Overview Notes

for a course on

Siting of Nuclear Power Plants

to be given at

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Siting of Nuclear Power Plants - Course Outline

This course will provide some insights into the issues involved in siting a nuclear power plant, from the perspective of both the utility and regulator, under the following headings:

1. General factors associated with the siting of large electrical generating plants;
2. Special factors associated with selection and approval of (a) site(s) for (a) nuclear power plant(s)
   - 2.0. Overview
   - 2.1. Seismicity
   - 2.2. Geological, hyrdogeological, hydrological factors
   - 2.3. Meteorological factors
   - 2.4. Population distribution
   - 2.5. Land use
   - 2.6. External events (other than earthquakes)
3. Site approval process in selected countries
4. Site approval system and requirements in Canada
5. Considerations of radioactive waste

The emphasis will be on sections 2 and 4, in particular on how the various factors may affect radiological safety.

1(a). General factors in siting a nuclear power plant

A nuclear power plant is basically a large electrical generating facility. As such it shares a number of siting factors or requirements with large fossil-fueled plants.

Among these are:

- **the need for a supply of water for the turbine condenser and other cooling needs;**
- **reasonable proximity to a main electrical grid;**
- **access for heavy equipment**
- **reasonable access to source of skilled labour, equipment, supplies, etc., for operation**

In seeking a site for a nuclear power plant a utility must balance the engineering and economic factors, such as those above, with the special requirement to minimize the radiological risk as will be examined in the several parts of section 2.

1(b). General factors in siting a nuclear power plant (cont.)

Water supply:

- The most economical arrangement for condenser and cooling water is a once through system using fresh (not sea) water.
- Sea water cooling is feasible and is used in many installations around the world. (In Canada, the Point Lepreau NGS in the province of New Brunswick uses sea water cooling.) However, this requires, typically, the use of an intermediate circuit to minimize the problems associated with salt water, with the added costs that implies.
- When the water supply is limited, cooling towers are often used, but they bring extra costs and possible environmental and aesthetic concerns.

1(c). General factors in siting a nuclear power plant (cont.)

Proximity to grid:

- **An obvious factor related to the distance to a main grid is the cost of the connecting transmission line, which is directly related to its length.**

- **The grid should be large enough that the addition of the output of the nuclear power plant does not de-stabilize it.**

  (A good discussion of the problems associated with adding a nuclear power plant to a small grid is given in the IAEA Technical Report Series No. 271 *Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity*.)

- **A nuclear power plant requires a reliable, back-up, supply of electrical power to maintain safety systems in the event of a total reactor shut-down.**

1(d). General factors in siting a nuclear power plant (cont.)

Access for heavy equipment:

- Many components of a nuclear power plant are very large and / or heavy;
- Access by water or rail is highly desirable

Access to personnel and supplies:

- The most important component in ensuring safe operation of a nuclear power plant is a skilled and competent operating staff - such people like to live in pleasant surroundings with reasonable access to goods and services.
- An operating nuclear power plant needs many on-going supplies of a wide and diverse nature - therefore, reasonable access to sources of such supplies is desirable.

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Task 1: From the consideration of engineering and economic factors, such as outlined in this section, suggest five possible sites for a nuclear power plant (assume two units of a size similar to a CANDU 6) in Thailand with brief rational for your selection.

(Some of these will be chosen for a further evaluation against the special factors associated with nuclear power plants.)

2(a). Special factors in siting a nuclear power plant

2.0. General:

The special aspect of a nuclear power plant is the potential for the release of a significant quantity of radioactive material. From this perspective of nuclear safety, the primary objective in siting a nuclear power plant is the protection of the public and the environment from the effect of a release, accidental or normal, of radioactive material.

There are two fundamental considerations in assessing a potential site for a nuclear power plant:

- site characteristics that could affect the safety of the plant or the transfer of radioactive material, and,

- the potential impact of the plant on the surrounding area, population and environment.

2(b). Special factors in siting a nuclear power plant (cont.)

2.0. General (cont.):

Site characteristics affecting the safety of the plant include:

- **2.1. Seismicity of the area**
- **2.2. Geology and hydrogeology os the site**
- **2.3. Meteorology of the area**
- **2.4. Hydrology**
- **2.5. Potential external events - both natural and man-made.**

Among site characteristics that could affect the potential impact on the area are:

- **2.6. Population distribution**
- **2.7. Land and water use**
- **2.8. Special environmental features**
- **2.9. Historical and cultural features**
- **2.10. Proximity to international border**

Each of these factors, in both categories, will be discussed briefly.

