NUCLEAR TRAINING COURSE

COURSE 131

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Site
SELECTION FACTORS

There are many factors which influence the selection of the site for a power generating station. The site chosen for a nuclear electric generating station must satisfy requirements in addition to those of the conventional fossil fired station. The factors affecting the choice of sites can be categorized in a number of ways such as:

(a) Economic factors common to fossil-fired and nuclear stations. These may alternatively be called "engineering" factors and will include the following:

1. Load requirements and transmission facilities.
2. Availability of water supplies.
3. Elevation of ground relative to water supplies.
4. Availability and cost of land.
5. Cost of site preparation.
6. Type of land and its ability to support foundations.
7. Availability of materials.
8. Transportation and access facilities.
9. Labour costs.
10. Living accommodation and living conditions.
11. Local or national zoning and building restrictions.

(b) Safety factors or "environmental" factors which are pertinent only to nuclear stations. The following factors can be placed in this category:

1. Reactor type and power.
2. Containment.
3. Population density.
4. Exclusion area requirements.
5. Surrounding land use.
6. Waste disposal facilities.
7. Meteorology and gaseous effluent dispersion.
8. Geology and hydrology.
9. Municipal, inter-provincial, federal and international considerations.
10. Floods, earthquakes, storms, tornadoes and hurricanes.

(c) Psychological factors including:

1. Social acceptability of nuclear installations.
2. Public relations.

The choice of site of a nuclear station may well be a compromise between a number of the above factors which conflict. There may well be conflicts between factors in any one group and between factors from different groups. For instance, proximity to load centres could conflict with the availability of water supplies or the cost of land or labour costs. On the other hand the proximity to load centres could conflict with low population density requirements and low cost of land could be a factor difficult to achieve if a large exclusion area is required.

The sites and layouts chosen for early generating stations built in Canada, U.S. and the U.K. were selected mainly on the basis of isolation and water supply. However, licensing authorities are under pressure from utilities to relax the isolation siting restrictions on the basis that the nuclear industry has a proven safety record and that engineered safety features which can be provided on nuclear stations in populated areas can more than compensate for the additional risks involved.

Greater stress is placed today on the engineered safeguards, especially quality of the containment and reliability of the safety equipment. Consequently licensing authorities have permitted construction of nuclear stations closer to large population centres. Social acceptability of nuclear stations has, therefore, become a more important factor and could well be a decisive factor.

Governmental Regulations

The design and siting of the nuclear generating stations is usually supervised by a government regulating body. In Canada, the Atomic Energy Control Board is the regulating agency for atomic energy. It discharges its responsibilities for reactor safety with the assistance and advice of the national and provincial Departments of Health and of Labour and of a Reactor Safety Advisory Committee (the "RSAC").

The Reactor Safety Advisory Committee was formed in 1956. Its members are scientists and engineers from federal and provincial government departments and other organizations.

The RSAC, assisted by the officers of the Atomic Energy Control Board, follows the design and construction of a new reactor and its operation after it is completed. Authorization to start construction is not granted by the Board until the RSAC believes that a reactor of the proposed type can be built and operated safely on the proposed site. A license to operate is not granted until the reactor has been constructed and commissioned to the satisfaction of the RSAC and when it is convinced that the reactor can be operated safely.

ASSIGNMENT

1. (a) List four of the most important economic factors which affect the selection of a thermal generating station.

   (b) Show how these factors may conflict with one another.

2. (a) List four of the most important safety factors which affect the selection of a nuclear generating station.

   (b) Give examples of how these safety factors may conflict with economic factors.

3. Describe how the emphasis has shifted from some factors to others in site selection and explain how this has resulted in psychological factors becoming more important.

4. What are the functions of the Atomic Energy Control Board and how is it assisted in discharging its responsibilities?

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SAFETY OR ENVIRONMENTAL FACTORS

Nuclear power stations present a potential hazard because of the possible spread of radioactive material to the surrounding area, following an accident. Approval for the construction of such a station can only be obtained if it can be shown that the design of the station meets certain requirements which depend on the site chosen. Analysis of the site in relation to the hazards associated with it must show that the potential radioactive effluents, which may result from normal operation or from the occurrence of a credible accident, will not result in a health or safety hazard to the public.

