JORDAN NUCLEAR ENERGY PROGRAM

INTERNATIONAL ADVISORY GROUP REPORT

SUBMITTED TO THE GOVERNMENT OF JORDAN

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EXECUTIVE SUMMARY

An International Advisory Group (IAG) has been formed of world experts on nuclear power, nuclear safety, its regulation and other nuclear activities to provide independent advice to HM King Abdullah II and the Government of Jordan (GoJ) on the Jordan Nuclear Energy Program.

This report provides the expert views of the IAG on the Jordan Nuclear Energy Program and its progress. It does so based on the IAG's joint experience and expertise. It is hoped that the Group's views will assist the people of Jordan, the Parliament and the Government in their consideration of Jordan's peaceful use of nuclear energy.

In this report, conclusions, commendations, and/or recommendations, appropriate to that subject, were generated by the IAG for consideration by the GoJ and are reproduced below against each chapter:

1. Introduction

COMMENDATION

The clear commitment at the highest levels to international Conventions, Treaties and Standards is a very welcome foundation for the Jordanian program.

2. Global Perspective

COMMENDATION

Jordan deserves commendation for carefully analyzing its energy situation and its options, and embarking on a well-planned path to acquire nuclear energy.

3. Safety of Nuclear Power Plants (NPPs)

CONCULSIONS

1. Nuclear power is one of a variety of power generation sources that can have an impact on human health. To achieve high levels of safety, given its high energy density and large inventory of radioactivity, special attention is needed to:
   - Control nuclear and chemical reactions;
   - Provide cooling for the heat from such reactions; and
   - Contain the radioactive materials and radiation.
2. The overall safety focus must address all technology, human, managerial, and institutional aspects.
3. From experiences derived from three major accidents and the thousands of reactor years of safe operations, the global safety regime has significantly improved in all aspects to enable the benefits from operation of NPPs while minimizing the risks arising from nuclear power. Nevertheless, as any nuclear accident has the potential to lead to community disruption and significant socio-economic loss by land contamination with radioactive substances and loss of energy supplies, every country

operating nuclear power needs intense focus and scrutiny to achieve safe operations and a strong safety culture, assisted by international peer review.

4. Ionizing Radiation: Exposures, Risks and Opportunities

CONCULSIONS

1. Radiological releases, and hence impact on health and environment, from normal operation of a modern NPP can be kept much below those from natural exposures, and are a small fraction of natural variations of terrestrial exposure in different areas of Jordan.
2. Energy production from uranium is a closed process, no carbon dioxide is produced in operation, making it one of the few available low-carbon electricity producing technologies, at par with large hydro, and without the intermittency of wind and photovoltaics.
3. Waste heat production and water consumption for its disposal through wet cooling towers are the same as for large coal-fired power plants. Through the proposed use of community waste water, no direct competition with drinking water ensues.
4. Mining, power plant operation and waste disposal as foreseen in the Jordanian program will follow strict present day international protection standards and do not pose undue environmental or health risks. Radiation exposures of the Jordanian population are dominated by natural and medical exposures, but will not be markedly increased by the proposed nuclear program.
5. As shown from the many safe reactor years in countries of similar population size (Belgium, Finland, Sweden, Switzerland), the probability of large releases from major accidents can be reduced to a very low level, thus making nuclear power a sustainable option for modern societies.

5. Regulatory Framework

COMMENDATION

Jordan has aggressively engaged with the IAEA in the development of its nuclear program and has sought and obtained extensive peer reviews. This openness should help to provide Jordan with the capacity to have an effective and responsible regulatory system.

7. Human Resource Development

COMMENDATION

Jordan has a solid foundation, founded on a clear vision, for developing the culture and human resources needed for a successful nuclear program.

RECOMMENDATIONS

1. To achieve the broader aspects of the vision more work needs to be undertaken to extend the development of human resources and a nuclear culture, especially into the Jordanian supply and construction industry.

2. Jordan should evaluate the need for hiring full time, international experts in the early stages of the program in key disciplines to provide oversight of critical areas (for example, nuclear plant construction, project management, quality assurance, safety, licensing, and outreach) as well as to mentor newly trained Jordanian graduates. In addition, expert Jordanian staff must be available to enable Jordan to be an intelligent customer through the nuclear energy development program, including providing intelligent oversight of products from consultants.

8. Jordan Research and Training Reactor

COMMENDATIONS

1. Jordan has a clear roadmap for its Nuclear Energy Program starting with the Jordan Research and Training Reactor (JRTR), allowing it to attract, train, educate and retain personnel, thereby forming the human infrastructure basis for a successful Nuclear Energy Program.
2. Cooperation among JRTR, Jordan University of Science and Technology (JUST), and King Abdullah University Hospital is established.
3. Jordan and JUST deserve commendations for starting their nuclear engineering training well before the JRTR is operational. Their approach for virtual remote access is now a model for international development of nuclear education programs in the absence of a research reactor.

RECOMMENDATIONS

1. The cooperation with JUST and the radiation medicine community should be strengthened in parallel with the installation of appropriate beam lines and products.
2. Cooperation with other universities and institutes in the country and abroad should be established.
3. Cooperation with Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) should be investigated. This would also open the possibility to establish a regional center for neutron and photon science.
4. Jordan should provide attractive working conditions for researchers to attract and retain the top quality staff that are needed, and to assure that students from Jordanian universities are encouraged to apply their training in Jordan. JRTR could develop into a regional education and training center.
5. As a first goal, production of radioisotope kits for use in Jordanian and regional hospitals should have priority over the production for business purposes.

9. Uranium Project

COMMENDATIONS

1. JAEC has followed a carefully developed path to utilize indigenous resources in exploring for uranium resources within Jordan with appropriate augmentation by international experience and experts.

2. The intent of JAEC to use the currently identified modest uranium resources initially to support only Jordanian NPPs is logical, but can certainly be expanded in the future if substantially larger resources are identified and uranium market prices recover.

RECOMMENDATION

The path outlined by JAEC is appropriate in developing indigenous uranium resources, exploring for additional resources including the large phosphate deposits, and utilizing international enrichment and fuel fabrication capabilities. Economic considerations should guide whether Jordan should seek to pursue enrichment and fuel fabrication, subject of course to compliance with obligations under the Non-Proliferation Treaty and other applicable treaties and agreements.

10. Fuel Cycle and Waste

Front End of the Fuel Cycle

COMMENDATION

The present strategy for new fuel supply is sensible and should be enacted.

RECOMMENDATION

Consideration should be given to ensuring that there are no technical reasons for having 10 years of new fuel on the site to guarantee energy supplies.

Spent Fuel

COMMENDATION

A viable strategy for spent fuel management is being pursued with priority given to repatriation.

RECOMMENDATION

A local or regional repository should be considered as an alternative option for spent fuel.

Waste

RECOMMENDATIONS

1. While the strategy for radioactive waste management is considered to be appropriate more should be done to firm up the provisions including scope and funding.
2. The proposals for a near surface repository for low and intermediate waste should be developed further, brought forward and include the specification for the on-site reactor waste processing and packaging.

Transport

RECOMMENDATION

The transportation of new nuclear fuel, radioactive and spent fuel should be more clearly addressed and suitable facilities and resources made available on an appropriate timescale.

11. Nuclear Power Plant Project

COMMENDATION

Jordan has carefully followed the IAEA milestone approach in developing the legal, regulatory, and human infrastructure basis for a successful Nuclear Power Plant Project (NPPP) and multiple IAEA review missions confirm their success along this path.

RECOMMENDATIONS

1. Unless it has already been done, the strong economic case for, and absence for many attractive alternative options to the NPPP should be fully developed and carefully discussed with the citizens of Jordan. Discussions on the safety of modern, more passively safe plants should be highlighted in public discussions, especially targeting women and schoolchildren.
2. The final EPC must cover all aspects of plant operation and fuel supply and potential used fuel takeback.
3. Jordan should join the MDEP group associated with the VVER class of reactors.
4. Unless already done, parliamentary debate and approval of the Jordanian-Russian IGA must be a step toward development of greater support for the program.
5. Jordan should initiate a second track, including focusing on a SMR option, to assure that electricity is available on the time line required by national demands.
6. The IAG notes that Jordanian regulator, JAEC, and JNPC are short of experienced staff required for projects of the magnitude being undertaken by Jordan. Hiring of international experts in key disciplines may be essential in the near term to provide oversight and mentoring of newly trained Jordanian graduates as well as oversight of hired consultants. JNPC requires staff experts (not only consultants) in a wide range of fields, including technical, financial, project management, and legal issues.
7. The Jordanian regulator, JAEC, and JNPC must have competitive/appropriate salary and benefits that enable each entity to recruit (domestically and internationally) and retain the top quality staff that are needed, and to assure that students from Jordanian universities are encouraged to apply their training in Jordan.
8. Jordan may have an opportunity to actively pursue re-activation of 123 negotiations with the United States, taking account of its fundamental commitment to international Conventions, Treaties and Standards with international review.
9. Jordan may want to explore international efforts in optimizing the integration of nuclear and renewable energy sources.

12. Outreach, Stakeholder Engagement

COMMENDATION

By regional standards, Jordan has a well-developed nuclear science and radiation medicine community. On-going and new academic training activities will allow basing the proposed nuclear activities on a domestic work force. This provides a wide indigenous basis for outreach programs and stakeholder engagement.

RECOMMENDATIONS

1. JAEC should develop and work closely in partnership with other governmental agencies to provide understanding and information for the public on the rationale, importance, and safety aspects of the Nuclear Energy Program, and of the benefits of nuclear applications in general, such as the benefits of medical applications. This is particularly important with respect to women and schoolchildren.
2. As soon as possible, JNPC should staff a professional communications branch with recognized experts.
3. The risk of brain drain exists and might increase due to new nuclear activities in neighboring countries. A stimulating working environment including appropriate remuneration will be needed to maintain local capacities.
4. Proactive information on the many aspects of beneficial nuclear applications in medicine, basic science, food & agriculture, environment and cultural heritage studies should be generated for the media, opinion leaders and the public.
5. The well-developed medical community of Jordan, and medical communities in neighboring countries should be encouraged to be active stakeholders in the development of radionuclides for diagnostic radiology and, eventually, for therapy and palliation.

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DEFINITIONS AND ACRONYMS

ABBREVIATION	DESCRIPTION
ASE	AtomStroyExport
BFS	Bankable Feasibility Study
CJ	Central Jordan
CJA	Central Jordan Area
CJUP	Central Jordan Uranium Project
CP	Competent Person
EMRC	Energy and Minerals Regulatory Commission
EPC	Engineering-Procurement-Construction
FP	Fission product
GoJ	Government of Jordan
HQA	Hasa-Qatarana Area
IAG	International Advisory Group
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGA	Inter-Governmental Agreement
IRRS	Integrated Regulatory Review Service
JAEC	Jordan Atomic Energy Commission
JNPC	Jordan Nuclear Power Company
JNRC	Jordan Nuclear Regulatory Commission
JORC	Joint Ore Reserves Committee
JRTR	Jordan Research and Training Reactor
JSA	Jordan Subcritical Assembly
JUMCO	Jordanian Uranium Mining Company
JUST	Jordan University of Science and Technology
KDC	Korean Atomic Energy Research Institute and Daewoo Engineering & Construction
MDEP	Multi-National Design Evaluation Program
NAA	Neutron Activation Analysis
NTD	Neutron Transmutation Doping
NEPIO	Nuclear Energy Program Implementing Organization
NPP	Nuclear Power Plant
NPPP	Nuclear Power Plant Project

DEFINITIONS AND ACRONYMS

ABBREVIATION	DESCRIPTION
OL	Operating License
PDA	Project Development Agreement
PIPh	Pre-Investment Phase
PWR	Pressurized Water Reactors
RAOS	Rusatom Overseas
SESAME	Synchrotron-light for Experimental Science and Applications in the Middle East
SMR	Small Modular Reactor
TMI	Three Mile Island
TSO	Technical Support Organization
WANO	World Association of Nuclear Operators

1. INTRODUCTION

An IAG - (see Appendix A for membership) has been formed of world experts on nuclear power, nuclear safety, its regulation and other nuclear activities to provide independent advice to HM King Abdullah II and the GoJ.

This report provides the independent expert views of the IAG on the Jordan Nuclear Energy Program and its progress. It does so based on the IAG's joint experience and expertise. It is not an audit or review against international or national standards. Such an audit is the province of the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO), and takes significantly more time and resources than the IAG could commit. In writing this report the IAG does not seek to promote the development of a nuclear power program in Jordan in recognition that the consideration of Jordan's peaceful use of nuclear energy is a decision for the Jordanian people, the Parliament and the Government.

The Group met for the first time from 1st to 3rd February 2016 in Amman. It was provided with briefings by experts from Jordan Atomic Energy Commission (JAEC), Jordan Nuclear Power Company (JNPC) and the Energy and Minerals Regulatory Commission (EMRC); had a hearing with HM King Abdullah II, the Prime Minister, members of the Parliamentary Energy Committee led by the Deputy Speaker of the Senate and the Speaker of the House of Representatives; and visited the research reactor and the nuclear teaching laboratory at the Jordan University of Science and Technology (JUST) where a meeting was held with the University President. Appendix B provides the outline of the IAG program. Appendix C provides a list of documentation provided to the IAG.