2(c). Special factors in siting a nuclear power plant (cont.)

2.1. Seismicity:

- A major concern in the safety analysis of a nuclear power plant or other major nuclear facility is the likelihood of a "common cause" event that could damage not only the operating systems but also many, or all, of the various "barriers" that are created to ensure safety (such as the independent safety systems that are part of CANDU nuclear power plants).
- In many parts of the world, seismicity, the potential for earthquakes, is a major factor, if not THE major factor in the selection of a site for a nuclear power plant. For some countries, such as Japan, the choice becomes one of "the least worst", since the entire country is prone to earthquakes. Nuclear power plants, as other major construction projects, can be designed and built to withstand fairly severe earthquakes but at a significant extra cost.
- The potential for earthquakes should be determined both from historical records and from a study of the seismotectonic nature of the area. A design basis vibratory ground motion needs to be defined for the site, taking into account not only the seismicity of the area but also the specific geological conditions at the site.

(IAEA Safety Guide 50-SG-S1 provides further guidance on this issue.)

2(d). Special factors in siting a nuclear power plant (cont.)

2.2. Geology / hydrogeology:

- A nuclear power plant involves large sized buildings which require sound foundation. The site should provide coherent, stable geological structures. The potential for liquidification, as may be caused by an earthquake, should be evaluated and avoided. The immediate site area should be examined for sub-surface features such as caverns, abandoned mines, etc., which could lead to collapse, subsidence or uplift. The geotechnical characteristics must be analyzed.
- Surface faulting should be avoided. If surface faults are evident they should be assessed for the likelihood of displacement (movement) at or near the surface.
- The possibility of slope instability, such as land and rock slides caused by heavy rains, should be studied. Such a potential need not rule out a possible site but it must be taken into account in the design bases for the plant..
- The hydrogeological characteristics of the area need to be examined to determine the nature of the ground water, and the magnitude and the direction of its flow. This is of particular importance if the ground water in the vicinity is used for human consumption or for irrigation. The existence of ground water flow need not prohibit the choice of a site but must be taken into account in the design of the plant and of associated monitoring.

2(e). Special factors in siting a nuclear power plant (cont.)

2.3. Meteorology:

- **Atmospheric dispersion is the most likely way that radioactive material, which may be released from the nuclear plant, could be transported and result in the exposure of people or contamination of land. It is essential, therefore, to have a good understanding of the local meteorology to enable analyses of the potential consequences of releases of radioactive material. Actual measurements of dispersion are desirable but are not usually available at the time of site selection. Dispersion characteristics can be predicted from standard meteorological factors.**
- **Sites in confined valleys may cause difficulties because of the channeling of winds which would reduce the normal dispersion effect.**
- **Detailed guidance on atmospheric dispersion calculations is available from a number of sources, e.g.,**
  - IAEA Safety Series 50-SG-S3
  - Canadian Standard ....CAN3-N288.1 *Guidelines for Calculating Derived Release Limits for Radioactive Materials in Airborne and Liquid Effluents from Normal Operation of Nuclear Facilities*

2(f). Special factors in siting a nuclear power plant (cont.)

2.4. Hydrology:

The characteristics of adjacent or near-by rivers, lakes or oceans need to be understood, both for analysis of the behaviour, spread, of liquid radioactive releases and for the determination of the heating effect by the condenser cooling water: 2/3 of the heat produced in the reactor. At many sites the temperature rise of the water, is a major environmental or social concern, e.g., where the adjacent waters are extensively fished, the increased temperature of the water can cause a change of the species that habit the area.

2.5. External events:

- The major nuclear safety concern about "external events" is the potential to cause "common cause" failure of both the operating systems of a nuclear plant and of the many protective "barriers" or safety systems. Therefore, the potential for external events that could affect the plant, whether natural or man-made, must be evaluated.
- Examples of natural events are: floods, tornadoes, tropical cyclones (hurricanes or typhoons), tsunamis.
- Man-made external events can include chemical explosions, dam failures, aircraft crashes, etc. (In Germany, the high density of military aircraft led to a requirement for nuclear power plants to withstand a direct crash.)

2(g). Special factors in siting a nuclear power plant (cont.)

