

Analytical Architectural Study on Nuclear Power Plants

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Abstract: This paper aims to study the architectural design and components of Nuclear Power Plants (NPPs). It is also focusing on the simulation system. Its main objective is to set general guidelines for architects. They should be aware of the basics of nuclear facilities designs and components. A traditional nuclear power plant consists of a nuclear reactor, a control building, a turbines building, cooling towers, service buildings (an office building & a medical research center) and a nuclear & radiation waste storage building. Bushehr nuclear power plant in Iran and Angra nuclear power plant in Brazil have been chosen as examples. Furthermore, this paper presents design analyses for Bushehr nuclear power plant and Angra nuclear power plant that include design theory (linear design and radial design) and positive & negative aspects of these designs. At the end of this paper, results and recommendations on the architectural and urban aspects of nuclear power plants are revealed.

Key words: Analytical study, architectural study, nuclear power plants, nuclear power reactors.

1. Introduction

The nuclear history started in 1934, when the Italian scientist Erino Fermi discovered the uranium. The German scientist Ida Noddack and Erino Fermi put a definition of the nuclear energy “the fission of a heavy nucleus into two middle weight nuclei that produces a huge amount of energy as a result of a nuclear reaction” [1].

Nuclear energy is one of the most important factors for the human development. Energy is the key element for the flourishing of all civilizations throughout the human history. Developing countries need to ensure energy sources in their development plans to use them properly. The international reserve of oil is 46 years. The oil reserve in the Middle East is more than 90 years and it could be less than 10 years in Asia, Europe and America. So, the imports of oil for these countries will rise remarkably in the coming decade as a result of having an oil reserve shortage. It is noticed that the CO₂ emissions have been increased due to the human activities, especially energy generated from coal and natural gas, and the use of oil products in transportation and aviation [2].

The acid rain is a type of rain that contains various acids. It has a destructive effect on plants and marine life. It is mostly formed from nitrogen compounds and sulfur emanating from human activities. Those compounds will form acids due to interacting with the air. In the last decade, many governments work hard on establishing laws to prevent the emulation of these acidic components. The main sources of them are the huge power plants which emulate 70% of sulfur dioxide and 30% of nitrogen dioxide, transportations and petroleum industries [3].

Therefore, governments should depend on renewed sources of energy in building sustainable societies. A nuclear power plant that generates 1,000 megawatts needs 26 tons of uranium annually. This amount of energy needs 1.5 million tons of oil, 2.2 million tons of coal and 1.1 million tons of natural gas. There is a big difference between nuclear energy and other sources of energy [4].

Only three developed countries owned 49% of the nuclear power plants all over the world: USA, France and Japan. While, Spain has six nuclear power plants and nine nuclear reactors which generate 26% of its electricity. Canada has five nuclear power plants and nine nuclear reactors which generate 15% of its electricity. South Korea has four nuclear power plants

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and twenty one nuclear reactors which generate 29% of its electricity. Sweden has five nuclear power plants and ten nuclear reactors which generate 45% of its electricity. As for India, it has seven nuclear power plants and twenty nuclear reactors (two of them are under construction) generate 3% of its electricity [4].

The amount of nuclear fuel needed for generating a big quantity of electric energy is much less than that of coal or oil. For example, a ton of uranium generates electric energy much more than millions of barrels of oil, or millions of tons of coal. In addition, using solar energy is more expensive than the nuclear energy [4]. For this reason, this paper is important as it reveals the need to study nuclear installations and give recommendations to the architects on how to deal with these vital facilities that have an increasing demand on the international, regional and national levels. Due to the situation of the international reserve of non renewable energy sources and the great potential of the nuclear energy, the nations should rely on the nuclear energy on the national and international levels for sustainable development. This paper presents NPPs components in details to dissolve the mystery of NPPs. Also, the paper presents design analyses for Bushehr nuclear power plant in Iran and Angra nuclear power plant in Brazil. These analyses include the design theory (linear design and radial design) and positive & negative aspects of these designs. Bushehr NPP in Iran and Angra NPP in Brazil have been established to contribute in the development of developing countries.

2. Design and Components of a Nuclear Power Plant

Nuclear reactors are huge installations that control the nuclear fission process and provide suitable conditions for its continuation without causing explosions during serial fission. The nuclear reactors are used for the purposes of power generation and removal of salts and other minerals from the water. They are also used in conversion of certain chemical elements into other elements and create isotopes with

the effectiveness of radiation used in various purposes. The nuclear reactor could also be defined as an integrated system where investment serial fission reaction in production of slow or fast neutrons and emission of fission heat transmitted by the radiator to the cooling towers for reuse again, or to the steam generators (in power reactors) for the production of steam to rotate the turbines to generate electricity [5].

Nuclear reactors are divided into three main types [6]:

- (1) Educational research reactors;
- (2) Commercial research reactors;
- (3) Advanced application reactors (high tech).

Research reactors are used to conduct scientific research and the production of isotopes for medical and industrial purposes. They are not used for power generation. At the moment, there are 284 nuclear research reactors work worldwide in 52 countries. Research reactors are ranging in capacity between 2 megawatts to 30 megawatts [7]. The power reactors are used to generate electric power. At the moment, there are more than 55 nuclear power plants work to generate nuclear energy which convert into electrical energy, and the number can be increased as a result of the expansion in the construction of the reactors due to the need for power generation. Power reactors are ranging in capacity between 55 megawatts to 1,200 megawatts [8].

Nuclear reactor has been evolved throughout history from just a hall to conduct research tests inside a small research reactor that produces 2 megawatts of power. To a huge building contains (the entrances, exits, management and control offices, locked out corridors and escaping avenues, piping system to control the reduction or increase of the interaction, treated airtight concrete core includes the reactor and bars of interaction, control and safety equipment, electronic control systems, monitors to follow the interaction, heavy water stores, pipes of chilled water, steam outlets, etc.), the architectural design of the reactor develops with the development of each generation of

reactors. Therefore, the pressurized water reactor needs a building which has a different design than gas-cooled reactor [9].

