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Comparative Architectural Study on Nuclear Power Plants

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Abstract This paper aims to study the architectural design of nuclear power plants (NPPs). It is also focusing on the requirements of International Atomic Energy Agency (IAEA) for the design of nuclear power plants. Architects should be aware of the basics of nuclear facilities designs. Koeberg nuclear power plant in South Africa and Atucha nuclear power plant in Argentina have been chosen as examples. This paper presents design analyses for Koeberg nuclear power plant and Atucha nuclear power plant. These analyses include design theory (linear design and radial design) and positive & negative aspects of these designs. 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.

Keywords Comparative study, architectural study, nuclear power plants, nuclear power reactors.

Introduction

On December 20, 1951, at the Experimental Breeder Reactor EBR-I in Arco, Idaho, USA, for the first time electricity - illuminating four light bulbs - was produced by nuclear energy. EBR-I was not designed to produce electricity but to validate the breeder reactor concept. On June 26, 1954, at Obninsk, Russia, the nuclear power plant APS-1 with a net electrical output of 5 MW was connected to the power grid, the world's first nuclear power plant that generated electricity for commercial use. On August 27, 1956 the first commercial nuclear power plant, Calder Hall 1, Eng-land, with a net electrical output of 50 MW was connected to the national grid. As of February 04, 2016 in 31 countries 442 nuclear power plant units with an installed electric net capacity of about 384 GW are in operation and 66 plants with an installed capacity of 65 GW are in 16 countries under construction [1]. Nuclear plants, like plants that burn coal, oil and natural gas, produce electricity by boiling water into steam. This steam then turns turbines to produce electricity. The difference is that nuclear plants do not burn anything. Instead, they use uranium fuel, consisting of solid ceramic pellets, to produce electricity through a process called fission.Nuclear power plants obtain the heat needed to produce steam through a physical process. This process, called fission, entails the splitting of atoms of uranium in a nuclear reactor. The uranium fuel consists of small, hard ceramic pellets that are packaged into long, vertical tubes. Bundles of this fuel are inserted into the reactor [2].

Requirements of International Atomic Energy Agency (IAEA) for the Design of Nuclear Power Plants [3]

International Atomic Energy Agency has set requirements for the design of nuclear reactors (research or power reactors). These requirements are:

1. General requirements

(1) The possibility of conducting unannounced inspections. Provide the spaces completely with digital cameras to follow up the movement inside the reactor. Delegates from IAEA follow up these tapes;

(2) International Atomic Energy Agency reviews the design depending on the construction license of the concerned countries. It also reviews insurance operations, administration, auditing, control, fuel management and radioactive waste transport operations.

2. Special requirements for the site of nuclear power plants

After the site was named by the country which will build NPP, a group of experts from IAEA will evaluate the site according to the following requirements:

(1) Matching of the site for the environmental requirements (wind directions, nearby agricultural areas, groundwater and its vulnerability with radiation, distance from earthquakes centers, volcanoes and insurance against floods & hurricanes);
(2) Transport of radioactive waste to burial places by land routes, sea or trains. Secure the means of transport of such waste and design of a private road network;
(3) Ability of the site for future expansion, in the cases of the desire to increase the capacity, or build a new reactor;
(4) Ability of the reactor for the immediate dismantling or the termination of the site;
(5) Approval of the region residents on the site selection by the local council, the provincial council or the state council. Some countries allow the commercial construction of nuclear power plants. The country gives the license through the regulatory bodies or atomic energy authorities;
(6) The nearness of the reactor from a source of water facilitates the completion of the interaction cooling processes. There is a severe need for water supply in case of emergency, especially in boiling water reactors (PWR).

3. Special requirements for the general design of nuclear power plants

The design of a nuclear power plant contains [a nuclear reactor building, a control building, a turbines building, cooling towers, service buildings (an office building and a medical research center) and a nuclear &radiological waste storage building]. The design of a research reactor contains three buildings [a research reactor building, a research center and a waste storage building]. The most important design parameters that must be considered are:

(1) Advanced fuel cycle;
(2) Control operations;
(3) Probabilistic risk assessments;
(4) Human factors;
(5) Reactor technology and economics.

