

Siting assessment of a water–electricity cogeneration nuclear power plant in Egypt

Aly Karameldin, Samer Mekhemar*

*Reactors Department, Nuclear Research Center, Atomic Energy Authority, PO Box 13759, Anshas, Cairo, Egypt
Tel. +202 457-1616; Fax +202 462-0778; email: SamerMekhemar@hotmail.com*

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Abstract

Fresh water sources in Egypt are less than 13% of the world average per capita. To meet growing water and electricity demands, projections were made up to the year 2025 considering population growth, rise in standard of living, and development plans. A medium-sized nuclear desalination reactor was found to be a viable choice. This study was made to determine a suitable site for a plant in the water-scarce coastal governates of Matrouh, Red Sea, North Sinai, and South Sinai. Considering the effect of extreme climatic and geomorphological conditions on the plant and the effect of the plant on the area, it was found that the coastal strips from El-Arish to Rafah and from El-Dabaa to Saloum are the most suitable areas for construction of a nuclear power plant.

Keywords: Siting; Water; Electricity; Cogeneration; Nuclear

1. Introduction

In Egypt, the annual average fresh water supply per capita is less than 13% of the world average. The great rate of population increase, improved standard of living, and development plants require a continuous increase of fresh water resources. But the Nile valley is a water-stressed area, and there is a great shortage and uneven distribution of fresh water resources.

There is also a shortage in the coastal governates of North Sinai, South Sinai, Red Sea, and Matrouh, located in the Sinai peninsula. An assessment of these sites was made according to water demands and their projections up to the year 2025.

2. Population, water and electricity projection

The population of Egypt doubled in the 50 years from 1897 to 1947, increasing from 9.7

*Corresponding author.

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Table 1
Population projection for different sites

	2000	2005	2010	2015	2020	2025
Matrouth	230,000	255,000	283,000	313,000	374,000	385,000
N. Sinai	274,000	304,000	337,000	374,000	414,000	459,000
S. Sinai	59,000	66,000	73,000	81,000	889,000	81,000
Sinai	334,000	370,000	410,000	454,000	503,000	458,000
Total Egypt	64,500,000	71,500,000	79,200,000	87,800,000	97,300,000	107,900,000

million to about 18 million. A second doubling was during the 30 years from 1947 to 1976, and a third doubling between the years 1966 to 1996 to 59.3 million. The growth rate has decreased from 2.8% in 1986 to 2.1% in 1996 [1] and 2.08% during the period from 1986 to 1996 [2]. Using this growth rate, the population projection of these sites is indicated in Table 1. The total population of Egypt is expected to be almost 108 million in 2025.

3. Siting

In selecting a suitable site for a dual-purpose nuclear power plant, definition of the design must be made [3]. A site survey and assessment for a nuclear dual-purpose power desalination plant is made as follows:

- Selecting an appropriate location where there are only acceptable features and no unacceptable ones.
- Evaluating the design for protecting the plant against extreme limits of external events such as earthquakes and floods, and the expected events, which the plant could withstand to continue operating for its life-span, such as operating earthquakes.
- Assessing the characteristics of the site relevant for the potential impact from the plant on the environment at normal or under accidental conditions.

3.1. Phenomena to be considered in siting

Two categories of phenomena relevant for siting of nuclear power plants are:

- Effect of the environment on the plant such as earthquakes, extreme meteorological phenomena, air crashes, and explosions, since it may not be possible to protect the plant. Design bases are determined against which the plant should be protected.
- Effects of the plant on the site; for example, population distribution, atmospheric dispersion, diffusion in water, etc. The results of the study of the effect of these phenomena were performed by the determination of the characteristics of the dispersion in air and water. This was considered as a basis for calculating the consequences of potential accidents and normal releases.

3.2. Extreme events

There are natural extreme events and man-induced extreme events that could damage the plant if it is not properly protected. The natural extreme events include ambient conditions such as temperature, humidity, wind, rainfall, etc. These may occur rarely in a particular site, such as tornadoes, earthquakes, torrents, floods.