The nuclear fission generates heat. The nuclear power plants use this generated heat in the reactor (such as pressurized water reactors, boiling water reactors, gas-cooled reactors etc.), which transfer by the cooling water of the reactor to the steam generator in the process of generating steam. The generated steam passes through turbines to convert the steam energy into revolving mechanical energy which operate power generators. Steam comes out of the turbine to the condenser. The maintenance of the nuclear reactors is very complex because of their radioactivities. The determinants of quality are very strict over the purity of the water to ensure the maintenance of the boiler from rust and oxidation to less degree. The nuclear reactor uses enriched uranium in the form of "pellets" of the fuel. The size of each one of them is about the size of the currency and its length is about an inch. The pellets are formed as long bars known as packets and kept inside the highly insulation compressed chamber. In many nuclear power plants, there are immersions for the packages in the water to keep them cool. Other plants use carbon dioxide or dissolved metal to cool the reactor core [10].

Linking of the project elements with each other is the main challenge facing the architect. First, he is required to determine the main spaces and how to allocate them. He should provide a link between the services spaces and the main spaces without affecting their function. The design of a nuclear power plant should provide a maximum safety for workers in the reactor, and to ensure that, they will not have any injuries or problems, whether in normal operating or in cases of accidents. This requires the provision of exits for safety and escape stairs in order to provide instant means of quick and safe departure. The nature of the existing equipments inside the plant spaces (such as the main reactor space) is different. The architect deals with spaces that have specific heights depending on the

measures designed for reactor installations. Pressure Water Reactor (PWR) (Fig. 1), for example, differs from Boiling Water Reactor (BWR) (Fig. 2), which would require an architect in collaboration with the main manufacturers of the reactor so that he can master the design. This is evident in the designs big companies such as Toshiba, Westinghouse, General, Electric, etc.. These companies provide an architectural design that accompanies the project.

The design of the nuclear power plant has four types [11]:

- (1) Architectural design: includes architectural design, landscaping and supervision of the construction of buildings and finishing works;
- (2) Civil design: includes the site implementation works, concrete and reinforcement works and supervision of the construction of buildings;
- (3) Mechanical design: includes the installation of pipes and welds works, and installation of the devices, especially in the reactor;
- (4) Electrical design: includes sensors and wiring, the installation of measuring equipment and communication equipment with control rooms.

The nuclear power plant consists of:

2.1 Nuclear Reactor

Nuclear reactor includes main spaces such as reactor space, diesel generators, refueling, the required power space for the performance of the interaction, the withdrawal space of this energy, cooling interaction operations and emergency systems.

Nuclear reactor building is the most important building of the plant. It is the building in which the required interaction had been performed. The rest of buildings are considered to be facilities for it. Therefore, the designer must provide protection and safety for the building in the first place, as well as, working on reducing costs as much as possible. The Japanese architect who design (Valley Tenssee) reactor was careful for seismic risk of the region and the process of securing the building in the first place.

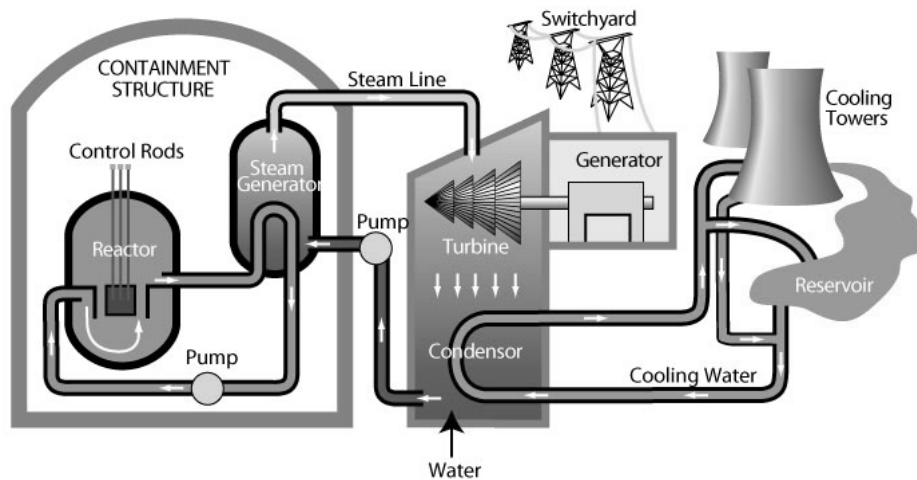


Fig. 1 Pressurized water reactor [12].

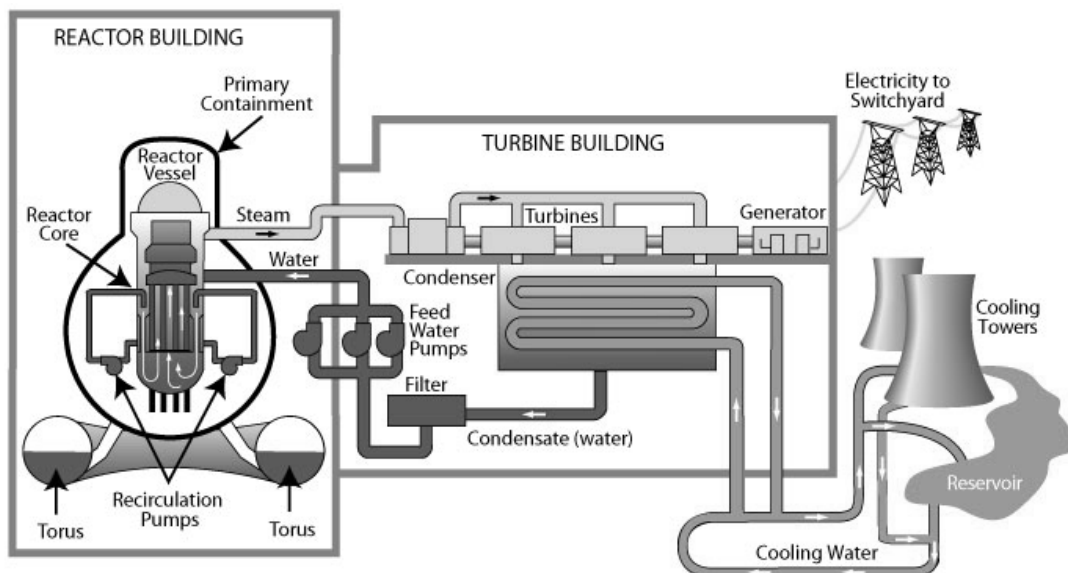


Fig. 2 Boiling water reactor [13].

