# CHAPTER 10

# CIVILIAN NUCLEAR POWER IN THE MIDDLE EAST: THE TECHNICAL REQUIREMENTS

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For a developing country contemplating the construction of its first nuclear power plant (NPP), the technical requirements alone can appear daunting. This is before the legal, regulatory, economic, and political dimensions are brought into the mix. As the International Atomic Energy Agency (IAEA) noted in a recent report, launching an NPP "is a major undertaking requiring careful planning, preparation and investment in a sustainable infrastructure that provides legal, regulatory, technological, human and industrial support to ensure that the nuclear material is used exclusively for peaceful purposes and in a safe and secure manner."[1]

Against this background, this chapter seeks to examine the feasibility of three proposed new nuclear power programs in the Middle East: in Egypt, Saudi Arabia, and Turkey. Its aim is to explore the extent to which each of these countries currently has "what it takes," i.e., meets the technical and regulatory requirements, to build and operate an NPP. These three states have been chosen because, of all the states that have recently shown an interest in nuclear power, there has been the most speculation about their intentions. Moreover, these three states are useful case studies. Turkey, for instance, which has both a relatively strong economy and a relatively well-developed nuclear program, is representative of Libya. Saudi Arabia, like the United Arab Emirates (UAE) and Qatar for instance, is very rich but has comparatively little extant nuclear expertise. Egypt, a relatively poor state which already has extensive nuclear expertise, lies at the other end of the spectrum and, in this respect, appears to be unique among Middle Eastern states.

All three states have shown interest in nuclear energy at various times over the past half century. As discussed below, Egypt and Turkey have made repeated attempts to acquire nuclear reactors but without success. This chapter aims to shed some light on the question of whether it will be different this time and hence to contribute to the broader debate about the management of the "nuclear rennaissance." In spite of the growing literature about the intentions of states seeking to develop nuclear power, remarkably little has been written on this question of capabilities.[2] The answers that this chapter provides should be regarded as preliminary. They are based on an analysis of available open-source literature, and consequently there are a number of issues that we fully acknowledge are not authoritatively addressed. Issues requiring further study are indicated in the text.

The chapter begins with a framework for analysis which sets out in generic terms the technical, legal, and regulatory requirements to build and operate an NPP with a capacity of approximately 1 gigawatt (GWe). The framework is then applied to Egypt, Saudi Arabia, and Turkey. The chapter identifies the areas in which the three countries are currently deficient and, in doing so, generates greater understanding of the feasibility of proposed new nuclear power programs in the Middle East.

## A FRAMEWORK FOR ANALYSIS

The difficulty of developing a first NPP clearly depends on a number of factors including, most importantly, the degree to which the host state uses external assistance. In this chapter, we make the following assumptions about the nuclear power project:

1. The NPP will be of approximately 1 GWe capacity;

2. The NPP will be supplied by a major supplier state (such as Russia, the United States, France, Germany, South Korea, Canada, etc.)

3. The NPP will be either a pressurized water reactor (PWR) or a boiling water reactor (BWR);

4. The NPP will be procured from an external supplier under a "turn-key" contract, which includes the provision of fuel and the repatriation of spent fuel. Whether, in practice, any supplier state is willing to take back spent fuel (repatriation) remains to be seen. Nevertheless, this assumption is still included because it leads to conservative conclusions;

5. The NPP contract will include a technology transfer clause, including training, to help the host state establish a domestic skills base, as well as local suppliers capable of supporting the nuclear power sector; and,

6. The NPP will be run by the host nation through an operating organization with the requisite "rigor, culture, ethics and discipline needed to effectively manage nuclear power technology with due regard to the associated safety, security, and nonproliferation considerations."[3]

This set of assumptions is *not* a prediction about how any given state will choose to develop nuclear power; it is a model that might be adopted and that we utilize here to make the ensuing discussion more concrete. There are, of course, other plausible models. For instance, a state could further reduce the challenge of developing an NPP by contracting out its operation, as well as construction, to an external supplier.

Based on this model, the analytical framework is broken down into the following components: (1) the staffing requirements for the operation and maintenance of the NPP; (2) the legal and regulatory framework for the siting, construction, commissioning, operation, and decommissioning of the NPP; (3) the suitability and reliability of the electricity grid for the NPP and its proper and safe operation; and (4) the waste management and decommissioning requirements. The extra requirements imposed by desalination, which has been cited as one possible use for an NPP, have not been included since they are very modest. Typically, for instance, desalination represents "less than 5% of the total plant cost."[4]

The framework is largely based on IAEA guidance. To test whether this guidance is actually reflective of state practice, the framework is illustrated with the case of Slovenia. This country was selected because it has relatively modest national resources and operates just one NPP (a PWR) at Krško (jointly with its neighbor, Croatia). The Westinghouse-supplied reactor is rated at 730 megawatt (MWe) gross[5] and the fuel is provided by the supplier.[6] The plant commenced commercial operations in 1983,[7] and as a result of the dissolution of Yugoslavia, the Krško NPP is jointly owned by Slovenia and Croatia with half of the electricity generated going to each country.[8]

## STAFFING REQUIREMENT FOR THE CONSTRUCTION AND OPERATION OF AN NPP

When first contemplating the development of nuclear power, several staffing requirements need to be taken into account. Most obviously, there is the need for "a fully staffed nuclear power plant operation, maintenance, and technical support organization."[9] The IAEA estimates that this requires between 200 and 1,000 staff.[10] Indeed, in 2007 the Krško plant employed 573 staff.[11] However, a report published by the Office of Technology Assessment in 1993 noted that staffing at "single unit nuclear plants" in the United States increased from an average of about 150 employees to over 1,000" from 1977 to 1990. This expansion in the number of operating personnel occurred partially as a result of larger plants going online but also because of growing regulatory requirements, among other things.[12] Moreover, it is unlikely that the figure of 1,000 includes the personnel required to refuel and refit nuclear power plants every 12 to 24 months. For example, a July 1975 study notes that the annual refueling operation performed by General Electric at Boston Edison's 690 MWe Pilgrim nuclear power plant in Plymouth, MA, took "about 6 weeks" with General Electric (GE) bringing in about 40 specialized personnel to oversee the work along with a further 80 staff employed by subcontractors to provide assistance.[13] It is quite probable that these numbers have grown since the mid-1970s in part because of expanding regulatory requirements.