4. Special requirements for design of Nuclear Power Plant

Choose a suitable site for NPP. Design the nuclear power plant that will serve the region according to the following requirements:

(1) Importance of the preserving of the environment and the commitment of the safety factor around the site;
(2) Design flexibility to allow easy movement inside buildings;
(3) Full insurance, the motility and the instant evacuation of the building during the accidents;
(4) Provide corridors and movement paths with clear signs which have signs of the Agency (IAEA);
(5) Place warning signs in clear spaces for customers, especially places that contain high radiation;
(6) Full radiation protection for employees inside and outside the building;
(7) Link the reactor buildings with a data network which appears within the control building. It shows all the processes that occur in any building and shows the evacuation processes in emergency situations;
(8) Comprehensive review for the construction program at the design stage, during implementation, before operation and during operation. Analyze of fuel movement from the fuel building to the reactor (time span). The full load tests of the reactor. Conduct the simulations to upgrade the reactor;
(9) The design of the reactor should be completed after different stages. These stages should not be less than 3 stages of future expansion;
(10) Isolatation and easy separation for the spaces from the rest of the building protect the reactor in case of accidents and terrorist attacks. This procedure reduces the caused damages to the lower levels;
(11) The dimensions of the spaces fit with the nature of the used instruments and devices within the reactor according to the type of reactor (boiling water reactor, pressurized water reactor, gas-cooled reactor,….etc.) and according to the nature of the reactor (research reactor or power reactor), which requires coordination with civil, mechanical and electrical design operations;
(12) Protect the workers inside the reactor by providing exits and escape stairs. Provide easy movement in emergency situations.

The main external hazards which threaten the reactor are (seismic effects, military attack and terrorist attacks). The impact of seismic effects can be avoided during the structural design. Foundations can withstand the seismic effects that can hit the region. The Japanese nuclear reactors are important models for the design near earthquakes belts.

The aircraft crash or projectiles in case of war requires a flexible design to secure the interaction and to bear the explosive objects. The external body of the reactor core consists of two layers of reinforced concrete. In this case, protection system will shut down the reactor. The engineering authority of IAEA will review the design of the reactor to give the license.

Comparative Architectural Study on Two Nuclear Power Plants

This paper presents the components of two nuclear power plants in details to dissolve the mystery of NPPs that encounter increasing demand on the international and national levels. A NPP 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 &radiological waste storage building.

Analytical Architectural Study on Koeberg Nuclear Power Plant in South Africa

Koeberg is a city in South Africa (Fig. 1). This research studies Koeberg nuclear power plant. It has been established for the purpose of energy production, nuclear researches and desalination of sea water.

1. History of Koeberg nuclear power plant [4].

In 1976, South Africa began the construction of the nuclear power plant in the city of Koeberg. It is the only reactor in South Africa (Fig. 2). Also, it is the only reactor in the continent of Africa. The first unit was opened in 1984 while; the second unit was opened in 1985. In 2005, the Energy Commission of South Africa has developed the reactor under the supervision of the International Atomic Energy Agency (IAEA).

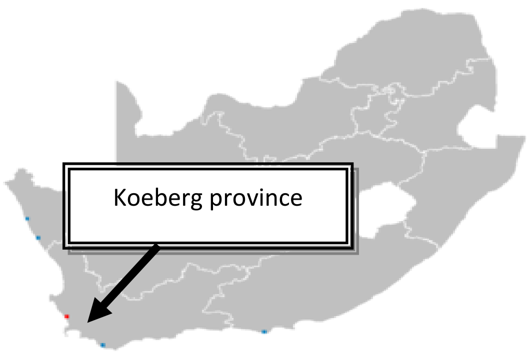


Figure 1: Koeberg province, South Africa [5].

Figure 2: Koebergnuclear power plant in South Africa [6].

Figure 3: Layout of Koebergnuclear power plant in South Africa [6].

Figure 4: The relationship between Koebergnuclear power plant buildings and touristic villages viewing the ocean [6].

Site characteristics

2. Historical overview of Koeberg city [4]

(1) The nuclear power plant is located on the Atlantic Ocean in Koeberg city on the west coast of South Africa (Fig. 1). Koeberg city is located 30 km from (Cape Town) city which is the economic capital of the countr;

(2) Koeberg nuclear power reactor is a pressurized heavy water reactor;

(3) The National Electricity Company operates the reactor;

(4) Koeberg nuclear power plant is designed to provide the economic capital (Cape Town) with electricity. Also, it is designed to provide many touristic projects viewing the Atlantic Ocean with electricity (Figs. 3 and 4).