Thus the site must be shown to be suitable for a given station design or, since the site is likely to be selected first, the effectiveness and reliability of the containment and protective devices must be shown to be effective for a given site. Siting criteria and guides are issued by governmental regulating bodies such as the Atomic Energy Control Board in Canada and the U.S. Atomic Energy Commission. Such guides are discussed in this lesson.

Containment

Primary concern from the safety point of view is from accidents where the reactor fuel is damaged and fission products are released and present the following hazards:

1. Direct radiation
2. Release from the containment of gaseous and volatile fission products.

The latter consideration is generally the limiting hazard because of the protection against direct radiation provided by a reactor building wall and an exclusion area. Under certain meteorological conditions the fission products would be dispersed to the surrounding population where they may be inhaled and ingested. The quantity of certain fission products that is necessary to cause serious injury is relatively small. The worst offender is iodine. To prevent a rapid and gross release of fission products to the environment in the highly unlikely event of an accident in which fuel and its cladding melts and the heat transport piping fails, a containment system is used.

All systems containing, or potentially containing, significant quantities of radioactive material and operating at elevated temperatures or pressures are placed within a containment shell designed to:

(a) limit the release of radioactive material to a value set by the exposure criteria for the particular site involved.

(b) withstand the total energy release possible from the contained system. The pressure increase would be limited by a dousing system or by connecting the containment shell to a separate building kept under vacuum.

(c) have adequate provisions for testing at predetermined intervals.

It must be remembered that the fuel, the fuel sheath and the heat transport system provide normally reliable containment and that the containment shell is an additional measure in case of successive failures of each of the primary containment features. The containment system must be effective when the maximum credible accident occurs. Such an accident must be defined on a realistic basis. Much work has been done recently on the severity of the maximum credible accident and the upper limit of fission product release following reactor core meltdown. Destructive and non-destructive testing of reactors have provided valuable information on reactor safety considerations and further measurements are proposed which will permit a better assessment of the maximum credible accident. More extensive operating experience and a better knowledge of the magnitude of possible accidents will allow more lattitude in the design of containment systems. However, at present negligible fission product release is likely to be demanded, especially when the site is close to large population centres, and the Canadian containment systems are designed for such low leakage rates.

<u>Exclusion Area and Population Density</u>

Although the probability of a serious accident is a function of design, the risk in terms of exposure of the population depends also on an exclusion area and population density. In Canada, the Atomic Energy Control Board issued a preliminary "Power Reactor Siting and Design Guide", which is intended to indicate the suitability of any site for a given design, or alternatively, to specify the required effectiveness and reliability of the containment and protective equipment for a station at a given site. The guide assumes that the station is designed in three structurally and operationally independent divisions:

(a) the process equipment which includes the reactor core, the fuelling equipment, heat removal equipment, control element and the instrumentation needed for regulation and operation. They do not include equipment and instruments added only for safety.

(b) the protective devices which includes equipment which is intended to limit the damage that can result from the failure of any part of the process equipment. In particular it is intended to prevent damage to the reactor fuel, which is the source of the fission products. They include the automatic trip system, emergency cooling system, emergency power supplies and standby equipment.

(c) the containment provisions already considered which may include containment shells, vapor suppression systems and involve the dampers of the ventilation system and the doorways and their interlocks.

The protective devices are intended to prevent or reduce the escape of fission products from the fuel into the building enclosure, if there is a failure of essential process equipment. The containment provisions prevent or reduce escape of radioactive material from the building if both process equipment and protective devices fail.

The guide then gives reference dose limits for individual and population exposure for:

(a) Normal operation

(b) Failures of process equipment only

(c) Failures of process equipment combined with failures of protective devices

These reference dose limits are shown in Table I. The table gives maximum annual dose limits to the public outside the exclusion area due to the normal operating effluents including continual effluent emission and occasional blowoffs and purges (Argon-41, tritium and possibly fission products). As may be seen from the table, the effects of normal operating effluents are combined with that resulting from failures of the process equipment. All failures of process equipment only, regardless of size, are included in this category. The assumed frequency of such a failure is once in 3 years. The Advisory Committee of the AECB may accept a claim, from the designers, that the average frequency is not greater than this because a few years of operation of the station would show how valid such a claim turns out to be. A review of the claim could then be made if this was considered necessary. More optimistic claims have not yet been accepted because it would take too long to confirm such claims by operating experience. Because this frequency is so high, they are regarded as a feature of normal operating experience.