“Expected” events are the ones expected to occur once or more during the life-span of the plant, obtained by extrapolation of historical

data. The plant should be able to withstand these events and continue operation.

“Limited” events are very rare ones which the plant must be able to withstand without large radioactive release. The design basis event is selected on either deterministic or probabilistic approaches or a combination of both. Meanwhile, man-induced extreme events occur such as air crashes, chemical explosions, etc.

3.3. *Extreme values*

These applications may include the following:

- Extreme values of the environmental variables, which are dependent on the validity of the initial samples. For world regions at which the data set is not very large, use can be made of the statistics of similar regions that have larger sets of data.
- Extreme meteorological phenomena, such as tornadoes or hurricanes, where the practical approaches recommended for selecting the design basis events are different for each type of event. For tornadoes, in many countries a value of the order of 10^{-7} to 10^{-6} per year is adopted for this global probability. However, for both phenomena, when the design basis tornado or design basis hurricane has been evaluated, proper engineering parameters such as maximum pressure, rate of change of pressure, and maximum wind speed are selected and assigned as input to the designers of the plant.
- Extreme hydrological phenomena, located along the rivers and coasts. A design-basis flood has been evaluated with a probability lower than 10^{-4} year. The most widely used method for evaluating the run-off is the unit hydrograph, which represents the mass of flow of the river resulting from a unit rainfall excess (precipitation less losses) uniformly distributed over the basin. It is normally derived from a proper extrapolation of the record of the floods on the rivers, having

obtained the design basis mass flow from the maximum probable precipitation with the unit of hydrograph technique. The maximum level of the water is evaluated with the usual methods of hydrology, taking into account the previous status of the basin to the maximum probable precipitation fall and the proper combination of waves generated by the wind and other phenomena that affect this level (such as tides on estuaries).

- Design-basis ground motion, in which a model for the seismicity of the region based on the study of the seismotectonic provinces is identified with their related maximum potential of earthquake (limit values).
- Man-induced events such as air crashes, chemical explosions, and drifting of poisonous or explosive clouds. All of these sites are on airline routes.

3.4. *Effects of the plant on the site*

The distribution of population around the nuclear power plant should be such as to allow the establishment of a workable emergency plan in case of accident, where the population within certain areas around the plant and in the sector at which the blowing of the wind could be affected. These variables for the analysis of population distribution are:

- The number of people within circles or areas with the nuclear power plant at their center. The number of people within segments of sectors centered on the plant, with angles of 20° to 30° , and is limited by increasing the radii.
- The population within the areas which cannot be easily evacuated such as jails, hospitals, schools, etc.
- Transient population (vacationers, nomads, etc.) which can convene in the proximity of the plant during a particular period.

Simple guidelines exist for the final evaluation in which the doses may be calculated and their acceptability assessed. These are based on the radioactivity released from the plant in normal and accidental conditions.

3.4.1. Atmospheric dispersion

To evaluate the possible impact of the plant on the environment, the atmospheric characteristics of the site have to be assessed. An appropriate diffusion model of airborne material at the site has to be developed, and off-standard situations have to be carefully evaluated (e.g., sea coasts with important reefs).

3.4.2. Dispersion in water

To evaluate the possible impact of the plant due to releases in the hydrosphere, the uses of water around the plant have to be analyzed. Also, the characteristics of the site for dispersion in water have to be assessed. Particular importance has to be given to open reservoirs of water ducts, wells and to the industrial uses of water. Investigations must be performed to evaluate a suitable model for dispersion in surface and groundwater.

4. Analysis of siting parameters

For the design of nuclear power plants the interactions between the plant and environment are considered. These include population, meteorology, hydrology, geology, and seismology. Off-site services, upon which the safety of the plant and the protection of the public may depend, are electricity supply and fire-fighting services [4]. Through a proper selection of a site, the cost of the plant can be minimized and safety maximized [5].