3. Analysis of Koeberg nuclear power plant, South Africa

1. Site characteristics

(1) Topography and levels

Unpaved flat land and does not have a large difference in contour and levels (Figs. 3 and 4).

(2) Climatic factors

Deal with climatic element in a traditional way.

(3) Water sources

The nuclear power plant depends on the Atlantic Ocean waters.

2. Main function of the nuclear power plant

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

Figure 5: The external formation of the Koebergnuclear power plant, South Africa [7].

3. Planning and Design Theories

(1) Layout

Linear design (Fig. 7)

(2) Visual concept

Relatively poor visual experience as a result of repetition and boredom in using some elements (Fig. 5).

4. Analysis of the urban

(1) Positive impact effects

- Site viewing the Atlantic Ocean (provide a water source for cooling operations);
- Site is an extension of several urban industrial and touristic projects;
- The project is a nucleus for many industrial, touristic and urban projects;
- The site is close to some touristic villages.

(2) Negative impact effects

- The site is close to many important touristic villages which viewing the Atlantic Ocean;
- Lack of awareness among the population with protection plans in case of emergency;
- The site is close to touristic villages, led to many casualties in the field of tourism;
- The occurrence of more than one accident in the reactor led to stopover periods before restarting the reactor again.

5. Design Standards (Fig. 6)

(1) Natural environmental systems and preservation of the environment

Average interest with environmental aspects. The presence of sea water desalination plant to supply several touristic villages with drinking water. The maintain of the beaches and do not pollute them.

(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.

6. Design criteria (Fig. 7)

(1) Dominant thought; Creative – Economic - Functional Thought; (2) Reactor space site; Linear relationship between the centers of the two reactors. The buildings appear as one unit.; (3) Idea of design

It (linear design) is based on an imaginary main axis linking the two centers of the two main cylinders of the two units. 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.

The movement axes are the same. Non - symmetrical design. The distribution of the buildings on the eastern side with a high degree, while the distribution of the buildings on the western side with a low degree.

The two reactors are in one building. Two cylinders have been designed for the two reactors. The two reactors are controlled by one network and one control room. The distribution of the services to facilitate the monitoring of the processes and activities.

(4) Analysis of design concept

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

1. Sea water desalination plant.
2. Main reactor.
3. Research and medical centers.
4. Uranium stores.
5. The main control building for security operations and the main entrance of the reactor.
6. Sea water entrance to the plant to cool the reactor.

Figure 6: Analysis of layout of Koeberg nuclear power plant, South Africa [6].

(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 cylinder;
- Despite the use of two units for power generation, but the link between them in one building reduce the establishment costs of more than one building. Deal with the two units by one building.

(6) Negative aspects of the design

- The existence of the two units in one building increases the loading on the spaces that operate the two units, in addition to, the difficulty of separation in case of malfunctions;
- The plant does not have a future expansion. Also, it does not have a suitable place to build new reactors.

(7) Dominant character

The typical design of this type of reactors. The distinctive cylider contributed to the uniqueness of the design.Especially, it is the only reactor in the continent of Africa.