Despite the choice of location in a mountainous area, the designer was careful not to display any of the project elements for any surprises.

Design of the reactor building needs to study many of the views. Reactor building follows functional buildings used by many users. There is a power engineer, workers, technicians, scientists and control building engineers. Many of the staff of these buildings work for long hours, which makes the designer is always trying to eliminate negative effect of the building on the psychology of workers that makes them feel bored or depressed. So, surrounding the building

with a distinctive landscaping system may be canceling this sense from the workers in these buildings. The study of the standards for the reactor building and its compatibility with the machinery are the most important factors that should be included in any logical design [14].

Ideal standards for reactor building spaces [15]:

- (1) Reactor pressure vessel
 - Internal height 21 meters;
 - Internal diameter 7.10 meters;
 - Wall thickness 174 mm.
- (2) Containment

- Height 36.10 meters;
- Internal diameter (maximum) 29 meters.

(3) Reactor core

- Maximum height 3.71 meters;
- Internal diameter 5.16 meters.

2.2 Control Building

It has a control room, an automated computer network associated with the reactor and a reactor cooling system. The area of the main control room should not be less than 15×15 meters, up to 15×30 meters (Fig. 3). This room is often designed in the form of horseshoe shape.

Control room (Fig. 4) includes three systems:

(1) Follow-up system for the reactor cooling pumps, the secondary cooling systems and the main system for the cooling water;

(2) Control system for the level of pressure inside the reactor, the reactor cooling system and the emergency operations;

(3) Operating system for the emergency case. In case of an accident or an emergency, this system should alert on all workers by using the light clarifying plates or the audio stimulation [16].

2.3 Turbines Building

It is a building which contains the turbines that generate the electricity which move directly to the power network (Fig. 5). It is often placed away from the reactor. The link between the reactor and the turbine building is the steam path resulting from the water boiling by the reaction temperature or energy path resulting from water boiling. The spaces of the turbines building are often huge. Turbines are large equipments to generate electricity. So, the use of Steel Truss System in construction of the turbines building is the best.

Turbines building is a building which converts the generated energy by the interaction into useful energy for mankind. Turbines building is often designed on the hangar shape. It also includes control rooms,

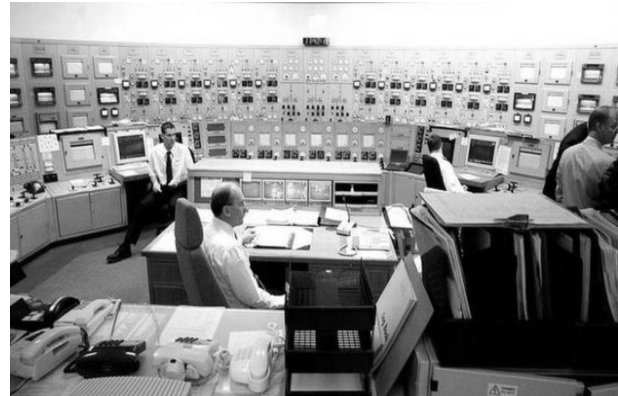


Fig. 3 American design of the control room [17].



Fig. 4 Japanese design of the control room [18].



Fig. 5 Turbines for generating electricity [19].

administration rooms, operators' rooms, maintenance rooms and storages. Turbines space commensurates with the size of the turbines. Turbines should be connected with the electricity distribution centers by electricity transmission wires [16].

2.4 Cooling Towers

They are special towers to permit the resulting steam



Fig. 6 Cooling towers of nuclear power plants [20].

from the cooling operations to come out. Condensed water is discharged into the river water or sea water according to the plant site, but the power of evaporation that accompanies the condensation process is high. So that, cooling towers are used for the disposal of this steam (also used to cool the water after the third radioactive cooling cycle), that has been heated in the condenser. The water temperatures may reach up to 90 Fahrenheit degrees. The height of the cooling tower may rise up to 40 meters (Fig. 6) [16].

2.5 Services Buildings

They include an administrative building (administrative offices, security & surveillance offices and health safety measurement stations) and medical research and follow-up centers [16].

2.5.1 Office Building

Administrative building dimensions are normal administrative dimensions, taking into account being appropriate for the activities occurring within the space, and the psychological and visual dimensions of the users of the space, especially after modern medical research has shown that the nature of desktop activity psychologically affect the workers. Therefore, the designer should allocate suitable entrances for these spaces. The use of administrative spaces are: management and supervision of operations, maintenance, radiation protection, chemistry, security,

insurance and control, nuclear performance monitor, nuclear engineering, electrical and mechanical systems, programs and tests, design and modification, support and maintenance operations, procurement, documentation, microfilming, printing, licensing support, electrical maintenance offices and mechanical rooms of computers that control all other buildings.

2.5.2 Medical Research Center

Developing countries that have nuclear reactors added buildings for Medical Research to take advantage of the ability of radioactive isotopes to treat many serious diseases, especially cancer. The experiments have proven the success of the radioactive isotopes in the elimination of cancerous growth. These facts represent a great hope for the victims of this disease, so the presence of a medical center for treatment radioisotope as one of the main buildings surrounding the nuclear reactor is an important factor. Also, it expresses another portion of population that may exist in urban area around the plant, which confirms the success of the thought that the plant is a nucleus of an integrated urban society for doctors and patients. The main departments of the medical center are: department of medical biology, department of cyclotron, department of medical isotopes and department of radiation pharmacy.

