as they emerge.

[71] Practical Considerations to Begin Resolving the Final Spent Fuel Disposal Pathway for Countries with Small Nuclear Programs

https://www.ifnec.org/ifnec/jcms/g_10234/2016-ifnec-practical-considerations-to-begin-resolving-the-final-spent-fuel-disposal-pathway-for-countries-with-small-nuclear-programs?details=true

- Develop estimates of life-cycle costs for a national DGR in order to quantify the avoided costs that would be associated with participation in an MNR. It is also suggested in the following Section that this might more usefully be carried out as a joint exercise with other potential participant countries.
- Ensure that segregated funds are being established and accumulated to cover the future costs of disposal and clarify whether these could also be used to pay for MNR disposal services outside the country if these were to become available.
- Countries potentially interested in hosting an MNR should explore the financial and societal impacts on their country. The first step might be to analyze independently the business case produced and published by the Royal Commission of South Australia.

8.1.2 Cooperative activities

When a group of countries interested in advancing a regional MNR concept has been established and possible MNR solutions are being explored and developed, cooperative activities will become increasingly important. These will include:

- Discussions on RW and SNF ownership, takeover and liability options, and their implications for both MNR user countries and potential host countries.
- Evaluation of the life cycle costs for an MNR so that these can be compared to costs of national disposal in the potential user countries. These could be based on generic DGR concepts that would be applicable to the inventories of all participant countries.
- Assess the characteristics of each national inventory with respect to disposability in the generic DGR concepts being explored as possible MNR solutions and thus to establish boundary conditions for a facility.
- Discuss options for financing an MNR by the partner/user countries.
- Discuss the contracting options between a host (service provider) and user countries.
- Consider whether to establish a new multinational WMO to manage an MNR program and, if so, how to structure, manage and finance it.
- Start sharing RD&D and predisposal activities, equipment and capabilities.
- Undertake joint data collection studies with respect to SNF and RW characterization, packaging, transport route options, etc., to facilitate sharing an MNR.
- Assess how national regulatory approaches and standards might be applied to and possibly harmonized for an MNR.

Countries such as Jordan that are currently prevented by policy from offering themselves as a host must, nevertheless, address issues related to the potential host country. For example:

- they must be convinced that any proposed MNR will be state-of-the-art with respect to international standards and likely to meet their own regulatory standards and requirements;
- they should be prepared to declare their interest publicly at an early stage of a potential MNR project, so that the credibility of the project is enhanced in the potential host country and in the international community.

8.2 Evolution of Jordan’s disposal policy towards dual track

If dual track is incorporated into national policy in Jordan, then further information will be required on certain topics and decisions will be required on a number of questions. The responses to these questions can be integrated into a strategic decision-making framework

and it is recommended that a program of work be established to work on these matters. The most critical of the information requirements and questions include the following:

- What are Jordan's expected waste streams, forms and volumes (SNF, operating wastes, decommissioning wastes, etc.) over the first 60 years of its nuclear program and which of these should be routed to geological disposal? A start has been made on this, as described in Section 5 and Appendix 1.5.
- Is SNF to be regarded an asset or a liability – now and in the future? As noted previously, this question does not need to be answered urgently, but the alternative scenarios need to be considered in planning.
- What back-end options (take-back, reprocessing, etc.), if any, might be sought from the country of origin of the nuclear technology that Jordan selects as its development / technology partner?
- Are there specific challenges in developing a DGR in Jordan that could affect the feasibility of implementation of national disposal (siting, achieving public acceptance, financing, technical capacity and capability, etc.)?
- What are the estimated costs of developing a national DGR and how do these compare with selected possible model MNR costs?
- What are the current or proposed funding and financing arrangements/mechanisms for RWM in Jordan and how are these managed?
- What are the resource implications and skill sets for running a dual track program that includes consideration of both national and multinational approaches? As discussed previously, these are not expected to be significantly different, but require consideration.
- Do the economic, political and strategic benefits of participation in cooperative efforts to develop an MNR clearly outweigh any potential drawbacks that can be identified?

These questions should be addressed initially at a high-level, when considering adopting the dual track approach. It is suggested that the information gathered could be used to carry out a multi-attribute decision analysis exercise to weigh the advantages and disadvantages of dual track, which can then be used to inform decision making.