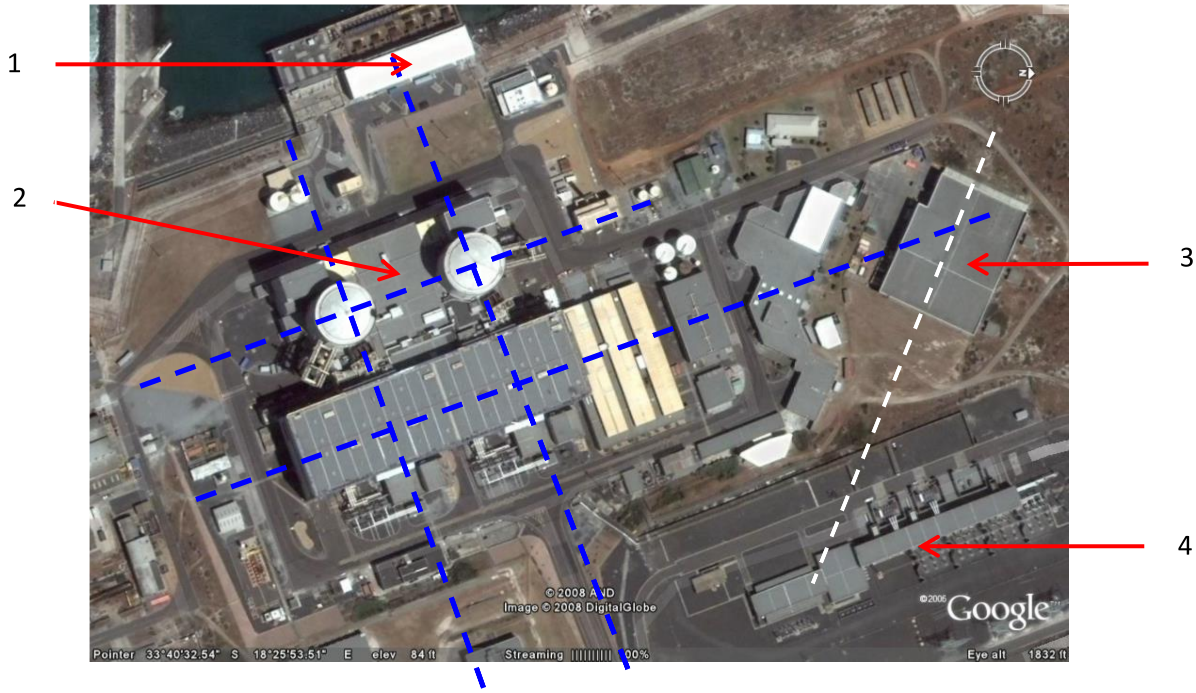


Figure 7: Linear design of Koeberg nuclear power plant, South Africa [6].

Analytical Architectural Study on Atucha Nuclear Power Plant in Argentina

Buenos Airesis the capital of Argentina(Fig. 8). This research studies Atucha nuclear power plant. It has been established for the purpose of energy production, nuclear researches and medical researches.

1. History of Atucha nuclear power plant [8]

It is one of the main two reactors in Argentina. Atucha reactor and Embalse reactor support Argentina in the field of electricity and nuclear energy researches. In 1960, Argentina started its nuclear program. In 1983, Argentina began to develop its nuclear program. It began to build the Atucha reactor (Fig. 9). Argentina nuclear program includes (power generation – nuclear research - sea water desalination - medical research... etc). Argentina began to build the second unit in Atucha reactor and the second unit in Embalse reactor to increase energy sources.

2. Historical overview of Buenos Aires city

(1) The nuclear power plant is located on the Paraná de Las Palmas River. It is located 100 km from the center of Buenos Aires city which is the capital of Argentina. Buenos Aires city is viewing the Atlantic Ocean(Fig. 8). The nuclear power plant serves 14 millions. La Plata city is the capital of the province;

(2)The plant is located in the center of the province. It follows the Atomic Energy Commission in Argentina.The area of the reactor is 2.5 km^2. The type of the reactor is a Pressurized Heavy Water Reactor (PHWR);

(3) The nuclear power plant had been designed to supply the capital of Argentina with electricity. It has a research center which contributes in the development of nuclear and medical researches;

(4) In 1968, the nuclear power plant had been started. In 1974, it had been inaugurated;

(5) The first unit produces 357megawatts.

3. Analysis of Atucha nuclear power plant, Argentina
1. Site characteristics
(1) Topography and levels
Argentina has a beach on the Atlantic Ocean. The proximity of the site from the river gave an impression of poor of the site selection (Figs. 10 and 11).
(2) Climatic factors
Deal with climatic element in a traditional way.

Figure 8: Buenos Aires province [9].

Fig. 9 Layout of Atuchanuclear power plant in Argentina [6].

