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External Human Induced Events in Site Evaluation for Nuclear Power Plants

SAFETY GUIDE

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INTERNATIONAL
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EXTERNAL HUMAN INDUCED EVENTS IN SITE EVALUATION FOR NUCLEAR POWER PLANTS

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FOREWORD

by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission for Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Facilities and human activities in the region in which a nuclear power plant is located may under some conditions affect its safety. The potential sources of human induced events external to the plant should be identified and the severity of the possible resulting hazard phenomena should be evaluated to derive the appropriate design bases for the plant. They should also be monitored and periodically assessed over the lifetime of the plant to ensure that consistency with the design assumptions is maintained.

1.2. This Safety Guide recommends actions, conditions and procedures and provides guidance for fulfilling the requirements of the Safety Requirements publication, Code on the Safety of Nuclear Power Plants: Siting [1], that concern human induced events external to the plant. The present publication is the first revision of the Safety Guide on External Man-Induced Events in Relation to Nuclear Power Plant Siting issued in 1981 as Safety Series No. 50-SG-S5.

1.3. The general requirements to be followed for establishing design bases are those established in Ref. [1]. As required in Ref. [1], "the potential in the region for external human induced events that may lead to radiological consequences from the nuclear power plant shall be assessed" and consequently adequate design bases for the plant, for the purpose of preventing such radiological consequences, are required to be derived for those external human induced events which can affect safety.

1.4. Full consideration should be given at the stage of site selection to the possibility of disregarding locations having at present, or in the foreseeable future, a potential for severe external human induced events which may jeopardize the safety of the proposed plant and for which engineering solutions may prove unfeasible or impracticable.

1.5. Large, potentially hazardous facilities are relatively easy to identify as to both location and the associated hazards. Consideration should also be given, however, to the potential for effects resulting from minor activities or from activities that might evolve or newly develop in the foreseeable future and which could lead to serious consequences, including effects of potential sources near or as part of the non-nuclear part of the plant. Such activities may occur only occasionally, depending on the practices in a particular locality. It is not possible to produce a comprehensive list of potential sources of external human induced events, since each site is different and practices with regard to industry, transportation and land use may differ from region to region and from country to country. However, a list of likely sources is presented and discussed in the present Safety Guide.

1.6. The recommendations and information set out herein are derived from practices in States for protecting nuclear power plants against human induced events external to the plant. In accordance with this practical experience, no graded approach for human induced events is presented here and therefore only one intensity level for each interacting event is expected for consideration in the design basis. In some instances this approach is complemented with a lower level action to be added deterministically to the design basis and considered in conjunction with different acceptance criteria; however, such a solution can be considered the introduction of a different load case (see, for example, Section 5).

1.7. The establishment of the design basis for any external human induced event depends upon a knowledge of regional characteristics as well as of the conceptual or preliminary design of the proposed plant. In view of the dependence of the plant design on regional characteristics, the safety features of the site and the plant should be examined by iteration. In all cases, before final acceptance of any combination of particular plant and site, enough information should be made available on the design of the plant to allow an expert judgement to be made of the possibility of realistic engineering solutions to the problems associated with external human induced events.

OBJECTIVE

1.8. The purpose of the present Safety Guide is to provide recommendations and guidance for the examination of the region considered for site evaluation[1] for a plant

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[1] For a nuclear power plant, site evaluation typically involves the following stages:

— *Selection stage.* One or more preferred candidate sites are selected after the investigation of a large region, the rejection of unsuitable sites, and screening and comparison of the remaining sites.

— *Characterization stage*. This stage is further subdivided into:
  - Verification, in which the suitability of the site to host a nuclear power plant is verified mainly according to predefined site exclusion criteria;
  - Confirmation, in which the characteristics of the site necessary for the purposes of analysis and detailed design are determined.

— *Pre-operational stage*. Studies and investigations begun in the previous stages are continued after the start of construction and before the start of operation of the plant to complete and refine the assessment of site characteristics. The site data obtained allow a final assessment of the simulation models used in the final design.

— *Operational stage*. Appropriate safety related site evaluation activities are carried out throughout the lifetime of the facility, mainly by means of monitoring and periodic safety review.

in order to identify hazardous phenomena associated with human induced events initiated by sources external to the plant. In some cases it also presents preliminary guidance for deriving values of relevant parameters for the design basis. This Safety Guide is also applicable for periodic site evaluation and site evaluation following a major human induced event, and for the design and operation of the site's environmental monitoring system. Site evaluation includes site characterization; consideration of external events that could lead to a degradation of the safety features of the plant and cause a release of radioactive material from the plant and/or affect the dispersion of such material in the environment; and consideration of population issues and access issues significant to safety (such as the feasibility of evacuation, the population distribution and the location of resources). The process of site evaluation continues throughout the lifetime of the facility, from siting to design, construction, operation and decommissioning.

