BASIC PROFESSIONAL TRAINING COURSE

Module IX

Siting Considerations and Environmental Impact Assessment

IAEA
International Atomic Energy Agency
Background

In 1991, the General Conference (GC) in its resolution RES/552 requested the Director General to prepare 'a comprehensive proposal for education and training in both radiation protection and in nuclear safety' for consideration by the following GC in 1992. In 1992, the proposal was made by the Secretariat and after considering this proposal the General Conference requested the Director General to prepare a report on a possible programme of activities on education and training in radiological protection and nuclear safety in its resolution RES1584.

In response to this request and as a first step, the Secretariat prepared a Standard Syllabus for the Post-graduate Educational Course in Radiation Protection. Subsequently, planning of specialised training courses and workshops in different areas of Standard Syllabus were also made. A similar approach was taken to develop basic professional training in nuclear safety. In January 1997, Programme Performance Assessment System (PPAS) recommended the preparation of a standard syllabus for nuclear safety based on Agency Safely Standard Series Documents and any other internationally accepted practices. A draft Standard Syllabus for Basic Professional Training Course in Nuclear Safety (BPTC) was prepared by a group of consultants in November 1997 and the syllabus was finalised in July 1998 in the second consultants meeting.

The Basic Professional Training Course on Nuclear Safety was offered for the first time at the end of 1999, in English, in Saclay, France, in cooperation with Institut National des Sciences et Techniques Nucleaires/Commissariat a l'Energie Atomique (INSTN/CEA). In 2000, the course was offered in Spanish, in Brazil to Latin American countries and, in English, as a national training course in Romania, with six and four weeks duration, respectively. In 2001, the course was offered at Argonne National Laboratory in the USA for participants from Asian countries. In 2001 and 2002, the course was offered in Saclay, France for participants from Europe. Since then the BPTC has been used all over the world and part of it has been translated into various languages. In particular, it is held on a regular basis in Korea for the Asian region and in Argentina for the Latin American region.

In 2015 the Basic Professional Training Course was updated to the current IAEA nuclear safety standards. The update includes a BPTC text book, BPTC e-book and 2 “train the trainers” packages, one package for a three month course and one package is for a one month course. The “train the trainers” packages include transparencies, questions and case studies to complement the BPTC.

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Editorial Note

The update and the review of the BPTC was completed with the collaboration of the ICJT Nuclear Training Centre, Jožef Stefan Institute, Slovenia and IAEA technical experts.
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1 SITE SELECTION

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe the objectives of the siting process.
2. Define the different phases involved in the siting process.
3. Describe the process for the regional analysis to identify potential sites.
4. Describe the screening process of potential sites to select candidate sites.
5. Describe the ranking process of candidate sites to obtain the preferred candidate site or sites.
6. Describe nuclear security considerations.
7. Explain the overall decision making process for site selection.

The primary means of preventing accidents and mitigating their consequences is ‘defence in depth’, which is provided by an appropriate combination of specified systems and measures, one of which is suitable site selection.

Ensuring that the site is suitable is an essential part of ensuring that a nuclear power plant or other nuclear facility can be operated safely.

There are five aspects of the site that need to be considered. The site needs to be such that:

- The frequency and severity with which the plant will be subjected to natural external hazards, such as earthquakes, tsunamis and high winds which exceed the protection provided by the design of the plant is acceptably low.
- The frequency and severity with which the plant will be subjected to human made hazards, such as an aircraft crash, which exceed the protection provided by the design of the plant and administrative controls, is acceptably low.
- The feasibility of implementation of an emergency plan in the case of a nuclear accident.
- The negative impact of the plant on humans and the environment is acceptably low.
- No environmentally protected areas or of special heritage significance are adversely affected.

This module addresses the way in which these objectives can be met. It is primarily aimed at countries that do not have an existing nuclear power plant.

The way in which a site should be selected in order to achieve these objectives is addressed in Chapter 1 below and the subsequent evaluation of the chosen site is addressed in Chapter 2.
To evaluate the last two objectives, an environmental impact assessment is required and how this should be carried out is addressed in Chapter 3.

**1.1 Introduction**

Site selection for an NPP is a complex process. It involves a multitude of criteria and considerations; some are related to safety, while others are socio-economic. In many cases overriding public perception issues and strategic concerns could be the decisive factors.

Site related activities for a nuclear power plant start from the inception of the project and continue until the installation is finally decommissioned.

The siting process and the site evaluation process include five different stages.

The siting process for a nuclear installation consists of the first two stages of these five, i.e. site survey and site selection (see Fig. 1.1). In the site survey stage, large regions are investigated to find potential sites and to identify one or more candidate sites. The second stage of the siting process is site selection, in which unsuitable sites are rejected and the remaining candidate sites are assessed by screening and comparing them on the basis of safety and other considerations to arrive at the preferred candidate sites.

Site evaluation is the process that extends from:

- the last stage of the siting process (i.e. the stage of evaluation of the candidate sites in order to arrive at the preferred candidate site(s));
- the detailed site characterization stage for the selected site to confirm its suitability, its characterization and derivation of the site related design bases for the nuclear installation;
- the confirmation and completion of the assessment at the pre-operational stage for the installation (i.e. during the design, construction, assembly and commissioning stages); and finally to
- the operational stage of the installation included within the framework of periodic safety reviews. Thus, site evaluation continues throughout the operating lifetime of the installation, with appropriate components covered in the final safety analysis report, to take into account changes in site characteristics, the availability of data and information, operational records, regulatory approaches, evaluation methodologies and safety standards.
The second stage of the siting process, site selection, includes part of the site evaluation process and is the overlapping stage between the siting process and the site evaluation process (see Figs 1.1 and 1.2). After the site selection stage, the suitability of the site is confirmed and a complete site characterization is performed, together with finalizing the derivation of the design basis in relation to external events during the site characterization stage. This process eventually leads to the preparation of the site evaluation report as the basis for the site section of the preliminary safety analysis report for the nuclear installation. All the site related activities, involving confirmatory and monitoring work, are considered in the pre-operational stage. Following approval of the final safety analysis report for the nuclear installation, the site evaluation at the operational stage starts. This includes the monitoring and re-evaluation work conducted throughout the operational stage and, especially during periodic safety reviews of the installation. This work is generally reported in the periodic safety reviews. Outcomes in comparison with those for the stages of the siting process and the site evaluation process are described in Fig. 1.2.
There are three important steps that typically receive input from the site survey, site selection and site evaluation processes before construction starts. These are:

- The decision regarding the ‘suitability’ of the preferred site, i.e. confirmation that the site has no characteristics that would preclude the safe operation of a nuclear installation;
- The definition of the site related design basis parameters on the basis of the site evaluation report;
- The development of the Site Section of the preliminary safety analysis report or preliminary safety case which, among other things, demonstrates that the site related design basis parameters have been appropriately taken into account, in particular through the design features of the nuclear installation and the measures to be taken for the site.

### 1.2 Phases of the siting process

The siting process consists of a series of related activities with the objective of selecting suitable sites for a new nuclear installation. The process applies a number of screening criteria to eliminate those sites with attributes which contribute unfavourably to the safety of the installation. The siting process for a nuclear installation is illustrated in Fig. 1.3.
Below, the outline of a typical project description for a site selection study is given. Typically previous studies have been performed for each region in a country. These studies may be related to site selection for a nuclear or other critical facility, or more commonly they may have been to support prospecting for oil or gas reserves. It is important to consider all these investigations and take advantage of them to the greatest extent possible.
This project description is of course not unique. Depending on the extent of previously conducted studies, there may be deviations from this scheme.

**Regional analysis to identify potential sites**

**Purpose**
In this phase it is important to **consider all potential sites** and **not to risk discarding a potentially suitable site**. Any uncertainty in this process should be biased towards retaining sites that may eventually be rejected. The mistake of discarding sites which may eventually be acceptable (or even preferred) should not be made, because it is always possible to eliminate sites but it is difficult to reconsider them once they have been rejected.

**Methodology**
As the objective is to retain a relatively large number of sites at the end of this phase, the criteria that have been used before (if previous studies exist) could be relaxed. Brief site visits may be made to verify the results of the desk studies.

A typical database includes information on the following aspects:
- Geological;
- Hydrogeological;
- Seismological;
- Fault displacement;
- Volcanological;
- Geotechnical;
- Coastal flooding including tsunamis;
- River flooding;
- Meteorological events;
- Human induced events;
- Population, land use, water use and environmental impacts.

**Tasks**
Task 1. Review of previously performed studies:
- Review of the data used;
- Review of the criteria used;
- Review of the methodology used.

Task 2. Updating of studies (data, criteria and methodology):
  - Check the validity of previous results (sites selected);
  - Check whether other sites can be identified in the region.

Task 3. Identification of new potential sites in new region(s):
  - Establish a database similar to that of the previously studied regions, including the updates;
  - Select potential site(s) using the updated criteria and methodology (these comprise areas of several square kilometres).

