GOVERNMENT OF INDIA

MONOGRAPH

ON

SITING OF NUCLEAR POWER PLANTS

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SITING OF NUCLEAR POWER PLANTS

1. INTRODUCTION

Siting, design, construction, operation, and de-commissioning are the five major stages during the life time of a nuclear power plant. Important factors affecting selection of site for major industrial installations, including nuclear power plants (NPPs) are availability of required infrastructure, economics, sociological aspects, general safety in terms of its impact on the public and environment, technical feasibility and finally engineerability of the site. Safety of the plant personnel, public and the environment from radiological hazard is the most important consideration for siting of nuclear power plants.

Like any other facilities, nuclear power plants are also designed to withstand the loading effects due to hazards from external events. Events of origin external to the plant operation are termed as external events. External events are of two classes; due to natural phenomena and human induced. Examples of external events due to natural phenomena are earthquake, wind, flood, etc. The human induced external events are explosion, missiles, aircraft impact, mining etc. The magnitude of such loads for design of NPP is termed as design basis and is derived based on more stringent criteria compared to that for other conventional facilities.

Siting is the process of selecting a suitable site for a facility, including appropriate assessment and derivation of the related design bases. Siting process involves two basic stages – site survey and site evaluation, Figure-1.

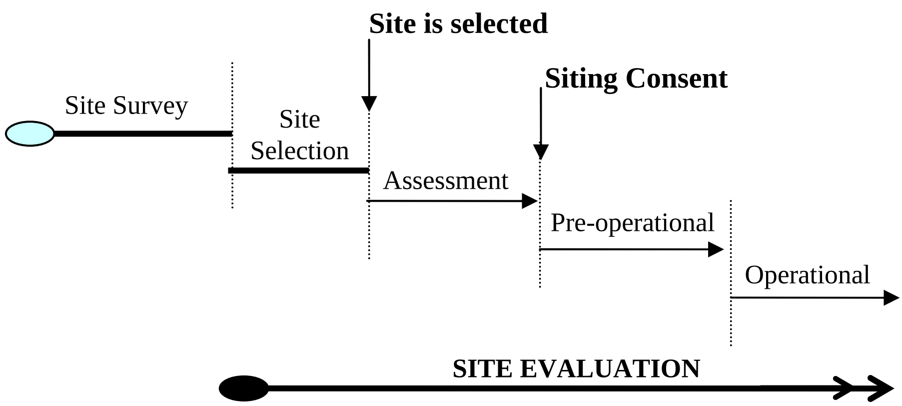


Figure 1: Different phases of activities related to siting of a nuclear power plant

Activities during site survey stage are identification of prospective locations, collection of information/data related to factors affecting site selection and conducting preliminary investigations. Site evaluation, in general, involves,

i) Demonstration of acceptability of the site using the related information/data and satisfying established criteria for selection of NPP sites.

ii) Derivation of site related design basis.

Site evaluation is continued till the end of operating life of the plant to ensure safety against hazards associated with external events. This is important due to changing perception of the hazard from external events as well as changing natural and/or human made environment in the site region over time.

Atomic Energy Regulatory Board (AERB) formulates safety requirements for nuclear and radiation facilities to assess their safety during siting, design, construction, commissioning, operation and decommissioning stages. The Board issues Codes and Standards for regulating nuclear and radiation safety and associated quality assurance requirements. Several safety guides and manuals have been published by AERB for implementing the safety requirements of these Codes and Standards.

Evaluation of a site by AERB for regulatory consent starts on receipt of application from utility after completion of site selection process. In addition to the requirements specified by AERB, the stipulations of other applicable Legislations and Acts also need to be met for siting NPPs in India. The Central or State Government agencies, as the case may be, have been identified to regulate the provisions of these acts and the applicants are required to obtain necessary clearances from these agencies. Important legislations that have major influence during site evaluation stage are Environment Protection Act, 1986 and, associated Environment (Protection) Rules, 1986 and the Environment Impact Notifications, 1994 as amended in 2002. These legislations are implemented by the Ministry of Environment and Forests (MoEF). Public consultation is an essential pre-requisite for obtaining clearance of an NPP project. The State pollution control board (SPCB), in a pre-specified manner, conducts the public hearing. After completion of the public hearing, the project proponent addresses the environmental concerns expressed during public hearing and makes appropriate changes in the draft environment impact assessment and environment management plans. The MoEF clearance is given after the study of the environmental impact assessment (EIA) report and the documents on outcome of the public consultations.

This monograph brings out the regulatory procedures followed by AERB to evaluate the site of nuclear power plant but does not cover the procedures/ regulations by other Government agencies.

2. BASIC REQUIREMENTS

For nuclear power plants, the ‘site’ includes the area surrounding the plant enclosed by a boundary, which is under effective control of the plant management. Current mandatory requirement of AERB siting code is that an exclusion zone of atleast 1.5km radius around the plant is to be established and this area should be under the exclusive control of the station wherein public habitation is prohibited. Though the exclusion zone distance could be greater than 1.5km, depending on the land acquisition and future expansion plans, the radiation dose limits for public are specified by AERB at 1.5km distance from the plant.

In addition, a sterilized zone around the exclusion zone covering an area upto 5km radius around the plant is also established. Only the natural growth of population is permitted in the sterilised zone, but planned expansion of activities leading to enhanced population is regulated. In relation to this, certain other desirable characteristics are also mentioned in the code. Figure 2 depicts different zones that are defined in relation with the NPP site.

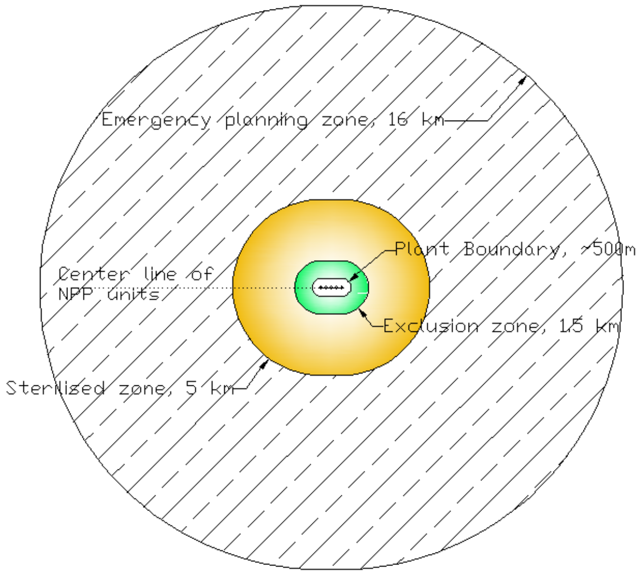


Figure 2: Distance of different zones as defined in AERB siting code, from the reactor centers of NPP.