The scientific activities focus on the benefits of the peaceful applications of atomic energy in the health field, with an emphasis on [21]:

- (1) Use of nuclear technology in the field of early detection of cancer and diagnosis using pictorial techniques;
- (2) Early detection of cancer and follow up to determine the severity of the disease and warnings;
- (3) Conducting of various researches and studies to screen the cancer in terms of incidence, diagnosis and treatment and to identify warning using nuclear techniques;
- (4) Conducting of various researches and studies to screen the heart disease using nuclear photographic techniques;

(5) Input of modern nuclear technologies in the field of nuclear medicine;

(6) Use of radioactive pharmaceuticals in order to diagnose and treating the various medical conditions;

(7) Production and quality control of isotopes for positrons and gamma emitters;

(8) Operating and maintenance of cyclotron (a device for developing the medical isotopes);

(9) Production of new isotopes using Cyclotron and follow up its various medical applications.

2.6 Nuclear and Radiological Waste Storage Building

It is one of the most important buildings of the nuclear power plant. It contains solid and liquid waste. The waste should be reserved in this building for period up to twenty years before being transported off-site for the burial in places far away. The waste storage building should be designed in order to contain all storage types of waste, whether horizontal or vertical storage. The waste is a product of nuclear fuel after a continuous consumption process. Also, there is a liquid fuel which is placed in containers. There is a vital need to protect these facilities from terrorist attacks or natural factors such as earthquakes, hurricanes and

volcanoes [16].

Dimensions of horizontal storage spaces:

Height is 6 meters. Dimensions are not less than 15 meters \times 15 meters.

Dimensions of vertical storage spaces:

Height is 10 meters. Dimensions are not less than 25 meters \times 25 meters.

Dimensions of storage spaces for containers that contain radioactive fluids:

Height is not less than 4 meters. Dimensions are not less than 6 meters \times 6 meters.

3. Simulation System (Simulator)

It is one of the most important systems that operate nuclear reactor system, especially before the full operation of the reactor operations, or before any modifications on the operating system of the reactor. Simulation system is the full operation of the devices of the reactor (Fig. 7). It is an imaginative process. The reactor appears in the control room as it is already working. It can represent an emergency case, and how to deal with it, such as cases of power outage, stop of cooling water pumps, a malfunction in the control arms, etc.. So, the simulation system is the most important

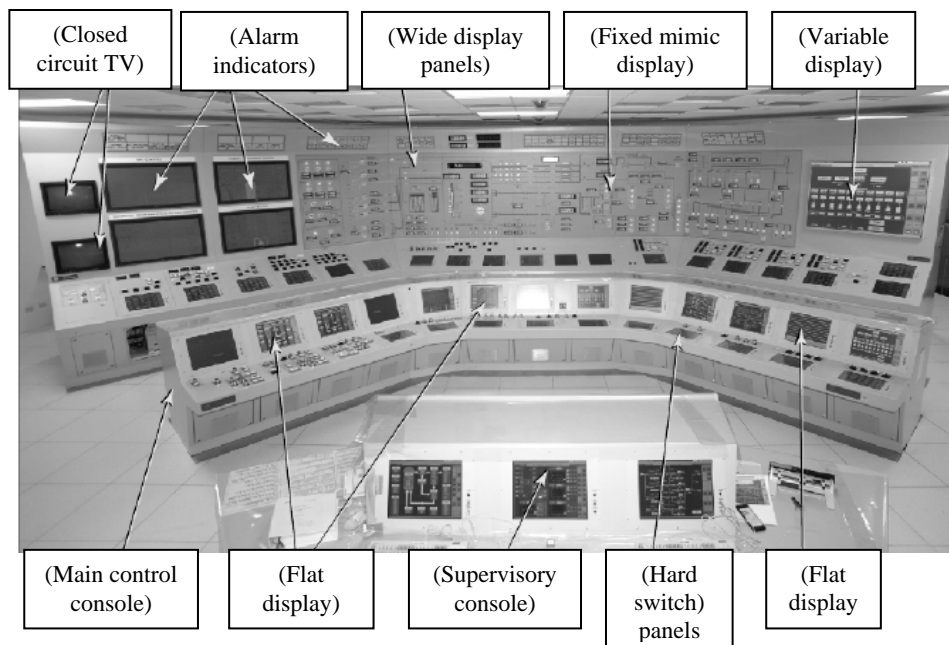


Fig. 7 Simulator within the main control room [23].

program that should be included in the reactor. The control room workers should be trained to follow up these experiments to measure the speed of the reaction in emergency situations and provide external support via the internet or networks [22].

4. Analytical Architectural Study on Bushehr Nuclear Power Plant in Iran

Bushehr is a city in Iran (Fig. 8). The research studies Bushehr nuclear power plant. It has been established for the purpose of energy production, nuclear researches, medical researches and desalination of sea water.

4.1 History of Bushehr Nuclear Power Plant

In 1953, Iran's nuclear program started. Suitable sites were selected for the establishment of the reactor (Fig. 9). Tehran Nuclear Research Center (TNRC) was founded. It contained the first research reactor. Its capacity was 5 megawatts. In 1967, the center was inaugurated. The enriched uranium was used in the reactor. In 1974, Iran decided to begin the construction of the first nuclear power plant in the city of Bushehr on the Arab Gulf coast with the capacity of 23 megawatts. It was intended to reach 1,196 megawatts by the year 1981. In 2007, it started with the capacity of 1,000 megawatts. In 2007, its capacity was reached 1,000 megawatts [24].

Historical overview of Bushehr city [24]:

- (1) The nuclear power plant is located on the Arabian Gulf in south of Bushehr city. It is an industrial city with a variety of investments;
- (2) Bushehr city is located about 1,200 km southwest of the capital Tehran;
- (3) Bushehr province is a densely populated province (8 million people) and it faces the Arabian Gulf (Fig. 8). It is one of the most important provinces;
- (4) Bushehr nuclear power plant is designed to provide Bushehr city with high electric energy and for the development of industrial projects in the city. It was



Fig. 8 Bushehr province in Iran [25].