**Data Requirements**

Data that are available either from previous studies or that can be gathered from public sources are used. No site-specific investigations need to be made. The data involve items such as population density, proximity to towns and cities, land use, access and transportation, proximity to hazardous activities, meteorology, topography and bathymetry, availability of cooling and industrial water, grid connection, geotechnical conditions, proximity to natural hazards, environmental impact considerations (proximity to environmentally protected areas) and others as required.

**Deliverables**

A report describing the work performed should be prepared. The data, criteria and the methodology used should be described. The potential sites should be described with their positive and negative aspects. A brief description of the sites that have been considered in the process but eventually discarded should also be given, substantiating reasons for rejection.

**Screening of potential sites to select candidate sites**

**Purpose**

The purpose of this phase is to narrow down the sites to a manageable number so that a detailed comparison and ranking can be made (in Phase 3). Also in this phase a specific area is identified for each site, i.e. the boundaries of the selected sites are better defined.

**Methodology**

The criteria selected should be able to discriminate between potential sites without eliminating all of them. This may need an iterative approach. Furthermore, it is important that the candidate sites have different attributes and are not all located within the same region or sub-region. This is to avoid the possibility that an unexpected factor discovered in a later investigation could have a negative effect on all the candidate sites and cause all of them to be rejected.
Tasks

Task 1. Development of criteria for the selection of candidate sites:
- Revise the criteria used in Phase 1, to eliminate less attractive sites;
- Iterate the criteria levels to check their effectiveness;
- Identify other criteria that have discriminatory qualities.

Typical screening criteria could be for example when there is no practical solution to:
- Meeting national requirements for exposure of the public to ionising radiation;
- Feasibly implementing emergency measures to mitigate the effect of a nuclear accident;
- The presence of a “capable fault” that has the potential to affect the safety of the installation;
- The potential for collapse, subsidence or uplift of the land surface that has the potential to affect the safety of the installation;
- The potential for liquefaction of the subsurface materials has the potential to affect the safety of the installation;
- The potential for an aircraft crash;
- The potential for a chemical explosion in a nearby chemical plant or on a nearby transport route;
- The potential for loss of the ultimate heat sink.

Task 2. Data collection and verification:
- Collect available data on topics that have not been considered so far;
- Verify the data that have been collected in Phase 1;
- Visit each site, collect a limited amount of data through site investigations over an area of about 1 square kilometre;
- Prepare a systematic, consistent and uniform database for each potential site and with regard to each topic considered.

Task 3. Identification of candidate sites:
- Using the established criteria and the collected data, identify a
reasonable number of candidate sites (for example, 3 – 6);
- Visit each candidate site once again to confirm the results.

Data Requirements
The data used in Phase 1 need to be enhanced in two ways. Firstly, data related to topics not covered in Phase 1 should be collected. Secondly, the data need to be uniform for all sites if a reasonably comparable basis is to be established. For this reason further collection of data may be needed for sites where such information is lacking. The data to be collected can be divided into the following categories:
- Magnitude and frequency of external events of natural origin;
- Magnitude and frequency of events of human induced origin;
- Impact of the facility on the population and the environment, including aspects related to emergency planning;
- Legal aspects;
- Socioeconomic and cultural aspects;
- Economic aspects (access, availability issues);
- Public acceptance aspects.

Deliverables
A report describing the work performed should be prepared. The data, criteria and the methodology used should be described. The candidate sites should be described in detail, including maps and photographs. Topographic maps on a 1:50000 scale for a distance of 10 km around each candidate site should be prepared. These maps should include information on the transportation infrastructure, population centres and sources of external human induced hazards.

Comparison and ranking of candidate sites
Purpose
The purpose of this phase is twofold: (i) to confirm that there are no features at the sites that would preclude the construction and operation of an NPP, and (ii) to compare the candidate sites and rank them in the order of their attractiveness as an NPP site. Safety and economic aspects play the major role in this comparison process.

Methodology
The confirmation of the suitability of a site may require limited site specific work such as geophysical profiles or boreholes (for example to demonstrate that there are no “capable faults” in the site area). The exclusion criteria should be selected in such a way that engineering, site protection or administrative measures would not be able to compensate for the negative attribute(s) of the site. Otherwise, i.e. if it is possible to compensate for it, then the cost of providing these measures could be included in the comparison and ranking process. In fact, cost differentials can be used as an objective measure for obtaining a similar level of safety for each site. Simple calculations should be performed to obtain estimates of design basis parameters.
One criterion for ranking candidate sites may be the **likelihood that the specific site parameters are within the standard plant parameter envelope of potential suppliers** of nuclear installations. Suppliers of technologies for nuclear installations typically offer non-site-specific generic design information for consideration in cases of bounding envelopes being used in the siting process. This information identifies some of the design bases for cases of site-related loads. Such information should be used either to screen out candidate sites, or to decide where design changes may be necessary to bring the design parameters within the site bounding envelope.

**Tasks**

Task 1. Confirmation of the suitability of the sites (i.e. no exclusion factors):
- Identify the potential weakness(es) of each site that may be a basis for excluding it from further consideration;
- Conduct appropriate site-specific investigations and analyses to determine whether the site possesses any negative features as an NPP site.

Task 2. Establish criteria for comparison and ranking: calculate the required parameters using simple methods:
- Criteria related to the standard design parameters of the NPP with respect to external events;
- Criteria related to the design of the NPP with respect to its environmental impact;
- Criteria related to the operational efficiency of the NPP;
- Cost differentials with respect to reference conditions.

Task 3. Identify the preferred candidate site(s):
- Using the established criteria quantify the selected attributes of each site (see Table 1.1);
- Select the site(s) that rank(s) highest as the preferred candidate site(s);
- Prepare a portfolio of the highest ranked sites.

The differential costs are calculated as follows:
- A standard design for the NPP is assumed (e.g. designed for 0.3g, Cessna type aircraft impact, tornado load of F=3, etc.);
- A standard site is assumed for parameters such as grid loss, elevation with respect to cooling water source, etc.;
- The attributes of each site are evaluated with respect to these reference values;
- Taking into account that some cost differentials are once only and others continue throughout the lifetime of the plant.

**Data Requirements**

For Task 1 of this phase, it is possible that detailed data will be required for some sites obtained through site investigations. For the comparison and ranking task, economic data are needed. Here, it is not
required to know the design details of any particular plant because eventually the differentials are relative. Data needed for the simplified calculations of external hazards and other design parameters related to the site should be collected.

Table 1.1: Differential cost of a site (example).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial cost (total)</th>
<th>Continued Cost (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic (0.4g)</td>
<td>$X_{A1}$</td>
<td>$Y_{A1}$</td>
</tr>
<tr>
<td>Aircraft impact (Cessna)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tornado (F3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soil improvement</td>
<td>$X_{A4}$</td>
<td>-</td>
</tr>
<tr>
<td>Coast elevation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water temperature</td>
<td>-</td>
<td>$Y_{A6}$</td>
</tr>
<tr>
<td>Grid loss</td>
<td>-</td>
<td>$Y_{A7}$</td>
</tr>
<tr>
<td>Infrastructure development</td>
<td>$X_{A8}$</td>
<td>-</td>
</tr>
<tr>
<td>Required stack height</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Need for cooling towers</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cooling water pumping</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater pumping</td>
<td>-</td>
<td>$Y_{A11}$</td>
</tr>
<tr>
<td>Site cut and fill</td>
<td>$X_{A13}$</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$\sum X_{Ai}$</td>
<td>$\sum Y_{Ai}$</td>
</tr>
</tbody>
</table>

**Deliverables**

A report describing the work performed should be prepared. The data, criteria and the methodology used should be described. The preferred candidate sites should be described in detail including maps and photographs. The documentation pertaining to confirmatory studies regarding site acceptability should be included. **The basis for the site comparison and eventual ranking should be clearly explained.**

**Nuclear security**

Security is an important aspect that needs to be considered in the siting process. The requirements for establishing a secure site include:

- Having a site of sufficient size to establish secure boundaries.
- The ability to control the approaches to the installation.
- The absence of site characteristics that could compromise security measures.
- The absence of potential threats from threat assessments performed for the location of the proposed site.

**Decision making**

The above analysis considers the safety, security and economic aspects of the selection of an NPP site. There may be several alternatives for the eventual ranking of the candidate sites in arriving at the list of preferred candidate sites. The approach outlined above is an objective approach in that the differential cost parameter is
minimized, all other aspects being equal. Here, the assumption is made that a site with certain deficiencies, e.g. higher seismic input, will be as equally safe as one with a lesser seismic input as long as they are both designed to the required level (the demand coming from the site characteristics). The negative aspect of the site with higher seismic input is quantified by the cost differential in the design and construction of the NPP for the higher seismic level.

Other methods consider weighting factors for various attributes of the site. These tend to become subjective and a ranking of all aspects using this method does not necessarily convey the information related to differential cost.

It is very important that the process of site selection is transparent. There may be misconceptions about the effects of an NPP on the environment both among the public and also among the decision makers in the country. Communicating the scientific facts relating to the interaction of the NPP with the site and its environment is a very important part of the site selection process. When there are misconceptions about these issues the site selection process may become distorted and objective criteria may be used only to a limited extent. This results in a selection process which is not optimal.