In order to operate an NPP in an effective and safe manner, the workforce will require technical skills in a range of disciplines including nuclear engineering, instrumentation and control, electrical engineering, mechanical engineering, radiation protection, chemistry, emergency preparedness, refueling and refitting operations, and safety analysis and assessment.[14] Creating this expertise requires "enhanced educational opportunities for nuclear science and technology."[15] At Krško, for instance, more than one-third of the 573 staff have what is described as, "higher, high, or university education."[16] On top of the relevant "scientific, engineering, and other technical education," NPP staff are usually expected to have "3 or more years of specialized training and experience prior to the initial fuel loading" of the plant.[17] In terms of staffing requirements for the operation of a first NPP then, a credible plan will require education and training programs to produce the human resource base to ensure that there is "a continuing flow of qualified people to all areas of the programme. . . ."[18]

Under our model, a great deal of the necessary training and experience is initially provided by the external supplier of the NPP as part of the contract (again, using this assumption leads to conservative conclusions; whether all suppliers are willing and able to provide this level of service in practice remains to be seen.)[19] For reasons of long-term sustainability, however, we also assume that the host state also wants to establish a domestic skills base and local suppliers who are capable of supporting the NPP in the future. Here, international assistance may also be useful.[20] In Slovenia, for example, the Krško plant is a member of Westinghouse's Pressurised Water Reactor Owners' Group.[21] It is also a member of the Nuclear Maintenance Experience Exchange (NUMEX) in order to further assist with relevant knowledge transfer.[22] Moreover, to address the challenge of an aging workforce, the IAEA recently participated in a joint mission with the World Association of Nuclear Operators at Krško to capture tacit knowledge from retiring workers.[23] Based on the available literature, it is impossible to assess the effectiveness of these programs.

## LEGAL AND REGULATORY REQUIREMENTS

A country embarking on a nuclear power program needs to establish a comprehensive legislative framework encompassing all issues related to the application of nuclear energy. The framework needs to cover site selection, licensing, commissioning, decommissioning, safety, security, safeguards, transport, and liability as well as "the commercial aspects related to the use of nuclear material."[24] While the legal frameworks of other countries can be used as a guide, there is a need to localize the framework by taking into account the existing constitutional and legislative base of the country, "cultural traditions, scientific, technical and industrial capacities, and financial and human resources."[25]

When planning a new nuclear power program, a process needs to be established for the regulatory organization to authorize the siting, commissioning, and operation of the NPP. This process can (but does not have to) incorporate an independent safety review of the reactor design—a particularly challenging task. The regulator will also require "the capabilities to plan and implement the review and safety assessment activities of the proposed facility throughout its life."[26] There is also some "shared functions" including, for example, "emergency preparedness and response, national and international cooperation, dissemination of technical and scientific information, environmental assessment, and communication with the public and other stakeholders."[27] The regulator should be able to fulfill its mandate in an independent manner with "clear authority and adequate human and financial resources."[28] However, the principal responsibility for the safety of facilities lies with the operating organization.[29]

Legislation covering liability in case of an accident is particularly important but also complex to implement. Liability is discussed in depth in another chapter in this volume, but one issue worth discussing here, because it has the potential to significantly affect the development of nuclear power, is the 1997 Convention on Supplementary Compensation for Nuclear Damage (CSC). The CSC links "countries with strong nuclear liability systems . . . [to] distribute the economic burden among several countries through a system of contributions by the member States in the unlikely event there were another catastrophic nuclear accident."[30] As of May 2008, only four states (Argentina, Morocco, Romania, and the United States) had the ratified the convention, and it had not yet entered into force.[31] However, U.S. nuclear firms have made it clear that they will not trade with states that have not adopted the CSC.[32] In contrast, French and Russian firms probably will. Preparing and implementing liability legislation is a significant challenge for a regulator but does affect the nuclear assistance that states can receive.

Based on an examination of existing national regulatory structures, the IAEA estimates that a nuclear regulatory organization comprising "30–50 staff members would be necessary for starting the implementation of a nuclear power plant programme."[33] It is important that "the technical training, knowledge, and capabilities” of these employees is “adequate for competent interaction with the owner/operator, supplier organizations and consultants.”[34] External help is generally available to develop the required human resources.

The Slovenian regulator, the Slovenian Nuclear Safety Administration (SNSA), employed 34 people in 1999 comprising engineers, physicists, and other technical and administrative staff.[35] Croatia’s State Office for Nuclear Safety commenced work on June 1, 2005.[36] As of March 29, 2007, 12 of the Office’s 18 staff positions had been filled.[37] This makes a total of 52 staff devoted to the regulation of nuclear safety in both countries, although it does not appear that staff from Croatia’s State Office for Nuclear Safety are connected to the Krško plant. Interestingly, whether the figure is 34 or 52 staff, this appears to be relatively staff heavy when only one nuclear power plant is involved. In the United Kingdom (UK), for example, some 250 staff work in the safety activities of the Nuclear Directorate in the Health and Safety Executive (HSE) which regulates the country’s nuclear industry; three fifths of this figure are technical staff.[38] The HSE is responsible for regulating nuclear safety at 10 nuclear power plants (19 reactors in total) as well as conversion, fuel fabrication, enrichment, and reprocessing facilities at Springfields (conversion, fuel fabrication), Capenhurst (enrichment) and Sellafield (reprocessing, MOX fuel fabrication).

The SNSA’s 1999 budget was €1·4 million.[39] As a result of purchasing an American NPP, Slovenia has acquired a good knowledge of American regulations and benefits from the U.S. training regime; SNSA inspectors are trained at the U.S. Nuclear Regulatory Commission, and the SNSA receives information on modifications to NRC regulations when they are implemented.[40] The Slovenian experience would suggest, therefore, that the choice of country from which to buy an NPP should not be seen as related solely to initial design and construction characteristics, but rather as a long-term partnership including the emulation of that country's regulatory standards. However, the extent to which different suppliers are willing and able to offer this degree of cooperation is an open question.

## ELECTRICAL GRID REQUIREMENTS

A country's existing and planned electrical grid must also be taken into account when contemplating the initiation of an NPP. The main issues in this respect include whether the grid is stable and large enough to absorb the planned output from the NPP, and whether it is sufficiently reliable to ensure the steady and safe operation of the plant. It is generally accepted that an individual power plant should not constitute over 5-10 percent of a grid's total installed capacity.[41] Moreover, it is also necessary to have two independent and reliable sources of electricity for the plant to assure the continued operation of the reactor control systems. This could turn out to be a particular challenge for developing countries, even those with large electricity grids.