Fig. 9 Sites of Iranian nuclear reactors [26].

opened in April 2007 in cooperation with Russia and it produces 1,000 megawatts.

4.3 Analysis of Bushehr Nuclear Power Plant, Iran

4.3.1 Site selection

(1) Topography and levels

Unpaved flat land and does not have a large difference in contour and levels (Figs. 10 and 11).

(2) Climatic factors

Deal with climatic element in a traditional way.

(3) Water sources

The nuclear power plant depends on the Arabian Gulf waters.

4.3.2 Main Function of the Nuclear Power Plant

This nuclear power plant is used for energy production, nuclear researches, medical researches and desalination of sea water.

4.3.3 Planning and Design Theories

(1) Layout

Linear design (Fig. 12).

(2) Visual concept

Distinctive visual experience. Its distinction is partly due to media focus on the design and uniqueness of performance (Fig. 11).

4.3.4 Analysis of the Urban

(1) Positive impact effects

- Site viewing the Arabian Gulf (provides a water source for cooling operations);
- Site is an extension of several urban industrial and governmental projects;
- The project is a nucleus for many industrial and urban projects;
- There is a station in the plant for desalination of sea water and to provide safe drinking water for the province.

(2) Negative impact effects

- The location is close to the residential area, which may psychologically affect the residents of the region;
- Lack of awareness among the population with protection plans in case of emergency.

4.3.5 Design Standards (Fig. 13)

(1) Natural environmental systems and preservation of the environment

Ignore the environmental aspects, and not to exploit the well featured site of the reactor, with the greatest emphasis on the functional aspects.

(2) Flexibility and ease of movement in accordance with the requirements of IAEA

Obtain the flexibility factor and the ease of movement, according to the reports of International Atomic Energy Agency.

(3) Radiation protection



Fig. 10 Perspective snapshot of the plant [27].



Fig. 11 Perspective snapshot of the plant [27].

Achieve the protection factor from radiation, according to the reports of the International Atomic Energy Agency.

4.3.6 Design Criteria (Fig. 14)

(1) Dominant thought

Economic-functional thought.

(2) Reactor space site

It is situated as a major center for all nuclear power plant items.

(3) Idea of design

It (linear design) is based on a main axis linking the two main domes of the two buildings which contain the two reactors. From the middle of this axis a main axis has been designed to connect all auxiliary buildings of the two reactors. The services and activities have been distributed by this axis on both sides.

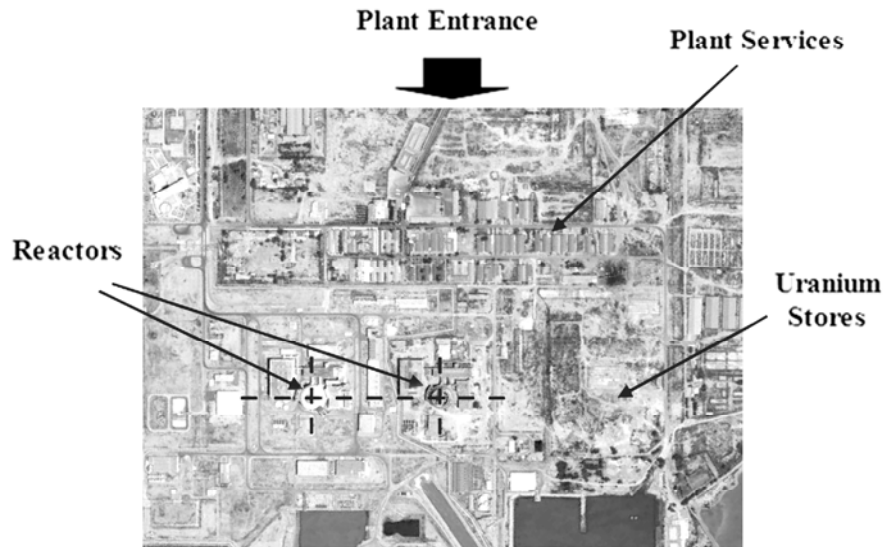
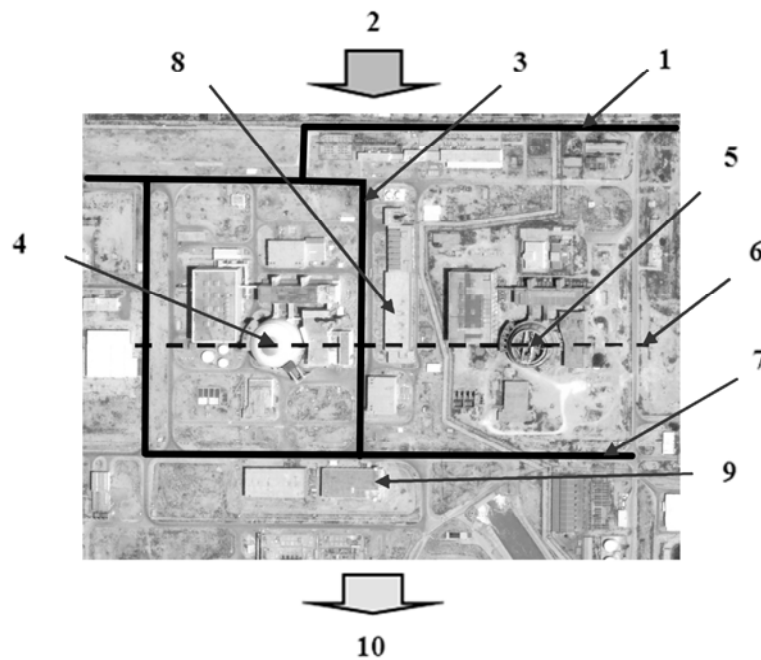
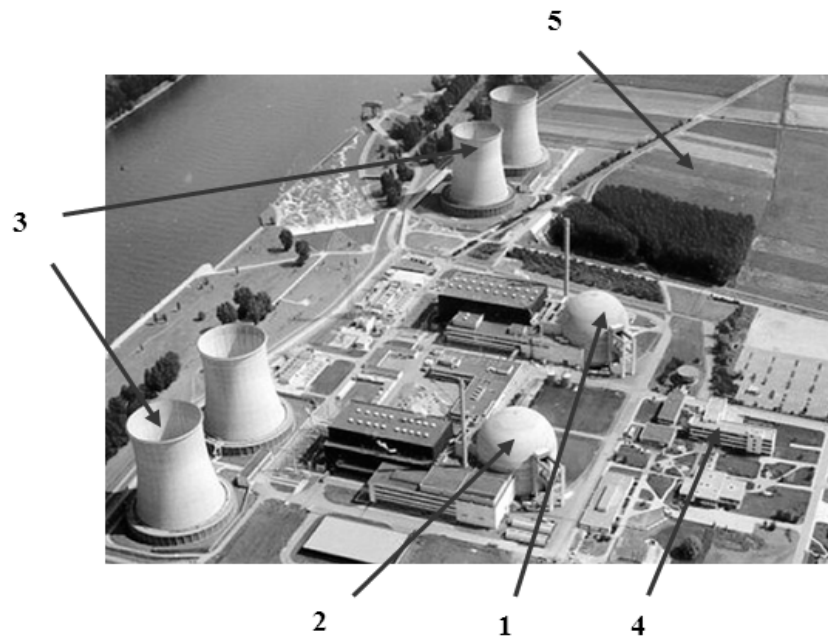