This report starts with some background information. In Chapter 2 it provides an expert view on the global perspective for nuclear power, in Chapter 3 the safety of NPPs is covered, and Chapter 4 outlines the prevailing expert view on the risks of ionizing radiation and the principles associated with protecting people and the environment. Then in Chapter 5, an outline is provided of Jordan's Nuclear Energy Program. (Appendix D provides additional information on Jordan's Nuclear Energy Program)

After providing this background, the report provides IAG views in the following chapters on:

- Regulation;
- Human resource development;
- JRTR, and non-power applications;
- The Uranium Project;
- Nuclear fuel cycle and waste management;
- The NPP; and
- Stakeholder engagement.

Conclusions, commendations, and recommendations are developed and discussed in the text and, in addition, are collected in the Executive Summary.

Commendation

The clear commitment at the highest levels to international Conventions, Treaties and Standards is a very welcome foundation for the Jordanian program.

2. GLOBAL PERSPECTIVE

2.1 Introduction

2.1.1 Energy

In countries around the world today, including Jordan, three major questions must be considered when evaluating their energy situation:

- Energy security- do we have enough economically attractive energy available for dispatch as needed?
- Energy independence- where does that energy come from?
- Climate change - will CO_2 emissions endanger our planet for years to come?

When considering these issues, it has become apparent to Jordan, as well as many other countries, that nuclear energy is the only source of base-load energy that addresses all these issues with technologies economically available today.

With respect to energy security, if a country embarks on construction of NPPs, it can build them to provide as much capacity as is needed. Similarly, in considering energy independence, Jordan can benefit from its uranium resources and the capacity to acquire fuel-related services from a variety of sources and to store a fuel inventory. In addition, the climate change issue is becoming ever more important and, as nuclear energy does not emit carbon, it will help to reduce carbon emissions dramatically over the coming years.

Even after the 2011 Fukushima accident, which, like the earlier Three Mile Island (TMI) and Chernobyl accidents, led to strengthening of international safety norms, nuclear power remains strong around the world. Any predictions for a recession in nuclear power have not come to pass. As of February 2011, just a month before the accident at Fukushima, there were 443 NPPs operable in the world. Of these, 41 are currently shut down in Japan, but there are still 439 power plants worldwide that are operable today, which is approximately the same number as just before the Fukushima accident. In addition, 66 NPPs are currently under construction, whereas prior to the Fukushima accident there were 62 power plants under construction. In addition there are today 330 power plants seriously being proposed in various countries, whereas in February 2011there were 322 power plants proposed. Additionally there are 158 power plants being considered, albeit still on the drawing board. However, some countries, such as Germany, have decided to phase out nuclear power.

An analysis of these numbers, which are constantly changing, shows that the number of NPPs that will provide energy for the world has not significantly changed since the Fukushima accident. What has changed is the location of these plants. Today, Asia, America and Russia dominate the scene.

2.1.2 Politics

The commitment to nuclear power is affected both by politics and the financing problems arising from the high capital cost of construction. Just after Fukushima, a decision was made by Germany to temporarily shut down the seven oldest NPPs pending a review (moratorium). Thereafter, the German parliament made a further decision to close the older plants for good and to allow a fixed amount of energy to be produced from newer plants.

Eight plants, with about 11 GWe are still operating but will be phased out by 2022. Nevertheless, the electricity contribution by NPPs in Germany in 2014 was still 14%.

The decision to close the NPPs has not yet worked out in the way that had been planned. Renewables have proved to be expensive and produce only a fraction of the energy needed by Germany. This is understandable as Germany is not a place where solar energy is going to be a reliable source of energy. Wind is a bit more cost effective and reliable, but it too is unpredictable and intermittent. As a result, Germany is burning coal, its own and some imported from America, much of which is lignite and very polluting for the atmosphere.

In addition, the country is now buying more gas from Russia (as well as nuclear energy from France). This increased use of fossil fuels is causing carbon emissions to rise. In addition the price of electricity has increased dramatically and businesses are feeling increasingly disadvantaged.

Another political example is France, which produces almost 80% of its energy from 59 NPPs, and demonstrates stable, clean, safe production. However, during the recent election campaign Monsieur Hollande argued that France should not be so dependent on nuclear energy, and promised that such dependence would be reduced by constructing more renewables. To date, no nuclear plant in France has ceased operation.

Other nations have made quite different decisions. The UK is embarked on an extensive program to develop new nuclear energy capabilities as part of mixed clean energy program. China has the largest nuclear plant building program in the world, where 24 plants are under construction (out of 66 units under construction worldwide). The Japanese government has enabled restarting some of their closed reactors after upgrades and their safety is confirmed by a new, strengthened, regulatory authority. The Administration in the United States has emphasized that nuclear energy must be a key part of an all-of-the-above clean energy strategy and has provided incentives for new nuclear plants. Each of these examples shows that nuclear energy is a complex political, technical, and social question in many countries.

2.1.3 Nuclear Today

NPPs generate base-load electricity at a 91% capacity factor in the United States. Fossil plants, which frequently are used in a load-following mode, and intermittent renewables have lower capacity factors (combined-cycle natural gas, with a 50.3% capacity factor; coal-fired at 58.9% and wind at 32.3%). Nuclear energy is the only scalable base-load energy source that is also low carbon. It is agreed by the International Energy Agency (IEA), and most other authorities.

By 2050 the IEA's 2 degree climate change scenario predicts that nuclear will be the largest source of carbon-free electricity at 18%. This is because the population will increase and demand will grow for electric vehicles so that more electricity will need to be provided. In addition, nuclear may have to fill more gaps if other low-carbon resources (especially Carbon Capture, Sequestration and Utilization applied to fossil energy) fail to deliver. Indeed, many believe that a return to the rates of new build in the 1980s will be required.

Sixteen countries depend on nuclear power for at least a quarter of their electricity. France still produces around three-quarters of its power from nuclear energy, while Belgium, Czech Republic, Finland Hungary, Slovakia, Sweden, Switzerland, Slovenia and Ukraine produce one-third or more. South Korea and Bulgaria normally get more than 30% of their power from nuclear energy, while in the USA, UK, Spain, Romania and Russia almost one-fifth is from nuclear. Some countries that do not have their own NPPs, such as Italy and Denmark, still get almost 10% of their power from nuclear by importing it from other countries.

In Japan, operation of nuclear plants was suspended for almost four years for relicensing against new regulatory requirements. But idle units are gradually coming back into operation. However, during this time, power companies in Japan had to import additional gas, coal and oil at about $30 Billion per year to replace the nuclear energy, thus contributing to a negative trade balance.

In addition to the NPPs referred to above, 56 countries operate approximately 240 research reactors and over a third of these are in developing countries. More than 30 countries are actively exploring a nuclear power program. A further 180 nuclear reactors are found in 140 ships and submarines.

Accordingly, the highest rate of new build in 25 years is currently taking place with approximately 66 new reactors under construction. In general, these new build projects are taking place in countries where there is political commitment to nuclear as part of a regulated energy market. It is very difficult to build new NPPs today without some government involvement.

2.2 Nuclear Power in the Middle East

Jordan currently has a population near 9 million and imports 95% of its energy needs at a cost of about one-fifth its GDP. In 2012 due to gas supply constraints from Egypt, its electricity supply was 84% from heavy fuel oil and diesel, instead of from natural gas, which had previously provided the majority.

Jordan now seeks greater security as well as lower electricity prices. Jordan has significant uranium resources, some in phosphate deposits. About 6800 MWe of new generation are needed by 2030, with about one-third of this projected to be nuclear. [NOTE: Further discussion of the Jordanian situation will be provided in other parts of this report].

The UAE is currently embarking upon an ambitious nuclear power program in consultation with the IAEA and significant capacity is expected to be on line by 2020. It is using Korea Electric Power Company KEPCO expertise to build and initially run it. It accepted a $20 billion bid to build four commercial nuclear power reactors, total 5.6 GWe, by 2020 at Barakah. All four units are now under construction. The first is more than 75% complete and is expected to be on line at the end of 2017.

Saudi Arabia is the main electricity producer in the Gulf States. Its population has grown from 4 million in 1960 to almost 30 million in 2014. Demand is growing by 8% per year and peak demand is expected to be 60 GWe by 2020. It now consumes one quarter of its oil production for domestic use and, while energy demand is projected to increase substantially, oil production is not. By 2030 a large proportion will be consumed domestically, much of it for electricity generation.

Saudi Arabia plans to install 24 GWe of renewable electricity capacity by 2030 and 50 GWe by 2032, and is looking at the prospects of exporting up to 10 GWe of this to Italy or Spain during winter when much generating capacity is under-utilized.

Iran has a large nuclear power reactor in operation and a second is planned. In addition, Iran also had a major program developing uranium enrichment, a proliferation sensitive activity which was concealed for many years. Iran is now limiting its enrichment-related activities and ceasing its work on heavy water-related projects, under the internationally agreed Joint Comprehensive Plan of Action. Most enriched uranium has now been removed from the country.

Egypt set up its Atomic Energy Commission in 1955, which became the Atomic Energy Authority the following year. In Egypt, gas resources are expected to be severely depleted in 20 years. The growth in demand for electricity is growing by about 7% per year. In November 2015 Russia and Egypt signed an intergovernmental agreement to collaborate in the construction and operation of a NPP equipped with four 1200 MWe units in El Dabaa. In addition, a memorandum of understanding was signed between the Russian and Egyptian regulators "in order to facilitate further development of the nuclear infrastructure" required for the project.

2.3 Financing Methods for New Build

NPPs are capital intensive assets. Accordingly, current financing models seek to make construction loans easier and cheaper, and reduce the risk of cost escalation in construction, as well as to increase certainty of income for the utility once the plant is running.

A current trend is for the plant vendors and suppliers to take a stake in the plant, giving them an economic interest alongside the utility. This approach also helps them to assist in getting their product acquired and licensed. This is happening in the UK with Japanese vendors Toshiba and Hitachi, as well as EDF, taking stakes in new build projects. Below are some of the successful models.

2.3.1 Regulated Market

Under the governance of a public service commission, utilities operating in some US states are paid a fixed amount per unit of electricity and their plan for any new build must be agreed upon by the commission. This gives both sides a great deal of certainty. The risk to the utility is reduced because it is guaranteed a defined future income stream. The utility with commission approval can also increase its income as it incurs new build expenses, which means it can borrow much less money than would otherwise be needed. In addition, it also can get better interest rates on loans, due to certainty of income once the plant is running.

2.3.2 State Export

This is the kind of financing used by Russia and South Korea, and perhaps will be used by China in the future. The exporting country loans money to the importer to pay for the plant. This makes it a one-stop-shop for the importer and gives the exporter a great deal of control and certainty. The importer, however, has to be comfortable about making a very long-term strategic deal with the exporter. Russia is offering this kind of deal to Hungary and many other countries. By comparison Western vendors like Areva, GE or Westinghouse have to rely on export loans, which are not so comprehensive.

2.3.3 Build-Own-Operate

Another one-stop-shop model for an importing country is being used by Turkey, where plants are being built by a consortium, which will then go on to operate them. Usually electricity will be sold at an agreed rate to the host country for a certain amount of time (15-20 years). Russia is leading one Turkish project and Engie (formerly GDF-Suez) is leading the other. In the Russian Build-Own-Operate model, this agreement can include long-term fuel supply and take back of used fuel.

2.3.4 Contract for Difference

The UK is pioneering this model and other European countries may replicate it. In this case a mechanism is set up by government, but paid for by electricity users, which guarantees a minimum price for electricity for a certain number of years. This gives certainty of return to the investor and avoids the government having to take any risk in the construction phase. In operation, the generator will sell its electricity on the open market. If the market price is below the contractual 'strike price' then the government mechanism will make up the difference so the generator is assured of that income. If the market price is higher than the strike price, then the generator must pay the difference to the government.

2.3.5 Finnish Model

In this model, a group of large power consumers (in Finland it is paper mills and other manufacturers) set up a non-profit company, TVO, to provide them power at cost. It has worked very well for TVO, but no other countries or cultures seem able to replicate it. It may work for smaller reactors in the future.

2.3.6 State Industry

In India, Korea, China and Russia, the nuclear industries are integrated and state-owned, which means they have long planning horizons, a great deal of credit, and a great deal of certainty. They build their power plants by planning ahead according to government policy, using some cash reserves and borrowing the rest with benefits from government credit ratings. Often state-owned or domestic companies will do the construction, and because these companies are very experienced, they tend to get the plants completed on time and budget. It is therefore not a surprise that most of the new build today is financed in this way.

2.4 Summary

The main advantages of nuclear are energy security, energy independence and energy reliability as well as an energy source that is practically carbon-free while providing stable electricity prices for the long term. Building NPPs can give a country as much base-load energy as it needs, and that country will be less dependent on imports of oil and gas. There are a variety of financing models but all to some degree involve government enabling activity.