The site evaluated for locating an NPP is considered acceptable from the safety point of view, if there are technical solutions by engineering measures available to site related problems, giving assurance that the proposed plant could be built and operated so that radiation dose to the plant personnel, public and environment is within prescribed limits specified in AERB safety code 'Code of Practice on Safety in Nuclear Power Plant Siting", AERB/SC/S. These limits are specified in a very conservative manner and the provisions of the code are in line with international practice.

Important considerations in selection of an NPP site are topography, accessibility, infrastructure for transportation, construction facilities, township for staff, and availability of power, feasibility of power evacuation and availability of cooling water along with other important safety aspects related to geology, seismology and meteorology.

A large region is investigated to select one or more candidate sites on the basis of safety and other considerations. Rejection criteria, generally given in terms of screening distance values (SDV), are applied at site selection stage to shortlist the candidate sites. For many hazards like toxic gas release, explosion, etc., the hazardous effect diminishes as one moves away from the origin of the event, and beyond a particular distance the event will be of no concern. SDV reflects this distance.

Subsequent to application of rejection criteria, evaluation of the candidate sites is carried out. Level of detail needed for site evaluation varies according to the type of installation. NPP siting requires the highest level of detail.

Three basic aspects that govern siting of nuclear power plant are:

- Impact of external events, both natural and human-induced, on the plant.
- Impact of the plant on site, environment and public.
- Factors affecting implementation of emergency measures in public domain.

In addition, there are number of other considerations like cooling water requirements, availability of infrastructure, etc that have significant bearing on the siting activity of NPP.

Criteria for assessment of siting of an NPP are specified in the siting code AERB/SC/S and related safety guides published by AERB. The safety guides address in detail the acceptable procedures for meeting the requirements laid down by the siting code. Table-1 contains the list of related safety guides published by AERB. Safety guides published by International Atomic Energy Agency (IAEA) are also considered.

Table -1 : List of AERB safety guides related to siting of NPPs

	Safety Series No.	**Title**
1.	AERB/SG/S-1	Atmospheric Dispersion and Modelling
2.	AERB/SG/S-2	Hydrological Dispersion of Radioactive Materials in Relation to Nuclear Power Plant Siting
3.	AERB/SG/S-3	Extreme Values of Meteorological Parameters
4.	AERB/SG/S-4	Hydrogeological Aspects of Siting of Nuclear Power Plants
5.	AERB/SG/S-5	Models for Radioactive Dose Computation Methodologies from Radioactivity Concentrations in Environment
6.	AERB/SG/S-6A	Design Basis Floods for Nuclear Power Plants on Inland Sites
7.	AERB/SG/S-6B	Design Basis Floods for Nuclear Power Plants at Coastal Sites
8.	AERB/SG/S-7	Man-Induced Events and Establishment of Design Basis Events (Draft)
9.	AERB/SG/S-8	Influence of Site Parameters on Emergency Preparedness
10	AERB/SG/S-9	Population Distribution and its Analysis in Relation to Siting of Nuclear Power Plants
11	AERB/SG/S-10	Quality Assurance in Siting
12	AERB/SG/S-11	Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites

All criteria/requirements related to siting can be broadly classified into the following:

1. Rejection criteria: For locating the plant, these stipulations need to be satisfied, other wise the site is deemed rejected. No engineering measures can satisfactorily overcome the detrimental effects of not meeting these criteria, e.g. no possibility of ground failure, minimum distance from military installations, etc.

2. Mandatory requirements: These requirements are related to those phenomena whose effects shall be considered in the design of NPP and evaluated during the siting process; e.g. wind, rainfall/flood, vibratory motion due to earthquake, etc. Usually, suitable measures can be adopted to take care of these phenomena in the engineering of the plant.

3. Desirable requirements: Non fulfillment of these requirements does not affect the plant attributes related to radiological safety e.g. distance to facilities handling inflammable/ toxic/explosive substances, population around site, etc. The design basis parameters of the plant are altered at the cost of economic penalty. Modifications of some activities/procedures of this class during plant operation may also have economic impact, e.g., evacuation of population surrounding the plant area in the event of an off site emergency.

Safety of the plant against external events is ensured either by observing SDV (wherever applicable) or by engineering the site and plant to mitigate the hazard caused by such events. If the hazard is located beyond SDV, capability of that particular hazard to cause damage at site is considered to be negligible by engineering measures. Some of the external events where this concept is applied include distance to a seismic fault that is capable of movement during an earthquake, proximity to airports and defense installations, distance from industries storing toxic or explosive substances, etc. Depending on the severity of the hazard and engineerability against the hazard, SDVs are used as a rejection criterion or as a criterion for ready acceptance. AERB safety code, AERB/SC/S delineates in detail the SDVs related to different types of external events. Table-2 contains the rejection criteria and SDVs, if applicable. The existence of places like architectural/historical monuments, pilgrimage centers, or tourist interest within 5 km calls for rejection of site. Environmentally sensitive locations like national parks, sensitive marine environment/biota may also impose rejection of candidate site.

Site characteristics and characteristics of natural environment in the site region, which may affect safety of the nuclear power plant are investigated and assessed for a projected time period encompassing the lifetime of the plant. Hazards associated with external events are characterized in terms of parameters that can be used as the basis for design for the plant. Effects of the combination of these hazards with ambient hydrological, hydrogeological and meteorological conditions as well as the plant internal events are given due consideration while deriving their design basis values.

The criteria to derive design basis parameters of external natural hazards like earthquakes, floods, cyclone, wind are based on the concept of mean recurrence interval (MRI). Mean recurrence interval is defined as the mean time between the occurrences of two successive events of a given type averaged over a large number of occurrences, that are equal to or greater than a given magnitude. Due to the statistical nature of the variability of the parameters, the design value of a parameter considered in engineering of the plant should have MRI much larger than the life time of the facility.