Characteristics affecting impact on area

2.6. Population density:

- When nuclear power was first being introduced population density was a major concern. This arose from early (in the 1950s) theoretical studies of the consequences of a major release of fission products that predicted tens of thousands of deaths. Initially, the position taken by most countries with nuclear power programmes at the time was to locate plants in areas of low population density and, further, to require an "exclusion zone" around the plant that was totally controlled by the nuclear power plant operator (licensee).
- With the evolution of safety systems and containment it is, at least theoretically, possible to locate a nuclear power plant anywhere.
- There remains, however, the question of achieving practical emergency measures, such as evacuation, in the (unlikely) event of a significant release of radioactive material from the plant. The ability to develop such emergency plans depends considerably on the social and political structure of the country and, for evacuation, on the transportation infrastructure. If other factors are relatively equal, the choice of a site with a lower population density would be prudent. In any event, the potential for population growth must be considered, since the existence of the plant will likely increase the economic prosperity of the area.

2(h). Special factors in siting a nuclear power plant (cont.)

2.7. Land and water usage:

Some agricultural and aquacultural (or fishing) activities are particularly sensitive to radiation or the effect of heated (condenser cooling) water. For example, radioactive iodine, which is a major fission product and is volatile (and therefore readily released and dispersed) is concentrated in the milk of cows that graze on contaminated grass. Some crustaceans (shell fish) concentrate certain radioactive elements. As mentioned under "hydrology", a temperature rise of the water in a river, lake or shore area of an ocean can lead to a change of species of fish inhabiting the waters.

2.8. Special environmental features:

A current trend in environmental assessments of the impact of nuclear facilities is the examination of the effect of radioactive releases on non-human species. It appears that some species may be particularly sensitive. However, in contrast to the concern for individual humans, in most cultures the question for non-human species is the survival of the species in that particular habitat. Nevertheless, the biota, both animal and plant, of the region needs to be studied with an eye for species particularly sensitive to radiation.

In some countries aesthetic environmental values are important, such as the appearance of cooling towers.

2(i). Special factors in siting a nuclear power plant (cont.)

2.9. Historical, cultural factors:

Most countries with long histories wish to preserve sites and structures having particular historical or cultural significance. This could preclude the selection of an, otherwise, technically suitable site.

(As an example, the Wolsong site in Korea, which now has four CANDU units in operation or under construction, was moved a few kilometres from the originally selected site because of an underwater tomb of an ancient king.)

2.10. International borders:

Since a potential accident in a nuclear power plant can lead to consequences (radioactive releases) that can extend for many kilometres, a site near an international border raises the problem of appropriate treaties with the neighbouring country. Since inter-country relations can change, even if there is agreement it would seem prudent not to site a nuclear power plant close to an international border.

There is an international treaty on the notification of neighbouring countries in the event of an accident.

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Task 2: For the sites that we chose among those suggested in Task 1, select the one that you feel best meets all of the various criteria outlined in this section. Be prepared to defend (provide the rationale for) your choice.

3(a). Site approval process in selected countries

Finland:

Background: Finland is a small country with a central government. It has two utilities with nuclear power plants, one of which is privately owned , the other state owned. there is a central nuclear regulatory body - the *Finnish Centre for Radiation and Nuclear Safety* (STUK), which reports to the Minister for social Affairs and Health. the overall licensing authority is the Council of State (the senior governing body).

Site approval: Approval of a proposed site in Finland is part of the first formal stage of licensing of a nuclear facility - Decision in Principle. For this stage the applicant must submit:

- a description of the proposed site
- a description and analysis of environmental effect and of the plans for preventing or mitigating these
- general description of plans for management of spent nuclear fuel and radioactive waste

This is in addition to information on: competence of the applicant; description of applicant's financial resources and of the economic viability of the project; and a description of the proposed plant.

3(b). Site approval process in selected countries (cont.)

France:

Background: France has a centralized form of government and a state-owned utility (Electricite de France - EdF). It has a very large nuclear power program. Two Ministers share authority over nuclear facilities - Industry, and Environment. In addition the Minister of Health must give consent. There are two technical organizations that conduct reviews- the *Direction de la* surete *des installations nucleaires* (DSIN), which is within the Ministry of Industry, and the *Institut de protection et de surete nucleaire* (IPSN), which is part of the *Commissariat a l'energie Nucleaire* (CEA).

Site approval: There is, nominally, one application to construct the installation, leading to one "decree" to setup (build). In practice there are several approval steps. Applications are referred to the DSIN and the IPSN for review. Their work is coordinated by a Groupe Centrale which reports to the head of DSIN. The applicant is required to hold public information meetings. A draft decree is developed by the Ministers of Industry and Environment and sent to the Interministerial Committee for Large Nuclear Installations and also to the Minister of Health for his consent. The Prime Minister issues the final, formal, decree.