REFERENCE DOSE LIMITS IN NORMAL AND ACCIDENT CONDITIONS

Situation	Assumed Maximum Frequency	Meteorology to be used in calculation	Maximum Individual Dose Limits	Maximum total Population Dose Limits
Normal Operation	100%	Weighted according to effect, ie, frequency times dose for unit release	0.5 rem/yr whole body 3 rem/yr to thyroid (1)	10^4 man-rem 10^4 thyroid rem/yr
Process Equipment Failure	1/3 year	As above		
Process & Protective Equipment Failure	1/1000 yr	Either worst weather existing at most 10% of time or Pasquill F condition if local data incomplete	25 rem whole body 250 rem thyroid (2)	10^6 man-rem 10^6 thyroid-rem

(1) For other organs use 1/10 ICRP occupational values

(2) For other organs use 5 times ICRP annual occupational dose (tentative)

TABLE I

The limits quoted are consistent with the recommendations of the ICRP and ensure that the probability of injurious effects from radiation on any one member of the public is small. Not only is the individual dose limit specified but also the total population dose limit which is obtained by multiplying an individual dose by the population density and integrating over the exposed area outside the exclusion area. These limits set the requirements for the effectiveness of the protective devices and the containment provisions. For low population densities the individual dose limits determine these requirements. If the population density is high the number of people receiving significant exposure becomes important and the population dose then becomes the limiting factor and the more exacting become the design requirements. For example, the permissible leakage from the containment shell at Pickering, following say a loss of the heat transport fluid, would be much less than at Douglas Point under similar circumstances.

In calculating the effect of these types of "normal" releases, weighted dilution factors must be used which take into account the wind distribution and the frequency of different dilution conditions.

More serious accidents are those in which a process equipment failure coincides with failure in either protective equipment or containment provisions. These events may cause greater individual and population dose to the public but are much less frequent (10^{-3} per reactor year or once in 1000 years per reactor). Coincidental failure is presumed to be such a rare event that the reference dose limits are based on the effect of a single exposure. The dose limits under these conditions are called design dosage limits because the designer is expected to design the station so that they will not be exceeded under certain assumed conditions. It is necessary to assume the conditions of the accident because they are unpredictable and assumptions that the designer may make are specified in order to give him a more definite design requirement than the vague concept which has been called the worst credible accident. The assumptions deal with the kind of accident, the amount of fission product release and the atmospheric conditions at the time of the accident. All these assumptions are pessimistic unless exceptional circumstances warrant modification or until experience and experimental data dictate otherwise.

The restriction which the design dose limits impose on the reactor design may be illustrated by considering a 1500 megawatt thermal reactor surrounded by an exclusion area of 1 kilometer (0.62 miles) radius and located 20 kilometers (12.5 miles) from the centre of a city. The city has a population of 10^6 people and covers an area of 400 sq km (155 sq miles) with an average population density of 2500 persons per square kilometer (6500 persons per square mile). The population density outside the city area is assumed to be negligibly small. Table II gives the release of radioactive material from the station which is permitted by the various design dose limits.

TABLE II

CIRCUMSTANCE	FISSION PRODUCTS	INDIVIDUAL DOSE CURIES	POPULATION DOSE CURIES
		Release per year	Release per year
Normal operation and process failure only	Mixed	2.1×10^6	2.5×10^7
	I-131	1600	1.1×10^4
		Release per event	Release per event
Process failure accompanied by failure of protection or containment	Mixed	2.04×10^5	5.5×10^6
	I-131	260	2400

As can be seen the most restrictive conditions are the maximum individual doses at the boundary of the exclusion area. On the other hand, if the population density in the city were 10 times greater, the population dose limit for I-131 would be more restrictive than the individual dose limit.

The exclusion area radii and population densities for NPD, Douglas Point and Pickering are shown below in Table III.