In the coastal governorates, design and suitability were considered and summarized. Considerations when designing the plant include floods, tsunamis, earthquakes, tornados,

hurricanes, and aircrashes, while the suitability events include extreme events. They are chemical explosions, surface faulting, slope stability, and collapse of the site surface.

4.1. Red Sea, Gulf of Suez and Gulf of Aqaba sites

These sites are on the earthquake sectors of the Red Sea–Suez Gulf–Cairo–Alexandria–Aqaba Gulf–Dead Sea [6]. They are bounded by faults where seismic manifestations seem to indicate that the southern part of the Red Sea is opening separately from the northern parts of the fault. The opening process may also extend into the northern regions of the Red Sea, Gulf of Suez, and Gulf of Aqaba [7].

There is no record of tsunamis, volcanoes, or floods. The geomorphology of these sites indicates that the levels of this site range from 200 to more than 1500 m above sea level. The mountain chains make piping difficult. The geology of these sites indicates that they are made of sand dunes and basement rocks. South Sinai is an area of frequent moderately dangerous torrents, while in the Red Sea area there are occasional moderate and highly dangerous torrents.

The plant can have an influence on the site as water diffusion in the wells and springs. Red Sea shores have three sodium sulfate water wells, a calcium chloride water well, seven magnesium chloride water wells, and a sodium bicarbonate water well. Aqaba Gulf has two natural cold springs, while the Suez Gulf has natural hot springs and three magnesium chloride water wells. The basin drainage of this area is the Red Sea and Aqaba Gulf basin.

The plant can have an influence on the site, as the wind speed in these areas is greater than 5.6 m/s, which maximizes atmospheric dispersion [8]. Railways have not yet been extended to these areas. A number of existing and proposed protected areas are in the domain of these sites.

4.2. North Sinai and Matrouh sites

El-Arish to Rafah strip and El-Dabaa to El-Sallum strip: The strip from El-Arish to Rafah is far from the Red Sea–Suez Gulf–Cairo–Alexandria earthquake sector, and far enough from the Mediterranean Sea East–Cairo–El-Fauum sector, and the El-Aqaba Gulf–Dead Sea sector. The El-Dabaa to El-Sallum strip is far from any earthquake areas. The two strips are far from the northern and southern fault sector, Ethiopian–Red Sea fault sector, and the Red Sea–Suez Gulf fault sector, while El-Dabaa to El-Sallum strip is included in the Mediterranean Sea fault sector on the earthquake sectors of the Red Sea–Suez Gulf–Cairo–Alexandria sector, El-Aqaba Gulf–Dead Sea sector [6].

There is no record of tsunamis, volcanoes, floods, tides on estuaries and sand dune movements. The levels of these sites are below 200 m above sea level. There are no mountains, which make the piping work an easy job.

The geology of these sites indicates that they are mainly of sand dunes. There are no torrents in El-Arish to Rafah strip and from the El-Dabaa to El-Sallum strip, except infrequent, moderately dangerous torrents at Fuka to the Marsa Matrouh area.

The plant can have an influence on the site as water diffusion in the wells and springs. There are two magnesium chloride water wells near El-Dabaa, and another two near Marsa Matrouh. The drainage of this area is the Mediterranean Sea basin. The plant may not have an influence on the site, as the wind speed in the El-Arish to Rafah strip is less than 3.1 m/s. At El-Dabaa to El-Sallum strip the wind speed reaches 5.28 m/s, which does affect atmospheric dispersion [8].