The IAEA published the Safety Series document 50-SG-S9 on “Site Survey for Nuclear Power Plants” [1] as far back as 1984. It is the only IAEA safety standards document from the first generation of safety standards that is still applicable in 2014 when the fourth generation of safety standards is being published. However, it will be soon superseded by DS 433 “Site Survey and Site Selection for Nuclear Installations” [2], which has been approved for publication.

1.3 Questions

1. Describe the objectives of the siting process.
2. Describe the consecutive stages in a) the siting process and b) the site evaluation process.
3. Describe the process of the regional analysis to identify potential sites.
4. Name the tasks that are performed in the screening process to select candidate sites.
5. Describe the ranking process of candidate sites to obtain the preferred candidate site or sites.
6. Describe the nuclear security considerations that need to be taken into account in the siting process.
7. Describe the key aspects of the decision-making process for site selection.
2 SITE EVALUATION

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe the general requirements and safety considerations for site evaluation.
2. Explain the effects of external hazards on the safety of a nuclear power plant.
3. Describe the impact of a nuclear power plant on the environment.
4. Describe the concept and importance of emergency planning.

2.1 Introduction

Site evaluation is a process that starts after the selection of the site and continues throughout the lifetime of the NPP. It is a well regulated activity and the IAEA has issued a comprehensive set of detailed safety standards on the subject (Refs. [3] – [12]). This chapter is therefore based entirely on the available IAEA safety standards documents.

The site evaluation that is done immediately after the selection of the site constitutes a chapter of the Preliminary Safety Analysis Report of the NPP. It also contains all the information related to the radiological aspects of the Environmental Impact Assessment Report. Finally, the parameters that are derived in relation to site characteristics are used in the preparation of the bidding documents. Site related parameters may influence the plant design to a significant extent and consequently the costs related to engineering and construction.

It is customary to produce a report entitled the Site Evaluation Report (SER) which serves as the source material for all the other documents mentioned above.

It is possible to use the data and information produced in the Site Selection phases described above. However, this should be done with caution because all the activities performed during the Site Evaluation stage fall within the scope of the Management Systems (or Quality Assurance) Programme (Refs. [13] – [15]). Therefore it is important to have the previously collected data checked and verified before using it in site evaluation.
2.2 Major constituents of site evaluation

The evaluation of an NPP site is made up of three major topics. These are:
- Effects of the region and the environment on the safety of the plant – external hazards;
- Effects of the plant on the environment and the region;
- Demonstration of the feasibility of an effective emergency plan considering the population and other factors.

All three topics are closely related to safety. The IAEA Safety Standards treat these aspects in a comprehensive manner.

The three major topics of site evaluation are introduced in the IAEA requirements document NS-R-3 [3] in the following two paragraphs of the Objective section:

“Paragraph 2.1. The main objective in site evaluation for nuclear installations in terms of nuclear safety is to protect the public and the environment from the radiological consequences of radioactive releases due to accidents. Releases due to normal operation should also be considered. In the evaluation of the suitability of a site for a nuclear installation, the following aspects shall be considered:
- The effects of external events occurring in the region of the particular site (these events could be of natural origin or human induced);
- The characteristics of the site and its environment that could influence the transfer to persons and the environment of radioactive material that has been released;
- The population density and population distribution and other characteristics of the external zone in so far as they may affect the possibility of implementing emergency measures and the need to evaluate the risks to individuals and the population.

Paragraph 2.2. If the site evaluation for the three aspects cited indicates that the site is unacceptable and the deficiencies cannot be compensated for by means of design features, measures for site protection or administrative procedures, the site shall be deemed unsuitable.”

All the data gathered and investigations performed for the site should be aimed at demonstrating the suitability of the site in relation to the design of the plant. If the design of the plant is not known at this stage of the project, the site evaluation process will identify site related requirements that the design should meet. For example, if the site conditions demand that a seismic input of 0.4g (with an associated response spectrum) is appropriate, then the seismic design of the plant should be able to meet this requirement in a conservative way. This is
what is meant by ‘compensating for by means of design features’.

Other ways of compensating for site deficiencies are also possible. For example, dykes may be built along the bank of a river to protect the site against flood hazards. When such a measure is taken, it should be ascertained that the flooding around the site area does not negatively impact the emergency measures that need to be taken. Furthermore, it should be noted that the dyke becomes a ‘safety system’ and should be designed with requirements commensurate with its safety significance.

Finally, if design or site protection measures are not sufficient for compensating for the deficiencies of some aspect of the site, then administrative measures could be employed. This type of measure is generally (although not exclusively) used to provide protection against human induced events. For example, if a railway train that passes very close to the site could carry an explosive cargo which could jeopardize the safety of the plant, administrative measures should be taken to ensure that the amount of explosives transported at any one time is well below the limit determined by the screening distance. Similar measures may be taken in relation to road, sea or river traffic. Also ‘no fly zones’ could be established to limit air traffic over the site. It should be noted, however, that administrative measures may not be reliable and depend on authorities outside of the operating organization and the nuclear safety regulator. In fact, the last sentence of Paragraph 2.6 in NS-R-3 makes the preference very clear: “…Design features and protective measures are the preferred means of ensuring that risks are kept acceptably low.”

2.3 General requirements and considerations

The general requirements for site evaluation may be summarized as follows:

- **Site evaluation is an ongoing process.** This is because the characteristics of the site may change with time. For example, the population may increase or new sources of human induced events may appear near the site. The perception of the risk due to external events may also evolve. New data may become available, or new events may occur. Global changes in the climate may also cause new types of extreme meteorological or hydrological events to appear (e.g. tropical cyclones may occur in places where initially these were not considered to be credible). Finally, it may be decided to build new nuclear installations at the site. The whole site needs to be considered together and the potential interactions between the different installations should be taken into account. It is now an IAEA recommendation and international practice to evaluate the site characteristics during each Periodic Safety Review of the plant (normally every ten years).
- **Although not strictly in the domain of nuclear safety, associated**
topics that can be easily addressed using the data obtained should also be considered. These involve thermal and chemical releases, as well as the interaction of nuclear and non-nuclear effluents.

- Both the severity and the frequency of external events need to be considered. Therefore, the data collected and the investigations and evaluations performed should target not only the potential extreme values but also the rate of occurrence of these events. This is in line with the general tendency of the IAEA Safety Standards to take into consideration risk informed aspects. Such ‘frequency’ or ‘rate’ information is the basis for conducting probabilistic safety analyses for external events.

2.4 Effects of external hazards on the safety of the plant

External hazards may be of natural origin or they may be human induced. These natural external hazards may be related to the earth, water or the air.

Earth related external hazards of natural origin

Earth related natural hazards are earthquakes, volcanoes and geological and geotechnical hazards such as soil liquefaction, slope instability, subsidence and collapse.

At the moment, there are three safety guides related to these hazards. These are the Safety Guide No. SSG-9 on Seismic Hazards in Site Evaluation for Nuclear Installations [8], Safety Guide No. SSG-21 on Volcanic Hazards in Site Evaluation for Nuclear Power Plants [12] and NS-G-3.6 Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants [11].

Evaluation of seismic hazards

The evolution of Safety Guide No. SSG-9 on Seismic Hazards can be summarized in accordance with:

**Generation I – 50-SG-S1 (1979)**
- Distinction between low and high seismicity countries (the Guide being valid for high seismicity countries);
- Relation between probabilistic and statistical approaches;
- Collection of varied and sometimes inconsistent national approaches;
- Recommendation for generic RS (USNRC RG 1.60).

**Generation II – 50-SG-S1 (Rev. 1, 1991)**
- Seismotectonic modelling using a four-scale approach; regional, near regional, site vicinity, site area;
- Applicable to all countries (no distinction between low/high seismicity);
Seismogenic structures and zones of diffuse seismicity;
- Deterministic with an option for probabilistic approach;
- Minimum requirement for 0.1g design;
- Clear definition of a “capable fault”;
- Site-specific RS.

- More emphasis on uncertainties;
- More guidance on new topics of data generation such as paleoseismology;
- More guidance on probabilistic seismic hazard analysis;
- Decoupling of design response spectra and hazard-based response spectra (site-specific).

The reasons and the basis for a new revision (Generation IV) can be summarized as follows:
- Feedback from seismic safety reviews since 2002, some involving Probabilistic Safety Hazard Analysis (PSHA);
- Need to include other nuclear installations;
- International experience in PSHA such as Pegasos;
- Recent strong seismic activity recordings in California and especially Japan;
- Exceeding of design basis hazards in Japan (Onagawa and recently Kashiwazaki-Kariwa NPP);
- Preparation for new plant construction.

Experience from the recent earthquakes in Japan has been especially informative. The earthquake that occurred in Japan in June 2008 caused a peak vertical acceleration of 4.0 g, a new record.

In the meantime, re-evaluation of the seismic hazard at existing nuclear power plant sites has also resulted in appreciably higher hazard results. The use of different approaches in various member states (deterministic and varying probabilistic approaches) has also contributed to the need for a new revision.