Table 2: Rejection criteria with respect to various hazards for siting of NPPs

Sl. No	Hazard	Rejection criteria and SDV, if applicable
1.	Earthquake	Site falling in seismic zone V as per BIS 1893
2.	Earthquake	Distance from capable fault < 5km
3.	Earthquake	Potential for soil liquefaction
4.	Earthquake/ Geological	Potential for slope instability which cannot be mitigated by engineering measures
5.	Earthquake/ Geological	Potential for ground collapse/subsidence/uplift which cannot be mitigated by engineering measures
6.	Geological	Possibility of formation of sand dunes
7.	Aircraft impact	Distance from small air fields < 5km
8.	Aircraft impact	Distance from major air ports < 8km
9.	Aircraft impact	Distance from military air fields < 15km
10.	Explosion	Distance from military installations storing ammunitions < 10km

Note: 1.: Environmentally sensitive locations like national parks, sensitive marine environment/biota may impose rejection of candidate site.

2:. Existence of places like architectural/historical monuments, pilgrimage, or tourist interest within 5 km of site imposes rejection of candidate site.

The site is also evaluated with respect to safety aspects of storage and transportation of input and output materials, for example, new fuel and spent fuel as well as radioactive wastes including possible combined effect of nuclear and non-nuclear effluents.

The preferred means of ensuring that the risks associated with the plant are within prescribed limits are engineering of the site and appropriate design features of the plant. If evaluation indicates that the overall risk cannot be kept within the acceptable limit by means of design of the plant, engineering of the site or administrative procedures, the site is deemed unsuitable.

A site is re-evaluated if a new plant or other nuclear facilities are proposed to be built adjacent to the existing ones.

3. IMPACT OF EXTERNAL EVENTS ON THE PLANT

The operational status of a nuclear power plant is generally divided into two conditions, normal operating condition including anticipated operating occurrences, and abnormal conditions. Abnormal conditions are related to postulated accident scenarios in the plant. Though radiological hazard during normal operation is of extremely low consequence, the hazards due to accident scenario are of concern. The accident could be caused by internal event or external event. An internal event is caused by undesirable occurrences during plant operation which has its origin within the plant boundary. Loss of coolant accident (LOCA), main steam line break (MSLB), etc are examples of internal events causing accident scenario.

3.1. External Events Due to Natural Phenomena

1) Earthquakes and surface faulting

Earthquakes are low probability events which are capable of producing severe consequences. Shaking (vibration) and ground failure/rupture are the main effects created by earthquakes, that cause damage to buildings or other structures and facilities.

The earth's crust comprises of different sets of plates and these plates move slowly relative to each other at rates ranging from less than 1 to about 16 centimeters per year. The movement causes plates to converge in contact regions between the plate boundaries, and diverge in some other boundaries. The difference in speed of movement between the plates causes stress buildup and, in turn, increases potential energy in the plate. When the built-up stress exceeds plate's capacity, it ruptures leading to release of the energy stored. The faces of ruptured area also move with respect to each other so as to achieve the total displacement that was restrained in the past. All these, ultimately, result in earthquake. The plate boundaries are located both under the sea as well as on the land.

The location inside the earth where the rupture of plate starts causing earthquake is known as hypocenter or focus, and the corresponding point located above on the surface of the earth is known as epicenter. The ruptured area along which the displacements have occurred is termed as a fault.

Ground rupture occurs when the ruptured fault, which caused the earthquake, intersects the ground surface and the fault displacement could be observed with naked eye. The severity of the earthquake at a site depends on the complex combination of the energy released during the earthquake (measure of which is magnitude), its distance from epicenter/hypocenter, and the local geological, geomorphological geophysical conditions as well as seismological status.

The Indian standard code, IS 1893, "Criteria for earthquake resistant design of structures", divides India into four seismic zones. As per this classification, zone V is associated with the areas of maximum seismicity and zone II with the minimum. As per present regulation, an NPP is not located in India at a site in zone V. The main reason is high possibility of ground failure in the areas falling in zone V, which is principally in the Himalayan regions. Higher economical penalty is another reason.

Hazards due to earthquake induced ground motion are assessed considering seismotectonics status of the region within which the site falls, along with site specific conditions. Data and information from geological, geophysical, seismological and geotechnical investigations are collected/analysed. The level of details in data collection increases as one gets closer to the site. A region within a radial distance of 300km from the site is investigated for collection of relevant data. If adequate data for the site region are not available, data from sites with similar geological, geotechnical, seismotectonics and seismic wave propagation path characteristics are used. Reservoir induced seismicity that could be caused by existing dams or those proposed to be built in the region is also considered while assessing the earthquake potential of the region. The detailed guidelines for assessment of seismological hazard at site and estimation of design basis parameters are provided in AERB guide AERB/SG/S-11.

Towards obtaining valuable insight about the seismicity of the region, microseismic measurements of the site region that are capable of measuring very small magnitude earthquakes are conducted for at least 3 years. Microseismic events are those earthquakes having magnitude 3.0 or below on Richter scale.

Potential for ground rupture is assessed from geological, geophysical, geomorphological, geodetic and seismological data. The presence of a fault in the vicinity of the site increases the chance of ground rupture during the earthquake. Hence, if there is an evidence of a capable within SDV, the site is deemed unacceptable. Capable fault is the one which has a potential for rupture at or near the ground surface.

The design basis vibratory ground motion is derived for two levels of earthquakes, S1 or Operating Basis Earthquake (OBE) level and S2 or Safe Shutdown Earthquake (SSE) level. SSE represents the maximum potential vibratory ground motion that can be expected for the region (with MRI $\geq$10,000 years). In the event of this level of earthquake, the only consideration is to keep the radiological risk to the public below the acceptable level. Hence only those safety systems, which are needed to meet this requirement, are designed for this high level of earthquake. Another vibratory ground motion, OBE, (with MRI ~100 years) is also specified. All plant systems are expected to continue to function when subjected to OBE. If the plant experiences ground motion above this, the plant shall be shutdown and inspected. These motions are expressed by appropriate parameters such as site specific response spectra for various damping factors, durations of shaking and time histories.

Another phenomenon that can occur during earthquakes is liquefaction of soil strata. Liquefaction is the settlement of the ground in areas underlain by loose saturated sand/silt due to vibration caused by an earthquake event. For the highest level of vibratory ground motion expected at the site, the liquefaction potential is evaluated. The possibility of seismicity induced ground subsidence is also explored. If such potential exists, the site is rejected.

2) Geological hazards

Geological hazards are the types of adverse geologic conditions that are capable of causing damage or loss of property and life. These hazards include landslides (lateral displacement of earth materials on a slope or hillside), rock falls, rock avalanche and debris flows, sand dune migration, etc.

Potentials for slope instability (land/rock slides, land erosion, snow avalanches) as well as collapse, subsidence or uplift of the site surface are assessed during site evaluation. Effects of related hazards are assessed using reliable methods of investigation and appropriate analyses are carried out for safe engineering of the plant. The susceptibility of the site/region for the formation of sand dunes is studied. If the location is found to be vulnerable, the site is rejected.