For nuclear power to be adopted, universities, industry and government must all play their parts. Innovative, strong independent regulations, as well as robust reactor designs, are needed. There also needs to be a holistic approach to safety in order to ensure comprehensive safety, building confidence in the management of nuclear technology and earning stakeholder trust. Most importantly, the risks need to be put into perspective. The radiation risk is real, but so are the risks of not using nuclear power and instead using fossil fuels.

2.5 Commendation

Jordan deserves commendation for carefully analyzing its energy situation, and its options, and embarking on a well-planned path to acquire nuclear energy.

3. SAFETY OF NUCLEAR POWER PLANTS

3.1 What is Safety of a NPP?

Safety means freedom from unreasonable risk. In reality, no power generation technologies are free from risk, although the source of risk is different for each. Thus, on a conceptual level, safety refers to the control of recognized hazards in order to achieve an acceptable level of risk. Risks include health risk to humans as well as environmental, societal and economic risks. However, very often, discussion focuses only on health risk. As far as health risk is concerned, the risk of a NPP is dominated by accidental release of significant amounts of radioactivity that rarely happens (TMI, Chernobyl and Fukushima among 16,500 reactor-years of operation globally). In contrast, the risk of a coal-fired plant is dominated by continual environmental pollution and coal mine accidents, and the risk of a solar (photovoltaic) facility is from the production process of solar panels (such as crystalline silica dust and use of toxic dopants) and mining. In any comparison of risk a holistic approach should be adopted that includes all types and sources of risk including greenhouse gas emissions and waste.

Accidental release of radioactivity from a nuclear power reactor happens when fuel is overheated, damaged and radioactive Fission Products (FPs) in the fuel are released by breaking multiple protective barriers, finally leaking to the environment (i.e., leakage from containment).

Fuel damage is caused by failure of either controlling the chain reaction or failure of heat removal. Chernobyl was caused by the former, but modern light water reactors (using ordinary water, not heavy water) deploy inherent safety features to stop the chain reaction when fuel is heated.

Failure of heat removal occurs when all the multiple and redundant cooling systems fail. If fuel melts by decay heat (FPs decay to stable isotopes and, in the process, release energy, which is called “decay heat”), FPs are released from the fuel.

In the TMI accident in 1979 in the United States, fuel melted due to failure of heat removal, but the containment system was largely intact and retained most of the FPs inside. The Fukushima accident was caused by failure of heat removal as neither power nor cooling water supply was available, which resulted from loss of offsite power caused by the earthquake and by flooding of electric equipment rooms located at the basement floor. The tsunami height (14-15m) far exceeded the design basis and the lack of robust water-tight doors allowed the seawater to penetrate inside the reactor building.

3.2 How can Safety of NPPs be Improved?

Typically, this discussion focuses around three areas; technology, human/managerial skills, and institutional capacity. The world learned a great deal from the above three major accidents. From TMI, the industry and regulators learned the importance of risk assessment, of learning from operational experiences, and of man-machine interfaces that avoid operational errors. From Chernobyl, lessons included international scrutiny of reactor safety designs and the need for a robust safety culture. From Fukushima, lessons included preparedness for unexpected events, especially natural hazards, and the need for independent strong nuclear regulation.

Based on these lessons, reactor safety design worldwide has improved significantly by increasing the level of robustness of reactor systems by such means as deploying cooling systems that do not rely on external power, by preparedness beyond design basis and core melting, and by robust containment to retain FPs inside and to withstand an airplane crash.

Reactor designs are occasionally classified by generation (but this is not a safety-based classification), although generally later designs (III as compared to II) are improved just as any industrial product. Most Generation III or III+ plants currently in the market for new builds utilize a “passive safety system” that works without depending on external power to function and significantly reduces chances of human error. The Fukushima design certainly belonged to Generation II, yet the plants were still equipped with safety systems that work without external power for a certain period of time by use of decay heat as the energy source (this system worked for three days in Fukushima Unit 2). The problems of long-term loss of power were caused by the specific plant layout with installation of the electric equipment room at the basement level subject to flooding. Even Generation III+ designs, if they adopted a similar layout and failed to provide water-tight doors, would also be subject to a similar problem.

At TMI, there were no health effects. For the Fukushima accident, the United Nations Scientific Committee on the Effects of Atomic Radiation (consisting of international experts under the aegis of the United Nations) reports no acute fatality and foresees no discernible cancer fatalities by radiation, but noted mental health problems among evacuees. Except for Chernobyl where long-lived nuclides contaminated land, evacuees can come back home when relatively short-lived FPs decay, as is happening in Fukushima now.

Unlike toxic chemical substances, FPs decay. Their half-life (time for the radioactivity to decay by half) is nuclide-specific. Among volatile FPs released to the environment, noble gases have a short half-life, whereas I^{131} and Cs^{137}, two major FPs have half-lives of 8 days and 30 years, respectively. At TMI, no evacuation was necessary because of limited release of radioactivity (mostly short-life noble gases) to the environment. Nevertheless, NPP accidents potentially lead to community disruption and significant socio-economic loss by contaminating land with radioactive FPs, and by political reaction in the closing of plants. Fukushima is resulting in a global standard that applicants for construction of a new NPP should demonstrate that the design limits the effects of a reactor core damage to within the containment with no need for lengthy relocation (European Council Directive in 2014 and Vienna declaration to Convention of Nuclear Safety in 2015).

Safety is not achieved by design only. The operating organization, the regulator, and public officials need to be well prepared by considering that an accident may happen, even though the likelihood of occurrence is low. They need to create a culture for safety, individually and throughout the organization. Chernobyl was caused largely by inadequate design, but the social system in place then did not invite design reviews from outside and complacency prevailed. Complacency was also a factor in Fukushima due to limited attention to operational experiences from around the world, weakness in regulation and lack of a questioning attitude by the operating organization. If a design is good enough, a NPP accident can be prevented by:(a) scrutiny into what may happen and into how things can go wrong using a questioning attitude and subsequent comprehensive risk assessment, (b) listening to alternative expert views, and (c) learning from global good practices for safety and operational experiences.

The global safety regime requires institutional arrangements for an independent and competent regulatory body in order to enable safety-first and risk-informed decision-making. Independence, however, does not mean isolation from the licensee. Other institutional arrangements are necessary for emergency preparedness (not only by the operator but also by the regulator and government, local and other public authorities as well), for a nuclear liability system, for sharing experiences and for assistance with or from international bodies, etc.

A NPP is a complex system and needs high competence and knowledge in science and technology to regulate, as well as operate. Nevertheless, occasionally, some countries experience a lack of competence among regulators owing to inexperience, to frequent shuffling of personnel (although some limited rotation of regulatory personnel can be advisable to avoid any tendency for the regulators themselves to become complacent), or owing to limited incentives (salary, working conditions, etc.) to attract and retain experienced well-trained staff.

In light of the Fukushima accident, resilience is improved at every NPP by anticipating what may happen and by increased coping capability beyond the design basis including support from mobile equipment onsite and offsite. Realistic drills must be in place by considering that an accident can happen at any plant. Activity to nurture a culture for safety and risk assessment is essential in all sectors and must continue for the life of the plant, as otherwise complacency would eventually dominate. Assessment of natural and man-made hazards at each NPP site is not a one-time job at the time of licensing for construction; operators and regulators need to continuously update their analyses to ensure safety.

There is a well-established global regime to share operating experience at NPPs and to set safety standards. IAEA and WANO assist countries launching nuclear power in achieving appropriate levels of safety and security through peer reviews by global experts.

3.3 Conclusions

1. Nuclear power is one of variety of power generation sources that can have an impact on human health. To achieve high levels of safety, given its high energy density and large inventory of radioactivity,

   - Control nuclear and chemical reactions;
   - Provide cooling for the heat from such reactions; and
   - Contain the radioactive materials and radiation.

2. The overall safety focus must address all technology, human, managerial, and institutional aspects.
3. From experiences derived from three major accidents and the thousands of reactor years of safe operations, the global safety regime has significantly improved in all aspects to enable the benefits from operation of NPPs while minimizing the risks arising from nuclear power. Nevertheless, as any nuclear accident has the potential to lead to community disruption and significant socio-economic loss by land contamination with radioactive substances and loss of energy supplies, every country operating nuclear power needs intense focus and scrutiny to achieve safe operations and a strong safety culture, assisted by international peer review.

4. IONIZING RADIATION: EXPOSURES, RISKS AND OPPORTUNITIES

Ionizing radiation is a physical agent that carries enough energy to free electrons from atoms or molecules, thereby ionizing them and potentially causing damage. Ionizing radiation is made up of energetic subatomic particles, ions or atoms, and electromagnetic waves on the high-energy end of the electromagnetic spectrum.

4.1 Sources of Ionizing Radiation

Long-lived natural radioactivity, which survived since the formation of matter, is dominated by uranium, thorium and their radioactive decay products in soil and building materials, and by potassium 40. Solar radiation from fusion reactions in the sun provides another group of shorter-lived radionuclides which is dominated by carbon 14. Beginning with the 1940s, man-made radionuclides began to emerge in the environment. Atmospheric bomb tests were the dominant source but, to a much smaller degree, also accidental and controlled releases from the operation of power and reprocessing plants. Although easily detected by modern analytical tools, the contribution of man-made radioactivity to the global inventory of radioactivity remains very small, and is declining with better containment technologies and stricter regulations.

Large radioactive sources were produced on an industrial level, mainly for radiation cancer therapy but also for the sterilization of liquids and disposables in medicine, and for phytosanitary treatment of food. The trend today for production of ionizing radiation in industry and medicine is towards accelerators instead of radioactive sources, thus avoiding radioactive waste and security problems.

4.2 Exposures

Human exposures to ionizing radiation are dominated by natural sources and vary greatly in dependence of geology, housing technologies and elevation above sea level. Exposures resulting from modern technologies are led by medical applications, e.g. X-rays computed tomography, and nuclear medicine procedures such as positron emission tomography. Air travel is also a considerable contributor, especially for plane crews. Modern NPPs under normal operation are a negligible contributor. Exposures at the fence of the plant are a small fraction of the variation of natural exposures.

4.3 Health Effects

Ionizing radiation is genotoxic and therefore potentially harmful and even lethal to living beings, but can have health benefits in diagnostic radiology, cancer therapy and palliation.

Adverse health effects of radiation exposure fall into two categories:

- Stochastic effects, i.e., mainly cancer, but also heritable effects, developmental defects, cognitive decline and heart disease. Cancer development in exposed individuals is due to mutations in single somatic cells; heritable disease in offspring is caused by deleterious mutations in reproductive cells; and
- Deterministic effects (harmful tissue reactions) owing to the killing or malfunction of a large fraction of dividing cells in an organ following high radiation doses.

For today's radiation workers and members of the public, radiation levels are much too low to elicit deterministic effects, and also too small to lead to any measurable increase in stochastic effects. To be on the safe side, theoretical risks, albeit small, are estimated from a prudent linear risk model assuming that the incidence of cancer, the most important stochastic radiation risk, increases linearly with radiation dose, and has no threshold. Based on this conservative model, the most dangerous sources of radiation are again natural background and medical imaging.

4.4 Environmental Considerations

For the Jordanian nuclear program, mining and milling, NPP operation and waste disposal have a potential to generate radiological impact on the environment and indirectly on human health.

In the Jordanian case of uranium mining, ore deposits are surficial, i.e. in direct contact with the biosphere. Hence mining and removal of uranium does not bring new radioactivity to the human habitat, but even have the potential to reduce the local radiation level. The IAG notes that the proposed activities will follow international regulations for the protection of the environment or even undercut the limits.

Operation of modern NPPs has very little radiological impact on the environment in normal operation. As the splitting of uranium for energy production is a closed process occurring in fuel rods with several additional barriers and shielding towards the environment, radioactivity releases and radiation levels in the vicinity are small compared to radiation levels from natural radiation from terrestrial radionuclides and from the sun, which can be considered as a huge nuclear fusion power reactor. Radiation levels at the fence of a power reactor will be much lower than those experienced during a flight, where people lose most of the protection of the lower atmosphere against solar radiation.

In a comparison with fossil fuel power plants of similar size, it was shown that conventional coal-fired power plants release more radioactivity through their stacks than NPPs. This is due to traces of natural radionuclides, mostly thorium and uranium and their decay products, in the large amounts of fuel needed. Cooling water is a critical factor in the absence of the sea or large rivers. Again the needs are the same as for a fossil fuel power plant. In the especially critical situation created by the nation-wide water scarcity in Jordan, municipal waste water will be used. As the anticipated source is expected to grow, availability of water for irrigation from the sewage plant will not be critically curtailed.

The potential environmental or human health impact of a research reactor compared to the potential for a power reactor is negligible. It lacks the elevated pressure and heat of power reactors and has a much lower output (5-10 MW_{th} as compared to 3,000 MW_{th} for an output of 1,000 MW in electricity).

Disposal of spent nuclear fuel, activated reactor materials and medical nuclear waste is a global concern. It is proven in many countries, that low-level waste from industrial and medical applications can be safely and securely stored/disposed for the time period needed for radioactive decay. In this decade, the first geologically deep disposal facilities for spent fuel from power reactors will become operational in Scandinavia, thus proving that the nuclear fuel cycle can be closed without noticeable impact on the environment.