Some of the new aspects that are considered or expanded in Safety Guide No. SSG-9 (Generation IV) include:
- Uncertainties (site specific vs. imported);
- Epistemic uncertainties;
- Uncertainties treated in both PSHA and Deterministic Safety Hazard Analysis (DSHA);
- PSHA based on Simplified Epistemic Uncertainty Representation;
- More detailed PSHA guidance;
- Deterministic/probabilistic fault displacement evaluation for existing NPPs;
- Guidance for other nuclear installations;
- More emphasis on organizational aspects.
This is the first time that the probabilistic evaluation of fault displacement for new nuclear power plants has been considered in an international safety standard. Normally, for new plants, the potential for surface faulting (or fault displacement) at the site area of the nuclear power plant is a clear exclusion criterion. There are cases, however, where for existing nuclear power plants, this potential exists, although the probability of a significant displacement that can actually jeopardize the safety of the plant is very low. The new revision of this safety guide intends to bring clarity to this issue and a way of actually measuring the likelihood of potential displacement.

The approach to the evaluation of seismic hazards that is recommended in Safety Guide No. SSG-9 is a data-driven and model-based methodology.

The data that needs to be collected is given very high importance in the Safety Standard. The data may be geological, geophysical, seismological and paleoseismological.

The data and the recommended investigations are defined within four different scales of study as follows:

- **Regional**: a minimum radius of about 300 km and at a scale of 1:500000;
- **Near regional**: a minimum radius of about 25 km and at a scale of 1:50000;
- **Site vicinity**: a minimum radius of 5 km and a scale of 1:5000;
- **Site area**: fenced-in area, at a scale of 1:500.

It may be seen from these radius values and the scales of the studies that increasing detail is needed as the circles narrow around the site.

Based on the data collected in this way, a regional seismotectonic model is constructed. In this seismotectonic model, two types of sources are considered:

- Seismogenic structures (mainly faults and folds);
- Zones of diffuse seismicity (earthquakes which cannot be associated with tectonic structures).

**Once the model (as well as alternative models reflecting epistemic uncertainties) is established, then both deterministic and probabilistic methods are used to calculate the parameters needed for the seismic design of the nuclear power plant.** Actually, a PSHA is always needed because it serves as an input to the seismic PSA for the plant.

It should be noted here that there is no consensus amongst member states on the preference for a deterministic or a probabilistic approach. However, as the Safety Guide No. SSG-9 recommends, there is consensus on the proper treatment of uncertainties (both random or aleatory, as well as modelling or epistemic) regardless of the
methodology employed (i.e. either deterministic or probabilistic).

Regarding uncertainties in general, Safety Guide No. SSG-9 states the following in Paragraph 2.6: “The general approach to seismic hazard evaluation should be directed towards reducing the uncertainties at various stages of the process. Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the effort needed to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the process.”

If, however, the site lacks data regarding ground motion recordings from past earthquakes (which is the case for most nuclear power plant sites), the uncertainty related to the so-called “attenuation relationships” that needs to be imported cannot be reduced, and this must be properly accounted for in both the deterministic and the probabilistic approaches.

**Historically, several (usually two) levels of severity have been considered in the seismic design of nuclear power plants (SL-1 and SL-2 in the IAEA terminology).** In order to respond to this design need, seismic hazard studies have also targeted similar levels. These are defined in Paragraphs 9.1 and 9.2 of Safety Guide No. SSG-9 as follows:

“9.1. Typically, two levels of ground motion hazard, named SL-1 and SL-2, are defined as the earthquake design basis for each plant. The definition and application of these levels in plant design are explained in NS-G-1.6. [4] In design, the SL-2 level is associated with the most stringent safety requirements, while SL-1 corresponds to a less severe, more probable earthquake level that normally has different implications for safety. When probabilistic seismic hazard analysis is used, either a reference annual frequency of exceedance is needed, derived on the basis of data from experience, for example, or a performance based approach may be taken.”

“9.2. Regardless of the method used to evaluate the ground motion hazard, both SL-1 and SL-2 levels should be defined by means of appropriate spectral representations and time histories. The ground motion should be defined for free field conditions, at the level of the ground surface or key embedment depths and in line with user requirements. The ground motion for reference bedrock conditions should be given, provided that a good geotechnical database is available. Ground motions at the foundation level and at the surface can then be computed, with account taken of the transfer functions of the overlying soil layers. Consideration should be given to the appropriate interfacing of the defined reference ground motion and the site response analysis.”
The ground motion hazard is defined by a spectral representation and energy content. Depending on whether a deterministic or a probabilistic approach is used, these could have different names. The traditional way of representing the design basis ground motion is a response spectrum and a set of time histories that match this response spectrum. Of course, both horizontal and vertical components of the ground motion need to be considered.

One very important aspect of the evaluation of seismic hazards is the assessment of the potential for surface faulting at the site. This refers to the permanent displacement caused by a tectonic feature (either a fault or a fold) at or near the surface that has the potential to adversely affect safety related structures of a nuclear power plant.

The existence of a “capable fault” at a nuclear power plant site is considered an exclusion criterion.

For this reason the definition is quoted below (See Paragraph 8.4 of Safety Guide No. SSG-9):

"8.4. On the basis of geological, geophysical, geodetic or seismological data, a fault should be considered capable if the following conditions apply:
(a) If it shows evidence of past movement or movements (such as significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to conclude that further movements at or near the surface may occur. In highly active areas, where both earthquake data and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years (e.g. Upper Pleistocene–Holocene, i.e. the present) may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods (e.g. Pliocene–Quaternary, i.e. the present) are appropriate.
(b) If a structural relationship with a known capable fault has been demonstrated such that movement of the one fault may cause movement of the other at or near the surface.
(c) If the maximum potential magnitude associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to conclude that, in the current tectonic setting of the plant, movement at or near the surface may occur."

Evaluation of volcanic hazards
Volcanic hazards are not a major concern for most nuclear power plant sites. However, there are a number of countries which operate nuclear power plants and also those which intend to do so in the near future where volcanoes are located in the near region of a nuclear power plant site (i.e. within a distance of about ~25 - 30 km). For this reason, the IAEA started to develop a safety standard on this subject.
in 1995, published a Provisional Safety Standard in July 1997 and, after ten years of utilizing this provisional safety standard in a few countries, produced a Safety Guide in 2012 (SSG-21 [12]).

In some ways, the draft safety guide on the evaluation of volcanic hazards is similar to the safety guide on the evaluation of seismic hazards. The approach to the collection of data, the determination of the capability of a volcano, the methods of evaluation and the monitoring recommendations have noticeable parallels. However, the parameterization of the effects of a volcano is very different from earthquakes (where only vibratory ground motion and fault displacement are considered).

The following phenomena are considered in the evaluation of volcanic hazards: ballistic projectiles, fallout of pyroclastic material, pyroclastic flows and surges, air shocks and lightning, lava flows, debris avalanches, landslides, debris flows, lahars and floods, volcanic gases, ground deformation, earthquakes, tsunamis, geothermal anomalies, groundwater anomalies and opening of new vents.

**Evaluation of other geological and geotechnical hazards**

The present Safety Guide on this subject is **NS-G-3.6** [11] and is entitled Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants. The guidance that is provided there is related to geotechnical hazards such as liquefaction and slope instability. The focus is on the dynamic behaviour of soil and therefore the seismic input that is determined from NS-G-3.3 [8] is very relevant.

This safety guide is a bridge between site evaluation considerations and design aspects of soil and foundation safety.

The two main considerations for the performance of soil under seismic loads are related to the dynamic response of the soil (so-called site response) and the potential for the soil to fail (i.e. loss of bearing capacity). Detailed guidance is provided on the in-situ and laboratory investigations to be followed and the necessary data to be collected.

The following is a sample list of geophysical field investigations:

- Seismic reflection and refraction surveys;
- Cross hole seismic tests;
- Uphole/downhole seismic tests;
- Ambient vibration measurements;
- Electrical resistivity;
- Nuclear well logging;
- Gravimetry and microgravimetry;
- Magnetic techniques;
- Georadar measurements.

And a sample list of geotechnical field investigations:

- Flat jack tests;
- Hydraulic fracturing tests;
- Direct shear stress tests;
- Plate loading tests;
- Pressure meter tests;
- Static and dynamic penetrometer tests;
- Vane shear tests;
- Pumping tests.

Furthermore, static and dynamic laboratory tests need to be performed as follows:
- Soil index and classification (Atterberg limits);
- Tests to identify the physical and chemical properties of soils and ground water;
- Soil moisture and density tests;
- Consolidation and permeability tests;
- Shear strength and deformation capability tests;
- Shear, biaxial or triaxial tests;
- Cyclic triaxial tests;
- Resonant column tests.

Liquefaction is a particular issue for saturated granular soils when subjected to cyclic loads such as earthquakes and NS-G-3.6 provides guidance regarding the assessment of this phenomenon. The characteristics and parameters important for this evaluation are as follows:
- Groundwater regime;
- Grain size distribution;
- Standard penetration;
- Cone penetration;
- Relative density;
- Undrained cyclic strength;
- Strain dependence of soil properties;
- Past liquefaction history.