Fig. 12 Linear design of Bushehr nuclear power plant, linking the centers of two domes to link the design of two reactors [28].



1. The main road leading to the plant.
2. The plant's main entrance.
3. The main road leading to the two reactors in the middle of the plant.
4. The first reactor and its attachments.
5. The second reactor and its attachments.
6. The main axis which links between the two centers of the two domes of the nuclear power plant.
7. The alternative road behind the two reactors.
8. The control building.
9. The waste storage building.
10. The Arabian Gulf direction.

Fig. 13 Analysis of layout of Bushehr nuclear power plant [28].



1. The first reactor.
2. The second reactor.
3. The cooling towers leaking the steam resulting from the interaction process.
4. The waste buildings and the main laboratories.
5. The use of planting and good landscaping of the site to give a distinctive character for the plant.

Fig. 14 Analysis of perspective of Bushehr nuclear power plant [29].

(4) Analysis of design concept

- Clarity and simplicity-Ease of perception;
- Spreading-Pheasant-Ease of distribution;
- Relay.

(5) Positive aspects of the design

- Good employment of the elements and components in an integrated framework;
- Interest with the insurance operations of the reactor by changing the tracks. Confirmation of the overall shape of the design by using a distinctive dome.

(6) Negative aspects of the design

- The extreme adjacency between the two reactors.

(7) Dominant character

- The typical design of this type of reactors. The distinctive dome contributed to the uniqueness of the design.

5. Analytical Architectural Study on Angra Nuclear Power Plant in Brazil

Angra is a city in Brazil. This research studies Angra

nuclear power plant. It has been established for the purpose of energy production, nuclear researches, medical researches and desalination of sea water.

5.1 History of Angra Nuclear Power Plant

In 1970, Brazil decided to build two reactors (Angra 1 and 2) to provide it with its needs of electricity and the development of researches in the nuclear field. Brazil began to develop an advanced nuclear program and launched an international tender. In 1971, the company (Westinghouse) had got a license to build the first reactor (Angra 1). The region had been selected between Rio de Janeiro city and Sao Paulo city. In 1975, Brazil decided to become self-sufficient in the field of nuclear technology. There was a cooperation protocol between Brazil and West Germany to supply Brazil with three units of energy production. Their capacity was 1,300 megawatts. In 1982, the first reactor had been opened. It produced 626 megawatts. In 2000, the second reactor (Angra 2) had been opened. It produced 1,270 megawatts (Fig. 15) [30].



Fig. 15 Layout of Angra nuclear power plant, Brazil [28].

5.2 Historical Overview of Angra City

(1) The nuclear power plant is located in Angra city. It faces the Atlantic Ocean. It was located between the two largest cities in Brazil: Rio de Janeiro and Sao Paulo. Rio de Janeiro is the ancient capital of the country (Fig. 16). It is the economic capital and the second most important city after Brasilia;

(2) The type of the reactor is pressurized heavy water reactor;

(3) The nuclear power plant serves 13 millions;

(4) The nuclear power plant had been designed to supply the main cities with the electrical needs, as well as, the development of the country's nuclear ability in research, medical and technical fields;

(5) In 1975 the nuclear power plant was started. In 1982 it was inaugurated;

(6) The first unit produces 626 megawatts [30].

5.3 Analysis of Angra Nuclear Power Plant, Brazil

5.3.1 Site Selection

(1) Topography and levels

Highly efficient in dealing with the natural contours of the site and good exploitation of the green mountains.

(2) Climatic factors

Deal with climatic element in a good way.

(3) Water sources

The reactor depends on the Atlantic Ocean waters.

5.3.2 Main Function of the Nuclear Power Plant

This nuclear power plant is used for energy production, nuclear researches, medical researches and desalination of sea water.

5.3.3 Planning and Design Theories

(1) Layout

Radial design

(2) Visual concept

Rich and distinctive visual experience characterized by the richness of elements and vocabularies (Figs. 17 and 18).



Fig. 16 Rio de Janeiro province in Brazil [31].



Fig. 17 The external formation of Angra nuclear power plant [31].