The site is also investigated for subsidence of ground due to occurrence of geological feature called ‘karst’, mining activity and oil extraction. Karst is a special type of landscape that is formed by the dissolution of soluble rocks. During rainfall, water seeps into the soil. The water becomes weakly acidic when it reacts chemically with carbon dioxide in the atmosphere and the soil to form carbonic acid. This acidic water, when passes through the bedrock, dissolves the rock material which eventually forms into cave passages and caverns, which is termed as karst. Incase potential of such geological hazards exist and no practical engineering solutions are available to mitigate their effects, the site is deemed unsuitable.

3) Meteorological events

Meteorology is the branch of science that deals with the phenomena of the atmosphere, especially weather and weather conditions. Meteorological parameters like wind speed, rainfall intensity as well as total rainfall, storms, cyclones, maximum and minimum temperature play a major role in the design of the NPPs from the safety view point. Rainfall forms an important input to other processes like estimation of maximum flood water level at the proposed site whereas wind speed is necessary to study structural safety particularly for tall structures like cooling towers, stacks, transmission line towers etc. Structures important to safety are to be designed to withstand the extreme values of these parameters that are likely to occur during the lifetime of the facility maintaining its integrity and functional capacity. The design basis parameters that are considered in the engineering of plant against the effect of these hazards have a very low probability of exceedance during the lifetime of the facility.

The design basis values of the meteorological parameters mentioned above are often evaluated using the extreme value analysis. This method helps to generate a value of meteorological parameter corresponding to a given MRI, based on the historical data available for these parameters. MRI for some of the external parameters are given in

Table 3. Acceptable procedures for estimation of design basis parameters corresponding to a given MRI are elaborated in AERB guide, AERB/SG/S-3.

Table 3: Mean Recurrence Interval for some of the external parameters

Natural Hazard	**Parameter**	**Mean Recurrence Interval (Years)**
Wind speed	a) Extreme wind (Used for safety assessment against wind induced missiles) b) Severe wind	10000 1000
Precipitation (Max. daily rainfall)	Maximum daily rainfall (Used for estimation of design basis flood)	1000
Cyclone data	Pressure drop	1000

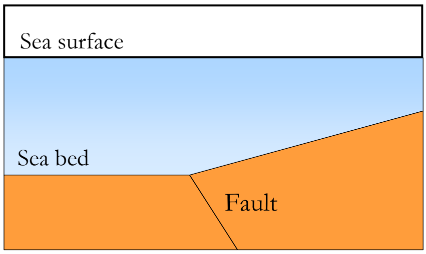
The meteorological and climatological characteristics of site region are investigated to derive extreme values of the meteorological variables such as wind, precipitation, snow, temperature, storm surges, and rare meteorological phenomena such as tornadoes, tropical cyclones. Under the influence of high wind velocities, the materials on the ground (e.g. wooden poles, vehicles etc.) could be lifted into air and could form a projectile which can impact the plant structures in the form of a missile. Potential missile hazard associated with tornadoes and tropical cyclones is also considered and adequate design measures are incorporated if necessary.

4) Flooding

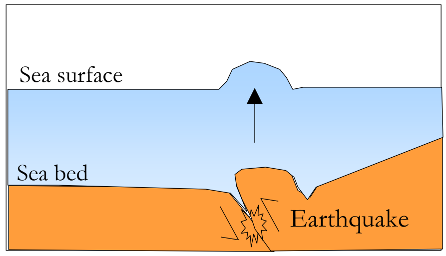
Nuclear power plants require large quantities of water for cooling purposes and are, therefore, suitably located either at coastal sites or at inland sites by the side of a reservoir or a river. It is therefore, imperative that safety of NPP is assessed against flooding. Establishment of design basis flood (DBF) for NPP requires identification of various phenomena relevant to the site conditions, which can result in flooding. This include surface run-off from precipitation, possible upstream dam failure, snow melt, high tide, storm surge, as well as earthquake induced water waves i.e., tsunamis and seiches. The details of estimation of flood hazard at inland and coastal sites are covered in AERB guides AERB/SG/S-6A and AERB/SG/S-6B respectively.

Assessment of design basis flood due to cyclone/extreme precipitation consists of two stages. In the first stage, the historical data on occurrence of cyclones and tornados in the region is collected. In addition, past data concerning wind speed, pressure drop during cyclones, dry and wet bulb temperature and severe precipitation for a period of 50 years (if available) is also collected. This data is then subjected to extreme value analysis to derive the extreme value of each parameter for design along with their corresponding mean recurrence interval. Extreme value analysis is a tool based on probability theory that predicts the possible estimate of the parameter with respect to mean recurrence interval under consideration. In order to predict the effect of these phenomena on the plant site, a mathematical model of the phenomena along with the site characteristics is necessary.

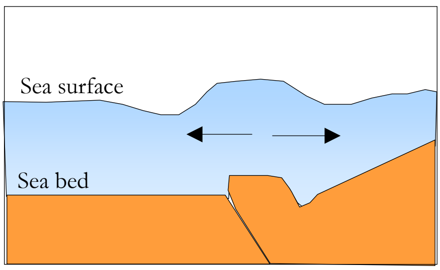
A suitable meteorological and hydrological model is developed to characterize hazard due to surface run-off with due consideration of limitations of available data and past changes in relevant characteristics of the region. Floods caused by failure of upstream dams/barrages or due to possibility of temporary blockage of rivers upstream/downstream caused by landslides/ice are also assessed with respect to the safety of the installation.



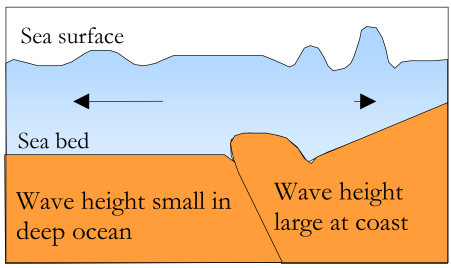
(a) Before earthquake



(b) Earthquake occurs, Faulting pushes large volume of water in the ocean upwards



(c) Tsunami generated, waves moves outward



(d) Tsunami wave height grows towards shore

Figure 3 : Stages in initiation and propagation of a tsunami wave

Due to difference in assessment of flood hazard from tsunamis and seisches when compared to cyclones and precipitation, a separate assessment is done to evaluate the hazard due to these phenomena. Tsunami is a series of waves created when a body of water, such as an ocean, is rapidly displaced. Earthquakes, mass movements above or below water, some volcanic eruptions and other underwater explosions, landslides, underwater earthquakes, and large asteroid impacts all have the potential to generate a tsunami. The term tsunami comes from the Japanese term meaning harbor wave. The effects of a tsunami can be devastating due to the immense volumes of water and energy involved.