Related to site response, the response spectra that are obtained using SSG-9 are modified to become the ‘site specific response spectra’ using the soil data obtained for the site. For this purpose standardized parameters for the soil profiles are utilized.

Related to foundations, guidance on soil-structure interaction is provided, both in terms of the required data and the methods to be used. General foundation stability is also considered, i.e. bearing capacity, overturning and sliding. Methods to calculate and monitor settlements and heaves related to the foundations are also provided.

Finally, earth structures that have safety implications are considered. These may be natural slopes, the failure of which may affect safety related buildings or structures. They may also cover structures built for site protection including dykes, dams, sea walls and breakwaters. Related to these, but found in almost all nuclear power plant sites, are
buried structures such as galleries, pipes, conduits and tunnels. The interaction of these structures with the surrounding soil mass needs careful consideration, especially when subjected to dynamic loads.

**Water related external hazards of natural origin**

Due to the need for large quantities of water for cooling their operational and safety related components, nuclear power plants are sited near rivers, lakes, man-made reservoirs or seas. Although there has been some thinking in this direction, at present no nuclear power plant uses ground water for cooling purposes.

### Because of their proximity to large bodies of water, floods are always considered as a potential hazard for nuclear power plants.

The cause of the flood may be different depending on the location of the plant with respect to the water body.


For coastal sites, storm surges, seiches (sudden change of the water level), tsunamis and storm waves should be considered and combined with tidal effects.

Storm surges are caused by pressure variations in the atmosphere and they produce long period effects which may cause metres of water to build up, especially in enclosed bodies of water (such as inlets, channels and gulfs).

Seiches may be caused by large earthquakes when enclosed (or semi-enclosed) bodies of water resonate with the long period seismic waves. This is basically a ‘sloshing’ problem where the tank is replaced by the enclosed body of water. They occur almost simultaneously with the earthquake (caused by the arrival of seismic waves near the body of water). Unfortunately, the database for historical seiches is very limited and simulation work is not well developed.

Tsunamis have received renewed attention after the Indian Ocean tsunami of December 2004 and the Fukushima accident in March 2011. Ocean wide tsunamis are caused by large fault ruptures at the sea bottom that can only be caused by major earthquakes (typically $M_w=8$ or over) or major underwater volcanoes. However, more localized tsunamis may be caused by any disturbance of the seafloor such as a submarine landslide. Unlike seiches, tsunamis reach land significantly later than the occurrence of the seismic event. Depending
on the epicentral distance, the travel time of a tsunami could be many hours before it reaches the coast. For this reason, a tsunami warning system may contribute to the safety of the nuclear power plant.

Both wind generated waves and tidal effects are combined with other coastal flood hazards before a safe plant grade is established. The normal protection from coastal flooding is to establish a ‘dry site’ through building the plant at an elevation somewhat above the calculated combined effects of coastal flooding. Here, the important point is to place all the safety related buildings and structures at an elevation sufficiently high for flood protection purposes. The way in which the ultimate heat sink (UHS) is designed is of major importance. The UHS should always be protected against the design basis flood.

**NS-R-3 requires probabilistic methods for the evaluation of all external events.** In addition to deterministic methods (which are more established in the profession at the moment), there is a need to understand the frequency of these extreme events in order to be able to incorporate each hazard within the framework of an external event PSA.

Nuclear power plants on river sites need to have the flood hazard evaluated using established methods. As for the coastal flooding, a probabilistic method should be used for similar reasons. In some cases, nuclear power plants are sited on man-made lakes created from rivers. The robustness of the man-made structures is very important in this case. The safety significance of such structures should be established and appropriate protection should be provided. Here flooding is not the only issue for the man-made structures. Earthquakes may also cause the failure of these structures and they should also be designed to withstand the design basis seismic loads.

One more issue to be considered for nuclear power plants on rivers is the existence of dams (or other water retaining structures) upstream. The hydrological or seismic failure of these dams may cause a flood at the site even if these structures are located hundreds of kilometres away. When establishing the plant grade all these potential failures need to be considered.

It is also possible to prevent flooding at a nuclear power plant site through site protection measures. This is valid both for river and coastal sites. Properly designed dykes, levies, breakwaters, etc. may be used for the flood protection of the site. Again, in the design of these structures, their safety significance should first be established and the required conservatism should be incorporated in their design.

Special consideration needs to be given to sites which are on estuaries. These sites may be subjected to a combination of effects from the river and the sea that may produce an exceptional high water level.
Extreme weather conditions may constitute a common cause to trigger unfavourable conditions both at sea and in the river, and lead to conditions that may initially appear as independent events.

Another cause of flooding at a site may be a sudden downpour. This is called a flash flood and it is generally associated with extreme weather (see the Section Air related external hazards of natural origin).

In regions which are low-lying and susceptible to large scale flooding, the protection of the site from floods either by raising the site (building a platform) or using site protection measures may not be sufficient. Consideration should also be given to the feasibility of emergency measures during the occurrence of a flood event.

In this regard (and in relation to all external events), NS-R-3 states the following: “Paragraph 2.29 The external zone for a proposed site shall be established with account taken of the potential for radiological consequences for people and the feasibility of implementing emergency plans, and of any external events or phenomena that may hinder their implementation. Before construction of the plant is started, it shall be confirmed that there will be no insurmountable difficulties in establishing an emergency plan for the external zone before the start of operation of the plant.”

Water related hazards are not only related to high water events. Low water levels are also of concern for nuclear power plants. In cases where a substantial drawdown is possible, such as during tsunamis and seiches, it should be established that the ultimate heat sink is not affected by this. In cases where low water levels in rivers continue for an extended period of time (during arid summers for example), the plant may need to reduce its power output in order to comply with environmental regulations.

**Air related external hazards of natural origin**

The wind hazards considered include tornadoes and tropical cyclones.

The current Safety Guide on this subject is SSG-18 and is entitled “Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations. The main topic of this safety guide is the evaluation of hazards related to extreme steady and rotating winds.

Tornadoes are generally described as violently rotating columns of air, usually associated with a storm. They may occur both on land as well as over bodies of water, in which case they are called water spouts. Their main impacts are the high wind, pressure differentials and missiles that are picked up and possibly thrown against nuclear power plant buildings and structures at very high velocities. Tornadoes may also be associated with cloudbursts which may cause local flooding.
Tropical cyclones have different names in different parts of the world; hurricanes in the Atlantic, typhoons in the north Pacific and severe cyclones in the Indian Ocean. Compared to tornadoes, they have much greater dimensions. Due to their very large radius of rotation they are felt as direct winds at any one location. Because of their regional (rather than local) nature they may cause floods both due to the rain they bring and the surges they may cause in bodies of water. Therefore their flooding effects need to be considered.

Aside from rare phenomena that are associated with certain parts of the world, there are general weather conditions that may reach extremes during the lifetime of the nuclear power plant. These include parameters such as wind speed, precipitation rate and temperature.

In consideration of the phenomena and parameters related to weather, it is important to recognize that these may not be samples of a stationary process and that what has happened during the past one hundred years may not necessarily be indicative of what will happen in the future. Although global warming is still a controversial issue, it is advisable to take a prudent approach when forecasting parameters related to meteorological phenomena.

Some parameters are actually more related to operational issues and not strictly of safety concern. For example, if temperatures (in the air and water) rise above the thresholds foreseen during design, this will affect operation in that a lower power output will be necessary. However, there are other phenomena which are clearly safety related. For example, if tornadoes or tropical cyclones start occurring with greater severity or frequency or if they start occurring in areas that were thought to be immune to them, safety issues will certainly arise.

Just like extreme heat, extreme cold may also cause problems. This is especially the case if the cooling water freezes and the ultimate heat sink is affected.

Again, while excessive wind may cause destruction extreme still conditions are also a cause for concern. To be able to provide for adequate dilution of airborne effluents, good dispersion is needed even in normal operating conditions when routine discharges are made. This topic is further explored in the section related to dispersion (Evaluating the Potential Effects of the Nuclear Power Plant in the Region and the Environment).

**Human induced external hazards**

In the vicinity of a nuclear power plant site there may be a multitude of sources of human induced hazards.
The current Safety Guide on this subject is NS-G-3.1 and it is entitled External Human Induced Events in Site Evaluation for Nuclear Power Plants [6].

It should be noted that NS-R-3 Site Evaluation for Nuclear Installations – Safety Requirements and NS-G-3.1 deal only with accidental human induced events. Other events that are the results of malicious intent are not covered in the safety standards. These types of events are considered within the framework of the protection from sabotage of nuclear installations. A good reference in this area is Security Series No. 4, Engineering Safety Aspects of the Protection of Nuclear Power Plants Against Sabotage [16].

The definition of an external event is important for events that are of human induced origin. In general, external events are thought to originate outside the plant boundary, i.e. where there is no administrative control by the plant. Internal events, on the other hand, are generally events such as internal fires, internal floods and sprays, falling objects (e.g. from the crane), pipe whip, etc. They are generally related to the operational processes of the plant. In NS-G-3.1, events that may originate within the boundaries of the site are also considered. These may be from sources which are not directly involved in the operational states of the nuclear power plant units, such as fuel depots or areas for the storage of hazardous materials for the construction of other facilities at the same site. Considerations relating to other nuclear power units as well as other types of nuclear installations such as fuel cycle facilities are important because administratively speaking they may in fact be outside the control of the plant management. Because of their close proximity to the plant neglecting the hazard that may originate from them could cause a safety lapse.