Several considerations related to the dual track approach have been addressed in this study, but if and when a practical project emerges and moves towards an implementation phase, much more detailed issues related to partner choice, host country choice, project risks, etc. will have to be examined. The results of a preliminary examination of some of these are already described in Appendix 3. However, a detailed analysis goes beyond the current phase of the present study, which is focused on the Jordanian decision to implement a dual track policy and strategy and not at present a decision to commit to a specific MNR implementation project.

8.3 Is a dual track policy appropriate for Jordan?

In the course of this study, it was suggested that a SWOT (strengths, weaknesses, opportunities and threats) analysis of pursuing a dual track approach would be informative. Participants from JAEC carried out a preliminary SWOT exercise towards the end of the project and the findings, together with additional inputs from the project participants, are shown in the matrix below. For the purposes of this exercise the following definitions were used:

- **Strengths:** factors whereby a dual track approach would strengthen the Jordanian RWM program.

- **Weaknesses:** factors that would make a dual track approach difficult to sustain or which could mean that the dual track approach would weaken the Jordanian RWM program.
- **Opportunities:** areas where the dual track approach would offer opportunities that could be beneficial to the Jordanian RWM program.
- **Threats:** factors that could threaten the feasibility or sustainability of a dual track approach.

Strengths	***Weaknesses***
• Requires no urgent commitment to choose national or multinational paths • Reduces sensitivity to delays or failure of national DGR approach • No significant additional funding required (limited immediate initial funds needed to pursue multinational cooperation) • Possibility to benefit from financial, environmental, political, legal, technical, security, safety and non-proliferation advantages of shared MNRs • Possibility to benefit from large economies of scale of MNR projects by sharing the high fixed costs of DGR projects • Larger immediate funds available for building robust engineering systems and human resources development compared with delayed funds that will accumulate after few years of commissioning in national approach • Wider technical expertise in group of dual track nations can be made available • Wider choice of geological environment for siting and wider options for DGR concepts • Can positively influence public approval of the DGR concept and the whole nuclear program	• Long-term political and governmental support required, including integration in energy strategy • Jordan is not currently able to offer itself as an MNR host, so could have a weaker position in a group of dual track countries • Dual track requires gaps in national legal RW management framework to be filled if MNR options are to be followed • Import/export legislation in potential MENA partner countries will need to change for a regional MNR to become feasible • Less local economic benefits and growth in Jordan if an MNR is used, except for the host country • Time schedule for disposal in the dual track approach is not entirely in Jordan's control • Requires a wider approach to public engagement in multiple partner countries • Possible liability issues and drawbacks in disposing RW and SNF if MNR project is canceled or stalled at a certain time
Opportunities	***Threats***
• Regional/global political benefits, especially if Jordan takes a leadership role in exploring regional dual track solutions (such benefits could be in the nuclear sector but could also accrue more broadly in other areas) • Strong cooperation with interested dual track countries: harmonizing legal, licensing, monitoring and quality control systems in partner countries leads to higher confidence • Collaboration in dual track approaches enhances regional security and safeguards • Increases the available technical capacities for all countries working together on MNR solutions • Potential to offer decreasing electricity prices due to reduction in disposal costs • Potential to achieve disposal sooner as compared to national DGR	• None of the countries involved is willing to consider hosting • Changes in political positions of potential partner countries with respect to shared solutions • Instability of geopolitical situation in parts of the MENA region • Not enough partner countries are willing to join an MNR project and consequently potential costs savings can be smaller • Defaults in funding • Cost and schedule delays

The outcome of the SWOT exercise is dominantly positive towards adoption of a dual track policy. The issues identified combine objective factors and more subjective evaluations. Consequently, a key recommendation with respect to future work is that it would be beneficial to repeat this SWOT analysis both with a wider group of stakeholders in Jordan, to capture a

broader range of opinions, and with the commission charged with making a decision on dual track policy, once the members have had the opportunity to consider this report.

8.4 The next steps towards a Jordanian dual track policy

The overall trend of this report has been to highlight the positive and beneficial aspects of embarking on a dual track policy – a trend that is supported by the outcome of the preliminary SWOT analysis. These considerations outweigh any potential disadvantages, although the national and regional specifics need to be assessed and explored in more detail. Various methods are available to do this, including more detailed SWOT evaluation and the use of multi-attribute decision analyses.