The evolution of tsunami subsequent to an earthquake has three phases, tsunami generation, propagation and wave runup, Figure 3. In the case of a convergent plate boundary located under the sea, part of the seafloor connected to the lighter plate may "snap up" suddenly due to pressure from the sinking plate, resulting in an earthquake. When this piece of the plate snaps up and sends sea bed moving upward with tremendous force, the energy of that force is transferred to the sea water. The energy pushes the water upward above normal sea level. This is the birth of a tsunami.

Once the water has been pushed upward, gravity acts on it. This forces the energy to spread out horizontally along the surface of the water. The wave speed is the square root of the product of acceleration due to gravity and the water depth. This phase is called tsunami propagation. Once a tsunami gets close to shore, it hits shallower region and velocity of wave decreases. Due to this decrease in velocity, the wave height increases considerably as the compressed energy forces the water upward. This phase is called tsunami wave run-up and is responsible for flooding and devastation in the coastal areas.

“Seiche” is a French word that means “to sway back and forth.”. Seismic seiches are waves set up on rivers, reservoirs, ponds, and lakes when seismic waves from an earthquake pass through the area. If the site is found vulnerable, the flood hazard due to these phenomena is assessed based on detailed mathematical models.

5) Shoreline and river bank erosion

Erosion is the carrying away or displacement of solids (sediment, soil, rock and other particles) usually by the currents generated by wind, water, or ice. Erosion is an intrinsic natural process but in many places it is increased by human interference. It is also possible that the material eroded from other locations may be carried by currents and deposited at some other locations. This process is called sedimentation. Erosion/sedimentation could affect the cooling water intake as well as outfall structures or the plant itself.

Erosion or sedimentation of sea coast takes place due to long term or short term processes. The long term phenomena include presence of natural structures like river mouth, and sediment transport along the coast. Short term factors include seasonal variations and various human made structures.

The assessment includes (1) establishment of the trend of the shoreline migration during short term and long term using the available data and information (satellite imageries, hydrographic charts, and survey of India topo sheets), (2) assessment of beach profile changes and transport of sand/soil along the shore during different seasons (3) evaluation of the impact of nuclear power plant cooling water intake and outfall structures / and other human made structure on the shore line. Incase of coastal sites, studies are carried out to establish that there is no potential for shore instability that could affect safety.

In case of sites located inland, the instability of lake or river side banks could be caused by erosion of side banks or due to changes in river course (meandering). Due consideration is given to this phenomena during the site assessment.

3.2. Human Induced External Events

Human activities relating to industry, military, mining, transportation, etc. in the region of the proposed site may have the potential to challenge the safety of NPP. It is therefore necessary to collect information regarding all human activities in the region of interest at siting stage of the nuclear power plant and evaluate their impact on the proposed plant under various postulated worst-case scenarios and design the NPP to withstand the effect, if necessary. AERB guide, AERB/SG/S-7 covers in detail various human induced events and procedures for estimation of corresponding design bases.

1) Aircraft crash

Most of the air crashes occur during takeoff and landing phases of flight. Hence existence of an airport in the site vicinity increases the potential of aircraft crash hazard on NPP. The location of site with respect to the distance to major and minor air fields, including military airports is identified. If these distances are greater than SDVs as defined in the AERB siting code SC/S, for respective types of airports, the location of site is considered as acceptable.

If the site falls within SDV for different types of airfields, a probabilistic study of aircraft crashing on the installation considering flight frequencies are carried out. If this probability is not acceptably low the site is considered unsuitable for establishing an NPP. With the advances made in an assessment of the hazards from aircraft impact including the effects of impact, fire and explosion, one can now estimate the consequences of impact also. This needs to be looked into in detail in a case-by-case basis.

2) Chemical explosions

Plants in the site region involved in handling, processing and storage of chemicals having potential for explosion or for production of gas clouds capable of deflagration/detonation, and the transportation routes for such chemicals are identified and associated hazards in terms of over pressure and toxicity are assessed. A site is considered unacceptable if such activities take place in its vicinity and no practical solutions are available to mitigate their effects.

During the site evaluation carried out for prototype fast breeder reactor (PFBR) located at Kalpakkam, Chennai, it was observed that some parts of a highway passes through 3.5km from PFBR site. Among various hazards arising out of transportation of commodities in this highway, the severest incident, i.e., accidental release of LPG from the LPG tanker was analysed in detail. The thermal and explosion effects due to accidental release were considered and it was ensured that the design of plant takes into account the adverse effects of these hazards.

3) Other important human-induced events

Information on blasting operations in the site vicinity and activities related to mining, drilling and sub-surface extraction/injection of fluids are carefully studied to assess their impact on safety of the installation. The region is also investigated for plants/activities either within or outside the installation boundary in which flammable, explosive, asphyxiate, toxic, corrosive or radioactive materials are stored, processed, handled or transported such that if released under normal or accident conditions, could jeopardize safety of the installation. The plants that could give rise to missiles are also assessed with respect to the plant safety.

Potential natural and human induced events that could result in loss of cooling water are identified. These events include blockage or diversion of a river, depletion of a reservoir, blockage of a reservoir or cooling water intake structure by ship collisions, oil spills and fires. If the probabilities and consequences of such events cannot be reduced to acceptable levels, then the hazards for the nuclear power plant associated with such events are to be established. If the hazards for the nuclear power plant are unacceptable and no practicable solution is available, the site is deemed unsuitable.

4. IMPACT OF PLANT ON SITE, ENVIRONMENT AND PUBLIC

Impact of an NPP on site, environment and public is of principally two types,

- Radiological impact, and
- Conventional pollution.

Objective of nuclear safety is to ensure that radiation dosage to the public beyond exclusion zone boundary is within prescribed limit during normal operation and within acceptable limit during abnormal condition. Second category of impact assessment is principally related to thermal and chemical pollution. As there exist engineering solutions to address both impacts, i.e. radiation dose and thermal and chemical pollution, their assessments are of mandatory types.

4.1. Radiological Impact Study

Radionuclides released from an NPP during normal operating conditions and under accident conditions eventually reach humans through various pathways. Pathways are routes through which people are exposed to radiation resulting in exposure/radiation dose to different parts of human body. This could be through

- inhalation, i.e., breathing of the contaminated air,
- ingestion, i.e., intake of contaminated food
- immersion, i.e., direct exposure of the body to radioactive material suspended in the atmosphere.