A major problem with electrical grids in many developing countries is that they are both small and unreliable. In such circumstances, any serious effort to launch a NPP requires a plan to improve the grid's reliability. It also entails a plan to increase the grid's size or to opt for a smaller NPP (although for the purposes of this chapter, we assume the former).[42] The grid size could be increased by domestic expansion or integration with grids in neighboring countries or on a wider regional basis. By integrating at the regional level, the resultant grid is likely to be significantly larger than a national system and probably more reliable as a result.[43]

Slovenia offers an interesting example. The Krško plant generates 40 percent of the total electricity produced in Slovenia.[44] On face value, this figure would suggest that Krško's contribution to the national grid is well above the level recommended by the IAEA. However, Slovenia is connected to the Union for the Coordination of Transmission of Electricity (UCTE) grid. Indeed, Krško reportedly plays a significant role in stabilizing voltages for UCTE as a whole.[45]

## WASTE MANAGEMENT AND DECOMMISSIONING REQUIREMENTS

Any politically-acceptable plan to initiate an NPP needs to account for waste management and decommissioning. In terms of high-level radioactive waste, one of the key assumptions highlighted earlier is that the external supplier is responsible for repatriating spent fuel (after a period of initial storage in proximity to the NPP). This requires only the construction of interim storage for spent fuel, not a long-term repository. An agreement with the external supplier to repatriate spent fuel obviously lessens the disposal demands on the recipient and generates international confidence in nonproliferation. The alternative to the repatriation of high-level waste is the construction of a national disposal site which "for a small nuclear programme could be prohibitively expensive."[46]

The quantity of low-level waste (LLW) produced by a nuclear reactor depends highly on the type of reactor and the way that waste is treated. For instance, in 1979, typical annual disposal volumes for LLW from commercial light water reactors were in the range of 500-1,500 $m^3$.[47] Since then, Western reactors have typically reduced disposal volumes by "at least an order of magnitude," whereas disposal volumes from Russian VVER reactors have remained essentially unchanged.[48] In the United States in 1997, for instance, the average disposal volume per reactor was about 55 $m^3$.[49] A state has to develop a repository for the final disposal of this LLW, which it would presumably handle "in accordance with the procedures that have been established for the management of existing radioactive materials, such as radioactive sources and radioactive waste generated by medical use of radioactive substances."[50]

Planning for the decommissioning of an NPP should be integral to the process of developing it. This involves planning for the clean up of all radioactivity associated with the NPP as well as its dismantling. While some 99 percent of the radioactivity is associated with spent fuel, the remainder involves "surface contamination of plant" and radioactivity from "'activation products' such as steel components that have long been exposed to neutron irradiation."[51] About 6,200 tons of radioactive material can be expected to result from the decommissioning of a 1 GWe PWR.[52] This requires a suitable site for final disposition.

One important reason for planning for decommissioning in advance is so that a country is able to opt for pre-payment by, for example, depositing money "in a separate account to cover decommissioning costs even before the plant begins operation."[53] Alternatively, as in the United States, an "external sinking fund (Nuclear Power Levy)" is the preferred method by which such a fund "is built up over the years from a percentage of the electricity rates charged to consumers."[54]

In the Slovenian context, responsibility for waste disposal and decommissioning is shared between Slovenia and Croatia.[55] Like many other countries, there is a debate in Slovenia over what to do with Krško's high level waste as the deal to supply the reactor did not include provisions for the repatriation of spent fuel.[56] Krško's waste and spent fuel is stored at the plant itself and existing capacity is reported to be sufficient until 2023.[57] On the decommissioning front, the Croatian government drafted a plan in September 2007 to set up a fund of €350 million for the dismantling of the Krško NPP to be funded equally by Croatian and the Slovenian governments.[58] Depending on the method of decommissioning Krško, roughly half the costs are attributable to spent fuel management.[59] While the Slovenian and Croation governments are obviously planning for the decommissioning of the plant, it would appear that the issue of long-term waste disposal has yet to be resolved, which illustrates the importance of factoring this in at the very outset of the planning stages.

## PLANNED NUCLEAR POWER PROGRAMS IN EGYPT, SAUDI ARABIA, AND TURKEY

Having set out a framework for examining the technical and regulatory requirements for the development of an NPP, we proceed to examine what that framework indicates about the challenges that Egypt, Turkey, and Saudi Arabia need to confront. It is informative to begin by providing some background on each of the country's nuclear programs and ambitions.

**Egypt.**

Egypt has had an interest in developing nuclear power since the 1960s. It entered into numerous sets of negotiations and even signed contracts for the provision of nuclear reactors with, among others, Siemens and Westinghouse, but without any significant results.[60] In September 2006, however, the Egyptian government announced that it was reinvigorating its civil nuclear power program. Currently the country's power requirements are fulfilled largely by oil and gas, but Egypt has been experiencing supply shortages at a time of rapidly increasing demand. The Energy and Electricity Minister Hassan Younis stated in March 2007 that under current projections Egypt will build "10 nuclear-powered electricity-generating stations across the country."[61] El Dabba is reported to be the location for the first NPP.[62] Several countries have recently said they would work with Egypt in the context of providing the technology and materials to launch a nuclear power program. These include Canada, China, France, Germany, Russia, South Korea, and the United States.

**Saudi Arabia.**

Saudi Arabia is perceived to be the prime motivator of the announcement by the Gulf Cooperation Council (GCC) in December 2006 which states that the organization is launching a "joint programme in nuclear technology for peaceful purposes, according to international standards and arrangements."[63] Their reported plan is to start developing a first joint NPP by 2009—a target that is certain not to to be met. The UAE appears to have made the most progress so far of any of the GCC states, and recently published a white paper on nuclear energy which "renounc[ed] any intention to develop a domestic enrichment and reprocessing capability."[64] For its part, Saudi Arabia has demonstrated an interest in developing a nuclear power capability since the 1970s, which has been motivated, in part at least, by its potential application in the field of desalination.[65] Several NPP supplier countries have offered their services to the GCC as a whole as well as to individual members. In addition to a commitment from the IAEA to provide technical expertise, Saudi Arabia has received offers of assistance from Russia, France, and the United States.

A "US-Saudi Memorandum of Understanding (MOU) on Civil Nuclear Energy Cooperation" signed in May 2008 commits the United States to:

> assist the Kingdom of Saudi Arabia to develop civilian nuclear energy for use in medicine, industry, and power generation and will help in development of both the human and infrastructure resources in accordance with evolving International Atomic Energy Agency guidance and standards.[66]

Under the MOU, Saudi Arabia also "stated its intent to rely on international markets for nuclear fuel and to not pursue sensitive nuclear technologies, which stands in direct contrast to the actions of Iran."[67] In doing so, Riyadh has committed itself not to develop uranium enrichment and plutonium reprocessing capabilities if it accepts U.S. assistance. This commitment is not binding if Saudi Arabia opts not to receive American assistance and deals with other suppliers instead (indeed, some have questioned the likelihood of the United States insisting upon this condition being written into a reactor procurement contract).