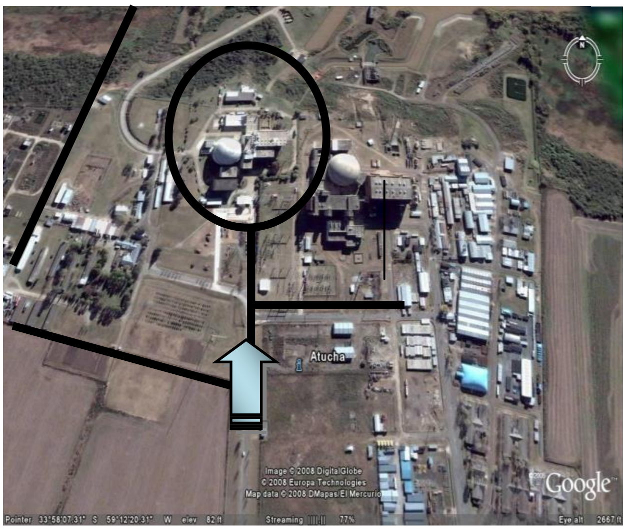


Figure 10: Layout of Atuchanuclear power plant in Argentina [6].

Figure 11: The River is located between Atucha reactor buildings and surrounding agricultural areas [6].

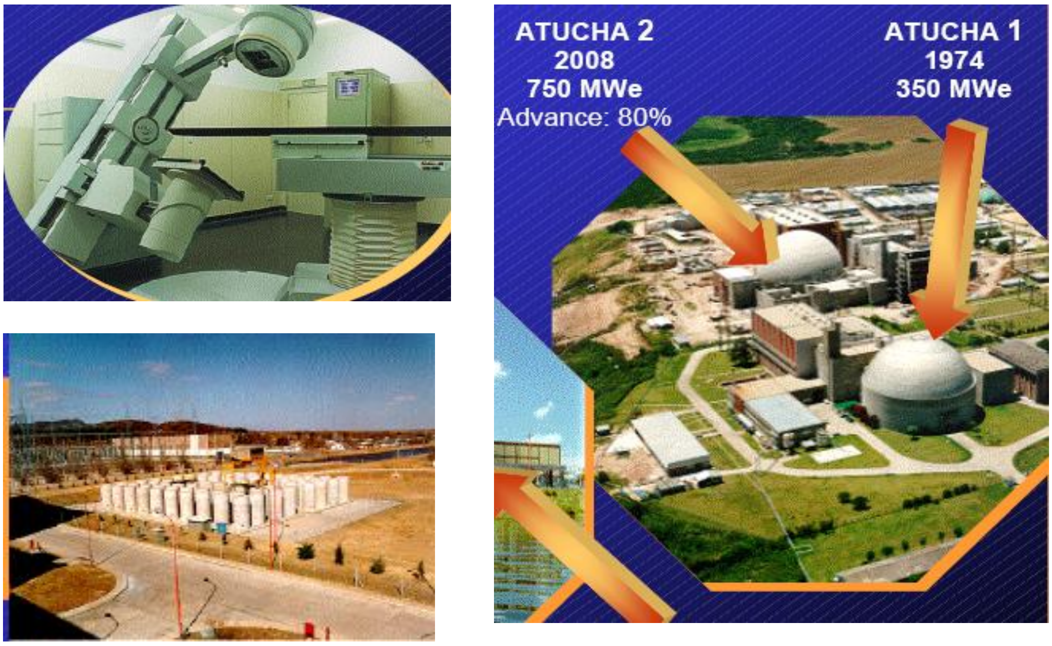


Figure 12: External formation of Atuchanuclear power plant, medical research center and nuclear & radiological waste storage building [10].

(3) Water sources

The reactor depends on the Paraná River waters.

2. Main function of the nuclear power plant

This nuclear power plant is used for energy production, nuclear researches and medical researches.

3. Planning and design theories

(1) Layout

Radial design (Fig. 14)

(2) Visual concept

Successful and distinctive visual experience characterized by the interferenceand sometimes by the lack of clarity (Fig. 12).

4. Analysis of the urban

(1) Positive impact effects

- Site viewing the Parana de las Palmas River. It is located in an isolated area from residential areas;
- The site is surrounded by many agricultural areas;
- The plant is a center for many industrial and urban projects;
- The plant is surrounded by an agricultural area, with processing for the establishment of several industrial areas.

(2) Negative impact effects

- The site is close to many of agricultural areas which have high population densities;
- The site is far away from the main residential areas in the capital (Buenos Aires);
- Lack of a control building at the entrance of the reactor;
- The river may be exposed to radioactive contamination due to the cooling of the reactor using the river water.