If the dual track route is followed, then a number of specific actions should be taken or considered by JAEC and other stakeholders. These have been developed from the previous discussion and are outlined in Section 9.3, together with suggestions for scoping studies (Section 9.4) that can further clarify key open questions in the proposed Jordanian dual track program.

9 Conclusions and Recommendations

The final section of the report presents the general conclusions of the study, overall recommendations for actions that could be taken by Jordan to respond to the conclusions, specific recommendations on the steps to be taken to initiate dual track and suggestions for further scoping work to explore some of the matters that have arisen in this project.

9.1 General conclusions

1. Jordan is developing a national program that ensures safe disposal of all categories of RW. However, disposal of all of the waste does not necessarily have to take place in Jordan, provided alternative MNR options become available and can be shown to meet international standards of safety, security and safeguards that are at least equivalent to those that would be accepted for disposal in Jordan.
2. Typically, countries that are exploring the possibility of exporting wastes are only considering sending their higher activity categories to an MNR, whilst using national facilities for the disposal of lower activity wastes. Jordan would thus be expected to develop a national disposal facility for disposal of NPP operating LLW (and LLW or ILW-SL from other sources).
3. The prudent approach to disposal planning is for Jordan to initiate a dual track program in which national competencies are built up in parallel with cooperation with potential MNR partners. This requires there to be a credible and active national program that could lead to a national DGR in a timely fashion, if that route is eventually selected.
4. When the dual track policy is implemented, Jordan should promote, monitor, develop and compare possible multinational disposal options with the national DGR project. Activities performed are complementary for both tracks, and Jordan can change track at any time if required and accelerate the national DGR project when necessary.
5. There is no urgency to decide which path of dual track to go down – national DGR or MNR – indeed it is not possible at this time for Jordan to make such decisions, as there are no MNR solutions available at present. It is recognized by those countries with a dual track approach that, as with their own national DGR programs, it will take decades for either option to become an operational reality. Consequently, these countries anticipate that their dual track approaches will remain open for many years and it will be a future generation of decision-makers that decides on the optimum route to take.
6. For either path of dual track, it takes many years to engage with stakeholders, assess opinions and possibilities, initiate and foster partnerships, and identify and explore possible solutions. These preliminary stages do not require a significant extension of resources, either in personnel or funding. Thus, while a dual track approach does not require any early commitment to one route or another, it does require energetic pursuit of both national DGR and MNR options from the outset.
7. Both a credible national program and active involvement in MNR initiatives require Jordan to expand its resources and skills, with competent organizations, skill sets and legal structures charged with the responsibilities of implementing, regulating and funding the program.
8. The time schedule for disposal in the dual track approach is not entirely in the control of each national program. Scheduling objectives thus require careful management within Jordan's policy development. It would not be advisable to delay progress with evaluating national DGR options because progress on possible MNR solutions is not assured.

9. Some countries participating in a shared MNR project might be willing to act as hosts for a repository, while others, like Jordan, are not. It is important for there to be a clear and frank discussion of national positions when entering MNR partnerships. However, it is unlikely and unnecessary that each partner irrevocably defines its own position at the outset. For example, it may take several years for a country to establish the technical feasibility of having its own national DGR or of acting as an MNR host. In addition, national political drivers, requirements and opinions are likely to change over the decades of a dual track program. For a dual track approach to be credible, there have to be sufficient indications within a reasonable timescale that any partnering project could actually achieve an MNR in one or more of the countries involved, and there eventually needs to be a project development plan so that all parties involved can understand roles and responsibilities clearly.
10. There are clear and significant economic benefits to Jordan in using an MNR; these are among the principal drivers that make the dual track approach attractive. These benefits would accrue from the sharing of fixed costs among several users where there are significant economies of scale to be had. For example, parallel studies for an MNR shared by several European countries suggested savings of 30% or more (depending on inventory) on the cost of disposing of their SNF and/or HLW inventories.
11. Jordan has some current legal/policy constraints on the transboundary movement of SNF and RW that would need to be addressed to make use of an MNR solution in a partner country.
12. Transfer of SNF and RW to an MNR has implications for waste transport, ownership and liabilities that would need to be resolved during the course of a partnering project.