**Turkey.**

Like Egypt, Turkey has tried on multiple previous occasions to develop nuclear power. These attempts have failed because of the economic costs involved as well as environmental, safety and proliferation concerns.[68] Today, Turkey is a net energy importer and nuclear power again appears attractive, given that its electricity consumption is increasing at a time of rising energy prices. In March 2008, Turkey issued a tender, calling for bids to construct the country's first NPP at Akkuyu on the Mediterranean coast. Potential technology suppliers for Turkey's renewed program include South Korea, Canada, Germany, and the United States.

## STAFFING REQUIREMENTS FOR THE CONSTRUCTION OF AN NPP

**Research Reactors.**

Research reactors are very useful for training a workforce in most, if not all, skills that are needed for an NPP. Although research reactor staff require additional training before being able to operate a power reactor, they are nonetheless among the most usefully-skilled personnel in a state constructing its first NPP.

From this perspective, the best prepared state is Egypt, which has two research reactors: the ETRR-1 (a 2 MWt Russian-supplied tank-type reactor) and the ETRR-2 (an Argentine-supplied 22 MWt pool-type reactor).[69] In particular, as a relatively high-powered research reactor, the ETRR-2 is especially relevant for training power reactor operators.[70] Nevertheless, given that between them, Egypt's two research reactors only employ a total staff of 60 (of which 22 are operators), it would be a challenge for Egypt to train the 200-1,000 personnel required for the operation of an NPP.[71]

Turkey definitely has one operational research reactor: the ITU-TRR (a U.S.-supplied 250 kW, TRIGA Mark II reactor).[72] This reactor, located at the Institute for Nuclear Energy at Istanbul Technical University, is less suited than Egypt's to training power reactor operators because it has a much smaller staffing complement (two operators and a further four staff). In addition, Turkey does have a second reactor, the TR-2 (a 1 MWt U.S.-supplied pool-type reactor that was subsequently upgraded to 5 MWt by Belgium), but reports on whether it is currently operational are contradictory.[73] Located at the Çekmece Nuclear Research and Training Center, it has been used for training, research, and isotope production.

Saudi Arabia does not have a research reactor. Saudi scientists have conducted theoretical studies into research reactor design and some very specific aspects of power reactor technology (such as the best type of concrete to use as shielding).[74] In addition, King Abdul Aziz University has reactor simulator software for use in training students.[75] Although of some relevance, such theoretical training cannot compensate for hands-on experience. If Saudi Arabia is to develop a nuclear power program, the purchase of a research reactor would likely be a useful investment.

**Nuclear Activities.**

A second key group of skilled personnel are those with experience of other relevant areas of industry or academia. Some of these could be of direct use in an NPP. For instance, although the model of nuclear power development used in this chapter assumes both fuel provision and take back, a state with experience with other parts of the fuel cycle (such as waste disposal or fuel fabrication for research reactors) would have personnel with training in disciplines such as radiation protection or chemistry who could be retrained to work in an NPP. More generally, the following material is intended to provide an indication of the overall level of nuclear expertise in a state. For instance, the fact that there are a relatively small number of Ph.D.s working in Saudi Arabia's premier nuclear research institution, the Atomic Energy Research Institute (AERI), is significant because it is presumed to be indicative of a general lack of nuclear expertise, not because a large number of doctoral-level scientists is necessarily required to operate a nuclear reactor. We have not attempted to develop a quantitative metric for the level of expertise required to operate a nuclear reactor, although it would be very valuable to do so.

Based on a survey of open-source literature, the fuel cycle activities conducted by Egypt, Saudi Arabia and Turkey are summarized in Table 10-1. Waste management has not been included but is discussed here.

| | Egypt | Turkey | Saudi Arabia |
|---|---|---|---|
| Mining | Exploratory mining[76] | Some research, survey work and feasibility studies into uranium; interest in thorium[77] | Some research, survey work and feasibility studies[78] |
| Milling | Significant research[79]<br><br>Facilities: Inshas Pilot Plant (used 1990—1996; little current information)[80]; Phosphoric Acid Purification Plant (Inshas, designed to extract uranium from phosphate ore; used for non-nuclear purposes)[81] | Significant research[82]<br><br>Facility: Koprubasi Uranium Pilot Plant (little information available; status unclear)[83] | Occasional research of slight relevance[84] |
| Conversion | Bench-scale experiments before 1982 (when Egypt's safeguards agreement with the IAEA entered into force);[85] one more recent publication of potential relevance[86]<br><br>Facilities: Nuclear Chemistry Building (Inshas) | Significant bench-scale research[87]<br><br>Facility: Nuclear Fuel Pilot Plant (Instanbul) | No activities identified |
| Enrichment | One bench-scale project of potential relevance[88] | One bench-scale project of potential relevance[89] | No activities identified |

**Table 10-1. Fuel-Cycle Activities in Egypt, Saudi Arabia, and Turkey.**

| | Egypt | Turkey | Saudi Arabia |
|---|---|---|---|
| Fuel Fabrication | Capability to fabricate fuel for the ETRR-2[90]<br><br>Facilities: Fuel Manufacturing Pilot Plant (Inshas); Nuclear Fuel Research Laboratory (Inshas)[91] | Significant bench-scale research<br><br>Facility: Nuclear Fuel Pilot Plant; Nuclear Applications Laboratory (METU)[92] | No activities identified |
| Reprocessing (including irradiation experiments and isotope separation facilities) | Continuous but low intensity bench-scale research from before 1982 to 2003;[93] some research conducted by the Atomic Energy Authority is potentially relevant[94]<br><br>Facilities: Hot cells at the ETRR-1 and ETRR-2 (Inshas) and the Hot Laboratory and Waste Management Center (HLWMC; Inshas);[95] Hydrometallurgy Pilot Plant;[96] Nuclear Chemistry Building;[97] Radioisotope Production Facility (under construction)[98] | Sporadic largely-theoretical research since 1980s[99] | No activities identified<br><br>Facilities: Hot cells at the King Faisal Specialist Hospital and research Center (Riyadh); separation laboratories at the Atomic Energy Research Institute[100] |

Based on an article by James M. Acton and Wyn Q. Bowen, "Nurturing Nuclear Neophytes," *Bulletin of the Atomic Scientists*, September-October 2008.