5. Design standards (Fig. 15)

(1) Natural environmental systems and preservation of the environment

The reactor is close to the river. Although there is no effect on river water due to the good performance inside the reactor, the use of river water in the cooling is one of the factors of vulnerability of the plant.

(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.

6. Design criteria (Figs. 13 and 16)
(1) Dominant thought
Economic - Functional Thought
(2) Reactor space site
Unique appearance of the reactor space. The reactor space is located below its distinctive dome.
(3) Idea of design
It (radial design) is based on an imaginary main center which is considered a radial center for the plant**.** The activities are distributed on only one side of the reactor. The other side of the reactor is dedicated for the construction of the second phase (Atucha reactor 2)and its associated services. The services are distributed around the reactor in an appropriate manner. The good design of the new reactor (Atucha 2) is the same design of the old reactor (Atucha 1). The design of the new reactor is compatible with the design of the old reactor.
(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

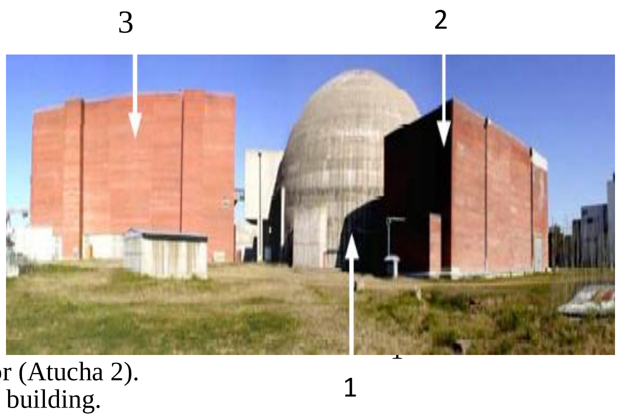
- Good employment of the elements and components in an integrated framework;
- Interest with the insurance operations of the reactor by changing the tracks. Confirmation of the overall shape of the design by using a distinctive dome that covers the reactor core to give a special uniqueness;
- Proximity of the service units from the reactor core did not decrease the strength of the design. The reactor building became a one unit. The plant has a suitable area for future expansion. The design direction of the first and second reactors is the same.

(6) Negative aspects of the design

- Lack of implementation of auxiliary buildings during the construction of the reactor, caused randomness in the distribution of auxiliary buildings (research centers, laboratories for uranium separation and processing).They have been implemented after the construction of the reactor at spaced intervals;
- The use of river water as a main water source for cooling the reactor may cause a risk on the surrounding area;
- The reactor is close to many of agricultural areas.

(7) Dominant character

- The use of a distinctive dome to cover the center of the second reactor. The domeis one of the architectural design vocabularies of the (Siemens) company.



1. The dome of the new reactor (Atucha 2).
2. The nuclear fuel processing building.
3. The turbines building.

Figure 13: Analysis of elevation of Atucha nuclear power plant, Argentina [10].

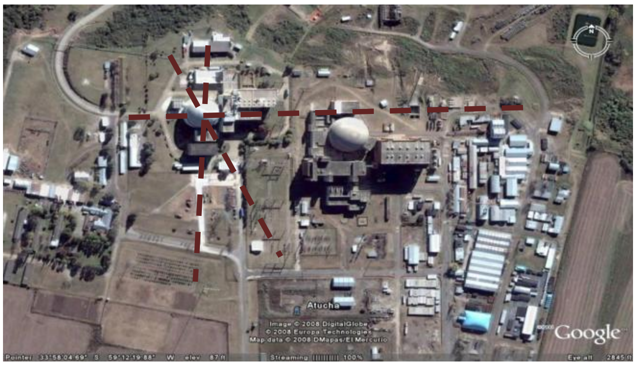
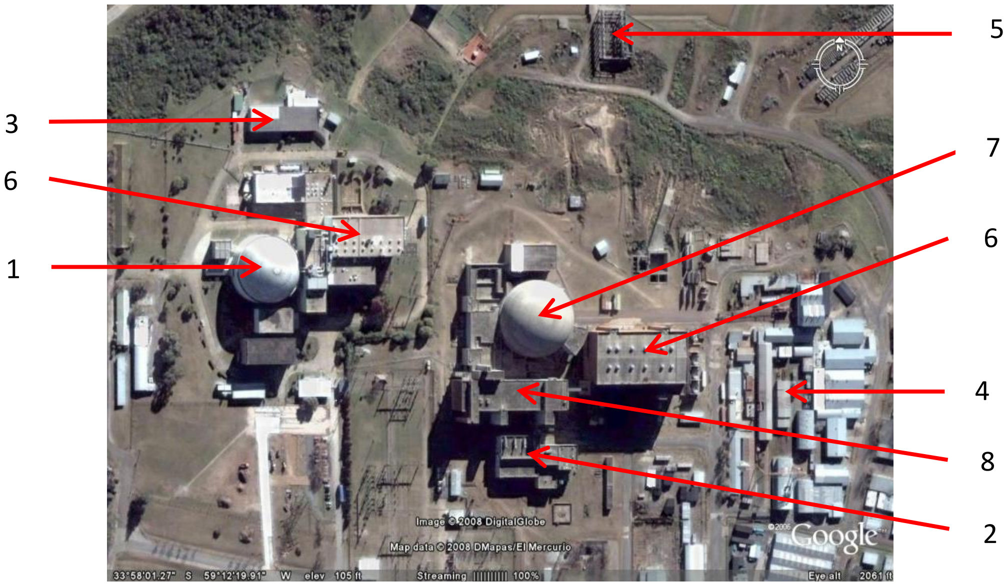