SCOPE

1.9. The external human induced events considered in this Safety Guide are all of accidental origin. Considerations relating to the physical protection of the plant against wilful actions by third parties are outside its scope. However, the methods described herein may also have some application for the purposes of such physical protection.

1.10. The present Safety Guide may also be used for events that may originate within the boundaries of the site, but 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. Special consideration should be given to the hazardous material handled during the construction, operation and decommissioning of units located at the same site. In some cases other nuclear facilities (such as fuel fabrication units or fuel processing units) may be located at the same site and therefore should be considered in the hazard evaluation for the plant. While this Safety Guide deals primarily with site characterization stages, it also contains useful guidance for the site selection, pre-operational and operational stages.

1.11. Recommendations for the development of the design bases for design basis external human induced events (DBEHIE) are beyond the scope of the present publication. Those recommendations are discussed in Ref. [2]. Fire effects are mainly dealt with in Ref. [3]. The other IAEA Safety Guides relating to design discuss the effects of human induced events on specific plant systems. For its part, Ref. [4] deals with periodic safety assessment and lifetime monitoring of environmental parameters.

1.12. In this sense, the present Safety Guide concentrates on the definition of hazards for the site and on the general identification of major effects on the plant as a whole, according to the reference probabilistic or deterministic criteria, which are to be used in a design or in a design assessment framework. The next step in the full determination of the design basis for a specific plant is carried out in a design context, being intrinsically dependent on the layout and design. This additional step is therefore discussed in the series of standards relating to design, together with the detailed loading schemes and the design procedures, owing to their constitutive dependence. Hence, in this Safety Guide, the term ‘design basis’ should be understood as being limited mainly to that part of the determination of the design basis that is independent of any procedure for plant layout or design.

1.13. In the selection between a deterministic and a probabilistic approach for hazard evaluation, several issues are determinant. These include: the availability of data for the site; the possibility of reliable extrapolation to lower excess values; the design approach to be adopted; the compatibility with national standards for hazard evaluation and design; and public acceptance issues. In this context, basic reference is made to a probabilistic approach for the site evaluation stage, while the derivation of single values on the probabilistic distributions to be applied in deterministic design procedures is left to the design stage. The procedures for probabilistic safety assessment (PSA) of external events, as part of the design assessment process, are discussed in another IAEA Safety Guide [5].

1.14. The present Safety Guide does not cover events resulting from the failure of artificial water retaining structures, even if they are human induced, since the consequences in terms of flooding of such a failure fall within the scope of Refs [6, 7]. Likewise, modifications to the groundwater table as a consequence of human activities (such as the construction of wells and dykes) are within the scope of Ref. [8].

STRUCTURE

1.15. Section 2 covers the general approach to site evaluation in relation to external human induced events. Section 3 addresses in detail the information to be collected as well as the investigations to be performed in order to compile a database for identifying potential sources at the beginning of the process of site evaluation. Section 4 deals with the use of the compiled database to conduct the site characterization by means of a screening process and detailed evaluation procedures. Sections 5 to 8 examine the application of this general method to specific induced events such as aircraft crashes, explosions and the release of hazardous fluids, while Section 9 covers general administrative considerations.

2. GENERAL APPROACH TO SITE EVALUATION IN RELATION TO EXTERNAL HUMAN INDUCED EVENTS

2.1. The Code on the Safety of Nuclear Power Plants: Siting (Ref. [1], para. 301) requires that external human induced events that could affect safety be investigated in the site evaluation stage for every nuclear power plant site. Thus, the region is required to be examined for facilities and human activities that have the potential, under certain conditions, to endanger the nuclear power plant over its entire lifetime. Each relevant potential source is required to be identified and assessed to determine the potential interactions with personnel and plant items important to safety.

2.2. It should not be overlooked that, in specific situations, a minor event may lead to severe effects.[2] In evaluating the need for protection against the effects of external human induced events, due account should be taken of the plant's operating procedures and any recommended administrative measures.[3]

2.3. A prognosis should be made for possible regional development over the anticipated lifetime of the plant, with account taken of the degree of administrative control that may be exercised over activities in the region. In this respect, allowance should be made for the fact that technologies in the chemical and petrochemical industries, as well as traffic densities, may evolve rapidly.