3(c). Site approval process in selected countries - United Kingdom

Background: The United Kingdom (UK) has basically a central government with a number of powers delegated to Scotland. The electrical utilities were state-owned up until a few years ago. Now they are privatized, with a separate utility operating the nuclear power plants.

The primary legislation affecting nuclear installations are: the *Nuclear Installations Act* of 1965, the *Health and Safety at Work Act* of 1974. The *Nuclear Installations Regulations* of 1971, and *the ionizing Radiation Regulations* of 1985 augment these basic Acts. The *Health and Safety at Work Act* created the *Health and Safety Executive* (HSE) and brought the *Nuclear Installations Inspectorate* (NII) under its broad direction. The HSE normally reports to the Secretary of State for Employment but for nuclear matters reports to the Secretary of State for Energy or the Secretary of State for Scotland.

Site approval: There is, nominally, just one step in the licensing process - a Site Licence. In practice the NII imposes many stages of approval. A proponent submits an application to the HSE, following consultation with NII since the requirements are not spelled out in legislation or regulation. The application must contain information on the proposed site and include plans for dealing with radioactive effluents, waste storage and the handling of spent fuel. Since this is, formally, a one step licence, a Preliminary Safety Report, giving a full description of the proposed plant and including safety analyses, must also be submitted.

The NII reviews the Preliminary Safety Report and other documents requested and advises the HSE. Typically the HSE requires the applicant to provide information to local authorities. Permission from the appropriate local authority is required for land use. the Secretary of State can hold a public inquiry if deemed necessary as was done for. Sizewell "B"). The HSE also consults its *Advisory Committee on the Safety of Nuclear Installations* (ACSNI). The licence is issued by the Secretary of State, with such conditions as the NII and HSE consider appropriate.

3(d). Site approval process in selected countries - United States of America

Background: The United States of America (USA) is a federal country but the authority over nuclear matters rests with the federal government.

- The USA has many utilities, most of which are privately owned, several nuclear vendors(designers) and several architect / engineers (which handle the balance of plant). The central regulatory agency is the United States Nuclear Regulatory Commission (USNRC). The major legislation is the *Atomic Energy Act* which was originally passed in 1954 and the *Energy Reorganization Act* of 1974 which abolished the *Atomic Energy Commission (USAEC)* and created the *Nuclear Regulatory Commission* (USNRC). Other laws also apply, most important the *National Environmental Policy Act* & other environmental legislation.

Site approval: The rules for the licensing process for nuclear installations are spelled out in regulations: *Title 10, Code of Federal Regulations (CFR), Chapter 1 - Nuclear Regulatory Commission* (10 CFR 1). There are two major steps - Construction Licence and Operating Licence.

- Recent amendments allow for a one step process with prior approval of the design. An Early Site Permit, also called a Limited Work Authorization (LWA) may be issued prior to a Construction Licence to allow for site preparation work, according to 10 CFR 2.
- The criteria for siting for nuclear reactors are set out in regulations (10 CFR Part 100). The submitted information is reviewed by the large staff of the USNRC and by the *Advisory Committee on Reactor Safeguards* (ACRS) and, if appropriate, by the *Advisory Committee on Nuclear Waste.*
- A public hearing is required before a Construction Licence can be issued. These formal hearings are conducted by a three-member *Atomic Safety and Licensing Board* appointed by the five-member Commission.
- An environmental assessment is required which is reviewed by the Environmental Protection Agency (EPA) and the state concerned , as well as by the USNRC.

4(a). Site approval system and requirements in Canada

Background

- Canada is a federation, with legislative powers divided between the central (federal) government and that of the ten provinces and two territories.
- Under the basic constitution, responsibility for health, worker safety, and resources rest with the provinces, but the federal government has, or can assume, powers affecting these areas if needed in the "national interest".
- In 1946, the federal government passed the *Atomic Energy Control Act* which gave it total control over all aspects of "atomic energy", with the full consent of the provinces.
- The *Atomic Energy Control Act* established the *Atomic Energy Control Board* and assigned it very broad powers to direct, control, and regulate: the development, research, production, of atomic energy; the prospecting for, mining, refining of uranium and thorium; the production, import, export, transportation, etc., of "prescribed substances" (which includes radioisotopes).
- The AECB has issued only general regulations, the *Atomic Energy Control Regulations.* These are largely procedural. More directed regulations have been issued dealing with: Transport Packaging of Radioactive Materials; Uranium and Thorium Mining; Physical Security, and Cost Recovery (fees), but nothing specifically on nuclear plant siting..