The main objective of the radiation impact assessment is to determine individual radiation doses as well as total population dose resulting from the plant. For this purpose, details of site characteristics affecting dispersion of radioactive materials, population distribution in the site region including their dietary habits, and use of land and water bodies are examined. There exist many exposure pathways leading to exposure of a member of public, but the dosimetric models indicate only a few of them to be really significant. These are known as critical pathways. A radionuclide which leads to a predominant dose through a pathway is termed as the critical nuclide

The mode of computing dose requires measurement (or prediction) of concentration of radionuclides in aquatic, atmospheric and terrestrial media. A site is acceptable if there are technical solutions to the site-related problems, which give assurance that the proposed plant can be built and operated with an acceptably low dose to the population of the region. Adequate engineered safety features are provided in the design of an NPP to prevent an accident and also to mitigate the consequences of an incident.

1) Activity dispersion through atmospheric pathways

Atmosphere is an important pathway to be considered in the assessment of the environmental impact of radioactivity releases from NPP. Estimation of concentration of released effluents in air and possible ground contamination needs an understanding of the relevant atmospheric dispersion and deposition processes. In addition to deposition (e.g. on vegetation), the dispersion through air could effect human beings through inhalation and immersion. Various pathways through which radioactive nuclides could reach humans through atmosphere are shown in Figure -4.

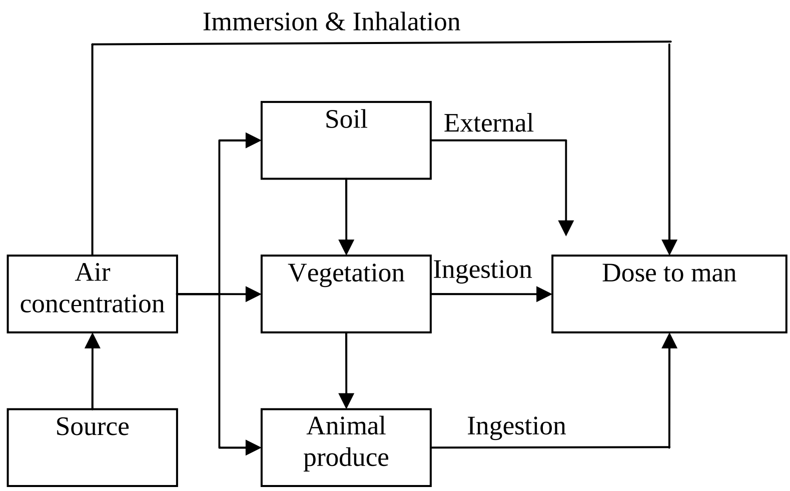


Figure -4: Atmospheric pathways for dose to human from NPP

Atmospheric releases from NPP can be either during normal operating conditions or off-normal / accident conditions. Effluents released through the stack or at the ground level are transported by wind and diffused by turbulence present in the atmosphere. The combined transport and diffusion mechanism is termed as dispersion, Figure 5.

The nature of release (source height, source strength), the type of sources (specific nuclide released), duration of release (puff/continuous) and the relevant atmospheric parameters could widely differ. The domain of atmospheric flow to be considered (micro, meso or synoptic scale) would be governed by the range of distances over which the assessment is to be made.

General meteorological data such as wind speed and direction, air temperature, precipitation, humidity, atmospheric stability parameters, and prolonged inversion conditions are collected from nearby meteorological stations for at least one full year and supplemented with any other relevant data from other sources.

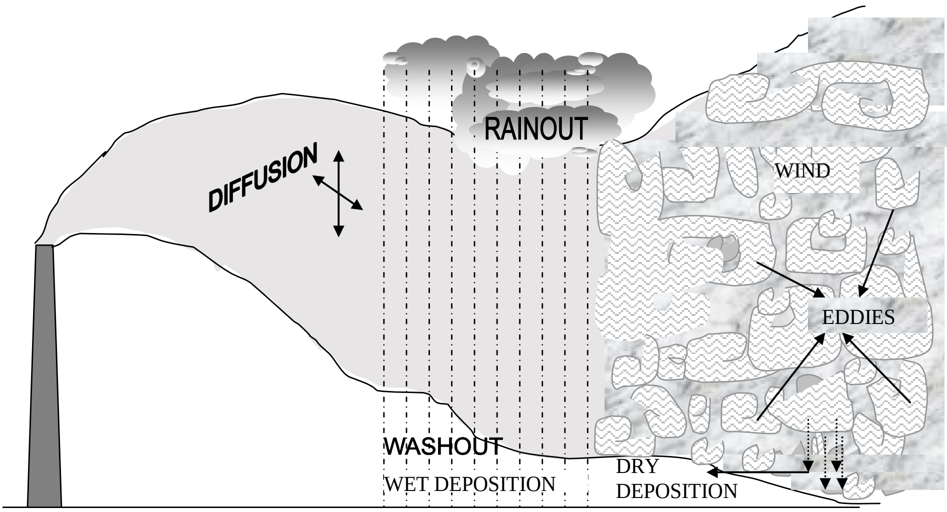


Figure 5: Behaviour of effluents released to the atmosphere and their modes of transport and deposition

Atmospheric dispersion of radioactive materials is assessed using appropriate numerical models which include all significant site specific and regional topographic features (river valleys, bowls, etc.) and characteristics of the installation (thermal interference from cooling towers, etc.) affecting atmospheric dispersion. AERB guide AERB/SG/S-1 covers in detail the methodologies for estimation of the dispersion of effluents released to atmosphere. A programme of meteorological measurement is initiated and carried out at the site at least 3 years in advance of commissioning of the installation.

2) Activity dispersion through surface water

The hydrosphere represent an important pathway by which radioactive materials discharged from NPP into the environment reach human beings. This includes both surface and subsurface water. The term ‘surface water’ refers to open bodies of water on the earth’s surface including sea. Although these water bodies form a continuum with ground water, a distinction has been made for purpose of dispersion analysis and dose assessment as the radionuclides are transported rapidly in surface waters. Surface water pathways for dose to man from source are shown in Figure 6.

The release of radioactive materials into surface waters could be routine, planned or accidental. The routine releases as well as planned short term releases are controlled to be within the limits specified by AERB.