Figure 14: The radial design of the Atuchanuclear power plant in Argentina [6].



1. The old reactor (Atucha 1) a dome shape. 2. Control building.
3. Medical research center.
4. Research center and laboratories for uranium separation processing.
5. Electricity generation center. 6. The turbines building.
7. The new reactor (Atucha 2) a dome shape. 8. The nuclear fuel processing building.

Figure 15: Analysis of layout of Atucha nuclear power plant, Argentina [6].

Figure 16: Analysis of perspective of Atucha nuclear power plant, Argentina [10].

Table 1: Evaluation of site characteristics, main function, planning theory, urban factors, design standards and design criteria for the two nuclear power plants which have different design concept.

No.	Site characteristics, main function, planning theory, urban factors, design standards and design criteria	Proposed Rate % Grade	Koeberg NPP Linear C. Grade	Atucha NPP Radial C. Grade
1	Topography and levels	5	3.5	4
2	Climatic factors	5	3	4
3	Water sources	5	4	3
4	Main function of the nuclear power plant	5	4	4
5	Visual concept	5	2.5	4
6	Positive impact effects	5	3.5	4
7	Negative impact effects	5	2.5	3
8	Natural environmental systems and preservation of the environment	10	4.5	6.5
9	Flexibility and ease of movement in accordance with the requirements of IAEA	5	3.5	4
10	Radiation protection	10	7	7.5
11	Dominant thought	5	3.5	4
12	Reactor space site	5	3.5	4
13	Idea of design	5	2.5	4
14	Design concept	10	6.5	8.5
15	Positive aspects of the design	5	2.5	3.5
16	Negative aspects of the design	5	3	3.5
17	Dominant character	5	2.5	3.5
	Total	100	62	75

Results

Due to the situation of the international reserve of non renewable energy sources, and the great potential of the nuclear energy, we should rely on nuclear energy on the national and international levels for sustainable development. Radiation safety is an important aspect in the design of NPPs. Site selection for placing a nuclear power plant 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 a heavily built-areas and are best situated in a rural or semi-rural districts.

Koeberg NPP wellutilizedwith the surrounding area to serve the design and the general layout of the plant. Koeberg NPP has been established in good agreement with the climactic aspects according to the site nature and conditions. Functionally, the design of Koeberg NPP focused on achieving reasonable rates of spaces and dimensions.

Atucha NPP has dealt well with the 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.AtuchaNPP 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 to the plant gives a spirit of excitement for the plant. Also, ther is clarity, ease of movement between the activities and the buildings and a keen interest with insurance operations.

The two plants have dealt accurately and carefully with the climatic elements depending on the circumstances and nature of the site. 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 buildings. It could be observed in Table 1 that Atucha nuclear power plant in Argentina (radial concept) is better than Koeberg nuclear power plant in South Africa (linear concept) in terms of design and planning.

Recommendations

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 aspects into consideration.

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 building).They are recommended to be able to work in close co-operation with other engineers from different departments.They are recommended to clarify the feasibility of establishing NPPs from urban, architectural and environmental terms.

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