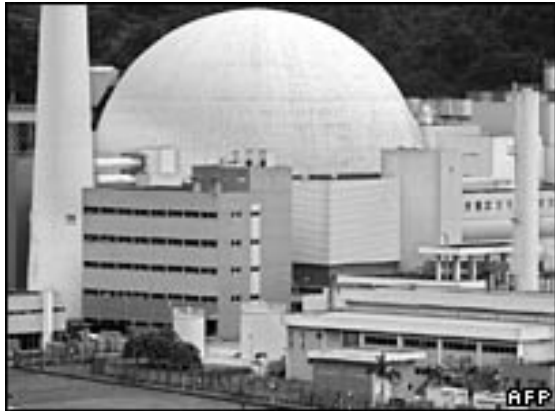


Fig. 18 Special dome of (Angra 2) reactor and the control building [31].

5.3.4 Analysis of the Urban

(1) Positive impact effects (Fig. 19)

- Site viewing the Atlantic Ocean. It is located in an isolated area from residential areas;
- The region is characterized by distinctive landscapes;
- The site is surrounded by a mountainous region which contributes in securing the site;
- The site is surrounded by an agricultural area. The site is equipped for the establishment of several industrial areas;
- Good planning of the site, in terms of movement corridors and the coordination of the site;
- The site is located in a peninsula. It is filled with a natural landscape. This gives the site distinctive views.

(2) Negative impact effects

- Site is isolated. It is surrounded by mountains from all sides. It may leave a negative impact among the workers of the nuclear power plant;
- Lack of clarity of the main corridors in the nuclear power plant planning. It may be due to the desire to secure the nuclear power plant.

5.3.5 Design standards (Fig. 20)

(1) Natural environmental systems and preservation of the environment

Good exploitation of environmental aspects, as well as the permanent periodic detection on the surrounding environmental vocabularies. Lasting contribution from the reactor in the development of the surrounding environmental protection operations.

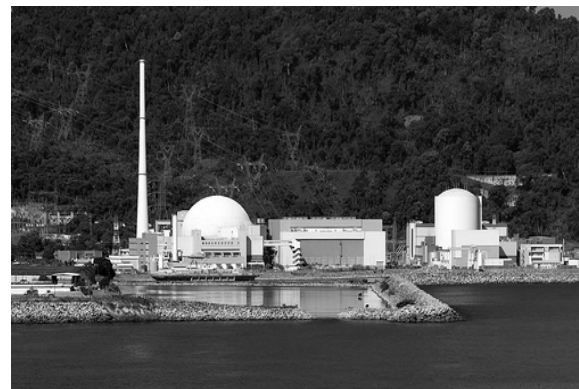


Fig. 19 Brazilian Angra nuclear power plant. Two snapshots from the ocean illustrate the excellent exploitation of the surrounding natural elements [31].

(2) Flexibility and ease of movement in accordance with the requirements of IAEA

Obtain the flexibility factor and the ease of movement, according to the reports of International Atomic Energy Agency.

(3) Radiation protection

Achieve the protection factor from radiation, according to the reports of the International Atomic Energy Agency.

5.3.6 Design Criteria (Fig. 21)

(1) Dominant thought

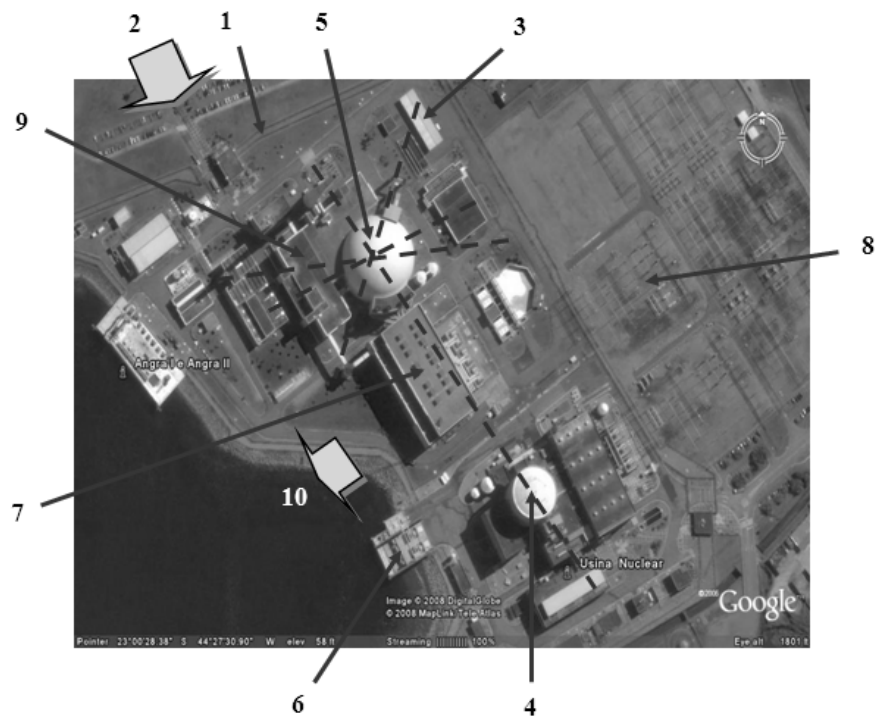
Philosophical-creative-functional thought

(2) Reactor space site

Unique appearance of the reactor space, the reactor space is located below its distinctive dome (Fig. 18).

(3) Idea of design

It (radial design) is based on an imaginary main center which is considered a radial center for the plant. The centers of the project spaces came from this center.



1. The main road leading to the plant.
2. The plant's main entrance.
3. The main entrance building, the nuclear exhibition and the parking garages.
4. The old reactor (Angra 1) as cylindrical shape.
5. The new reactor (Angra 2) is surrounded by its own services.
6. The station that supply the two reactors with sea water.
7. The turbine building.
8. The conversion of the electrical output to high power.
9. The nuclear research building.
10. The Atlantic Ocean direction.

Fig. 20 Analysis of layout of Angra nuclear power plant, Brazil [28].



Fig. 21 Analysis of perspective of Angra plant, it is completely surrounded by mountains except for the direction of the sea [31].

Table 1 Evaluation of site selection, main function, planning theory, urban factors, design standards and design criteria for Nuclear Power Plants which have different design concept.