In order to estimate the dose from these scenarios, a programme of investigations and measurements of surface hydrology of the site region is carried out to determine dilution and dispersion characteristics of water bodies, pick up of radioactivity by sediment and biota, transfer mechanisms of radionuclides, identification of exposure pathways to human beings through hydrosphere and indication of exposure pathways for the most significant nuclide. The above data are used to evaluate the impact of surface water contamination on population using suitable hydrological and radiological models. The acceptable procedures for studying the hydrological dispersion of radioactive materials in relation to NPP siting are brought out in AERB/SG/S-2.

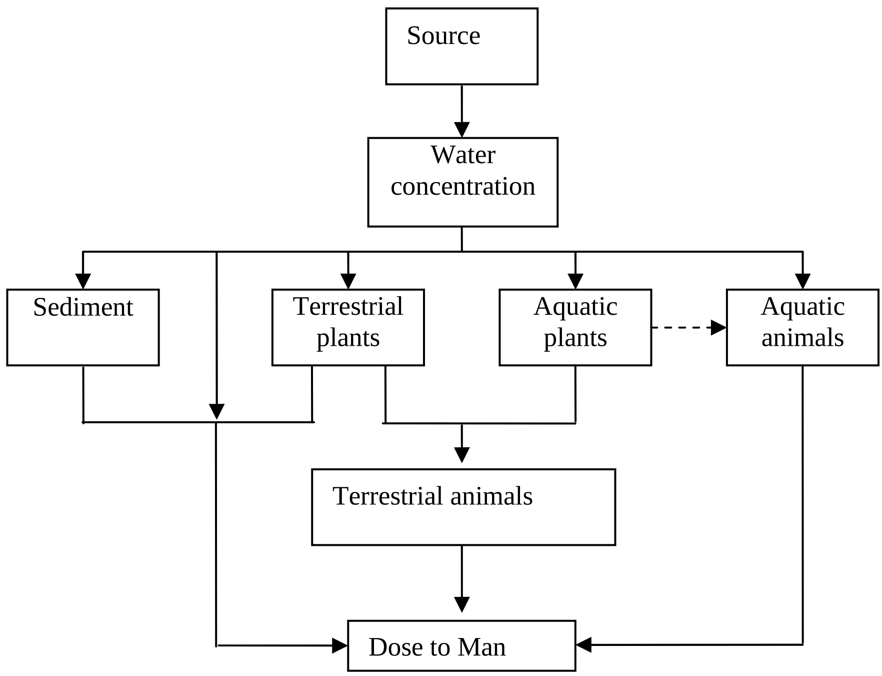


Figure 6: Surface water pathways for dose to man from source (NPP)

Some of the low level radioactive wastes generated during plant operation are stored in the sub-surface locations, like trenches within the plant area. The postulated sources for the radionuclide migration through sub-surface water are earth trenches, Reinforced Cement Concrete (RCC) trenches and tile holes storing low and intermediate level radioactive wastes. Rain fall, run off, surface storage and ground water recharge, porosity and permeability of the soil and rock formations are significant factors responsible for giving rise to different types of aquifers which control the sub-surface dispersion.

Hydrogeological investigations are carried out to study migration and retention characteristics of soils, dilution and dispersion characteristics of aquifers, and physical and physicochemical properties of underground materials, mainly related to radionuclides transfer mechanisms in ground water and their exposure pathways. Data and information obtained from the above investigations are used in simulating suitable models to assess potential impact of ground water contamination on the population. The details of investigations and methodologies for study of dispersion of effluents through sub-surface media are covered in AERB/SG/S-4.

3) Methodology of radiation dose evaluation

Level of details needed for the estimation of dose to members of public depends on the stages/states of NPP (e.g. site selection, normal operating conditions and potential accident conditions). At siting stage, it is adequate to use critical pathway-critical nuclide concept for the assessment of dose whereas all the relevant pathways for various radionuclides have to be employed during normal operating conditions to ensure compliance with dose limits specified by the AERB.

At siting stage, data related to the usage of environment in the vicinity of NPP are taken from sources of either the state or national level as data on amount of radioactivity release during normal operation, accident conditions, etc. and environmental dispersion characteristics may not be available. The past experiences of a similar plant are also taken into consideration. Since site specific meteorological data may also not be available at this stage, representative data from nearby meteorological stations are used. Dose calculations based on critical pathway-critical nuclide concept is considered adequate for this stage. Among radio-Iodines, I-131 specifically leads to significant dose through grass-cow-milk pathway and is considered in the assessment.

In the intervening period between the selection of site and commissioning of the plant, detailed site specific investigations on meteorological, hydrological as well as geohydrological parameters are undertaken. These data are collected round the year to cover all seasons.

The actual doses received by a member of the public will vary depending on many factors such as age, metabolism, dietary habits as well as usage of the environment, fishing and recreational activities. It is a normal practice in radiological protection to account for this variability by identifying an appropriate critical group. This group should be representative of a group of individuals in the population expected to receive the highest dose from the source of radiation under consideration (routine or accidental). It is to be ensured that the group is small and homogeneous with respect to age, diet and other habits that influence the dose received. AERB/SG/S-5 covers in detail the methodologies for estimation of radiation dose from radioactivity concentrations in the environment.

In case of a site with multiple nuclear facilities, the allowable dose limits to public, as stipulated by AERB are further divided or apportioned among these facilities. In the concept of dose apportionment, the primary dose limit of 1mSv per year for a member of the public is apportioned among the various facilities operating and planned at the same site, among atmospheric, aquatic and terrestrial pathways and also among specific radionuclides depending on the specific characteristics of the installation. A fraction of the dose limit is kept as a reserve for future expansions of the facilities at the site.

4.2. Population distribution

Population distribution is one of the several characteristics that are considered in the radiological impact assessment. The main aim is to assess the radiological impact resulting from releases of radioactive materials during normal operation and under accident conditions with a view to minimize the collective dose to the population.

Another reason for conducting population distribution study is preparation of emergency preparedness plans. It is desirable to locate the plants in the regions of relatively low population density. This would also allow easier implementation of emergency measures in the unlikely event of an accident. AERB/SC/S provides desirable population distribution in the region around the site. In case of a region with higher population density, the higher economic load and other constraints to achieve implementation of emergency preparedness programme will have to be taken into account.

The most recent census data of the site region are analyzed for deriving population distribution in terms of direction and distance from the plant. Additionally, data on land and water use, and dietary habits are also collected. An evaluation of potential radiological impacts of normal discharges and accidental releases of radioactive material, including reasonable assessment of releases due to severe accidents, is performed using this data. The details of analysis of population distribution in relation to siting of NPPs are outlined in AERB/SG/S-9.