4(b). Site approval system and requirements in Canada (cont.)

Site approval:

- Although only a Construction Approval and an Operating Licence are specified in the *Atomic Energy Control Regulations* there is normally a prior step of Site Acceptance. An application for Site Acceptance, containing a full description of the proposed site, along with an Environmental Impact Statement (EIS), is submitted to the AECB. The AECB will refer the application and the EIS to the *Canadian Environmental Assessment Agency* (CEAA) which will form a panel to conduct environmental assessment hearings. The applications for Site Acceptance must also include a summary description of the proposed installation.
- The staff of the AECB will examine the submissions primarily for the effect of the site characteristics on the proposed plant while the CEAA will focus on the impact of the installation on the area.
- There are no specific requirements for a site for a nuclear power plant in the AEC Regulations or the AECB's Regulatory Documents. However, all sites approved to date have been required to have an "exclusion zone"..
- Exclusion zone: Early in the Canadian nuclear power programme the AECB decided to require an "exclusion zone" of land totally controlled by the applicant / licensee having a minimum radius from the centre of the reactor(s) of 1,000 yards (3,000 feet). This has since been translated into metric units as 914 metres. That number suggests, unfortunately, three-figure accuracy while the original value was chosen somewhat arbitrarily based on the shortest distance that atmospheric dispersion models were representative and the largest area it was practical to ask licensees to own.

4(c). Site approval system and requirements in Canada (cont.)

Site approval (cont.):

In general, AECB staff have assessed a proposed site by examining all of the factors outlined in section 2 and applying their judgement. Following are some examples.

Seismicity:

- **Although all of the nuclear power plants built in Canada to date have been in the eastern part of the country where the general probability of earthquakes is not large, the likelihood of earthquakes has been closely studied.**
- **The applicant must propose a "design basis earthquake" with a maximum ground acceleration and a ground motion spectrum for the design of the plant.**
- **In keeping with the AECB's policy of on-going surveillance and review, the geotectonic nature of the area in which the Pickering and Darlington plants (on the shore of Lake Ontario) is currently being re-studied to attempt to determine if faults detected under the lake could become active.**

4(d). Site approval system and requirements in Canada (cont.)

External events:

- At the time of the proposal for the Pickering "B" plant (the addition of four more units to the original Pickering station) a plan was in existence to build a large international airport a few tens of kilometres north of the site. Considerable analysis was conducted on the likely flight paths and steps were taken to have the runways oriented so as to minimize the probability of landing pathways directly over the plant. At the same time the designers were required to show that the containment could withstand the impact of a large aircraft engine.
- For the Darlington plant, a main rail line ran through the intended exclusion zone. This was finally accepted on condition that a high berm be built so that an explosion of a train carrying explosives or chemicals would not affect the plant.

Population density:

- The original decision to allow the building of the Pickering nuclear power plant, which is about 40 kilometres from the centre of the city of Toronto, was taken only after the designers proposed the "vacuum" type containment system which is now a feature of all of the multi-unit stations in Canada. At the time, 1960s, the immediate area was very little developed. Predictions were made of the likely growth of population in the area, but these have proven to be low.
- Although there is no major concern about the safety of the surrounding population the increased number of people and the general development of the area has led to a complete review of emergency plans.

5. Considerations of radioactive waste

- A nuclear power plant generates radioactive waste of various forms. This includes: highly radioactive spent fuel; intermediate level wastes such as spent resins used in the reactor cooling systems; and a large volume of low-level waste arising from minor spills and general operation.
- The management of this waste must be anticipated in selecting a site.
- If the waste is to remain at the site there must be ample room to build the appropriate facilities. In general, low and intermediate level waste repositories can be built almost anywhere. However, even with well-designed and well-built facilities there is a chance of leakage into the ground water. If such a waste facility is planned to accompany the nuclear power plant the geology and hydrogeology of the area must be closely examined.
- To date, spent fuel, everywhere in the world, is being stored in water-filled bays or, after a suitable cooling period, in concrete silos. In Canada, and elsewhere, research and development has been conducted towards building deep geologic disposal facilities. In this context a great deal of study has gone into determining the desired geologic structures for such a depository - but that is not a matter directly related to the siting of a nuclear power plant.

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