4.5 Conclusions

1. Radiological releases and hence impact on health and environment from normal operation of a modern NPP can be kept much below those from natural exposures, and are a small fraction of natural variations of terrestrial exposure in different areas of Jordan.
2. Energy production from uranium is a closed process; no carbon dioxide is produced in operation, making it one of the few available low-carbon electricity-producing technologies, at par with large hydro, and without the intermittency of wind or photovoltaics.
3. Waste heat production and water consumption for its disposal through wet cooling towers are the same as for large coal-fired power plants. Through the proposed use of community waste water, no direct competition with drinking water ensues.
4. Mining, power plant operation and waste disposal as foreseen in the Jordanian program will follow strict present day international protection standards and do not pose undue environmental or health risks. Radiation exposures of the Jordanian population are dominated by natural and medical exposures, but will not be markedly increased by the proposed nuclear program.
5. As shown from the many safe reactor years in countries of similar population size (Belgium, Finland, Sweden, Switzerland), the probability of large releases from major accidents can be reduced to a very low level, thus making nuclear power a sustainable option for modern societies.

5. OVERVIEW OF JORDAN'S NUCLEAR ENEREGY PROGRAM

5.1 Background

Jordan's energy strategy aims to achieve a sustainable energy system through the diversification and optimal utilization of indigenous energy resources. Jordan's current dependence on a single source of energy to produce electricity has made its economy susceptible to frequent shocks. This has been especially evident following the interruption of the Egyptian gas supply and the need to replace it with more expensive fossil fuels to produce electricity. This has resulted in the need to consider the revision of Jordan's energy strategy and to adopt nuclear energy as a viable alternative to produce electricity as part of the energy mix. Furthermore, Jordan enjoys unexploited deposits of uranium throughout the country that can be utilized as feed material for its nuclear fuel. To accomplish these goals, Jordan built on it being a member of the IAEA since 1966, and has established close cooperation with the Agency especially in nuclear applications.

5.2 The Nuclear Power Plant Project

JAEC issued a Bid Invitation Specification in 2011 to international nuclear vendors and received technical and financial bids from three separate vendors: AtomStroyExport (ASE), Areva/Mitsubishi Heavy Industries Joint Venture (trading under the name "ATMEA") and Atomic Energy of Canada Limited. On a parallel track, JAEC issued an Investor/Operator bid to attract a strategic investor who will be responsible as well to operate the plant for at least five years. After an initial evaluation, JAEC kept ASE and ATMEA in the bidding process. In August 2013, following several rounds of clarification with the two vendors, JAEC selected ROSATOM State Corporation ASE and Rusatom Overseas (RAOS) as the Preferred Bidder (Technology Vendor, and Investor/Operator).

The NPP is currently envisioned as being composed of two Pressurized Water Reactors (PWR) based on the Russian AES-92 design. This design is a Generation III+ advanced light water reactor (VVER) based on the latest nuclear safety standards. The net-generation capacity is about 1000 MWe per reactor and the plant is expected to be in operation around 2025, with an operational life of 60 years.

5.3 The Uranium Exploration and Mining Project

JAEC's vision to transform Jordan to be more self-reliant in meeting its energy needs was encouraged by the discovery of uranium deposits in various parts of the country. This local natural resource would, if efficiently exploited, reduce the amount of cash flow outside the country in return for "fuel for energy" imports and, more importantly, helps to assure fuel supply to Jordan's planned NPPs.

5.4 Human Resource Development

Human resource development is one of Jordan's main challenges in its Nuclear Energy Program.

To address this challenge, JAEC's strategic objectives for human resource development include:

- Development of a nuclear undergraduate program in nuclear engineering at JUST.
- Collaboration with bilateral, regional and international organizations on nuclear power, safety and security.
- Provision of scholarships through coordination between JAEC and foreign academic institutions.

In this context, JAEC has been working with JUST and other universities in Jordan to establish specialized education in nuclear related fields. Moreover, JAEC has signed agreements with countries with well-established nuclear energy programs, enabling Jordanians to receive higher education degrees in nuclear sciences and engineering. At the moment, ninety four students have been sent to Russia, China, South Korea, Japan, and France on scholarships to obtain higher education degrees.

Among the most prominent achievements of JAEC in cultivating and developing human resources are the Jordan Subcritical Assembly (JSA) and the Jordan Research and Training Reactor (JRTR). JSA has been operational since 2013 and JRTR will be operational in 2016.

5.5 Regulatory Framework

Since the inception of Jordan's Nuclear Energy Program and following best international practice, the GoJ established the Jordan Nuclear Regulatory Commission (JNRC) in 2007 as a self-autonomous regulatory body.

The JNRC was empowered by Parliament to promulgate the legal, regulatory and security framework for implementing the nuclear energy program. JNRC was responsible for Jordan's general policy in the field of nuclear safety, nuclear security, and radiation protection. The main task of JNRC, as for any nuclear regulatory authority, was to regulate and control the use of nuclear energy and ionizing radiation.

In April 2014, a restructuring new Law No. 17, merged several governmental organizations, and it was decided to merge the regulatory bodies for radiation and nuclear applications, electricity generation and minerals in a new regulatory body named EMRC as a financially and administratively independent regulatory body regulating the energy sector in Jordan, the Regulatory work is further discussed in Chapter 6.

6. REGULATORY FRAMEWORK

6.1 Background

The IAEA's Fundamental Safety Principles (SF-1) place the prime responsibility for safety on the operator of a nuclear facility. But they also demand a backstop to assure that the operator fulfills its responsibilities. Principle 2 provides that "an effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained." Among other elements,

- "Have adequate, legal authority, technical and managerial competence, and human and financial resources to fulfill its responsibilities;" and
- "Be effectively independent of the licensee and of any other body, so that it is free from any undue pressure from interested parties."

This principle provides the context in which to view the regulatory arrangements in Jordan.

Jordan is proceeding to establish a comprehensive nuclear law and to promulgate the necessary regulatory requirements that must be in place to provide the legal framework to guide the licensing of nuclear power reactors. This is a formidable task given the wide range of matters that should be encompassed within that framework. Fortunately, there is extensive guidance that is available from the IAEA to assist in this effort, as well as various services offered by the IAEA to provide peer review. The extent to which Jordan has used and continues to use the IAEA Standards and Services is commendable.

6.2 Development of the Jordanian Nuclear Regulator

The history surrounding the Jordanian regulator is somewhat complicated. Jordan had a free-standing nuclear regulator until 2014. Then, as a result of comprehensive reform to simplify the government, a variety of previously separate regulatory entities were merged to create the EMRC. The EMRC is a body with five commissioners and a diverse set of obligations. One of the commissioners takes principal responsibility for nuclear matters, while other commissioners have other areas of focus. The "nuclear commissioner" is knowledgeable and experienced in nuclear matters and has assistance of a small group of specialized staff who focus on nuclear-related matters. The merger of a nuclear regulator into an organization with a diverse set of other responsibilities is very uncommon and is perceived outside of Jordan as diluting a national priority for strong independent nuclear regulation.

The principal current activity of the group is the licensing of the JRTR. As discussed elsewhere, this project is proceeding effectively. The IAG's judgment is that the current regulatory arrangements are functioning well today. But it is concerned about the future capacity and capability of the regulator as Jordan expands its nuclear activities.

One of the non-nuclear responsibilities of the EMRC is to monitor and assure a stable electrical system. A situation can be conceived in which there could be a conflict between a directive to assure stable electrical power, which might require a nuclear plant to remain on line, and a directive to assure nuclear safety as the highest priority, which might require a nuclear plant to be shut down (at least temporarily). It seems to the IAG that the existing regulatory arrangements suffer from the lack of the true independence that the Fundamental Safety Principles demand, and in addition may erode public confidence.

In this context, it is worth observing that part of the context for the accident at the Fukushima Daiichi Plant was the absence of an independent Japanese regulator. At that time the regulator was a part of the Ministry of Economics, Trade and Industry, which had the obligation to promote nuclear energy. The inherent conflict is understood to have resulted in a regulator that was weak and ineffective. In the aftermath of the accident, Japan has created a regulator, the Japanese Regulation Authority that is effectively independent and is now imposing stringent regulatory scrutiny on the industry. The regulator serves not only to assure safety, but also as a means to provide an understandably suspicious Japanese public with confidence that safety is being pursued by the nuclear enterprise.

One of the consequences of the advent of nuclear power in Jordan is the need to expand the range and expertise of the regulator. This will include the need to employ staff with a wide range of expertise, a need that Jordan recognizes. Many countries have created a regulator with a commission structure, including most prominently the United States, France, and Japan. The expectation is that the commissioners will share responsibility for decisions and can provide more effective and knowledgeable regulatory control than any single individual could.

6.3 Commendation

Jordan has aggressively engaged with the IAEA in the development of its nuclear program and has sought and obtained extensive peer reviews. This openness should help to provide Jordan with the capacity to have an effective and responsible regulatory system.

6.4 Recommendation

As part of the advancement of the legal framework for nuclear power in Jordan, a free-standing regulator should be established, staffed and funded appropriately for its expanded responsibilities, and with a commission made up of knowledgeable individuals who share responsibility for regulatory decisions.

7. HUMAN RESOURCE DEVELOPMENT

7.1 The Need

The peaceful use of nuclear energy requires different and significant human resource development to that normally present in a nation. This is particularly the case if that use involves a nuclear power program. The IAEA has emphasized this point by noting the need to develop the human resources for the State organizations required to effectively supervise and implement the nuclear program.

A nuclear power program requires a wide range of knowledge and experience, especially if it extends across the nuclear cycle, and to other areas such as medicine, agriculture and general industry. Furthermore, the range does not just stop at the engineering and scientific disciplines; it must also encompass “soft sciences” such as administration, management of large complex projects and legal issues.

If the country intends to use its local supply chain for some of the components, construction, installations, etc. of a nuclear reactor, then the range of transfer of knowledge and expertise has to extend to these areas as well, at least to the extent needed to satisfy unique nuclear quality programs. (The massive up-front investment and long return period for a typical nuclear power reactor demand its high reliability let alone the requirement to have exceptionally high safety standards.)

While a newcomer nation to nuclear power development may have to largely use foreign resources initially, it can develop its own indigenous nuclear experts and other human resources, especially if it has a well-established education system and has the foresight to have prepared the way. The country can then decide if, when and how it shifts the balance between using foreign expertise and building up its own. Even at the start of a nuclear program, however, a country needs a cadre of experienced, knowledgeable nuclear professionals in the country to act as an “intelligent customer” to know what it wants, how to decide from whom to procure foreign expertise, and be able to judge and own the product. Internal expertise may be supplemented by international consultants, but first the country must be an intelligent customer with its own full time resident experts.

This issue deserves very careful attention in Jordan. All elements of the program, JAEC, JNPC, and ERMC are under-staffed, and need experts with the relevant skills. Jordan may not have enough senior talent in these critical initial stages of its nuclear energy program. Hiring of international experts now may be essential to oversee, direct, and mentor the graduates of JUST as they move into these organizations and enable Jordan to be an intelligent customer for consultants used to supplement Jordanian staff.

A foundation stone for a successful nuclear program is a robust and vibrant culture for safety, security and quality amongst all those contributing to it. This has to come from the top and be embraced by all. It has to start early and cannot just be added later. Consequently, it should be an early part of all training and other programs to develop the human resources needed.

7.2 The Position in Jordan

Jordan has a strong basis of graduate level education in the sciences and in engineering. It has a particularly good reputation in the medical sciences. Additionally, it has for some years been sending good students overseas to nuclear-related graduate and post-graduate courses. It has a very small cadre of senior well-experienced nuclear professionals in both the development and the regulator sides of the program.

Against this basis, of particular note is the vision and guidance provided by HM King Abdullah II for the nuclear program: Jordan is a beacon for the safe secure development of the peaceful use of nuclear energy in the Middle East, particularly for those nations with little or no natural resources.

Noteworthy aspects of Jordan's commitment include:

- Its commitment to follow the best international standards for safety, security and safeguards;
- Its development of the real wealth of Jordan – its people. Jordan provides opportunities through its universities and facilities for its citizens to develop their knowledge and experience of the peaceful use of nuclear energy; and
- Its engagement with the public and other stakeholders openly, proactively and responsively.

The nuclear energy program is seen as stimulus for a wider industrialization and development of the country and will provide a particular drive for raising quality standards. As well it is recognized that it is a long-term commitment and investment in its people, spanning at least three generations. Jordan has a very young population with around a third still in school. This bodes well for securing the vision.