**Table 10-1. Fuel-Cycle Activities in Egypt, Saudi Arabia, and Turkey. (cont.)**

Egypt has the most impressive track-record record having conducted significant research and development (R&D) activities across the whole fuel cycle (except enrichment). Probably the most sophisticated fuel cycle facility in Egypt is the Fuel Manufacturing Pilot Plant at Inshas. This is a semi-pilot facility provided by Argentina to produce the fuel elements for the ETRR-2 reactor.[101] Although some of Egypt's activities were undeclared and subject to an IAEA investigation from 2004-05, its past activities demonstrate that it possesses a range of skilled nuclear workers and the means to train them.

Like Egypt, Turkey has conducted research into many stages of the fuel cycle. From open-source literature, the current status of many of these activities is hard to determine but, on balance, it appears that Turkish research and development efforts generally lag slightly behind those of Egypt. Nonetheless, the range of nuclear activities conducted by Turkey and the in-depth nature of some of this research clearly indicates that Turkey starts from the position of a relatively strong nuclear sciences base.

In contrast, Saudi Arabia has only limited experience of nuclear activities. In fact, the survey revealed that the only part of the fuel cycle of which Saudi Arabia has significant experience is mining and milling—the least relevant part from the perspective of developing nuclear power.

## NATIONAL TRAINING AND RESEARCH INFRASTRUCTURE

Based on the analysis provided above, it is evident that the three states considered by this chapter need to educate and train substantial numbers of scientists, engineers, and technicians. To accomplish this, they would require a strong university sector capable of producing suitable graduates. In addition, a strong national infrastructure capable of coordinating and implementing a national strategy would be a significant asset.

Turkey has a strong nuclear infrastructure based around several national organizations and universities.[102] Turkey's relative strengths in this respect are partly the result of the country's previous failed attempts to set up nuclear power plants. Turkey's biggest strength is perhaps its university sector. Our survey identified 11 universities that have significant teaching and/or research experience relevant to the development of nuclear power (in addition, a number of other universities also appear to have some kind of relevant expertise). Moreover, there are very strong interconnections between the universities and the Turkish Atomic Energy Commission (TAEK). These should enable the country to implement a coherent national strategy. Indeed, according to the OECD, in 2002 the Turkish government's energy R&D budget (excluding TAEK activities) was $3.33 million (and projected to rise to $5.51 by the following year).[103] By contrast the budget of TAEK was about $50 million. Although TAEK is responsible for conducting many activities other than R&D, these figures clearly demonstrate the importance accorded by the Turkish government to nuclear power as part of the state's potential future energy mix.

In addition to its universities, Turkey has eight national research institutions or facilities of potential relevance to a nuclear power program (although some, such as those that focus on the use of radioisotopes in agriculture, are only of tangential relevance).[104] Some of these institutions are listed in Table 10-1, or discussed elsewhere in this chapter. However, of particular relevance for developing a skills base is the Çekmece Nuclear Research & Training Centre's (CNAEM-CNRTC) which has a "programme of work" that is "coordinated with TAEK's nuclear programme in support of the national economy, and focuses on nuclear technology, applications and training."[105]

Egypt's nuclear infrastructure is broadly similar to Turkey's, if not quite as extensive. Seven universities in Egypt were identified as having significant teaching and/or research experience in fields relevant to the development of a nuclear energy.[106] Academics from a further two universities have published nuclear-related papers.[107] Of Egypt's universities, Cairo University, which offers postgraduate courses in nuclear reactors and radiation physics, appears to be the most important from a teaching perspective. As in Turkey, there are strong interconnections between Egypt's Atomic Energy Authority (AEA) and Egyptian Universities. There are six state-sponsored research centers in Egypt that are potentially relevant to the development of an NPP.[108] Of these, by far the most significant is the Nuclear Research Center at Inshas, where most of Egypt's key nuclear facilities, including its two research reactors, are located.

Saudi Arabia's nuclear infrastructure is considerably weaker than either Turkey's or Egypt's. Only King Abdul Aziz University was positively identified as offering relevant courses. In particular, the courses offered by the Nuclear Engineering Department include nuclear instrumentation, nuclear reactor safety, and nuclear desalination. It seems probable, however, that the other two universities in Saudi Arabia which have conducted significant nuclear-related research (King Fahd University of Petroleum and Minerals and King Saud University) also offer relevant courses (although no specific information on them was obtained). Faculty from at least four other universities in Saudi Arabia have been co-authored on at least one nuclear-related publication, suggesting that these universities may perhaps offer nuclear-related courses as part of their scientific curricula.[109]

The Atomic Energy Research Institute (AERI) is Saudi Arabia's premier state-sponsored institution for research into nuclear energy. It has four programs of potential relevance to a nuclear power program: industrial applications of radiation and radioactive isotopes, nuclear power and reactors, nuclear materials, and radiation protection. Based on its publications, however, the focus of its work appears to be on radioactive waste storage and environmental monitoring. Moreover, according to an interview in 2001 with the General Inspector of AERI, there are only 15 Saudi nationals working there who hold Ph.D.s in relevant subjects (in addition to a number of highly trained foreign workers).[110] Moreover, there are two Saudi state-sponsored institutes that focus on the civilian use of radioisotopes: King Faisal Specialist Hospital and Research Center (which has a cyclotron and hot cells for radioisotope production) and the National Research for Agriculture and Animals Resources Center (which has a Radiation Measurement Division).[111]

Egypt, Saudi Arabia, and Turkey have all initiated various technical cooperation projects with the IAEA to develop their skills base. It appears that all the projects that are of direct relevance to nuclear power are related to regulation, waste management, or desalination and are discussed below. One partial exception is a very general ongoing project with Egypt "[t]o enhance the National Information and Documentation Centre (IDC) to become the main national nuclear information services centre in Egypt."[112] It is interesting to note that Egypt has been by far the most active in its use of technical cooperation, having initiated 33 projects since 2000 (by contrast, Turkey has initiated 19 and Saudi Arabia, 13). This is suggestive of a very deliberate strategy by Egypt to improve its skills base. Moreover, from the information that is available, it appears that the technical cooperation projects with Egypt and Turkey are more narrowly-focused and more technically demanding than those conducted with Saudi Arabia, again suggesting the more developed state of the Egyptian and Turkish nuclear skills base.

Finally, we were unable to find out whether any of the three states were also attempting to develop their nuclear expertise by sending personnel to work on foreign nuclear power programs. This is significant because foreign programs could be a useful way of building a relevant skills base.