When dealing with human induced hazards, it is important to distinguish between events themselves and the effects or parameters that are associated with these events. Events originate from sources (either mobile or stationary).

The stationary sources that are considered in NS-G-3.1 are as follows:

- Petrochemical facilities;
- Chemical plants;
- Storage depots;
- Broadcasting network;
- Mining or quarrying operations;
- Forests and brush lands;
- Other nuclear facilities;
- High energy rotating equipment;
- Military facilities.

The mobile sources that are included are:
- Railways;
- Road vehicles;
- Ships and barges;
- Pipelines;
- Air corridors (both civilian and military);
- Airports (both civilian and military).

The events that can occur are explosions (both deflagration and detonation), collisions and crashes (of land, sea, or air vehicles), release of toxic and other hazardous gases, fires, and interference. The effects that these events can have on the plant, are:
- Pressure waves (impulse loads);
- Impact (i.e. mechanical impact);
- Heat;
- Asphyxiant (stifling) and toxic substances;
- Corrosive and radioactive substances;
- Vibration;
- Electromagnetic interference and eddy currents.

The potential for human induced events may evolve during the lifetime of the nuclear power plant much more than for natural events. Both the severity and the frequency of events may change and new sources may be added when the plant is in operation. As all these changes happen outside the control of the plant management, it is important to consider this potential for evolution during site evaluation.

**Generally, the first step is to collect all the available information related to potential sources of human induced events in the site vicinity (~ 8 km radius) and plot these on a map. This is called a source display map. After this is done, then information needs to be collected regarding all the characteristics of these sources relevant to the safety of the nuclear power plant.**

This should include data related to the severity of the consequences of an accident at the stationary sources. For example, if there is a military arsenal nearby, the maximum amount of explosives that may be accidentally ignited should be estimated. Especially in dealing with military authorities, it may not be easy to get accurate information for security reasons, and conservative estimates may need to be made. Any future development plans that are foreseen for the facility should be taken into consideration.

For mobile sources, estimating the amount of hazardous material that may be transported, for example, is more difficult. The capacity of vehicles to transport material has increased significantly over the past
fifty years and therefore, some projection is needed to estimate these maximum amounts for the future. Again, any future development (such as new roads, airports, etc.) of the transportation infrastructure should be investigated, and conservative estimates should be made when information is uncertain or incomplete.

After the collection of data related to the maximum potential consequences of accidents related to both stationary and mobile sources, and using the source display map that was prepared, the distances to these sources are determined. Using simplified and conservative approaches, the order of magnitude of the effects of these events (for example in terms of overpressure, impact, heat, etc.) are calculated in order to compare these with the design of the plant. Conversely, it is also possible to start with the inherent plant characteristics to derive distances for which various effects can be safely excluded from further consideration. These are called ‘screening distance values’ (SDVs). They are calculated for each source using a conservative approach such that the effects of the interacting events need not be considered further. The determination of the SDVs should take into account the severity and extent of the event, as well as the expected characteristics of the nuclear power plant to be located at the site. If no information is available for plant characteristics at this stage, some nominal values from a standard plant design may be used. These assumptions need to be verified after the plant design is known.

If it is found that the source is beyond of the calculated SDVs for the event under consideration then the source is screened out (See Paragraph 4.7 of NS-G-3-1).

The next step of the analysis is more involved. In this step only those events that have not been screened out are considered. For stationary sources which have not been screened out using the SDVs, it is necessary to estimate the probability of occurrence of the event (the accident) that may adversely affect the nuclear power plant. Usually data exists for frequencies of industrial or transport accidents and this information can be used to estimate the probability. This probability is then compared with the screening probability level (SPL) that needs to be established for the plant. The SPL is generally chosen to be about two orders of magnitude smaller than the probability level that would be taken as the basis for the design. This is done in order to take account of the uncertainties in the process of estimating the probability. If the probability of the event is smaller than the SPL, then the event is screened out (See Paragraphs 4.8 – 4.10 of NS-G-3-1).

The events which have not been screened out using the SDV and the SPL need to be investigated in more detail and using more sophisticated analyses. Those events for which these analyses indicate the need to be considered are identified as those for which
Protection is required.

**Protection can be provided through a robust design. Alternatively, site protection measures can also be used.** For example, barriers may be built between the source of potential explosion and the plant so that the barrier can withstand the overpressure. This will decrease the overpressure which the plant will experience. Another common way to deal with human induced events is the use of administrative methods and procedures. For example, the area around the plant can be designated as a “no fly zone” to prevent the possibility of commercial or military aircraft crashing into the plant. Or, if there is a railway near the site and the train may carry ammunition to or from an arsenal, it may be possible to limit the amount of explosive to a value where the plant would be outside the SDV. This involves coordination with military and railway authorities and it is difficult to guarantee its effectiveness throughout the lifetime of the plant. Administrative measures are regarded as the least attractive solutions because their effectiveness depends on human decisions and behaviour, and their implementation is outside the control of plant management and the regulatory authority.

### 2.5 Evaluating the potential effects of a nuclear power plant in the region and the environment

The Site Evaluation Report for a nuclear power plant covers all aspects related to its radiological impact on the environment.

This report serves as a source for three documents which need to be prepared for a nuclear power plant. Aside from the radiological part of the environmental impact assessment report, it also contains all the required information and analyses for the site chapter of the Preliminary Safety Analysis Report. Furthermore, site related information that is necessary for the preparation of bidding documents is also contained in the Site Evaluation Report.

All industrial facilities need to be evaluated in terms of their effects on the region and the environment. For nuclear power plants there is also the requirement for an environmental impact assessment. How this is regulated and which government body approves the environmental impact report differ from country to country. The environmental impact report for a nuclear power plant covers the radiological impact of the installation, as well as other impacts such as thermal, noise, etc.
The information needed for the site chapter of the Preliminary Safety Analysis Report is as follows:

- Transport and diffusion characteristics of effluents in air;
- Transport and diffusion characteristics of effluents in surface waters;
- Transport and diffusion characteristics of effluents in ground water;
- Direct and indirect transport pathways of radionuclides to the population (i.e. through direct exposure and via the food chain) – Land and water use;
- Population distribution and population centres (permanent and transitory) in the near region of the site (~25 – 30 km radius from the site);
- Identification of critical groups and habit surveys for these groups so that ingestion and external doses can be evaluated.

This requires a very detailed investigation programme that should normally cover at least a twelve month period to include all seasonal changes.

As with external hazards, NS-R-3 requires the following in Paragraph 2.25 “The design of the installation shall be such as to compensate for any unacceptable potential effects of the nuclear installation on the region, or otherwise the site shall be deemed unsuitable.”

Here the design of the containment and the selection of release points (e.g. the stack height) are the main design features that may compensate for deficiencies in site characteristics, such as an excessive number of still days or its proximity to population centres. It goes without saying that the plant workers are also considered in this evaluation process.

The current Safety Guide that deals with these topics is NS-G-3.2 Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants [7]. This Safety Guide was published in 2002 and it constitutes the integration of four previous safety guides on population distribution, dispersion in air, dispersion in surface waters and dispersion in ground water.

**Transport and diffusion of effluents in air**

The atmospheric conditions that influence the transport and diffusion characteristics of effluents should be thoroughly investigated.

Related to the objectives of these investigations, Paragraph 2.7 of NS-G-3.2 states the following: “The results of the meteorological
investigations should be used to confirm the suitability of a site; to provide a baseline for site evaluation; to determine whether local meteorological characteristics have altered since the site evaluation was made and before operation of the plant commences; to select appropriate dispersion models for the site; to establish limits for radioactive discharges into the atmosphere; to establish limits for design performance (for example, containment leak rates and control room habitability); and to assist in demonstrating the feasibility of an emergency plan"

Data needed for determining the meteorological conditions include wind vectors (i.e. wind directions and speeds), specific indicators of atmospheric turbulence, precipitation, air temperatures, humidity and air pressure. In order to assess turbulence it is important to measure the fluctuations in wind direction, temperature lapse rates, solar radiation levels and wind speed at different heights.

The meteorological monitoring programme that is started during site evaluation generally continues throughout the lifetime of the nuclear power plant. Generally measurements need to be taken at several elevations. A meteorological mast (generally about 100 metres in height) is commonly used for this purpose. When Doppler-SODAR instrumentation is used in lieu of a tall mast to characterize wind vector measurements, a measurement system should still be maintained to record the conditions at 10 m elevation as well as other elevations of interest (See Paragraph 2.31 of NS-G-3.2).