As well, Jordan is putting in place the facilities and arrangements to form the basis for developing its nuclear experience and expertise, in particular:

- The development of the JRTR;
- The provision of the Jordan Sub-critical Assembly and Nuclear Science and Engineering Laboratory Complex at the JUST incorporating a high performance computing laboratory, radiation detection and measurement laboratories, and an internet Reactor Laboratory;
- The decision in 2007 to start a BSc course at Jordanian universities with 110 nuclear graduates so far (with around a third being female), and more than a 100 students undertaking the course;
- The recent establishment of a separate Nuclear Engineering Department at JUST;
- The investment in sending excellent students for further study in nuclear related topics overseas;
- The early and successful use of: the interactive reactor laboratory, the IAEA support for nuclear education and training through e-learning and its International Nuclear Security Education Network, and the Asian Network for Education in Nuclear Technology; and
- International co-operation with other well respected universities particularly in the USA and France.

All this is based on the vision and a strategic plan for human resources development for Jordan. A national committee oversees the strategy.

There was an IAEA Integrated Nuclear Infrastructure Review Mission Phase 2 in August 2014 that noted the need for further development of detailed plans for human resources and expansion of them to embrace organizations other than the Operating Organization and Regulator. There will be a need to broaden the education and training requirement to cover the Jordanian supply and construction industry if the broader aspects of the vision are to be achieved, particularly in relation to quality, its inspection and its supervision. (There was some evidence from the visit to the JRTR that the construction was not of the highest quality in some parts.) In addition, there is a requirement for nuclear-specific training and development to range across the many levels of technical capability.

7.3 Commendation

Jordan has a solid foundation, founded on a clear vision, for developing the culture and human resources needed for a successful nuclear program.

7.4 Recommendations

1. To achieve the broader aspects of the vision, more work needs to be undertaken to extend the development of human resources and a nuclear culture, especially into the Jordanian supply and construction industry.
2. Jordan should evaluate the need for hiring full time, international experts in the early stages of the program in key disciplines to provide oversight of critical areas (for example, nuclear plant construction, project management, quality assurance, safety, licensing, and outreach) as well as to mentor newly trained Jordanian graduates. In addition, expert Jordanian staff must be available to enable Jordan to be an intelligent customer through the nuclear energy development program, including providing intelligent oversight of products from consultants.

8. JORDAN RESEARCH AND TRAINING REACTOR (JRTR)

8.1 Introduction

The Jordan Nuclear Energy Program presently includes the JRTR (to be operational in 2016) and the Nuclear Power Plant Project (NPPP), which is presently in the planning phase. The combination of the JRTR with the NPPP presents a logical approach to the development of a nuclear energy program. These nuclear projects will have significant positive impact within Jordan but also beyond. It will give Jordan an opportunity to take leadership in nuclear technologies and nuclear research throughout the Middle East.

8.2 Use of the JRTR

The JRTR will provide the training ground for engineers and technicians to operate, maintain and develop a nuclear reactor. In fact, the nuclear engineering training program at JUST started years ago and used a virtual reactor system, involving internet access to the North Carolina State University research reactor, to introduce students through "quasi-hands-on" operation of an actual reactor. To date, the JUST program has graduated about 100 nuclear engineers and their approach for virtual remote access is now a model for international development of nuclear education programs in the absence of a research reactor.

In addition, the JRTR can become the basis of a strong scientific program. To this end, the location of the JRTR near Irbid has been well chosen. Its vicinity to the JUST and to the King Abdullah University Hospital offers an ideal opportunity for research, education, and medical applications. It could and should become a regional center of excellence in nuclear research. The combination of operation and research will help to attract not only qualified scientific personnel but also qualified operational personnel challenged by continuous improvement demands from researchers and from the medical sector.

On the medical side, the production of a variety of radioisotope-based kits for diagnosis and therapy will be one of the immediate goals of the JRTR. Jordan is a well-developed country in the medical sector. Thus, the demand for medical diagnostics based on radioisotopes is high and continuous supply and increase in variety is of high importance for the country and the region. During the first phase of operation, emphasis should be given on satisfying the demand in the country and the development of an increased variety of isotopes over the economic aspects.

Concerning nuclear research, the JRTR offers many possibilities in the areas of physics, biology, chemistry, earth science, environmental science, and archaeology. Skilled manpower will be required and needs to be attracted. A close cooperation with the Nuclear Engineering Department at JUST is vital, but cooperation programs with IAEA and universities and research centers worldwide should also be set up. To assure a high quality of research work undertaken, a user community should be established to propose and review projects.

8.3 Future Developments

A future research cooperation between JRTR and Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), presently under construction in Allan near Amman, could offer exciting prospects. SESAME is the first synchrotron light source in the Middle East and will be the first true international center of scientific excellence in the region. Synchrotron light sources produce electromagnetic radiation that can be used to probe the structure and behavior of matter. They have become valuable tools in many fields of science, including biology, chemistry, materials science, environmental science, and archaeology. The areas of research are very similar to those that can be pursued using JRTR and the methods are complementary.

To some extent this situation can be compared with the European Photon and Neutron Science Campus at Grenoble with, in particular, Institut Laue-Langevin (ILL, high neutron flux reactor) and European Synchrotron Radiation Facility (photons). A cooperation with these institutes could be very beneficial in terms of training qualified people and of developing first class research projects. Jordan could envisage to become the Middle East Photon and Neutron Science “Campus”.

8.4 Commendations

1. Jordan has a clear roadmap for its Nuclear Energy Program starting with the JRTR, allowing it to attract, train, educate and retain personnel, thereby forming the human infrastructure basis for a successful Nuclear Energy Program.
2. Cooperation among JRTR, JUST and the King Abdullah University Hospital is established.
3. Jordan and JUST deserve commendations for starting their nuclear engineering training well before the JRTR is operational. Their approach for virtual remote access is now a model for international development of nuclear education programs in the absence of a research reactor.

8.5 Recommendations

1. The cooperation with JUST and the radiation medicine community should be strengthened in parallel with the installation of appropriate beamlines and products.
2. Cooperation with other universities and institutes in the country and abroad should be established.
3. Cooperation with SESAME should be investigated. This would also open the possibility to establish a regional center for neutron and photon science.
4. Jordan should provide attractive working conditions for researchers to attract and retain the top quality staff that are needed, and to assure that students from Jordanian universities are encouraged to apply their training in Jordan. JRTR could develop into a regional education and training center.
5. As a first goal, production of radioisotope kits for use in Jordanian and regional hospitals should have priority over the production for business purposes.

9. URANIUM PROJECT

9.1 Introduction

This chapter will focus only on the Uranium Project component of the front end of the Jordan Nuclear Fuel Cycle, and a later chapter will discuss waste handling and other activities associated with the back end of the fuel cycle.

The IAG was briefed extensively on the Central Jordan Uranium Project (CJUP). The IAG compliments the JAEC for its careful management of this project. The goal of JAEC is to utilize indigenous supplies of uranium for Jordan and perhaps for the surrounding region. Furthermore, JAEC has appropriately used international resources in exploring for uranium within Jordan and conducted its work with careful attention to international standards.

9.2 The Resource

The IAG notes that initial and even the long term annual plans for production of U_3O_8 (of 400 and 1,500 metric tons, respectively) from indigenous uranium ore are relatively small amounts compared to major international producers. In addition, many of the countries with large nuclear power programs are not self-reliant on their own uranium resources, but rather depend on the global availability of uranium as an international commodity. Furthermore, the identified resources in Jordan are of low concentration compared to some of the larger international producers but, offsetting that issue, the IAG also recognizes that the identified resources in Jordan are very easily accessible requiring minimal mining, which will help the economics of the project and the country. Given all these factors, the IAG concurs with JAEC that Jordan, without locating substantially larger and higher quality uranium resources, should not seek to compete with the largest international suppliers like Canada, Australia and Kazakhstan.

Nevertheless, the rationale for indigenous (and perhaps regional) use of the Jordanian resources may provide benefits to Jordan including control of energy source. These benefits certainly include utilization of Jordanian resources, local employment and, perhaps especially, development of the infrastructure necessary for uranium mining within Jordan.

The IAG support for use of the Jordanian uranium resources is conditioned on successful demonstration of larger scale production of U_3O_8 by Jordan, but the current progress in this area leads to confidence that the planned demonstrations later in 2016 will prove to be sufficiently economical to continue with the current plans.

The plans to further refine the estimates of both measured and indicated resources is appropriate and use of boreholes to explore deeper deposits than the surficial ones is a logical next step. Furthermore, Jordan has extensive phosphate resources and may want to consider utilization of those resources for uranium in the future.

9.3 Exploitation

JAEC has followed a logical path in exploring for uranium resources and in developing the economics of production. The use of trained Jordanian scientists and engineers is commendable, as well as the use of international experts. The path followed, which includes successful laboratory demonstration of yellow cake extraction and development of analytical laboratories to support current and future work, are logical steps in developing the nation's resources. The plan to develop a larger scale extraction pilot plant is consistent with the development of these resources.

It was noted in discussions that other valuable minerals, especially vanadium and titanium, are present in the uranium surficial deposits. This observation reinforces the IAG view that the CJUP may enable Jordan to develop the mining infrastructure that may be applied in the future to other valuable materials. Many of the world's uranium mines produce several byproducts. Similarly, Jordan might enhance the profitability of its own mining and extraction operations by pursuing co-production of byproducts along with uranium.

9.4 Other Developments

The IAG agrees with JAEC that consideration of enrichment and fuel fabrication within Jordan should be deferred until well into the future. Substantially larger operations than needed by the initial Jordanian NPP would be required to economically introduce Jordanian enrichment and fuel fabrication. Nevertheless, the IAG concurs that Jordan might consider its involvement in such work in the future, subject of course to compliance with its obligations under the Non-Proliferation Treaty and other applicable treaties, conventions and agreements, and let future economic decisions guide the logic of future expanded efforts within Jordan.

9.5 Environmental Impact

The IAG also notes, in response to some of the skeptical concerns within Jordan on the environmental impacts of uranium extraction, that the processes now being utilized in Jordan are very well understood from technical and safety perspectives. In the earliest days of uranium extraction in the world, the hazards were poorly understood, especially in deep underground mines, and health effects were observed in radon-exposed miners. But today, the safety precautions taken even in deep mines are readily available and, furthermore, the plan in Jordan to initially utilize surficial resources vastly reduces any possible hazards to negligible levels.

9.6 Commendations

1. JAEC has followed a carefully developed path to utilize indigenous resources in exploring for uranium resources within Jordan with appropriate augmentation by international experience and experts.
2. The intent of JAEC to use the currently identified modest uranium resources to initially support only Jordanian NPPs is logical, but can certainly be expanded in the future if substantially larger resources are identified and uranium market prices recover.

9.7 Recommendation

The path outlined by JAEC is appropriate in developing indigenous uranium resources, exploring for additional resources including the large phosphate deposits, and utilizing international enrichment and fuel fabrication capabilities economic considerations should guide whether Jordan should seek to pursue enrichment and fuel fabrication, subject of course to compliance with obligations under the Non-Proliferation Treaty and other applicable treaties and agreements.

10. FUEL CYCLE AND WASTE

10.1 Introduction

The nuclear fuel cycle for PWR involves: uranium mining, ore processing, conversion, enrichment, reconversion, fuel fabrication, fuel storage - (the front end of the fuel cycle); and then, after burning of the fuel in the reactor, spent fuel storage at the reactor site for initial cooling, after which either long term fuel storage and eventual disposal (an open cycle system) or reprocessing with recycling of the uranium and plutonium and disposal of the majority of the FPs through vitrification and eventual deep geological disposal.

Radioactive wastes are generated throughout the cycle and must be stored, processed, and eventually sent for disposal. These radioactive wastes will have a range of radioactivity requiring different processing, storage and disposal facilities.

10.2 Front End of the Fuel Cycle

Jordan has put in place a Nuclear Fuel Cycle Commission under the JAEC. Its policy on the front end of the fuel cycle is under development with the expectation that it will be submitted to the GoJ in the second quarter of 2016. The policy is founded on Jordan being fully compliant with the Non-Proliferation Treaty and all other associated international treaties, conventions, and agreements.

- Encourage the use of indigenous uranium and other nuclear materials;
- Allow the export and import of nuclear material;
- Allow for conversion and enrichment – abroad, multilateral and regional;
- Encourage research and development of front end fuel cycle capabilities based on commercial viability; and
- Develop capabilities to contribute to a regional fuel bank.

Clearly, this is an ambitious, long term set of goals and if such a policy were to be pursued on all fronts in the near term it would require a massive human and resource investment, and still would not be in place until after the planned date for the start of the first nuclear power reactor. At this stage, however, of development of nuclear energy in Jordan, the plan to focus only on uranium mining and processing is entirely reasonable. Nevertheless, the IAG concurs that Jordan should consider other aspects in the future, subject to compliance with the Non-Proliferation Treaty, and of other relevant international treaties, conventions and agreements.

Energy supply sources are a crucial issue for Jordan given its own lack of substantial indigenous natural energy resources (other than solar) and an unfortunate history of effectively single source supply that has been subject to significant price increase and cut-off. In general, most energy supplies are difficult to stockpile, whereas enough nuclear fuel for a reactor to operate for 10 years can be easily stored.