Two-way railways extend to these areas [6]. There is a proposed protected area at the domain of Fuka to Marsa Matrouh, which measures the release of radioactivity from the nuclear plant under normal and accidental conditions. The two strips have population densities of less than

Table 2
Climate at various sites

	Temp., °C	Wind speed, m/s	Rainfall, mm	Humidity, %
Sallum	20	4	93	67
El-Dabaa	19	5	120	66
El-Arish	20	2	110	72
Rafah	19	3	221	75

Table 3
Prevailing and annual wind direction

	Prevailing		Annual	
	Summer	Winter	Summer	Winter
El-Arish	NW	NW/SW	N/NW	S
Dabaa	NW	SW	N	W
Sallum	N/NW	W/SW	N/NW	NW/SW

4000 capita/km² [9]. These are rural so that they can be easily evacuated.

Table 2 gives average temperature, wind speed, rainfall, and relative humidity for the selected sites of El-Arish to Rafah strip, El-Dabaa, and El-Sallum [8,10,11]. The minimum and maximum sea water temperatures are 15.2°C in February and 28.6°C in August [12]. Table 3 gives the annual wind directions.

5. Electricity demand projection

The preliminary studies carried out by the Egyptian Electricity Authority (EEA) for grid integration and stability recommended that three power plants be interconnected to the grid. It is suggested that these shall be located on the east coast of Sinai, Sallum to the west, and Dabaa in the middle.

The average world electricity consumption per capita has increased from 1576 kWh in 1980 to 2027 kWh in 1996. The average world annual

Table 4
Electricity (MWe) projection for various sites

	2000	2005	2010	2015	2020	2025
Matrouth	32	51	81	128	203	322
N. Sinai	39	61	97	153	242	384
S. Sinai	8	13	21	33	52	83
Sinai	47	74	118	186	294	467

Table 5
Water deficit projection for various sites

	2000	2005	2010	2015	2020	2025
Matrouth	120	137	156	177	202	229
N. Sinai	143	163	186	212	241	274
S. Sinai	31	35	40	46	52	59
Sinai	174	198	226	257	293	333

rate of growth is about 1.59%, and the electric power consumption of North Africa and the Middle East has increased rapidly.

In 1980 and 1996 consumption was 483 and 1162 kWh, respectively, with an annual rate of growth of 5.64%. While during this period it was 380 and 924 kWh in Egypt, with an average annual rate of growth of 5.71% [13,14]. In 2025, the average electricity consumption in the Sinai Peninsula and Matrouh governorate will be 4091 and 2821 GW/h corresponding to an installed capacity of 467 and 322 MW, respectively.

6. Fresh water demand projection

The annual average world fresh water resources per capita in 1996 were 8338 m³/d: 69% for agriculture, 22% for industry, and 9% for domestic use. In North Africa and the Middle East, these ratios were 1035 m³/d: 90% for agriculture, 4% for industry, and 6% for domestic use. In Egypt the total annual water consumption

in 1996 was 55 billion m³ consumed by 59 million people [1,15]. The freshwater resource per capita therefore was 928 m³: 86% for agriculture, 8% for industry, and 6% for domestic use.

The Egyptian freshwater consumption per capita is less than 13% of the world's capita consumption. In addition, Egypt suffers from uneven distribution of fresh water. The Nile valley is a water-stressed area, while the governorates suffer a shortage of water resources. Several studies have been carried out by several authors on the water deficit projection in Egypt. Among these is one by the International Atomic Energy Agency on the potential of nuclear desalination as a source of low-cost potable water in North Africa [16] and another study at the Oak Ridge National Laboratory [17].

In the present scenario, 20% of the actual annual fresh water consumed per capita is considered with the engineering justification for industry, tourism, and domestic use. The groundwater, drainage reuse, sewage treatment, conservation of rainfall, etc., can be utilized for special

agricultural plants [18]. Therefore, 20% of the annual fresh water consumption per capita in 1996 was calculated to be 509 l/d. Table 5 gives the water deficit projection.

7. Conclusions

According to the above scenario for the water deficit and the demonstration option for a cogeneration/desalination–electricity reactor in TECDOC-898 [18], a medium-sized reactor for cogeneration of electricity and freshwater is a suitable and viable choice. The sites found suitable are the coastal strips from El-Arish to Rafah and from Dabaa to Sallum.

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