4.3. Environmental Impact Study

For meeting the cooling requirements of turbine condenser, water is drawn from sea, lake or river using intake structures. While passing through the condenser, temperature of the condenser cooling water rises and the heat is discharged to the ultimate heat sink. This is achieved by either discharging the hot water to the sea/lake/rivers though the outfall system or by rejecting heat to the open atmosphere through cooling tower.

It is ensured that with the given arrangement of intake and outfall structures, the temperature difference between the two legs at specified locations are within the limits stipulated by the State/Central Pollution Control Board or any other appropriate authority. Appropriate numerical/experimental model studies are generally conducted for this purpose. Moreover, regarding the chemical effluents discharged to water bodies or open atmosphere adherence to appropriate limits as specified by State/Central authorities is also ensured.

5. EMERGENCY PREPAREDNESS

For safe operation of NPPs, prevention, control and mitigation of various postulated accidents have been considered. Further, every NPP is also required to formulate comprehensive emergency plan, termed as emergency preparedness plan, which will help ensure public safety during those low frequency events, which can have a significant radiological impact in public domain. These plans provide for appropriate action, by way of protective measures, for implementation in proper time frame so that radiation exposures to members of the general public would remain within the intervention levels specified by AERB. Influence of site parameters on emergency preparedness is deliberated in AERB guide, AERB/SG/S-8.

Depending on the nature and severity of accident, the effect of the emergency may be restricted to either a small area of the plant or a few individuals or it may pause danger to the plant itself. In more severe cases, release of from the plant may contaminate the site within the site boundary or can propagate outside the site boundary. Taking these into consideration, emergency situations are classified as plant emergency alert, plant emergency, site emergency, and off-site emergency.

While the operating organization of the plant are responsible for handling the first three categories of emergencies, off-site emergencies are handled by the State authorities with the technical input and guidance from operating organization of the plant and regulatory authority.

During siting stage, the relevant site features that have a bearing on the various protective measures that may need to be initiated following an off-site emergency condition are assessed. The area within 16km radius of plant is designated as emergency planning zone (EPZ), Figure-2. The off-site emergency planning is prepared for this zone. The relevant information required for estimation of dose to public such as population data, land and water use, dietary habits, etc are collected, upto a radial distance of 30km. Full details of population distribution sector wise (16 sectors of 22.5 degrees in EPZ) is also obtained. It is ensured that population data takes into account all people employed at site including construction workers, if any. As cattle milk forms an intermediate pathway in the ingestion route for children, data on cattle population in rural areas is another input in the preparation of emergency plans for nuclear power plants.

While preparing the off-site emergency management plan, inputs/information of the State government machinery, evacuation routes including road and railway network in EPZ, communication facilities, buildings for sheltering both inside and outside EPZ, medical facilities, transport facilities, etc are assimilated and emergency management plans are prepared.

6. OTHER CONSIDERATIONS

During evaluation of a site, there may be a few site related characteristics which directly do not affect safety of the nuclear power plant but may have an indirect impact on plant safety. These are elaborated below.

6.1. Geotechnical Safety

Adequate geotechnical investigations are carried out to establish competency of the foundation medium for the installation structures under all static and seismic loading conditions. The ground water regime and its chemical properties are also studied.

6.2. Loss of Ultimate Heat Sink

Possibility of failure of down stream dam/barrage of an inland site, or draft caused by tsunami at a coastal site may result in loss of heat sink functions for a nuclear power plant. This aspect is scrutinized in detail. If the probability and consequences of such events cannot be reduced to acceptable levels, such events are included in the design basis for the plant. Availability of alternate heat sink is also an important consideration.

Other potential natural and human-induced events such as the blockage/diversion of a river, depletion of a reservoir, excessive marine organism, ship collisions, oil spills and fires, which could cause a loss of heat sink function for a nuclear power plant, are assessed and related hazards are established. If no practical solution is available to mitigate the hazards, the site is rejected.

6.3. Land and Water Use

Land and water use in the site region are characterised to assess potential effects of the nuclear installation and prepare plans for implementation of emergency measures under accident conditions.

6.4. Ambient Radioactivity

Ambient radioactivity of the atmosphere, hydrosphere, lithosphere and biota in the site region is assessed prior to commissioning so as to be able to determine the effects of the installation. The data also serve as a baseline in future investigations. For this purpose, an Environmental Survey Laboratory(ESL) is established at the site, well before the NPP goes into operation. In India, we have ESL functioning at all NPP sites.

6.5. Power Evacuation

Power evacuation is the process of transporting the electricity generated in the NPP to the national electric grid. Power evacuation scheme from the proposed plant is studied in detail considering transmission scheme, generation and load centers in the electricity network. Availability of adequate transmission links even during a grid disturbance is to be ensured. In the eventuality of a grid collapse, possibility of continuation of operation of the plant in an islanded mode is also checked and plant grid interaction studied carefully.

6.6. Transportation of ODC

Some of the equipment used in NPPs are heavy and have very large dimensions. These are generally transported from the factory to the nearest railway station/port and then to the NPP site through national highways and other State roads. Hence these are termed as over dimension consignments (ODC). In view of this, availability of transport route for movement of ODC is checked. If reprocessing of spent fuel, i.e., the fuel coming out of NPP, is to be carried out at another site, transportation of irradiated fuel in shielded cask is also considered in this connection.

7. QUALITY ASSURANCE

It is important to establish a quality assurance programme for safety in siting of a nuclear power plant (NPP) before commencing siting process. While determining the basic requirements, the specific requirements for inland stations and coastal stations are also to be taken into account. These requirements apply to management activities as well as performance activities related to siting.

During the siting process, the responsible organization (generally the owner-operating organization), establishes and implements a quality assurance program (QAP) in order to ensure that studies, evaluations and analyses of site related characteristics important to safety such as seismicity, meteorology, geology, hydrology as well as human activities in the vicinity of site etc. as detailed in siting code, are correctly performed and provide a consistent basis for making decisions about site selection. AERB guide AERB/SG/S-10 covers various aspects related to quality assurance in siting of NPPs.

Siting requires diverse inputs. Personnel associated with the activities need to be qualified and experienced in their respective fields so that they are competent to perform the assigned work and understand the safety consequences of their activities. Therefore, expertise is drawn from different groups within the organization as well as experts from other reputed institutions/research centers having specialisation in the particular field.

In addition, non-conformance control and corrective action process that defines how the errors in data collection, recording or reporting; calculations, reasoning, assumptions and conclusions should be dealt with are also implemented.

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