One of the objectives of the meteorological investigations is to derive appropriate models of atmospheric dispersion. These models are used for the following purposes (See Paragraph 2.38 of NS-G-3.2):
- To derive short term (a few hours) normalized concentrations and deposition values in order to assess the probability of occurrence of high normalized concentrations and contamination levels due to postulated accidents;
- To derive longer term (up to one month) time integrated normalized concentrations and deposition values for postulated accidents;
- To derive long term (about one year) time integrated normalized concentrations and deposition values for routine operations.

**Transport and diffusion of effluents into the hydrosphere**

Although surface water and ground water characteristics and the dispersion of effluents in these media are quite different, there are some commonalities.
The following properties and parameters should be estimated for radioactive discharges (See Paragraph 3.5 of NS-G-3.2):

- Radioactivity;
- Chemical properties;
- Physical properties of the liquid effluents;
- Flow rates for continuous discharges or volume and frequency of batch discharges;
- The variation of the source term over the duration of the discharge;
- The geometry and mechanics of discharges.

**Transport and diffusion of effluents into surface waters**

Depending on the site location, various forms of surface waters may be relevant. These are rivers, estuaries, open shores of large lakes, seas and oceans and man-made impoundments.

For sites on rivers, the information to be collected includes channel characteristics, flow rates and variations, variations in water levels, communication between the river and the ground water movements, thermal characteristics and variations with depth, concentrations of suspended material and deposited sediments, background levels of radioactivity, seasonal cycles of plankton and feeding and spawning cycles of fish. For estuaries additional information is needed on salinity distribution and the intrusion of saline waters into the river.

For coastal sites, shoreline characteristics and the bathymetry of the near region are important. Near-shore currents; their speeds, temperatures and directions should be studied, including the duration of current stagnation and possible reversals. Thermal stratification, sedimentation characteristics as well as background levels of radioactivity, seasonal cycles of plankton and the feeding and spawning cycles of fish need to be investigated.

**Transport and diffusion of effluents into ground water**
The ground water needs to be studied both on local and regional scales. Major aquifers and their relationship with the ground water in the site vicinity should be well identified. The information related to both local and regional hydrogeology should cover at least climatological data, initial concentrations of radionuclides, major hydrogeological units, recharge and discharge relationships, surface hydrology and the relationship between surface and ground waters.

**Direct and indirect ways of transport of radionuclides to the population**

To determine the effect of indirect pathways of exposure to radioactivity, a good understanding of land and water use is required.

For land use, it is important to identify land devoted to activities such as agriculture, dairy farming, wildlife and livestock as well as recreation. The consumption of milk by children is frequently the critical pathway. The collection and use of free foods such as mushrooms, berries and seaweed should be assessed. Foods that are imported from areas that may have been exposed to discharges should also be identified.

For water use, both surface and ground water resources should be investigated. Data on different water uses should be collected. These should include drinking water (for humans and animals), water for irrigation, water used for fishing and water used for recreational purposes.

**In investigating land and water use, an important concept is the critical group,** which is defined as follows (See footnote 5 in NS-G-3.2): “The critical group is a group of members of the public which is reasonably homogeneous with respect to its exposure to a given radiation source and given exposure pathway and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) from the given exposure pathway from the given source.”
Population distribution in the near region of the site

The purpose of investigations of the population distribution around a nuclear power plant site is twofold (See Paragraph 5.1 of NS-G-3.2):

- To evaluate the potential radiological consequences of normal radioactive discharges and accidental releases;
- To assist in the demonstration of the feasibility of the emergency response plan.

The specific nature of the population around the site should be determined, i.e. permanent or temporary (short or long term transient). It is also essential that reasonable projections of the population variation for the lifetime of the plant are made. This estimate should include possible migrations and population increases that may be caused by the construction of the nuclear power plant.

Three important paragraphs from NS-G-3.2 are given below to conclude the discussion on population aspects:

“Paragraph 5.11. The critical group associated with each nuclear power plant should be identified. Critical groups of the population with particular dietary habits and specific locations for particular types of activity in the region should be considered. The persons in the critical group may be located beyond national borders.”

“Paragraph 5.13. The results of the study on the characteristics and distribution of the population, together with results obtained in respect of the dispersion of radioactive material discharged into air, surface water and ground water, should be used in demonstrating that, for a proposed site and design and for normal operations, the radiological exposure of the population in the region remains as low as reasonably achievable and, in any case, will be within the limits set in the national requirements and those established in the Basic Safety Standards, even for the critical groups mentioned in Paragraph 5.11.”

“Paragraph 5.14. Information similar to that mentioned in Para 5.13 should be used to demonstrate also that, on the selected site, the radiological risk to the population that may result from accident states at the plant, including those which may lead to the implementation of emergency measures, is acceptably low and in accordance with national requirements, account being taken of international recommendations.”

2.6 Considerations for emergency planning

One of the most important aspects of the site evaluation process is the demonstration of the feasibility of an emergency plan.
These plans could be related to the population distribution, existing infrastructure, topography and geographical setting of the site, weather conditions and the likelihood of a natural disaster that may be concurrent with an emergency situation.

As stated above, the population distribution is only one factor that may affect the feasibility of an effective emergency plan. For this reason population considerations should not be assessed in isolation in the site selection and site evaluation process.

With a well-planned infrastructure it may be possible to protect relatively large populations during an emergency. On the other hand, if located in a particularly difficult area even a small village can present problems in the emergency response. If, for example, the only access road to a village (that is on the tip of a small peninsula) goes very near the nuclear power plant, the only evacuation alternative would be through sea transport, which may or may not be always possible due to weather conditions.

The likelihood of concurrent natural disasters should be seriously considered. **Recent probabilistic safety analyses performed for external events have shown that the contribution to core damage or large early release probabilities of external events may be very significant, frequently over 50%**. This means that the posterior probability of an extreme external event happening when an accident has occurred at the plant may be high. It is for this reason that it is important to consider additional contingencies for sheltering and evacuation purposes.

NS-R-3 clearly states that in cases when the feasibility of an effective emergency plan cannot be demonstrated at the site evaluation stage, “...the site shall be deemed unsuitable for the location of a nuclear installation of the type proposed.” (Paragraph 2.28).

### 2.7 Questions

1. Name some general requirements and considerations for site evaluation.
2. Describe the earth, water and air related hazards of natural origin.
3. Describe some human induced external hazards.
4. Describe some potential effects of a nuclear power plant in the region and the environment.
5. Describe briefly the concept and importance of emergency
planning.
3 ENVIRONMENTAL IMPACT ASSESSMENT

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the principles, objectives and requirements of the environmental impact assessment.
2. Describe the principles of the radiological risk assessment.
3. Explain the purpose of environmental monitoring.

A fundamental condition of the authorisation to build and operate a nuclear power plant is the Radiological Environmental Impact Analysis (REIA).

The Radiological Environmental Impact Analysis (REIA) is usually required at the same time or even before the Safety Analysis Report of the installation. REIAs of different characteristics are required at different stages in the decision/licensing process for an NPP. For example, REIAs are normally included in Site Surveys and Site Assessment reports. This analysis (REIA) assesses the radiological impact on people and the environment and sets up programmes for monitoring the anticipated effects of the NPP on the Environment, including incidents, in order to preserve the health of the population, and the safety of all life and property. In addition to the radiological effects, such as radiation risks outside the plant due to direct radiation and radioactive discharges, other environmental effects have to be considered. These include those due to the emissions of chemicals such as those used in anti-corrosion or anti-biological-fouling water treatments, thermal effects such as the warming of the water of the sea, river, air cooling towers or artificial lake used to cool the plant. Such thermal effects result in limits to allowable temperature increase of the water flow cooling the plant condenser. We consider in REIA only the radiation effects on the environment during normal operation (i.e. a non-emergency situation), but all issues must be assessed against the national/local environmental requirements or those of international agencies. The requirements and limits for the environmental radiological risk analysis are originally specified by each country, depending on its laws and regulations. Presently, the IAEA has available a comprehensive and harmonized set of principles, objectives, requirements and guidance to perform the activities necessary to control all the radiological issues posed by an NPP. These are presented briefly in the following.

3.1 Principles and objectives

The Fundamental Safety Principles, IAEA Safety Standards Series
No. SF-1, Vienna (2006), jointly sponsored by nine international agencies, establish one fundamental Safety Objective and ten associated broad Safety Principles which provide the basis and the measures for the protection of people and the environment against radiation risks.

The fundamental safety objective is “to protect people and the environment from harmful effects of ionizing radiation from all facilities and activities that give rise to radiation risks”, including nuclear power plants.

The protection of the environment is thus put at the highest level, the same level as the protection of people. Among the ten associated Safety Principles are Principle 4, “to justify that such facilities and activities yield an overall benefit”, and Principle 7, that “people and the environment, present and future, must be protected against radiation risks”. Corresponding standards and guides are set up to regulate compliance with these objectives. The potential radioactive contamination of the environment and the doses to people must thus be assessed, monitored and continuously minimized.

During normal operation of the plant, since the buildings containing radioactive materials have shielding to reduce the direct radiation level outside them, the radiological risks for the public arise mainly from the management of radioactive wastes. There are several ways in which exposure of the public can occur, as shown in Fig.3.1.