JAEC is adopting a staged and reasonable approach to the supply of nuclear fuel:

- Certainty of supply at world prices for the initial period of reactor operation (probably 10 years) through having it as part of the reactor vendor package backed up by intergovernmental agreements, with an option to extend to a reactor lifetime supply (60 years); and

- Flexibility to use other sources (including its own) through the reactor vendor, as part of the contract, being required to supply JNPC with all the necessary technical specifications and drawings for the fuel assembly to allow competitive supply (or in the longer term, indigenous supply).

10.2.1 Commendation

The present strategy for new fuel supply is sensible and should be enacted.

10.2.2 Recommendation

Consideration should be given to ensuring that there are no technical reasons for having 10 years of new fuel on the site to guarantee energy supplies.

10.3 Back-End of the Fuel Cycle

10.3.1 Background

The GoJ adopted a national policy for radioactive waste and spent fuel management in July 2015.

- Spent nuclear fuel is seen as a strategic resource and not as radioactive waste;
- Reprocessing within and outside Hashemite Kingdom of Jordan is allowed;
- Importation of radioactive waste is not permitted;
- Provides for the establishment of facilities to dispose of radioactive waste;
- Encourages the research and development of back-end fuel cycle capabilities based on commercial viabilities, with indigenous capabilities covering radioactive waste management and treatment facilities, spent fuel management and reprocessing facilities, and disposal facilities for radioactive wastes up to and including high (or heat generating) waste.

Again, to pursue all the elements of this policy would not be feasible for Jordan in the near term, but it has to have sufficient intelligent customer capability to procure what it needs from others, and sufficient capability to deliver indigenous facilities where required. Of course, as with the program at the front-end of the fuel cycle, any Jordanian activities at the back end must be in compliance with the Non-Proliferation Treaty and other applicable treaties and agreements.

10.3.2 Spent Fuel

The present intention for the Jordan nuclear program is that spent nuclear fuel will be stored on site in a spent fuel pool for a minimum of 10 years after which it will dry stored on site for at least a further 20 years. Increased capacity for longer storage and larger amounts of fuel could be provided. Thereafter, the full range of options is still open including direct disposal in Jordan, reprocessing, and repatriation to the country of origin. This last option is the one that is being actively pursued although some work is being undertaken to develop a repository capability, perhaps in co-operation with other states.

10.3.3 Commendation
A viable strategy for spent fuel management is being pursued with priority given to repatriation.

10.3.4 Recommendation
A local or regional repository should be considered as an alternative option for spent fuel.

10.4 Waste

10.4.1 Background
As noted above, radioactive waste will be generated by reactor operations. Medical and industrial use of ionizing radiation is likely to increase in Jordan as medical treatments advance, the population increases, and industry develops. These will also generate radioactive waste including redundant sealed sources.

The vendor of the nuclear reactor is expected to provide facilities for processing and storage of waste generated by operation of the reactors. This should include all forms of such waste – gaseous, liquid and solid. The proposals are that the storage capacity has to be sufficient for 10 years of operation of the reactor but capable of being increased to accommodate waste from 60 years of operation.

The national policy noted above includes a proposal for the early siting and development of a near surface repository for low and intermediate level waste, but it is observed that this will not be available until sometime (5-10 years) after initial operation of the reactor. It is presumed that such a facility will also have to accommodate the increased non-reactor radioactive waste generated in Jordan. At present it is not clear how the funding for dealing with such wastes will be arranged. Additionally, it is not clear that proposals for a near surface repository drive the specification of the form of the waste that is being processed and stored on the reactor site. This could be an issue if further processing and repacking of stored reactor wastes is required to fit in within the repository safety and environment case.

One of the issues with nuclear power operation and, especially with public acceptance, is clear, safe, secure, and funded radioactive waste management arrangements. A principle that assists in addressing this issue is that radioactive waste should not be allowed to accumulate on sites but be sent for disposal as soon as it is safe to do so.

10.4.2 Recommendations
1. While the strategy for radioactive waste management is considered to be appropriate, more should be done to firm up the provisions including scope and funding.
2. The proposals for a near surface repository for low and intermediate waste should be developed further, brought forward and include the specification for the on-site reactor waste processing and packaging.

10.5 Transport

10.5.1 Background
Transport of new nuclear fuel, radioactive waste and spent fuel does not appear to have been the subject of in-depth studies but will need to be addressed to ensure that the

infrastructure and suitable qualified personnel are available to undertake such activities. No doubt international nuclear fuel transport organizations can be used. But there will still be a requirement for local facilities such as appropriate receipt and dispatch facilities including suitable *craneage*.

10.5.2 Recommendation

The transportation of new nuclear fuel, radioactive and spent fuel should be more clearly addressed and suitable facilities and resources made available on an appropriate timescale.

11. NUCLEAR POWER PLANT PROJECT

11.1 Background

The rationale for this Project was thoroughly explained to the IAG who concur with it. With Jordan's importing fossil fuels for 98% of its electricity, experiencing past disruptions of natural gas supplies, and recognizing that only renewables and nuclear power can be readily expanded in Jordan with minimal carbon emissions, the logic for the Project is clear and compelling. Future demands for both electricity and water support the need for this Project as well. However, unless it is already being done and just not presented to the IAG, the IAG notes that the strong economic case for the Nuclear Power Plant Project (NPPP) should be carefully developed and explained to the citizens of Jordan.

The combination of the NPPP with development of indigenous uranium resources is a solid step towards greater energy independence for Jordan. The IAG agrees with JAEC that these nuclear projects will have significant positive impact within Jordan, from standpoints of energy cost and reliability, national income, human infrastructure and expertise building, and carbon emission reductions. Development of the legal and regulatory basis and human infrastructure within Jordan is highly commendable and follows international best practices; however, as noted earlier, Jordan may well not have all the senior managers with the required skills available today, and consideration should be given to utilization of international talent. Furthermore, Jordan is well positioned to provide strong leadership on nuclear technologies throughout the Middle East.

11.2 Development of the Project

JAEC also followed international best practices in requesting technology bids for the NPPP and used appropriate evaluation procedures. The IAG commends JAEC for requesting only plants offering significant passive safety, an important recent advance in plant safety. The cooling option chosen for the Amra site, following the highly successful model of the Palo Verde NPP in Arizona with its use of waste water, is excellent and highly appropriate for Jordan. The IAG commends the JAEC request that a reference plant be available, which significantly increases the confidence in any chosen design, and that any necessary improvements based on the experience at Fukushima be incorporated. The IAG noted and commends JAEC plans to confirm important aspects of the NPPP operation with its own evaluations, and passive safety should be one of those areas evaluated.

With regard to future evaluations of the selected plant, the VVER AES-92, the IAG noted that little mention was made of international cooperation. For that reason, the IAG highly recommends that Jordan join and participate in the international Multi-National Design Evaluation Program (MDEP). MDEP was established as an international group of regulators to enable countries exploring similar technologies to explore regulatory issues, certainly including safety, by sharing their own analyses. Initial working groups in MDEP were formed for the AP100 and EPR plants, but now there is a working group for VVERs. Participation in MDEP for the VVER would provide Jordan with access to evaluations done by several interested countries and would facilitate Jordan's evaluations. (Decisions on whether to utilize such external studies are always at the discretion of each country. Nothing in MDEP would bind Jordan to accept evaluations done elsewhere.)

11.3 Financing

The financing arrangements for the NPP procurement seemed somewhat nebulous to the IAG. Extensive reliance is being placed on financing from the Russian Federation, and it was not clear how the Jordanian side of the financial package would be completed. The IAG recommends that far greater clarity on the Jordanian financial package be developed, if it is not already completed, and that definition of the Jordanian financial package should enhance the willingness of the Russian team to commit their resources as planned on the existing schedule. Uncertainty on the financial structure of the overall program contributes to the general view of the IAG that timelines for operation of the first plant around 2025 may be optimistic.

11.4 Contracts

It was noted in the presentations that details of the final Engineering-Procurement-Construction (EPC) remain to be finalized as the AES-92 project proceeds, although a framework is already in place through the Inter-Governmental Agreement (IGA) between the GoJ and the Russian Federation. The IAG emphasized that the final EPC must include iron-clad agreements on fuel supply and potential used fuel-takeback. Supply of initial fuel loading and new fuel for some years in the future should be part of this EPC, but the IAG also recommends that some provision be made to utilize other sources for new fuel at some point in the future to assure that Jordan always benefits from a competitive market. It was not clear to the IAG whether Parliamentary approval of the IGA has been accomplished or is needed, but if it remains to be done, it might help to solidify support in the Parliament for the project.

11.5 Timescales

Given the extremely severe need for new electrical capacity within Jordan in the mid 2020's and the extremely tight (and possibly even overly optimistic) timelines to finalize aspects of the NPPP's progress, the IAG recommends that Jordan explore at least one additional parallel path toward other nuclear options. Given the size of Jordan's grid, the widely dispersed population centers, and the lack of water for cooling, the IAG recommends that JAEC initiate a separate track including Small Modular Reactors (SMRs) that are being studied in several countries. SMRs are probably needed for Jordan's future grid, as very few of the GW-class plants can be accommodated within Jordan's system, and initiating serious consideration of SMRs now (through an appropriate international tender process) could provide backup to the planned two AES-92 reactors and/or simply position Jordan for future SMR utilization. Several SMRs are licensed now and more will be licensed and deployed in the early 2020s.

To assure that all international options for such a SMR procurement are considered, Jordan must have a 123 agreement with the United States. The IAG was told that negotiations are not ongoing at present, but the IAG recommends that such negotiations be initiated.

11.6 Other Issues

The IAG noted the modest size of the Jordanian regulator (about 70 staff involved in nuclear regulation); the small number of staff at JAEC dedicated to the NPPP (less than 10) and the number of projects being undertaken simultaneously at JAEC; and the recent formation of the JNPC. Each of these entities will need significant additional staff as the NPPP continues and each appears to be significantly under-staffed for the magnitude of the projects being undertaken today. The IAG notes that careful attention must be given to resources for each of these entities, including the salary and benefit structure of each. In particular, each entity must be able to secure top quality staff from Jordanian universities and internationally, which requires that the salary and benefit structure among the three entities be competitive, in line with international practices. Jordan needs to be able to retain its own highly trained engineers for contributions in Jordan, and there will be (and already is) significant international recruiting ongoing within Jordan. And if Jordan does not have today enough senior personnel in key disciplines, they should actively seek to hire that expertise on the international market onto their staff (i.e., not via consultants) in order to assure that each Jordanian entity has the needed in-house expertise to be an intelligent customer. It is vital that each of these entities be staffed with highly trained, technically well-respected, leaders in each essential discipline. JNPC staff (not consultants) must exhibit expertise beyond the technical areas, to include project management, financial, and legal experts.

As an additional observation, Jordan is well positioned to make extensive use of renewables, especially solar energy. But until large-scale, very long term, storage options are available, the intermittent nature of solar means it cannot be used to support a reliable grid. In some countries, the United States, China, and France as examples, attention is being devoted to careful integration of both renewable and nuclear resources to optimize the contribution of both sources, and studies of such integration may be of interest in Jordan as well.

11.7 Commendation

Jordan has carefully followed the IAEA milestone approach in developing the legal, regulatory, and human infrastructure basis for a successful NPPP and multiple IAEA review missions confirm their success along this path.

11.8 Recommendations

1. Unless it has already been done, the strong economic case for, and absence for many attractive alternative options to, the NPPP should be fully developed and carefully discussed with the citizens of Jordan. Discussions on the safety of modern, more passively safe plants should be highlighted in public discussions, especially targeting women and schoolchildren.
2. The final EPC must cover all aspects of plant operation, fuel supply and potential used fuel takeback.
3. Jordan should join the MDEP group associated with the VVER class of reactors.
4. Unless already done, parliamentary debate and approval of the Jordanian-Russian IGA must be a step toward development of greater support for the program.
5. Jordan should initiate a second track, including focusing on a SMR option, to assure that electricity is available on the time line required by national demands.
6. The IAG notes that Jordanian regulator, JAEC, and JNPC are short of experienced staff required for projects of the magnitude being undertaken by Jordan. Hiring of international experts in key disciplines may be essential in the near term to provide oversight and mentoring of newly trained Jordanian graduates as well as oversight of hired consultants. JNPC requires staff experts (not only consultants) in a wide range of fields, including technical, financial, project management, and legal issues.

7. The Jordanian regulator, JAEC, and JNPC must have competitive/appropriate salary and benefits that enable each entity to recruit (domestically and internationally) and retain the top quality staff that are needed, and to assure that students from Jordanian universities are encouraged to apply their training in Jordan.
8. Jordan may have an opportunity to actively pursue re-activation of 123 negotiations with the United States, taking account of its fundamental commitment to international Conventions, Treaties and Standards with international review.
9. Jordan may want to explore international efforts in optimizing the integration of nuclear and renewable energy sources.

12. OUTREACH, STAKEHOLDER ENGAGEMENT

12.1 Nuclear Power

In some of the Parliamentary interactions with the IAG, it was evident that support for the nuclear energy program is not unanimous. Furthermore, in its technical meetings during its time in Jordan, the IAG heard only from the direct program participants, but success of this program requires energetic support from many elements of the GoJ, and from civil society beyond program participants. JAEC should work with other government agencies to build this broad support for nuclear power in Jordan. Government agencies with responsibilities in health, economy, environment, education, trade and other areas all have significant stakes and will realize significant benefits from the nuclear power program. For example, safety of the program with passively safe units might best be discussed by Ministry of Health and health professionals throughout Jordan. Similarly, economic attributes of the program might best be discussed by organizations other than JAEC, and may have far greater credibility if other experts in other disciplines are involved.