2.4. Unless a satisfactory engineering solution can be achieved for protection against those external human induced events which have not otherwise been excluded

[2] For example, in the safety review of the plant, the potential for a fire of small extent and with no direct effect on the plant was found. Examination of the power supply to the off-site emergency system showed that the power lines should be put underground to protect them against fire in order to prevent any impairment of safety related systems.

[3] In the case of protective doors, for example, the probability and consequences of an event occurring while they are open should be considered. It may then be decided whether or not special additional protection is necessary.

from further consideration, either the site should be deemed unsuitable during the siting stage, or appropriate administrative actions should be taken in the case of an existing plant. Public acceptance issues should also be addressed in the site evaluation stage.

2.5. A quality assurance programme should be established and implemented to cover those items, services and processes which may affect safety and which fall within the scope of the present Safety Guide. The quality assurance programme should be implemented to ensure that data collection, data processing, field and laboratory work, studies, evaluations and analyses, and all other activities necessary to follow the recommendations of this Safety Guide are satisfactorily performed and documented (see Ref. [9]).

3. DATA COLLECTION AND INVESTIGATIONS

TYPE OF POTENTIAL SOURCE

3.1. The sources of external human induced events may be classified as:

- — Stationary sources, for which the location of the initiating mechanism (explosion centre, point of release of explosive or toxic gases) is fixed, such as chemical plants, oil refineries, storage depots and other nuclear facilities at the same site.
- — Mobile sources, for which the location of the initiating mechanism is not totally constrained, such as any means of transport for hazardous materials or potential projectiles (by road, rail, waterways, air, pipelines). In such cases, an accidental explosion or a release of hazardous material may occur anywhere along a road or other way or pipeline.

IDENTIFICATION OF POTENTIAL SOURCES

3.2. Installations which handle, process or store potentially hazardous materials such as explosive, flammable, corrosive, toxic or radioactive materials should be identified as sources, even if associated with other on-site units under construction, in operation or undergoing decommissioning. The magnitude of the hazard may not bear a direct relation to the size of such facilities, but the maximum amount of hazardous material present at any given time and the process in which it is used should be taken into consideration. Furthermore, the progression of an accident with time, such as fire spreading from one tank to another, should also be considered. Pipelines for hazardous materials should be included in the category of items to be identified. Other sources to be considered are construction yards, mines and quarries which use and store explosives and which may cause the temporary damming of water courses, with possible subsequent flooding or collapse of ground at the site (see Ref. [10]).

3.3. With regard to aircraft crashes, a study should be made of airports and their takeoff, landing and holding patterns, flight frequencies and types of aircraft. Air traffic corridors should also be taken into account.

3.4. The conveyance of hazardous materials by sea or inland waterways may present a significant hazard which should be taken into account. Vessels, together with their loads and water borne debris, may have the potential for mechanically blocking or damaging cooling water installations associated with an ultimate heat sink.

3.5. Since experience indicates that the bulk of sea traffic accidents occur in coastal waters or harbours, shipping lanes near the site should be identified.

3.6. Railway rolling stock and road traffic, together with their loads, are potential sources that should be given careful attention, particularly for busy routes, junctions, marshalling yards and loading areas.

3.7. At military installations, hazardous materials are handled, stored and used, and may be associated with hazardous activities such as firing range practice. In particular, military airports and their associated traffic systems, including training areas, should be considered potential sources.

3.8. In examining the adequacy of a site in respect of external human induced events, attention should also be given to future human activities currently in the planning stage, such as for land with potential for commercial development. Such activities in the future may lead to an increased risk of radiological consequences or to sources of interacting events which do not exceed the screening probability level but may grow to reach that level.

Effects and associated parameters

3.9. The human induced sources of events mentioned earlier may cause events that can generate effects such as:

- — air pressure wave and wind;
- — projectile impact;
- — heat (fire);

— smoke and dust;
— toxic and asphyxiant gases;
— chemical attack by corrosive or radioactive gases, aerosols or liquids;
— shaking of the ground;
— flooding or lack of water;
— ground subsidence (or collapse) and/or landslide;
— electromagnetic interference;
— eddy currents into the ground.

3.10. Some of these effects are of considerably greater importance to safety than others. They could affect both the plant's facilities and items essential for safety, such as by affecting the availability of evacuation routes (the site might lose links to safe areas in the region), the possibility of implementing emergency procedures (access by the operator could be impaired), and the availability of the external grid and the ultimate heat sink. Although many effects may be associated with more than one potential source, usually one or two effects are dominant for each individual source.