## LEGAL AND REGULATORY REQUIREMENTS

Turkey already has a very well-developed legal and regulatory framework for the development of nuclear power which reflects its long history of contemplating the nuclear power option. The IAEA notes that the only significant omission is legislation relating to decommissioning.[113] However, such legislation is expected to result from a project initiated in 2000 to revise and update legislation in line with IAEA standards. Within Turkey's existing legislative framework, the "Decree Pertaining to Issue License for Nuclear Installations [RG No. 18256 of December 19, 1983]" is of particular importance. The licensing process for NPPs it sets out is the responsibility of the Nuclear Safety Department of TAEK and is a three stage process covering site selection, construction, and commissioning.[114] One site—Akkuyu, the site of Turkey's proposed NNP—is already licensed.

TAEK, which was established in 1982, is also responsible for all other aspects of licensing and regulation in Turkey. Its specific responsibilities are described as:

- "defining safety measures for all nuclear activities and for drawing up regulations concerning radiation protection and the licensing and safety of nuclear installations;"
- "issuing licences to both private and state enterprises conducting various activities involving radioactive materials, supervising the radiological safety of such enterprises, and ensuring compliance with licence conditions;"
- "issuing authorisations, permits and licenses related to the siting, construction, operation and environmental safety of nuclear installations;"
- "performing the necessary reviews, assessments, and inspections of these installations;"
- "limiting the operating authorisation in the event of non-compliance with the permit or licence;"

- "revoking licences and/or permits issued previously either temporarily or permanently, and submitting recommendations to the Prime Minister on the closure of installations covered by such authorizations;" and,
- "preparing the necessary rules and regulations governing the above operations."[115]

In terms of liability arrangements, Turkey is a party to the 1960 Paris Convention on Nuclear Third Party Liability, one of the two main international liability agreements.[116] It is also party to the 1998 Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention (the Joint Protocol), designed to link the Paris convention to the 1963 Vienna Convention on Civil Liability for Nuclear Damage, the other main agreement.[117] However, it has neither signed nor ratified the CSC.

Not only does Turkey already appear to have a comprehensive legal and regulatory framework in place, but it has been cooperating with the IAEA to improve it further. Of particular relevance is one ongoing technical cooperation project which aims "to increase the effectiveness of the regulatory activities in nuclear safety through enhancing the expertise and reviewing draft regulations on nuclear installation safety with respect to international standards."[118] However, as important as the regulations themselves is the ability of the regulator to assess compliance and enforce its decisions. The effectiveness of TAEK in this regard is hard to assess. TAEK has been working with the IAEA to improve its inspection and enforcement capabilities, but not so actively as in the field of legislation. For instance, a second aim of the project discussed above was "to increase the hands-on experience of some staff of the Department of Nuclear Safety (DNS) through on-the-job training."[119]

In practice, the success of an NPP depends as much on the project manager as it does the regulator. Here the situation is complicated by ongoing reform in the Turkish electricity market.[120] In 1993, the Turkish Electricity Authority which was split in two to form the Turkish Electricity Generation and Transmission Company (TEAŞ) and the Turkish Electrical Distribution Company (TEDAŞ). In 2001, TEAŞ was further split into the Electricity Generation Company (EÜAŞ), the Turkish Electricity Transmission Company (TEIAŞ) and the Turkish Electricity Trading and Contracting Company (TETAŞ). All these companies are state owned. Further unbundling followed by privatization is planned but it is proceeding slowly.[121] Under existing legislation EÜAŞ's role is limited to operating certain existing plants. It can only build new plants if the market is unable to meet electricity demand. Indeed, the tender for the prospective NPP at Akkuyu was issued by TETAŞ and calls for a private company to build and operate the facility.[122] Thus, in practice, it appears that Turkey plans to follow a slightly different model from the one considered in this chapter, in which EÜAŞ would oversee construction and then operate the plant. However, analyzing the ability of EÜAŞ to manage an NPP project is of more than just academic interest because EÜAŞ might be required to do so if the market cannot.[123]

The extent to which EÜAŞ could competently manage an NPP project probably depends on how much expertise it has inherited from TEAŞ. According to a study by staff of the Nuclear Power Plants Department of TEAŞ, one result of the three previous unsuccessful attempts to construct an NPP at Akkuyu is that TEAŞ "has gained the following capabilities and experience: site selection capability . . .; technical, administrative, commercial, and economical evaluation experience; capability of carrying out contract negotiations, and preparation of contract documents; experienced staff to prepare the bid specifications; trained and experienced technical staff to start and carry the project."[124] No information about whether this experience and knowledge has been transferred to EÜAŞ was available. Nevertheless, on balance, Turkey already appears close to meeting the regulatory and legal criteria laid out in the analytical framework.

Like Turkey, the regulatory structure of Egypt, shown in Figure 10-1, is primarily split between two bodies: The Nuclear Power Plants Authority for Electricity Generation (NPPA) and the Center for Nuclear Safety and Radiation Control (CNSRC), although both are part of the Ministry of Electricity and Energy.[125] The former body (set up by Law No. 13 of 1976) is responsible for proposing NPP projects, determining the bid specifications and overseeing the implementation of the project. It is hard to assess its effectiveness but, like the now-defunct TEAŞ, it has probably gained useful hands-on experience through its involvement in previous unsuccessful projects. Moreover, it has been working very actively with the IAEA to improve its capabilities. It has initiated four relevant technical cooperation projects since 2000 (two of which have now been completed), which, between them, have covered most of the process for initiating an NPP from feasibility studies to site assessment through preparing a bid invitation specification.[126] Egypt is a party to the both the Vienna Convention and the Joint Protocol but not to the CSC.[127]

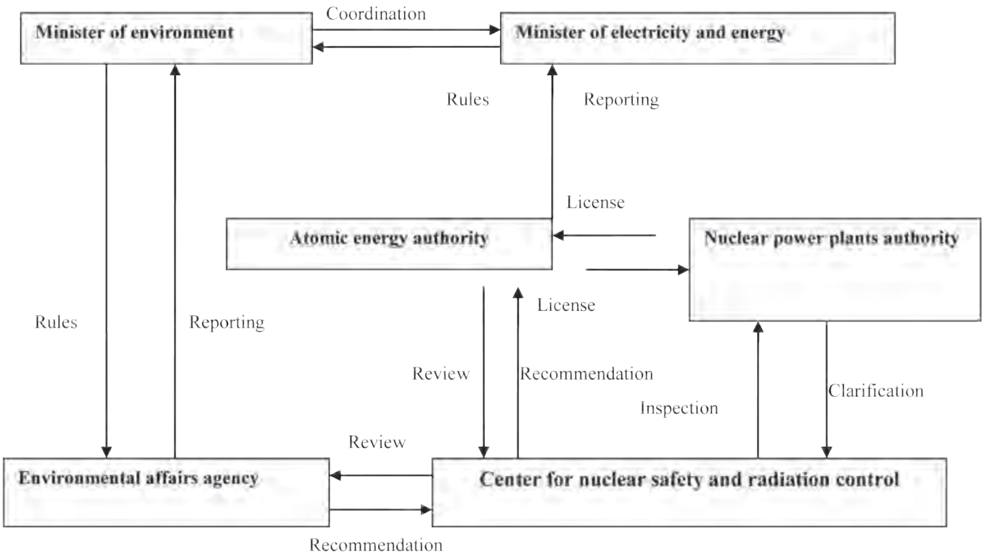


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**Figure 10-1. The Egyptian Regulatory System.**