**Figure 3.1:** Waste treatment options.

The first option, when possible, is to concentrate and dispose the solid or solidified wastes in a surface or underground repository. The second option is to treat gaseous or liquid wastes until their activity is below the levels that are permitted for discharge, so that they can be
released in a controlled manner and dispersed in the atmosphere or in liquid pathways.

### 3.2 Requirements

The applicable requirements are stated in the General Safety Requirements Part 3 No. GSR Part 3 publication from 2014 entitled “Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards” [17]. This publication superseded the old BSS-115 standard of 1996.

It contains the requirements for performing safety and dose assessments, establishing protection measures and programmes, and optimizing them periodically; for the discharge of radioactive substances to the environment; for monitoring programmes of public exposure; for exemption of consumer products from regulatory control, i.e. to be considered non-radioactive for all practical purposes; and finally for emergency plans for the population in case of accidents. Each NPP must have a radiation monitoring programme covering its area of influence.

### 3.3 Radiological risk assessment

The main safety guides dealing with management of releases leading to radiological environmental impacts are the following:

- RS-G-1.8 (2005), Environmental and Source Monitoring for Radiation Protection [18].
- WS-G-2.3 (2000), Regulatory Control of Radioactive Discharges to the Environment [19].

The Figure 3.2 below, taken from the Guide RS-G-1.8, shows all the human exposure pathways from an NPP source to the persons to be considered in assessing the highest potential personal total dose, i.e. the dose to the “critical group” (“reference person”), and the collective dose to the whole population. Figure 3.3 and Fig 3.4 show atmospheric and liquid exposure pathways, respectively.
Figure 3.2: Human exposure pathways.

Figure 3.3: Atmospheric exposure pathways.
The guide is actually applicable to the normal operation of all nuclear facilities, including those of the fuel cycle, to medium and long lived radionuclides widely dispersed in the environment following a radiation accident, or as residual waste from past practices and accidents, including the content of natural and man-made radionuclides in commodities, especially in foodstuffs and drinking water. **The monitoring programmes include radiation measurements and the collection of supporting information, as well as the assessment of doses to critical groups and to the whole population.** The total dose to a person is the effective external dose (e.g. exposure to radionuclides in an atmospheric plume or deposited on the ground) plus the committed internal dose due to inhalation (of airborne radionuclides, or re-suspended particulates from ground deposits), and ingestion of water and food containing radionuclides (dose calculated over 70 years for children and 50 years for adults).

**Monitoring for radiation protection of the public is divided into three types: monitoring at the source, monitoring in the environment (water, air, surfaces, concentration in foodstuffs etc.) and, in very rare cases, individual monitoring of members of the public.** The programmes of monitoring include measurements of radiation levels at the source and in the environment, radionuclide content in the media of release and in environmental samples and, in very rare cases, in the human body. Supporting programmes include other measurements and data collection activities, such as environmental characteristics (meteorological, hydrological, soil type, etc.), population characteristics (age distribution, food habits, occupation, etc.) and economic characteristics (land and water use, agricultural technologies, etc.). The environmental programme must start before the operation of the NPP or facility begins in order to establish the baseline reference levels for future evaluations of the environmental effects.

Models and measurements must be used to assess radionuclide transport mechanisms, doses to the population and potential concentrations in air, water, soil and food chains. Initial dose assessments before operation are based only on models. Later the
estimates must be verified and reassessed using measurements of actual concentrations in the releases and in samples of the land media, again using models of radionuclide dispersion and transport, and of uptake by plants and animals. The results are usually specified in terms of a percentage of the limiting annual radiation dose, or as the intervention levels of the dose received by the critical group.

Some models for assessing the radiological impact on humans are described in the IAEA Safety Report Series SRS-19 (2001), Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment [21]. This document is a comprehensive handbook of models and calculation procedures for every step of all the exposure pathways. Various models of increasing complexity are proposed for dose screening purposes, from a no dilution approach to a generic environmental model, or modified generic assessment or site specific model. If the doses estimated with a simpler model are not below 1/10 of the limits, a more complex model must be applied. As an example, Fig. 3.5 depicts a generic atmospheric dispersion model.

**Figure 3.5:** The most important processes affecting the transport of radionuclides released to the atmosphere.

The report SRS-19 contains tables of dose coefficients, for screening purposes, for the main radionuclides, from concentrations in the medium (Bq/m³) or on the ground (Bq/m²) to effective dose per year (mSv/a) through each pathway, and tables of collective effective dose commitment per unit discharge (man·Sv/Bq). SRS-19 also includes many examplary calculations.

The Safety Guide WS-G-2.3 (2000) describes the process used to
determine the authorized limits for discharges (in terms of activity per unit time), corresponding to individual doses not exceeding the dose constraints. These authorised limits must be used as the actual discharge limits for operation. This document also gives guidance on the application of the concepts of the BSS of exclusion or authorization, exemption and clearance of radioactive releases from regulatory control. The criteria for exemption or clearance are such that the effective dose to any member of the public is less than 10 µSv and the collective dose less than 1 man Sv. Information on the approach to determine clearance levels is presented in RS-G-1.7.

3.4 Feedback from environmental monitoring

The Safety Guide RS-G-1.8 gives guidance on interpreting monitoring results, i.e. assessing compliance with the discharge limits and reference levels for public exposure, assessment of protective actions in situations of emergency exposure, and assessment of remedial actions in situations of chronic (prolonged) exposure.

The measurement of releases and data from environmental and personal monitoring should be used to confirm that the actual doses which result from normal operations are well below the authorized limits.

Differences between predicted and measured values should be evaluated and improvements should be made to the monitoring programmes.

For cases of radiological or nuclear accidents, the general requirements and procedures for emergency preparedness and response are described in Module XVI of the BPTC. Conservative dose assessments based on real measurements must be used to determine protective actions.

In situations of chronic exposure, such as in the long term after an accident where BSS dose limits could be exceeded, the results of environmental monitoring should be used to assess the average annual effective doses received by population groups and critical groups once the main exposure pathways and the radionuclides contributing predominantly to the total doses have been defined. The benefits, in terms of the reductions in doses that are to be expected from remedial actions, are derived by using decontamination factors obtained by local experiments or other sources of information. Once the countermeasures have been taken, a confirmatory environmental monitoring programme should be conducted.
3.5 Questions

1. What are the basic principles and objectives of environmental impact assessment?
2. In general terms briefly describe the potential human exposure pathways from a nuclear installation.
3. Describe the importance of environmental monitoring around a nuclear installation.
4 ORGANIZATIONAL AND MANAGEMENT ASPECTS OF SITE SELECTION AND EVALUATION

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe the organizational and management aspects of site selection and evaluation.

Site selection and evaluation are the first steps in a nuclear project and they involve a very large number of disciplines and specialty areas. The investigations related to these activities are time consuming because they involve data collection, field work, laboratory testing, modelling, analyses, use of dedicated computer programs, and a considerable amount of expert judgment.

Particularly when the investigations are being performed for the first nuclear power project of a country, there may be issues related to the proper management of such a large and lengthy process. Often, new nuclear organizations do not have the required level of understanding regarding site issues and the specialized institutes of the country (such as the meteorological service or the geological survey) also have no experience in performing nuclear-related projects. The objectives may become unclear due to the lack of well-defined criteria and the project may evolve into a process of trial and error. There are many examples of site studies which have gone on for many years and even decades without producing tangible results, i.e. sites that have been approved and licensed by the nuclear regulatory authority.

A management system is needed that integrates all elements of an organization into one coherent system to enable all of the organization’s objectives to be achieved.

These elements include the structure, resources and processes. Personnel, equipment and organizational culture, as well as documented policies and processes are parts of the management system. The organization’s processes have to address the totality of requirements on the organization as established in, for example, IAEA safety standards and other international codes and standards.

For the site selection and site evaluation process, management system principles and implementation are essential. In any case they are required by GS-R-3. The most reasonable way to apply these principles is to follow the IAEA requirements and guidance in this respect. As the activities in the site selection and site evaluation process progressively take on greater safety significance for the planned nuclear power plant, a graded approach as recommended by GS-R-3 is appropriate.
Paragraph 2.6 of GS-R-3 states the following regarding the graded approach: “The application of management system requirements shall be graded so as to deploy appropriate resources, on the basis of consideration of:

- The significance and complexity of each product or activity,
- The hazards and the magnitude of the potential impact (risks) associated with the safety, health, environmental, security, quality and economic elements of each product or activity,
- The possible consequences if a product fails or an activity is carried out incorrectly.”

In the transition from site selection to site evaluation, the management system principles and requirements need to be taken into account. Data produced and investigations performed during the site selection stage should be used with caution in the site evaluation stage if a lower grade of control has been used in the management system processes for the site selection activities.

In practice, a training programme on management systems is generally needed for the personnel who take part in a nuclear power plant site selection and site evaluation programme. The overall management systems that the nuclear operator establishes need to be reflected in the constituent programmes of the specialized institutions or companies which take part in the site project.


### 4.1 Question

1. Which elements need to be integrated in the management system of an organization that is undertaking site selection and evaluation for a nuclear installation?
5 REFERENCES


The views expressed in this document do not necessarily reflect the views of the European Commission.