3.11. To illustrate the notion of 'interacting mechanisms', examples of originating sources, sequences of events and the main effects that result are given in Tables I–III. Table I gives facilities and transport systems that should be investigated, their relevant features and the initiating events generated from them. Table II gives the progression of initiating events and their possible impacts on the plant, and Table III gives information on the consequences of these impacts on the plant.

TABLE I. IDENTIFICATION OF SOURCES AND ASSOCIATED INITIATING EVENTS

Facilities and transport systems to be investigated	Relevant features of the facilities and traffic	Initiating event
STATIONARY SOURCES		
Oil refinery, chemical plant, storage depot, broadcasting network, mining or quarrying operations, forests, other nuclear facilities, high energy rotating equipment	Quantity and nature of substances Flow sheet of process involving hazardous materials Meteorological and topographical characteristics of the region Existing protective measures in the installation	Explosion Fire Release of flammable, explosive, asphyxiant, corrosive, toxic or radioactive substances Ground collapse, subsidence Projectiles Electromagnetic interference Eddy currents into the ground

TABLE I. (cont.)

Facilities and transport systems to be investigated	Relevant features of the facilities and traffic	Initiating event
Military facilities (permanent and temporary)	Types of activities Quantities of hazardous materials Features of hazardous activities	Projectile generation Explosion Fire Release of flammable, explosive, asphyxiant, corrosive, toxic or radioactive substances
MOBILE SOURCES		
Railway trains and wagons, road vehicles, ships, barges, pipelines	Passage routes and frequency of passage Type and quantity of hazardous material associated with each movement Layout of pipelines including pumping stations, isolation valves Characteristics of the vehicle (including protective measures) Meteorological and topographical characteristics of the region	Explosion Fire Release of flammable, explosive, asphyxiant, corrosive, toxic or radioactive substances Blockage, contamination (such as from an oil spill) or damage to cooling water intake structures Impacts of derailed vehicles
Airport zone	Aircraft movements and flight frequencies Runway characteristics Types and characteristics of aircraft	Abnormal flights leading to crashes
Air traffic corridors and flight zones (military and civil)	Flight frequencies Types and characteristics of aircraft Characteristics of air traffic corridors	Abnormal flights leading to crashes

TABLE II. EVOLUTION OF EVENTS AND IMPACTS ON THE NUCLEAR POWER PLANT

Initiating event	Development of event	Possible impact of each event on the plant[a]
Explosion (deflagration, detonation)	Explosion pressure wave Projectiles Smoke, gas and dust produced in explosion can drift towards the plant Associated flames and fires	(1) (2) (3) (4) (5) (6) (7)
Fire (external)	Sparks can ignite other fires Smoke and combustion gas of fire can drift towards the plant Heat (thermal flux)	(3) (4) (5) (6)
Release of flammable, explosive, asphyxiant, corrosive, toxic or radioactive substances	Clouds or liquids can drift towards the plant and burn or explode before or after reaching it, outside or inside the plant Clouds or liquids can also migrate into areas where operators or safety related equipment can be prevented from functioning	(1) (2) (3) (4) (5) (6)
Aircraft crashes or abnormal flights leading to crashes, collision of planes, projectiles Vehicle impacts	Projectiles Fire Explosion of fuel tanks	(1) (2) (3) (4) (5) (6)
Ground collapse	Ground collapse Interference with cooling water systems	(7) (8) (9)
Blockage or damage to cooling water intake structures	Interference with cooling water systems	(12)
Electromagnetic interference	Electromagnetic fields around electrical equipment	(10)
Eddy currents into ground	Electric potential into ground	(11)

[a] See Table III for an explanation of the numerals.