9.2 Overall recommendations

1. Jordan should update its policy and strategy for the long-term management of all its RW from all sources (medicine, industry, research, nuclear power operations, research reactor, facility decommissioning, etc.).
2. This update should include a dual track policy for geological disposal of its higher activity wastes (SNF, HLW ILW).
3. Regardless of whether Jordan follows the above recommendation to adopt a dual track policy, it should initiate a credible and active national program that could lead to a national DGR in a timely fashion.
4. The development of regional and international co-operation should not detract from Jordan's national responsibility for management of its RW and SNF, nor from the development of domestic options for waste management facilities.
5. The national RWM strategy should have clear objectives but should maintain flexibility to facilitate both the continued use of radiation technologies and the planning of the nuclear energy program. Associated target dates will depend upon the proposed schedules for implementation of nuclear power and should be revised in step with this planning. Some choices, such as whether to reprocess SNF or use direct disposal, siting options for disposal facilities, or full commitment to an MNR, do not need to be made definitively for many years, but should be recognized/identified, so as to enable their implementation when required.
6. Jordan should begin to explore all possibilities for involvement in MNR projects, with an emphasis on exploring and possibly promoting the potential for regional partnerships with neighboring countries. Jordan might wish to consider taking the lead in setting up a working group, such as an Arab Regional Forum, similar to the ERDO, with Jordan represented at government level. This Forum could explore a range of

RWM topics, such as regional storage, pre-disposal activities, sharing of mobile waste characterization or conditioning/packaging equipment, knowledge transfer, possibly also extending to broader nuclear power synergies, stability of production, grid maintenance and synchronization, etc. Its eventual aim would be to establish an Arab Regional Waste Management Organization.

7. When negotiating the supply of nuclear fuel, Jordan should explore the possibility of spent fuel take-back by the vendor country, if this option is available, although a policy to seek take-back will limit both the range of technologies and vendors that Jordan could consider. For an eventual program with multiple NPPs using different technologies and different fuel suppliers, partial take-back of the national SNF inventory is unlikely to contribute significantly to resolving the overall requirements for geological disposal.
8. Jordan should clearly communicate its policy, strategy, program and schedule to national stakeholders and the public, as well as the global nuclear community. It should consider societal outreach activities both in Jordan and in collaboration with MNR partner countries. Partner countries should share similar values and opinions on how to approach MNR siting and implementation.
9. Given the long lead times, regional discussions should be initiated soon, as the results of these deliberations will have long-term effects on Jordanian national decisions that will need to be taken in about 20 years' time (e.g., on whether to implement a national DGR).
10. National policy should begin to develop guidelines for the implementation of a fund to cover the eventual costs of waste disposal from the nuclear power program (and the eventual costs of decommissioning planned nuclear facilities). Although these costs will not arise until many decades into the future and consequently are uncertain, it is prudent to start a fund at the same time as the nuclear power plant enters into commercial operation. A small contribution from the price on nuclear electricity will readily accrue into the amounts needed for either a national DGR or participation in an MNR in the distant future. There are various ways in which this fund could be organized and governed, which should be evaluated as the national waste management program is being formulated, so that the fund can be established by the time that electricity is being generated. The funding mechanism agreed upon needs to be integrated into the financial model for the NPP.
11. To ensure that the international standards and best practices of RWM are met, a new law on RWM should be established. A small ad-hoc Waste Management Group should be established, in order to focus on the immediate waste management issues that affect the progress of the Jordanian nuclear power program. The proposed new WMO, the *Jordanian Radioactive Waste Management Corporation (JRMC),* should be established and be in place before any wastes are generated by the nuclear power program. The JRMC would be responsible for implementing both the dual track policy and the national RWM program for all wastes in the national inventory, including approval of their treatment, conditioning, storage and disposal, regulated by EMRC.
12. The JRMC should implement an RD&D and site evaluation program for LLW disposal facilities and evaluate the options for location and conceptual design of a DGR. This might include both a conventional DGR and/or a deep borehole disposal (DBD) facility. It should also prepare and evaluate cost estimates for storage, treatment and conditioning, and disposal of RW and SNF in a national, regional or international repository.
13. The JRMC should develop the national RW inventory and carry out storage and disposability assessments for all classes of waste, leading to the development of waste acceptance criteria (WAC) for storage and disposal in its planned facilities.