TABLE III

Radius (miles)	Population Densities (no/sq mi) NPD	DOUGLAS POINT	PICKERING
1	0	0	1,000
4	35	380	31,000
8	17	2,000	209,000
16	7	10,000	939,000
20	5	15,000	1,407,000
	Exclusion Area Radius (ft)		
	3600	3,000	3,000

It can be seen that the population density in Pickering G.S. is higher by a factor of 100 - 1,000 than in the case of Douglas Point G.S. This change was made possible by better knowledge of nuclear reactor safety over 6 years ago and better reactor containment resulting in essentially zero leakage to the environment. We see that "the distance factor can be engineered out".

Geology and Hydrology

Earthquake frequency and severity, soil conditions, ground, and surface affect the choice of a site.

Because of the possible serious effects of the earthquakes, regions of high earthquake frequency should be avoided. Provisions must be made in the design to prevent release of fission products in the case of the worst earthquake. The material used for the foundation for a reactor must be stable to assume minimum settling, as uneven settling may result in damage to the reactor piping, shielding and misalignment of control and safety rods and endanger reactor operation.

Recently a site for a large nuclear power station at Bodega Bay, California was abandoned because "it had not been proven that the structure had the ability to withstand a hypothetical three foot shear movement in case of an earthquake".

The hydrology and geology of a site should be favourable for the management of the liquid and solid wastes. Deposits of relatively impermeable soils over ground water are desirable because they offer varying degrees of protection to the ground waters depending on the depth of the soils, their permeability and their capacities for removing and retaining radioactive components of the effluents.

The hydrology of the ground waters is important in assessing the effect that travel time may have on the contaminants which might accidentally reach them at the point of their nearest usage. Site drainage and surface water hydrology is important in determining the vulnerability of surface water courses to radioactive contamination.

Low activity liquid wastes can be discharged to a body of water if its flow is adequate to dilute them to a safe level. In case of solid and liquid wastes it may be necessary to set aside part of the site for a burial pit.

Meteorology

The site meteorology is important in evaluating the degree of vulnerability of surrounding areas to the release of airborne radioactivity to the environment. Capabilities of the atmosphere for diffusion and dispersion of airborne release and prevailing wind directions are considered. Thus high probability of good diffusion conditions and wind direction away from populated areas during slow diffusion conditions would enhance the suitability of the site.

Two major meteorological factors involved in the atmospheric transport and dilution of airborne contaminants are wind and atmospheric stability. Climatological wind patterns at a proposed site should be examined to determine not only the prevailing direction and speed frequency distribution but also the probability distribution of the persistence of winds in given directions at given speed. Anomalous or preferential wind flows due to channelling by topography (narrow valleys proximity of mountain) or the effect of nearby lakes or rivers and effect of these wind flows on low altitude atmospheric transport should be assessed.

The atmosphere shows variations of several orders of magnitude in its capacity to dilute contaminants. These variations are closely related to the vertical temperature gradient of the air. When the air temperature decreases with height at a rate equal to or greater than adiabatic rate (5.4°F/1,000 ft), buoyancy forces are free to act and turbulence is enhanced. When the air temperature increases with height, an inversion or stable situation exists. Vertical motions are suppressed and turbulence and dispersion are reduced.

Typically, the frequency of near-surface inversion conditions in Southern Ontario are approximately 30% but this may be as high as 60% in certain localities.

ASSIGNMENTS

1. What is the primary hazard following an accident which results in damage to reactor fuel and why is it considered a hazard?

2. (a) What stages of fission product containment are there in a nuclear station?

   (b) What is the basic purpose of a containment shell or building?

3. (a) What three structurally and operationally independent divisions are assumed in the AECB's "Power Reactor Siting and Design Guide"?

   (b) For what conditions does the guide specify reference dose limits and why are the first two conditions grouped together?

4. (a) How do the reference dose limits under the first two conditions above affect reactor design requirements?

   (b) Why are total population as well as individual dose limits specified and how might this affect the reactor design requirements if the population density increases?

5. What are the "design dosage limits" and why are they so called?

6. List geological and hydrological factors which affect the choice of a site and comment briefly on the significance of each.

7. (a) What meteorological factors are considered in site selection?

   (b) Which conditions would be considered desirable and which are adverse conditions?