JNPC must be prepared for very significant public interest as the project progresses. JNPC must build a highly effective communications infrastructure, staffed with experts in public communication and with technical experts to address inquiries. Extensive educational materials, if they do not already exist, need to be prepared and available. As has been recognized in many countries, women, particularly better-educated women, are among the most vocal critics of nuclear energy. It is therefore important that the public outreach should include them specifically, as well as schoolchildren who need proper education on the subject. If they are not provided with information and understanding earlier, they may receive inaccurate or even prejudiced information before they are old enough to make their own decisions.

12.2 Peaceful Nuclear Sciences and Applications beyond Nuclear Power

Globally, the many beneficial nuclear applications besides nuclear power are led by medical applications. From biomedical research to screening, diagnostic radiology, cancer therapy and palliation, ionizing radiation for health is a multibillion business with double digit growth rates owing to aging populations and technological advances. The IAG notes that Jordanian specialists are well integrated into regional and international activities of the IAEA. To attract qualified staff and to create a positive investor environment, solid public support for the nuclear program of Jordan on uranium mining, research reactor applications and nuclear power production has to be developed. The IAG considers it of utmost importance to bring potential medical and scientific stakeholder, in areas like basic sciences, environment and cultural heritage, into the frame. The creation of a formal user community for the research reactor is to be encouraged.

Both the media and the public have to be exposed to information about the many nuclear applications which are driving scientific development and offer green and sustainable solutions to many problems faced by the growing world population. A good local example is provided by Sterile Insect Technology in the Jordan valley, which allows specific control of the medfly pest without contamination of agricultural lands and products, and without negative impacts on bees and other beneficial insects.

In the same context, the IAG considers the "Science for Peace" initiative of the well advanced SESAME project to be another important element in harnessing the potential of nuclear sciences and applications. Jordan as the host of this important interregional activity shows its dedication to the advancement of science. It will be able to broaden and strengthen its nuclear science community thanks to the many opportunities arising for advanced training and applications arising from dedicated beam lines. Synergisms might arise from interactions with the user community of the emerging research reactor.

12.3 National and Regional Setting

Radiation medicine in Jordan is well developed and has regional functions in patient care. In the view of the IAG, regional functions could be further developed. For example, the envisaged production of radionuclides and radionuclide based diagnostic kits may only be economically feasible in a regional setting; the Jordanian population does not create the critical mass for regular production of basic clinical radionuclides like I^{131} or Mo^{99}/Te^{99}. Potentially, two larger neighbors with war-ravaged clinical infrastructure could be geographically close customers for many years to come.

Proven reserves of uranium in Jordan are sufficient for about 100 GW years, e.g. for the whole life time of the first two reactors to be built. Beyond providing fuel security for an important fraction of domestic electricity production for many decades to come, export of yellow cake to regional customers could be envisaged, once the uranium market price has recovered and additional deposits have been developed.

Depending on the final choice of the reactor type, regional collaboration on the level of reactor operation, safety and security should be developed. Human capacity building, training and, later on, information exchange are obvious topics.

12.4 Commendation

By regional standards, Jordan has a well-developed nuclear science and radiation medicine community. On-going and new academic training activities will allow basing the proposed nuclear activities on a domestic work force. This provides a wide indigenous basis for outreach programs and stakeholder engagement.

12.5 Recommendations

1. JAEC should develop and work closely in partnership with other governmental agencies to provide understanding and information for the public on the rationale, importance, and safety aspects of the nuclear energy program, and of the benefits of nuclear applications in general, such as the benefits of medical applications. This is particularly important with respect to women and schoolchildren.
2. As soon as possible, JNPC should staff a professional communications branch with recognized experts.
3. The risk of "brain drain" exists and might increase due to new nuclear activities in neighbouring countries. A stimulating working environment including appropriate remuneration will be needed to maintain local capacities.
4. Proactive information on the many aspects of beneficial nuclear applications in medicine, basic science, food & agriculture, environment and cultural heritage studies should be generated for the media, opinion leaders and the public.

5. The well-developed medical community of Jordan, and medical communities in neighboring countries, should be encouraged to be active stakeholders in the development of radionuclides for diagnostic radiology and, eventually, for therapy and palliation.

13. CONCLUSION

This report summarizes the deliberations of the IAG with regard to the Jordan Nuclear Energy Program. Each chapter discusses a relevant area, and in each chapter general conclusions or specific commendations and/or recommendations are derived from the IAG studies. The conclusions, commendations, and recommendations were summarized in the Executive Summary and are discussed in each chapter.

The IAG is united in its goal to provide an expert independent report on the Jordan Nuclear Energy Program that includes actionable recommendations that should result in further strengthening the safety and viability of the existing Program.

APPENDIX A: MEMBERSHIP OF THE IAG

H.E. DR. MAROUF AL-BAKHEET	**Chair** *Former Prime Minister of Jordan*
LADY BARBARA JUDGE CBE	**Former Chairman** *UK Atomic Energy Authority*
DR. ROLF HEUER	**Former Director General** *CERN*
DR. MIKE WEIGHTMAN CB	**Former HM Chief Inspector** *Nuclear Installations & Executive Head of ONR*
PROF. DR. WERNER BURKART	**Former Deputy Director General** *IAEA*
DR. PETER B. LYONS	**Former Assistant Secretary** *Office of Nuclear Energy, DoE, USA*
PROF. AKIRA OMOTO	**Former Commissioner** *Japan Atomic Energy Commission, Japan*
DR. RICHARD. MESERVE	**President Emeritus** *Carnegie Institution for Science, USA*
DR. KHALED ELSHURAYDEH	**Secretary General** *The Higher Council for Science & Technology, Jordan*

APPENDIX B: PROGRAM OF THE IAG

DATE	ITEM
MON, FEB. 1st, 2016	Opening Remarks
	Presentation by H.E. Dr. Khaled Toukan "Overview of Jordan's Nuclear Energy Program"
	Presentation by Dr. Salah Eddin Malkawi "Human Resources Development for Jordan's Nuclear Energy Program"
	Meeting with His Majesty King Abdullah II
	Presentation by Dr. Kamal Araj "Jordan's Nuclear Power Plant Project"
TUE, FEB. 2nd, 2016	Meeting with the Prime Minister H.E. Dr. Abdullah Nsour
	Presentation by Dr. Khalifeh Abu Saleem "Jordan Research & Training Reactor (JRTR)"
	Meeting with the President of Jordan University of Science & Technology (JUST)
	Tour of Nuclear Engineering Department Facilities
WED, FEB. 3rd, 2016	Presentation by Dr. Samer Kahook "The Nuclear Fuel Cycle Commission"
	Meeting with the Deputy Speaker of the Senate H.E. Marouf Al Bakhit
	Meeting with the Speaker of the House of Representatives H.E. Atef Tarawneh
	Presentation by Dr. Majd Hawari "Nuclear Regulatory Framework"

APPENDIX C: DOCUMENTATION PRESENTED TO THE IAG

SUBJECT	DOCUMENTS
NPP	- Integrated Nuclear Infrastructure Review (INIR) Mission Phase 2 Report - Action Plan for INIR Report - JNPP summary
Uranium	- Articles on Central Jordan Uranium Project published in a special issue of Applied Earth Science Journal Volume 124, Issue 2 (June 2015) - Central Jordan Uranium Project: Estimation of Mineral Resources Report
JRTR	- Report of the Expert Mission on the Review of the Commissioning Program of the Jordan Research and Training Reactor - Action Plan for the IAEA Expert Mission
EMRC	- Integrated Regulatory Review Service (IRRS) Mission Report - Action Plan for the IRRS

APPENDIX D: ADDITIONAL DETAILS ON JORDAN'S NUCLEAR ENERGY PROGRAM

Background

Prior to 2001, nuclear applications were managed by the Nuclear Energy Department at the Ministry of Energy and Mineral Resources. In 2001, the Nuclear Energy and Radiation Protection Law (Law No. 29 for 2001) established the Jordan Nuclear Energy Commission to promote and regulate nuclear applications in the country.

In November 2006, a High Level Ministerial Committee chaired by the Prime Minister was established to develop a roadmap for implementing the nuclear energy program. The Committee acted as the Nuclear Energy Program Implementing Organization (NEPIO). The Committee produced a "roadmap" which outlined the strategic goals and activities to be undertaken to implement a nuclear power program.

In July 2007 two Laws (Nos. 42 and 43) took on the remit previously covered by Law No. 29 for 2001. Law No. 42 for 2007 addressed the establishment of the JAEC and Law No. 43 for 2007 addressed the establishment of the JNRC. Thus, the division of responsibilities between the promoter and regulator of nuclear applications in the country was clearly defined.

In January 2008, Law No. 42 for 2007 was amended, empowering JAEC to lead the development and implementation of nuclear strategy and to manage the nuclear energy program.

The "High Level Committee" was replaced by an Inter-ministerial Committee in 2009 and was chaired by the Minister of Planning, and included representatives from the Ministries of Energy, Environment, Finance, Water and Irrigation. The Chairman of JAEC and Director-General of JNRC were also Committee members.

In 2010, a new High Level Committee chaired by the Prime Minister, replaced the previous Inter-Ministerial Committee, and in July 2010, another NEPIO Steering Committee was formed.

Jordan's Nuclear Energy Program is composed of three main pillars: The NPP Project, the Uranium Exploration and Mining Project and Human Resource Development. It is intended that Jordan's Nuclear Energy Program is implemented with a high level of efficiency and transparency, in compliance with the best international standards of safety, security and non-proliferation.

The Nuclear Power Plant Project

On behalf of GoJ, JAEC signed the Project Development Agreement (PDA) with RAOS on the 22nd of September 2014. The PDA identifies project-specific activities to be carried out by both parties during the development phase as well as specific criteria required to support the investment decision. On the 24th of March, 2015, the GoJ and the Russian Federation signed the IGA on cooperation for the construction and operation of Jordan's NPP.

The Project is being implemented using a two-phased approach. Phase I (Pre-Investment Phase (PIPh)) includes concluding all financing requirements, site characterization and environmental impact assessment, in addition to the negotiations with ASE and the Strategic Partner, i.e., RAOS, on all Project related agreements. Phase II (Investment Phase) of the Project is the implementation and construction phase leading to operation, electricity production and, eventually, decommissioning at the end of the plant's lifetime.

The implementation of the Project is based on a Public Private Partnership model. At the outset, the Jordanian side will own 50.1% and RAOS will own 49.9%. ASE is the EPC contractor for the Project, whereas an affiliate of ROSATOM will be the Russian Strategic Partner and Operator for the NPP. GoJ has established in October 2015 the JNPC to be responsible for negotiating all commercial contracts with the Russian parties and implementing the Project through securing Jordan's debt and equity portion in the Project. After concluding all project agreements, JNPC will sign a Shareholder's Agreement and a Share Purchase Agreement with the relevant Russian Party in order to introduce them as a partner in JNPC thus forming the 'Project Company' that will be responsible for the construction, operation and decommissioning of the NPP.

JNPC was established as a Jordanian state-owned company to manage the PIPh. JAEC's role will continue setting the nuclear policy and strategy and manage future nuclear projects, act as the waste management organization, and in the future, it will provide Technical Support Organization (TSO) advice to both JNPC and the Regulator (EMRC) with the consideration to maintaining separation between the two groups providing the services. At the time the Decision to Invest is made, RAOS will purchase up to 49.9% of the shares of JNPC. However, JNPC and RAOS are open for other equity participation/investment in the Project and discussions are currently underway with interested investors. The Project Sponsors are currently initiating discussions with lenders to solicit and secure debt financing for the Project.

In 2009, JAEC launched environmental and feasibility studies for siting Jordan's first NPP. External international consultants were engaged to develop country wide survey study that explored potential sites in conformity with international safety standards.

A potential site considered for the location of the NPP was close to Aqaba, in the south of Jordan. However, considering the high seismicity of the region and the additional engineering cost to erect an NPP on this site, investigation was shifted to a new site located north of Amman, which includes approximately 10 km^2 of flat and undulating surface sufficient for the construction of the two nuclear units. The site was close to the main Assarma Wastewater Treatment Plant, and the quantity of treated wastewater is sufficient to meet the cooling water requirements for the NPP. However, after the Fukushima Daiichi Nuclear Power Station accident in 2011 and in response to public concerns to the proximity of the NPP to population centers, JAEC decided to move the study further away from population centers, 75 kilometers northeast of Amman on the edge of the northern desert near Qasr Amra area in the central part of Jordan. In November 2014, JAEC has selected an international consultant to carry out detailed site characterization and Environmental Impact Assessment (EIA) study, which will take about 2-3 years to be finalized.