14. The JRMC should also initiate plans for a SNF storage facility that would have sufficient capacity to provide flexibility when making choices on disposal options and their timings throughout the dual track program.
15. The JRMC staff should include both specialists and technical generalists, and project managers. It should establish contacts and exchange agreements with sister organizations in other countries and could establish a contact group of international advisors to help guide it through the formative period of its work with respect to technical and societal issues, as well as commercial, legal, project development and financing matters.

9.3 Specific actions to advance a Jordanian dual track approach

Actions that develop from the above conclusions and could form the initial steps recommended to move forward with a dual track approach are listed below. These actions are not sequential, and can all be initiated as soon as Jordan makes its initial decision to commit publicly to following the dual track approach:

- Carry out a detailed multi-attribute decision analysis exercise, along with a more detailed SWOT exercise with the involvement of key stakeholders and decision-makers, to document the pros and cons of dual track in a transparent manner and inform decision-making.
- Make dual track (explicitly introducing the term ‘dual track’) part of official Jordanian policy by including it in the next National Policy and National Strategy documents.
- Adapt the wording of any national laws or policy related to import or export of SNF and HLW to allow participation in an MNR project.
- Develop and implement a staged program of work that explores the technical siting feasibility of a national DGR and establish a work program to identify DGR concepts appropriate to the Jordanian inventory and geological environment.
- Make preliminary cost estimates for a national DGR program, including ranges and uncertainties, using data from other small programs as models.
- Establish a funding mechanism for the national RWM program that also allows for participation in promoting a regional MNR study.
- Establish formal links to, and participate in joint activities with, international organizations engaged in multinational cooperation and dual track disposal activities, such as the ERDO Association, so as to take advantage of the experience of other countries that are in the same situation as Jordan will be, when it introduces nuclear power.
- Continue and extend Jordanian participation in relevant international fora, such as the IAEA, AAEA, IFNEC and ERDO.
- Initiate an Arab Regional Forum on nuclear fuel cycle topics with national representatives initially from Egypt, Jordan, Saudi Arabia, and the United Arab Emirates.
- Within the Arab Regional Forum, establish joint projects to collaborate on predisposal activities: standardized waste characterization methods and recording, common inventory structures, storage planning, shared mobile facilities, security and safeguards, etc.
- Cooperate in disposal planning: DGR generic design development and comparisons, common waste acceptance criteria for generic disposal facilities, definition of common disposability assessments, generic RWM costing, shared DGR siting guidelines and

characterization techniques for arid regions, RD&D planning, security and safeguards, etc.

- Establish a regional ‘club’ of waste management organizations (equivalent to the European ERDO Association) and an equivalent ‘regulators club’, promoting knowledge transfer and information exchange. These could be more formal developments or evolution from the contact group.
- Use the regional ‘club’ to develop a roadmap of activities leading to a potential Arab region MNR. An eventual aim would be to establish an Arab Regional Waste Management Organization.

9.4 Scoping studies

Central aspects of the recommendations would benefit from further scoping studies. The following activities are suggested:

- Formulation of the content of the national waste management program: to formulate a national RWM program, a clear and updated national policy and strategy must be developed and documented in a transparent manner and approved. These could all be included and approved as one document or in a stepwise approach.
- Consideration of structural options for the establishment of a waste management organization (the proposed JRMC) and the definition of its work program, priorities and required funding.
- Study of options for the structure and functioning of a waste management fund.
- Evaluation of the potential for fuel leasing based on the experience of other NPP operators using such arrangements.
- Evaluation of the waste management technical, strategic, geopolitical and economic implications of fuel reprocessing, if this were to be offered to Jordan as part of a fuel provision package.
- Assessment of the potential scope and size of a regional MNR project with neighboring countries that are also developing nuclear power programs, based on available data reflecting the minimum technical requirements of Jordan and other potential partners.
- Strategic environmental assessment of the RWM options.
- Performance of a more detailed SWOT analysis of dual track adoption and of participation in an MNR project, with the involvement of decision-makers and other key stakeholders.
- Evaluation of the scale and likely costs of a national RWM program, including a DGR for different NP development scenarios in Jordan, including the possible use of a DBD facility for some types of waste.
- Development of a Project Development Plan for progressing the dual track approach, based on Jordan’s preferred positions on the elements contained therein.

It is suggested that each of these could form a short study that could be carried out over the next one to two years to provide input to national policy decisions and to facilitate establishment of the national RWM program.