No.	Site selection, main function, planning theory, urban factors, design standards and design criteria	Proposed Rate (%) Grade	Bushehr NPP Linear C. Grade	Angra NPP Radial C. Grade
1	Topography and levels	5	3	4
2	Climatic factors	5	3	4
3	Water sources	5	4	4
4	Main function of the nuclear power plant	5	4	4
5	Visual concept	5	3	4
6	Positive impact effects	5	3	4
7	Negative impact effects	5	2	3
8	Natural environmental systems and preservation of the environment	10	4	8
9	Flexibility and ease of movement in accordance with the requirements of IAEA	5	3	4
10	Radiation protection	10	8	8
11	Dominant thought	5	3	4
12	Reactor space site	5	3	4
13	Idea of design	5	2	4
14	Design concept	10	7	9
15	Positive aspects of the design	5	3	4
16	Negative aspects of the design	5	3	4
17	Dominant character	5	3	4
	Total	100	61	80

There is proximity between the service buildings and the reactor core. The use is more suitable shape for the design of the reactor. In spite of the implementation of the reactor (Angra 2) after many years of the reactor (Angra 1), the centrality of the design has made the design balance is linked to the center of the larger reactor (Angra 2). The design of reactor (Angra 2) is different from the design of reactor (Angra 1). The dome was used to cover the reactor (Angra 2) core, while the cylindrical shape was used to cover the reactor (Angra 1) core.

(4) Analysis of design concept

- Proliferation;
- Ease of perception;
- Equilibrium;
- Pheasant;
- The control of the main mass and an easily realization.

(5) Positive aspects of the design

- Good employment of the elements and components in an integrated framework;
- Interest with the insurance operations of the

reactor by changing the tracks. Confirmation of the overall shape of the design by using a distinctive dome that covers the reactor core to give a special uniqueness;

- Proximity of the service units from the reactor core did not decrease the strength of the design. The reactor building became a one unit;
- Change the shape of the second reactor from the first reactor, characterized the second reactor and make it visible and unique;
- Accuracy of the design, clarity of the passages, good employment of the services and the exploitation of the natural landscapes have contributed in the beauty of the design.

(6) Negative aspects of the design

- Change the shape of the second reactor from the first reactor, caused the obliteration for the design of the first reactor. It is not appearing due to the strength of the design of the second reactor (Angra 2);
- No distribution of the services away from the reactor core. No exploitation of the available spaces.

(7) Dominant character

The use of a distinctive dome is to cover the center of the second reactor. The use of a cylindrical shape is to cover the first reactor. The company which implemented the first reactor is different from the second company. The site has contributed in the uniqueness and excellence of the design.

It could be observed in Table 1 that Angra Nuclear Power Plant in Brazil (radial concept) is better than Bushehr Nuclear Power Plant in Iran (linear concept) in terms of design and planning, taking into account the radiation safety considerations. Angra NPP has big advantages over Bushehr NPP.

6. Results

The design of Bushehr NPP and Angra NPP is innovative. The linear design of NPPs is distinctive for its clarity, simplicity, realization, gradualism and easy distribution. The radial design of NPPs is distinctive for its clarity, simplicity, realization, equilibrium and clarity of the main space as a center for the buildings.

Bushehr NPP well utilized the surrounding area to serve the design and the general layout of the plant. Bushehr NPP has been established in good agreement with the climatic aspects according to the site nature and conditions. Functionally, the design of Bushehr NPP focused on achieving reasonable rates of spaces and dimensions, and on the natural aspects of the surrounding environment (water aspects, terrain, etc.).

Angra NPP has dealt well with surrounding urban which has been exploited to serve the design. The impact of surrounding urban has been reflected on the overall shape of the plant, its vocabulary and its interaction with the surrounding area. The plant has dealt accurately and carefully with the climatic elements depending on the circumstances and the nature of the site.

Angra NPP has shown keen interest with proportions of the spaces, good distribution of the services and good employment of the elements and components in an integrated manner. The addition of a new reactor which has a new shape to the plant gives a spirit of

excitement for the plant. Also, there is clarity, ease of movement between the activities & the buildings and keen interest with insurance operations.

Angra NPP tried to be environmental friendly by establishing an environmental studies and research center inside the plant and by establishing an exhibition which explains to the visitors how the plant works for the development of the region. The treatments, the materials and the colors have been selected in Angra NPP. The compatible materials with the surrounding area have been used which give a good impression to the plant customers.

Radiation safety is an important aspect in the design of NPPs. Site selection for placing a NPP is a very important aspect. Many factors should be taken into consideration such as topography, levels, climatic factors, natural environmental systems, water sources, radiation protection, etc.. NPPs sites should not be located in or near heavily built-up areas and are best situated in rural or semi-rural districts.

7. Recommendations

The architects are recommended to identify the suitable sites for constructing NPPs. They are recommended to clarify the feasibility of establishing NPPs from urban, architectural and environmental terms. They are recommended to design the different types of NPPs.

The architects who design NPPs should be aware of the nuclear reactors, safety requirements and other previous designs to produce designs with the required quality. They should be aware of the standards approved by the International Atomic Energy Agency.

The architects are recommended to deal with the buildings of a NPP as one unit controlled by the control building to serve the main building (the reactor). They are recommended to be able to work in close co-operation with other engineers from different departments.

The architects are recommended to design and plan the NPPs taking into consideration the radial planning

concept because it is the best with regard to radiation safety requirements. They are recommended to follow a scientific approach in designing NPPs and present ideas that achieve the desired requirement of a good design that takes all aspect into consideration.

The electricity problem in Egypt can be solved by nuclear power generation from the plants to be established. A plan should be set for spreading NPPs in Egypt with focus on the international experiences in the field of designing NPPs and establishing cooperation with countries and companies that have experience in this field.

The government, while taking a decision of establishing a NPP is recommended to put development plans in which a NPP is considered the base of development. The design of a NPP aims at improving the surrounding environment.

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