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Site

ECONOMIC FACTORS & SOCIAL ACCEPTABILITY

To ensure that nuclear power will make a major contribution to our generation needs, the nuclear generating stations must be built on the sites which utilities have available or which were planned for fossil fuel fired generating stations. The early practice of siting nuclear generating stations in remote areas set a precedent resulting in a heavy economic burden which the nuclear industry could never economically afford and need not afford. Developments in reactor containment and protective devices, as described in the previous lesson, has made possible the siting of the nuclear generating stations next to the large cities. The economic factors which are generally common to both nuclear and fossil fuel fired generating stations will now be discussed.

Social acceptability of the nuclear stations which may be a decisive factor in the final site selection is also discussed.

Economic Factors

1. Load Requirements and Transmission Facilities

   The most desirable location of generating stations is near load centres (usually large cities) in order to minimize transmission facilities required which are expensive and lead to transmission power losses.

2. Water Supplies

   A large continuous supply of cold and preferably clean water is required mainly for condenser cooling and for cooling a number of heat exchangers both in the conventional and nuclear parts of the stations. Elevation of the station above the water level must be kept to a minimum to avoid high pumping costs. Sites, therefore, are located mainly on waterfront properties.

   If no large continuous cold water supply is available, cooling towers or cooling ponds can be employed to give the desired cooling water.

   Proximity to a large body of water will also allow easy disposal of diluted radioactive wastes.

3. Land Consideration

The land should be suitable to support the heavy loads of the turbine and reactor building and equipment like the turbine generator and reactor. If the land is unsuitable to support the heavy loading, piling is required which increases the construction cost considerably, but often has to be employed as no suitable site can be found to satisfy the requirements mentioned before.

Cost of land and capability of future expansion are important considerations.

4. Transport and Access Facilities

This factor is not as important as in the case of fossil fuel fired generating stations where it is necessary to supply large amounts of coal. Nuclear fuel can be easily transported to the site by truck.

However, access is very important during the construction for transport of the general materials and special heavy pieces of equipment like the generator, turbine and calandria. Also, local availability of construction materials, like gravel and sand, should be considered.

5. Living Conditions for Employees

Economic, social and cultural conditions in the neighborhood of the selected site should be taken into consideration.

Operation of the station requires a fair number of highly skilled personnel who earn relatively high wages. These personnel generally desire to live close to cities or towns with all the amenities such as good schools, universities, good shopping, entertainment, etc.

Generally in isolated areas there is shortage of suitable housing and transportation presents a problem. These factors are eliminated when locating a station next to a city.

Our experience in hiring shows that we have little trouble in recruiting suitable staff, because of the possibility of working in a station located near a large city as opposed to working in one in an isolated area with few amenities.

The availability of suitable living accommodation during the construction phase is of importance. Unless such accommodation is available for the construction workers, added expense will be incurred in providing a construction camp.

Other Factors

Other factors which should be taken into account are:

Labour Costs

Proximity of manufacturing firms

Local or national zoning

Local or national building restrictions

Public Acceptance Aspects of Reactor Siting

It is not enough to make nuclear power technically feasible. It is also necessary to make it socially acceptable. Fortunately, Pickering G.S. site was accepted without any strong public objections. However, in the USA reactor siting experience is characterized by a degree of public turmoil such as that which has occurred near New York, San Francisco, Los Angeles and Detroit.

The difference in attitude may be due to greater association of nuclear power with atomic weapons and fallout. It may also be that there are strong coal interests competing with nuclear power in the USA.

There is probably very little public appreciation of the technical aspect of either nuclear or conventional fossil fuelled stations. Little is known by the general public of the safety aspects and safety records of reactors. However, fallout, fallout shelters and fission products are words of some significance.

Safety of nuclear power has high emotional impact, makes good news copy and is given wide publicity. Objecting groups in USA included many who were not locally affected but who appeared to secure satisfaction in attacks on large institutions or simply by being in the limelight.

In order to gain acceptability by the public of the proposed site it is necessary to undertake educational programs to assure the public, especially those near the proposed site, that no hazards to them exist. These programs should be in layman terms and should cover the operation of the station and its safety aspects. The benefits of nuclear power should also be clearly pointed out.

Public relations, carefully handled, can do much to decrease public concern and make nuclear stations generally acceptable.

ASSIGNMENT

1. Describe briefly the main economic factors affecting siting of the nuclear generating station.

2. Briefly discuss the public relations aspect of site selection.

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