CNSRC, which is a department of AEA, is a well-established body and already has responsibility for regulating both of Egypt's research reactors as well as all use of radioisotopes in Egypt.[128] Licensing in Egypt is a five-stage process divided into site approval, construction, fuel loading and commissioning, operating, and decommissioning. According to a recent IAEA survey "IAEA Nuclear Safety Standards (NUSS) shall be a main source of the Egyptian nuclear regulations" but that, in addition, Egypt "may also accept the safety criteria, codes, rules, and standards used in the vendor country."[129]

CNSRC is divided into the Regulatory Inspection and Enforcement Unit (RIEU) and the Review, Assessment and Licensing Unit (RALU).[130] A 2003 paper from CNSRC, which focuses on the work of RALU, outlined the Egyptian regulatory system, arguing that it is generally good and that some weaknesses previously identified with emergency planning have been rectified.[131] Since this chapter was published, Egypt has completed a technical cooperation project with the IAEA specifically focused on the work of RIEU.[132] Two additional projects which appear to focus on RIEU are currently underway, but little information is available on them.[133] All this suggests that CNSRC has identified inspection and enforcement capabilities as weak points in the Egyptian regulatory system, but that it is taking steps to rectify those deficiencies.

The national nuclear authority in Saudi Arabia is the King Abdul Aziz City for Science and Technology (KACST). Given the highly limited nature of nuclear activity in Saudi Arabia to date, it has only required a basic regulatory system, largely focused on the use of radioisotopes for medicine, industry, and agriculture. Moreover, there is evidence that existing regulation is generally weak. For instance, a 2001 study by King Faisal Specialist Hospital and Research Center and the University of North Texas that examined the use of gamma-ray cameras in hospitals found that ". . . only few centres performed acceptance testing on their cameras and few of these centres perform the minimum periodic quality control procedures for their gamma cameras."[134] Similarly, an undated study undertaken by King Abdul Aziz University discovered

> that in many, if not most, establishments the level of radiation protection needs to be increased to meet

> safety requirements. The absence of emergency plans and the lack of proper training on the use of measuring instruments became apparent. It was also observed that interest in radiation protection improvement was low.[135]

Not only does Saudi Arabia therefore need to develop a comprehensive legal framework but it must also inculcate an appropriate safety culture.

Saudi Arabia's expertise to oversee the bidding, construction, and commissioning process appears to be limited to a few (fairly dated) academic projects, which examine issues such as the siting of an NPP.[136] In addition, Saudi Arabia has no experience of IAEA inspections or of the accounting and control of nuclear materials. Indeed, although Saudi Arabia is a signatory to the Non-Proliferation Treaty, it currently does not have a safeguards agreement with the IAEA in force.[137] Neither it is a signatory to any of the main nuclear liability agreements.

## ELECTRICAL GRID REQUIREMENTS

Table 10-2 summarizes how installed capacity in Egypt, Saudi Arabia, and Turkey has changed in the most recent years for which information is available (2002-05 for Egypt, 2000-04 for Saudi Arabia, and 2004-07 for Turkey).[138] It shows: (1) total installed capacity for the start and end dates; (2) the average annual increase in installed capacity over that period; (3) the actual amount of electricity produced as a percentage of installed capacity (the capacity factor) in 2005; and (4) the percentage of the 2005 installed capacity that a 1 GWe NPP would have represented.

| | Start of period | | End of Period | | Average annual increase (%) | Capacity factor (2005, %) | % of IC (2005) represented by 1 NPP |
|---|---|---|---|---|---|---|---|
| | IC (GW) | Year | IC (GW) | Year | | | |
| Egypt | 16.7 | 2002 | 18.4 | 2005 | 3.3 | 67 | 5.4 |
| SA | 22.9 | 2000 | 29.1 | 2004 | 6.2 | 65 | 3.2 |
| Turkey | 36.8 | 2004 | 40.8 | 2007 | 3.5 | 48 | 2.6 |

**Table 10-2. Electricity statistics for Egypt (2002-05), Saudi Arabia (2000-04), and Turkey (2004-07).**

Clearly, demand for electricity is increasing rapidly in each of the three states considered by this chapter. All three states expect this trend to continue.[139] Although demand might conceivably decline if fuel subsidies in these states were abolished; realistically, all three states will continue to meet the IAEA's criterion that no one NPP should represent more than 5-10 percent of installed capacity. No information is available on the reliability or stability of the electricity grids in any of the three states under consideration. There have recently been electricity shortages in both Egypt and Saudi Arabia but these have been put down to a lack of capacity rather than transmission problems.[140] Likewise, no information was obtained on the availability of two independent power sources for an NPP.

One trend of interest is the emergence of electricity links between the grids of regional states. Turkey's grid, for instance, is currently connected to those of Azerbaijan, Armenia, Bulgaria, Georgia, Iran, Iraq, and Syria.[141] Saudi Arabia and Egypt are also part of emerging regional networks and are considering installing a direct connection between each other.[142] Although this trend does not affect the three states considered in this chapter with regard to their development of nuclear power, it would help the other states in the region (such as the other GCC states) that individually lack sufficiently large electricity grids to develop NPPs on a collective basis.

## WASTE MANAGEMENT AND DECOMMISSIONING REQUIREMENTS

Turkey possesses a relatively sophisticated waste management infrastructure for dealing with waste from medicine, industry, academia, and research reactor operation. All such waste is collected, treated, and stored at the Radioactive Waste Processing and Storage Facility (CWPSF) of the Çekmece Nuclear Research and Training Center. CWPSF was established with technical support from the IAEA and subsequently upgraded by Turkey. The activities carried out by CWPSF include the treatment of liquid waste in a chemical processing unit and the compression of compactable solids in a compaction cell.[143] This experience is relevant for handling the LLW from an NPP. Although the volume currently available for LLW disposal at CWPSF was not identified, it seems probable that Turkey would have to increase it to handle the quantity of LLW that might be expected from an NPP, but this is unlikely to pose a significant challenge.