The Uranium Exploration and Mining Project

Based on country-wide airborne magnetic and spectrometric survey conducted in the early 1980's, four areas with relatively high-level radiometric anomalies were identified to potentially contain significant amounts of surficial uranium deposits: Central Jordan Area (CJA), Hasa-Qatarana Area (HQA), Wadi Bahiya/Bayer Area; and Sahab Elabiad/Shediyya Area. These areas were subjected to varying levels of prospecting activities that included near surface radiometry measurements (car-borne and hand-held radiometry measurements), radon measurements, and grab sample analysis. Of these four areas, CJA and HQA were subjected to further prospecting activities that involved targeted bore hole and trench sampling programs.

Because of the nature of the surficial uranium deposit in CJA, CJA was selected for detailed uranium exploration activities and the CJUP was envisioned to be the first uranium project to be sponsored by JAEC. JAEC officially launched the Jordanian Uranium Mining Company (JUMCO) on January 2nd, 2013 to manage CJUP and has granted JUMCO exclusive exploration rights within the CJA, the rights of which extend until completion of a Bankable Feasibility Study (BFS).

The responsibilities assigned to JUMCO can be summarized as follows:

1. Exploration of uranium in CJA in accordance with international standards, enabling derivation of uranium resource estimates that are Joint Ore Reserves Committee (JORC) compliant.
2. Development of optimized uranium ore processing leading to the development of a pilot-scale mining plant.
3. Completion of a BFS for the purpose of producing yellow cake (U_3O_8) from CJA ore utilizing indigenous resources.
4. Securing financing required to launch full-scale mining plant(s) capable of producing ≈400 and ultimately ≈1,500 metric tons of yellow cake (U_3O_8) annually.
5. Utilize the product as feed material for Jordan NPP & a proposed regional fuel bank.
6. Marketing the product (yellow cake).

JUMCO has achieved significant progress in its pursuit to realize items [1] and [2] above, and is continuing its effort to fully realize these two tasks at hand. Work is also currently being conducted to support item [3]. The remaining items [4] through [6] cannot be completed until items [1] through [3] have achieved sufficient levels of maturity.

Until the end of March 2014, about 2,000 trenches were explored at a grid of 200mx200m covering an area of 86km^2. In conducting its work, JUMCO recruited a number of world-renowned experts in geology, sampling, QA/QC, database management, geostatistics, and resource estimation, all qualified as Competent Persons (CPs) per the JORC Code. The international team of CPs established the framework, guided and reviewed the work that has been carried out by JUMCO's geological teams. Results of the trenching were combined with drillhole data available from previous exploration campaigns and have been used for estimation of the uranium resources, which are documented in a JORC-compliant resource estimation report. These results, which reflect the work carried out by JUMCO until the end of March 2014, indicate that CJA contains approximately 269Mt of uranium ore at an average grade of 135ppm U_3O_8. This was estimated at the 94ppm U_3O_8 cutoff applied to the SMU blocks of 50mx50mx0.5m. This estimate is classified as Inferred Resources of the JORC Code.

Note further, by geostatistically extrapolating mineralized intersections in the trenches to the drilled parts of the CJA deposit outside the JUMCO explored trenches, indicate that the 'Surficial' mineralization can contain additional amounts of 40 to 150Mt of mineralization at an average grade in the range of 100 to 135ppm U_3O_8, i.e., 5 to 15Kt of U_3O_8. This potential 'Surficial' mineralization is classified as Exploration Results of the JORC Code. JUMCO published results in 2014 are presented in the table below.

Resources of CJA reported at 94ppm U_3O_8 as of March 31st, 2014

Region	Ore Tonnage (Mt)	Grade (U_3O_8) ppm	Metal (U_3O_8) tons
'Surficial' Mineralization	67.5	159.0	10,731
'Deep' Mineralization	201.7	127.2	25,658
Total	269.2	135.0	36,389
Exploration Results	40→150	100→135	5,000→15,000

CJA also contains areas with intense levels of ground gamma anomalies that have not yet been explored by JUMCO, but were subjected to prospecting activities by the Natural Resource Authority in the 1990's (as were other areas in CJA). Prospecting carried out by the Natural Resource Authority indicates that these areas have uranium mineralization similar to those in other areas of CJA. Since the issuance of JUMCO's maiden JORC-compliant report in 2014, these areas have undergone uranium exploration by trench sampling. Furthermore, JUMCO refined its trenching program in a selected number of areas that were reported in 2014. A revised resource estimation report is expected to be released by JUMCO in May 2016, in which about 5,000 tons of uranium are expected to be added as Inferred Resources and between 5,000 to 10,000 tons are expected to be upgraded to Indicated Resources of the JORC Code.

Metallurgical studies of the CJ ore commenced prior to the establishment of JUMCO, which have been carried out in the uranium extraction and processing laboratories of JAEC. The metallurgical studies continued under the auspices of JUMCO. These metallurgical studies were initiated to support the design of an efficient process flow sheet and optimize variables and parameters related to extracting uranium in the form of yellow cake from the surficial uranium ores of CJ. Furthermore, these metallurgical studies are intended to experimentally generate the required data for conducting feasibility analysis at all levels leading eventually to the BFS.

Three different phases of metallurgical tests were undertaken so far and a fourth phase is underway. The first phase consisted of preliminary investigation conducted on randomly selected samples produced from the trenches and cores collected by geologists in the exploration area. These samples were subjected to bench-scale leaching studies. The results indicated obvious amenabilities toward alkaline leaching. Moreover, the relatively soft host rocks were also deemed amenable to crushing and grinding processes. These bulk samples were subjected to series of physical and chemical testing. Uranium deportment analysis on these samples showed that uranium is distributed in all size fractions; indicating the relative abundance of uranium in the fines vs. the coarse fraction. Dynamic leaching tests confirmed the previous results obtained from the bench-scale leaching studies, but also revealed more information regarding the leaching kinetics, particle size effect on recoveries, and the maximum achievable recoveries.

Justified by the results obtained from the metallurgical tests of the first and second phases, a process flowsheet based on the heap leach concept was proposed. Testing this concept was started on a semi-pilot scale level using 1m high columns irrigation rates, reagent concentration, ore crush size, bed slumping characteristics, etc., were all investigated. Recoveries were relatively high and when checked, these recoveries matched the maximum achievable recoveries observed from the bench-scale leaching studies.

Guided by results of JUMCO's exploration so far, twelve areas within CJA have been identified for collection of bulk samples that have been deemed to exhibit characteristics that represent the CJA ore body. These samples, coupled with results of dry and wet abrasion tests and pending results of mineralogical studies conducted on a selected number of samples, will be utilized to carry out further metallurgical testing for pilot scale column tests (6m→9m high) and in the large box testing (3m wide by 3m deep by 6m high).

Phase I of the pilot scale plant was commissioned in JUMCO's field camp in December 2015, which consists of a six column test facility with 6m high columns (expandable to 9m high). Phase II of the pilot scale plant, which will also be constructed and launched in JUMCO field camp, is expected to be commissioned during the latter part of 2016.

The following summarizes results obtained from metallurgical testing that have been carried out so far:

- Amenability of the CJ ore towards alkaline leaching conditions.
- Ease of crushing and grinding, due to the relatively soft structure of the rocks.
- Uranium is distributed in all size fractions without any preferential distribution.
- Large percentage of mineralization is reasonably liberated.
- Heap leach testing indicated relatively high uranium recoveries, 80%→90%.
- Dry and wet abrasion tests indicated migration of uranium grains toward the finest cut, 45µm.
- Heap leach concept has reached a stage to allow testing for feasibility.
- Ore upgrade concept is under evaluation.
- Twelve bulk samples (600→700Kg each) deemed to represent the CJA ore will be subjected to detailed metallurgical testing for feasibility studies of the heap leach concept and for evaluating ore upgrade concepts.
- One large sample from a 5m wide by 5m long by 5m deep pit was also collected for testing for detailed metallurgical testing.

Human Resource Development – Key Facilities

Jordan Subcritical Assembly

JSA is the first nuclear facility to be constructed in Jordan, at JUST campus, for the purposes of education, training and experimental research. JSA adopts the vertical platform structure with the core vessel placed on a supporting structure while an operating platform surrounding the vessel is used for fuel loading and other operation and maintenance activities. The fuel used in JSA is similar to that employed in commercial NPPs. It consists of a number of fuel rods arranged in square arrays. Each fuel rod contains UO_2 fuel pellets with a U^{235} enrichment of 3.4 wt %, and the Zr-4 alloy as the cladding material. Light water is used as the moderator and coolant. JSA is driven by a pneumatically controlled Pu-Be neutron source.

Following the commissioning of JSA in 2013, it is mainly being utilized for Nuclear Reactor Physics Laboratory training of nuclear engineering students at JUST. Experiments conducted using JSA include, but are not limited to, approach to criticality, flux mapping, reactivity determination using source jerk method, Rossi alpha method, Feynman alpha method, and a number of other experiments.

Jordan Research and Training Reactor

JRTR is being built on the campus of JUST by Korean Atomic Energy Research Institute and Daewoo Engineering & Construction (KDC) consortium. The JRTR will provide a strong training and research platform for nuclear engineering students and other nuclear science experts. It will also be utilized for radioisotope production in support of regional medical, industrial and agricultural sectors. The JRTR is nearing completion and scheduled to undergo "Hot Commissioning" soon, and will be operational by the end of this year.

JAEC has been building JRTR as a tool to develop human resources for the NPPP and to enhance nuclear science and technology infrastructure in the country. The JRTR is partially funded from the budget of the GoJ and a soft loan from the Korean Government. KDC has been designing and constructing the JRTR through an EPC contract with JAEC.

The JRTR is being built on the campus of JUST to be the corner stone for a center of excellence in nuclear science and technology in Jordan. JRTR is a multipurpose, 5 MW_{th} upgradable to 10 MW_{th}, reactor. It uses the well proven LEU fuel type plate, U_3Si_2 in Aluminum matrix. The thermal neutron flux in the core center is 1.45E14/cm^2.s that decreases to 5.5E12/cm^2.s at the outer boundaries of the reflector. Twenty two in-core irradiation locations will be available mainly for Neutron Transmutation Doping (NTD), Neutron Activation Analysis (NAA), Radioisotope Production, Research, Training and Education. Particularly, three facilities for Ir^{192}, I^{131}, and Mo^{99} production using neutron activation will be operational at the start-up date. Also On-Power Loading and Unloading of targets shall be possible for Ir^{192} and Mo^{99}.

Three facilities of low-gamma background environment, for NAA will be operational. In particular, NAA requires thermal and epithermal spectra; two thermal and one epithermal spots will be available. The NAA Facility will be equipped with Pneumatic Transfer System. Very soft spectra can be utilized (a future plan). Two NTD locations for up to 6" ingots and one for up to 8" shall be available. Three other locations for future expansion will be available. Other locations can be utilized for various applications.

For the ex-core irradiation services, there will be four tangential beam ports and one thermal neutron column facing the core. The beam ports will be used for Neutron Radiography and two beam ports for Standard Applications. In addition, a future Cold Neutron Source is planned to be installed.

APPENDIX D: ADDITIONAL DETAILS ON JORDAN'S NUCLEAR ENERGY PROGRAM

The JRTR is being regulated and supervised by EMRC from which the construction and operation permits must be obtained. The application for the Construction Permit was submitted to the former JNRC in July 2011 and the Construction Permit was granted in August 2013, while the application for the Operating License (OL) was submitted to EMRC in December 2014 and the OL is expected to be issued soon. Most of the JRTR equipment and systems have been installed and they are being tested and commissioned. The hot commissioning phase will start after fuel loading in the core planned for early April. This process will continue until the handover of the project from KDC to JAEC, which is expected by the end of 2016.

The strategic plan of the JRTR for the period 2016-2020 has defined the following objectives for the JRTR:

- Education and training in support of programs in nuclear engineering and nuclear reactor operations.
- Forensic analysis (neutron activation analysis).
- Radioisotope production (Mo^{99}, I^{131}, Ir^{192}, and others) for medical and industrial applications.
- Neutron beam applications including nondestructive testing (neutron radiography), neutron scattering and neutron diffraction.
- NTD (silicon doping).

Regulatory Framework

EMRC, as a successor to JNRC, has continued the development of the nuclear regulatory framework. EMRC has received the IAEA IRRS mission and is now implementing the Action Plan to ensure the implementation of the IAEA recommendations and suggestions.

EMRC has steadily built its capacity and developed its human competencies to conduct its mission independently, placing nuclear safety and security as its utmost goal and priority. Consequently, the GoJ has approved the national nuclear safety policy upon which the new nuclear law has been drafted in a very comprehensive manner taking into account comments from the IAEA on the previous Law No. 43. The new law includes provisions for appeals against decisions of the regulatory body, provisions for nuclear and radiological emergency preparedness and response, as well as, criteria for release of facilities and activities out of regulatory control.

Assisted by IAEA expert teams as well as a consortium of international consultants and TSO (AdSTM, KINS) EMRC has already issued the OL for the operation of the JSA as well as the Construction Permit for JRTR, and recently its fuel import license. Currently, EMRC is also reviewing the JRTR OL submitted by JAEC in December 2014.