Egypt's radioactive waste facility is the Hot Laboratory and Waste Management Center (HLWMC) at Inshas.[144] Facilities at the center include a low and intermediate level liquid waste station and a radioactive waste disposal site. Like Turkey, Egypt would probably have to increase the volume available for disposal.

AERI is responsible for all radioactive waste disposal in Saudi Arabia and is reported to be preparing national standards for radioactive waste disposal.[145] Saudi Arabia currently has one waste storage facility, the Temporary Radioactive Waste Storage Facility. This facility consists of one room with a volume of 40 $m^3$.[146] This is smaller than the volume of LLW produced annually by a well-run nuclear reactor. Building a larger waste depository is, however, relatively straightforward. Harder might be developing the appropriate culture and skills for handling radioactive waste. A 1997 study, for instance, found that considerable amounts of radioactive iodine were disposed of in the domestic sewage system.[147] This suggests that Saudi Arabia currently lacks the appropriate safety culture for operating an NPP.

There is little evidence of any serious planning for decommissioning a nuclear reactor in Egypt, Turkey, or Saudi Arabia. This is a very significant omission. As argued above, it is important that plans for decommissioning form an integral part of nuclear power development plans.

## CONCLUSION

For any state, developing its first NPP is a daunting challenge. The only prerequisite which is currently met by any of three states is the size of their electricity grids (and this criterion is met by all three states). Of the remaining requirements, low level waste disposal is likely to be the easiest challenge to meet. Developing plans for decommissioning may prove more difficult. However, the most significant challenges are staffing and regulation. Here Egypt, Saudi Arabia, and Turkey do not start from the same position.

All three states require significant additional numbers of personnel before their first NPPs become operational. Egypt and Turkey are, however, in a much stronger position than Saudi Arabia to accomplish this. Both Egypt and Turkey possess a sizeable and sufficiently specialized national nuclear infrastructure, including a well-established higher education sector. Both states have experience working with nuclear materials in the context of research reactors and other parts of the fuel cycle. The principal difference between these states is that Egypt's research reactor program could probably provide more training opportunities than Turkey's. Saudi Arabia starts from a much weaker position. Not only does it have a significant shortage of skills in most, if not all, relevant areas but it also appears to have comparatively limited capacity to train skilled personnel. In addition, nuclear-related research in Saudi Arabia is relatively fragmented and, in contrast to Egypt and Turkey, there does not appear to be much of a coherent national strategy.

In terms of regulation, Turkey has the best developed framework. With the important exception of decommissioning legislation, it has no significant omissions in its legislative framework. In no small part, this is a result of the country having seriously contemplated the nuclear power option on several occasions over the past 30 years. Egypt does not appear to lag far behind. Its regulatory structure does not appear to be quite as comprehensive as Turkey's, but it has been cooperating very actively with the IAEA to rectify weaknesses. In both cases, it is hard to ascertain the effectiveness of the inspection and enforcement arms of the relevant regulatory bodies. Saudi Arabia has a significant distance to go before it has the legal and regulatory structure required even to start developing an NPP. Beyond the legislation itself, it also needs to develop, almost from scratch, a safety culture appropriate for the handling of nuclear materials and the human resources to manage an NPP contract and regulate all aspects of the plant's construction and operation.

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Department); Istanbul Technical University (Institute for Nuclear Energy, Metallurgical Engineering Department, Mining Faculty, Physics Department); Middle East Technical University (METU) (Chemical Engineering Department, Chemistry Department, Mechanical Engineering Department, Metallurgical Engineering Department, Mining Department, Physics Department); Suleyman Demirel University (Renewable Energy Sources Research and Application Centre [YEKARUM]).

103. *Turkey: 2005 Review, Energy Policies of IAE Countries*, Paris, France: IAE and OECD, 2005, p. 163, available from *www.iea.org/textbase/nppdf/free/2005/turkey2005.pdf*. According to this report, the regulatory and R&D activities of TAEK will be separated in 2005 by creating an independent nuclear regulator. It is not known whether this has occurred.

104. Ankara Nuclear Agriculture and Animal Research Centre (ANTHAM); Ankara Nuclear Research & Training Centre (ANEAM); Çekmece Nuclear Research & Training Centre (CNAEM-CNRTC); Experimental Test Facility (based in METU); Nuclear Energy Institute (based at Instanbul Technical University); Scientific and Technical Research Centre of Turkey (TÜBİTAK); Synchrotron Light for Experimental Science and Applications for the Middle East (SESAME, located in Jordan); Turkish Speaking States Nuclear Cooperation, Research and Training Centre (TUDNAEM).

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106. No information could be found to provide even a general idea of the number of academics qualified in nuclear science and engineering. The following universities were identified as having significant research and/or teaching experience in relevant fields: Ain Shams University (Nuclear Physics Laboratory, Physics Department); Alexandria University (Faculty of Science, Nuclear Engineering Department); American University in Cairo (Physics Department); Assiut University (Faculty of Science); Cairo University (Physics Department, Faculty of Engineering); Mansoura University (Physics Department); Tanta University (Mathematics Department, Physics Department).

107. Al Azhar University and Zagazig University.

108. Atomic Energy Authority; Middle Eastern Regional Radioisotope Center for the Arab Countries; National Research Center; National Center for Radiation Research and Technology; Nuclear Materials Authority; Nuclear Research Center.

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111. In 2001, there were 29 nuclear medicine departments in the Kingdom and a total of 44 gamma cameras. R. Y. Al Mazrou, J. Prince, and A. Arafah, "Nuclear medicine services in the Kingdom of Saudi Arabia," *European Journal of Nuclear Medicine*, Vol. 28, No. 8, August 2001 (supplement), p. 1150. There is also a Co-60 irradiation facility at AERI.

112. Project number EGY/0/017. Details of all IAEA technical cooperation projects are available from *www-tc.iaea.org/tcweb/default.asp*. Another possibility is a very general project on strengthening skills in Saudi Arabia (SAU/0/007). Because this project is still ongoing, very little information is available about it. However, a project with an identical description and title (SAU/0/005) has been completed and so is documented in more detail. This project was entirely about the peaceful uses of radioisotopes and so would have been of only tangential relevance to building skills for a nuclear power program.

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