TABLE III. IMPACT ON THE NUCLEAR POWER PLANT AND CONSEQUENCES

Impact on the plant	Parameters	Consequences of impact
(1) Pressure wave	Local overpressure at the plant as a function of time	Collapse of parts of structure or disruption of systems and components
(2) Projectile	Mass Velocity Shape Size Type of material Structural features Impact angle	Penetration, perforation or spalling of structures or disruption of systems and components Collapse of parts of structure or disruption of systems and components Vibration induced false signals in equipment
(3) Heat	Maximum heat flux and duration	Impaired habitability of control room Disruption of systems or components Ignition of combustibles
(4) Smoke and dust	Composition Concentration and quantity as a function of time	Blockage of intake filters Impaired habitability of control room and other important plant rooms and affected areas
(5) Asphyxiant and toxic substances	Concentration and quantity as a function of time Toxicity and asphyxiant limits	Threat to human life and health and impaired habitability of safety related areas Prevention of fulfilment of safety functions by operators
(6) Corrosive and radio-active liquids, gases and aerosols	Concentration and quantity as a function of time Corrosive, radioactive limits Provenance (sea, land)	Threat to human life and health and impaired habitability of safety related areas Corrosion and disruption of systems or components Prevention of fulfilment of safety functions
(7) Ground shaking	Response spectrum	Mechanical damage
(8) Flooding (or drought)	Level of water with time Velocity of impacting water	Damage to structures, systems and components

TABLE III. (cont.)

Impact on the plant	Parameters	Consequences of impact
(9) Subsidence	Settlement, differential displacement, settlement rate	Collapse of structures or disruption of systems and components, including buried pipes, cables
(10) Electromagnetic interference	Frequency band and energy	False signals on electric equipment
(11) Eddy currents into ground	Intensity and duration	Corrosion of underground metal components Grounding problems
(12) Damage to water intake	Mass of the ship, impact velocity and area, degree of blockage	Unavailability of cooling water

COLLECTION OF INFORMATION

3.12. The collection of information should begin early enough to enable the potential sources of external human induced events in the region to be identified at the stage of site selection. When a potential site has been identified, more detailed information may be necessary to identify reference hazards for external human induced events and to provide data for design basis parameters (the site characterization stage). Furthermore, during the plant's lifetime (the pre-operational and operational stages), more data should be available from monitoring of the site to be used in the periodic safety assessments [4, 5, 11].

3.13. First, a list of sources present in the region should be prepared and divided into different categories, such as stationary and mobile sources. The extent of the relevant region and thus the areas to be examined should be determined for each type of source; this will depend on a number of factors, including the type, quantity and condition of the hazardous material involved and the nature of any mobile source. Usually such areas will extend a few kilometres from the site, but in some instances this distance may need to be greater.

3.14. The procedure of identifying and initially categorizing sources implies that in the early stages of the investigation only such information should be collected as will allow the determination of whether or not the hazard associated with any source should be given further consideration.

3.15. Information about present and planned facilities and activities in the region should be sought from maps, published reports, public records, public and private agencies and individuals knowledgeable about the characteristics of local areas. This information, together with that obtained from the direct investigation of specific facilities which appear to have a potential for impact on the plant, should be verified and examined to identify those activities that should be investigated in greater detail.

3.16. Once the potential sources have been identified, they should be analysed and, as far as they can be readily determined, relevant factors such as the magnitude of the potential event, its probability of occurrence and the distance between the event and the site should be evaluated. It should then be decided which sources and events are important and are to be used in the evaluation of the site's suitability and in the design or assessment of the plant. For these purposes, only events potentially affecting the plant should be considered.

3.17. Assessment of the probability of occurrence of an event with an impact on the plant should begin with the evaluation of the probability of the initiating event and should continue with consideration of only the appropriate combination of probabilities for the associated sequence of events leading to interactions with personnel and with items important to safety.

3.18. For many categories of interacting events there is often insufficient information available concerning the region to permit a reliable evaluation of the probability of occurrence and of the probable severity of the event. It may therefore be useful to obtain statistical data on a national, continental or global basis. Values thus obtained should be examined to determine whether or not they need to be adjusted to compensate for unusual characteristics of the site and its environs. Where there is locally no basis for calculating the severity of the effects of an external human induced event, all available information and assumptions about that particular type of event should be obtained on a global basis so that design bases can be determined by means of engineering judgement.

STATIONARY SOURCES

3.19. The hazards presented to a nuclear power plant from stationary sources such as industrial plants and storage depots arise from the potential for explosions, fires and the formation of gas and dust clouds.

3.20. The information necessary for consideration of the hazards posed by stationary sources covers the following matters: the types of hazardous material involved and the quantities in store, in process and in transit; the types of storage (physical conditions) and processes (flow sheets); the dimensions of major vessels, stores or other forms of containment; the locations of these forms of containment; their construction and their isolation systems; their operating conditions (including the frequency of maintenance); and their active and passive safety features.

3.21. All available information on accidents and failures should be collected, with account taken of the active and passive safety features. Information on the possibility of interaction between materials in different stores or in process, which may lead to a significantly greater hazard, should also be presented.

3.22. Statistical data on the meteorology of the region as well as information on local meteorological and topographical characteristics of the area between the location of the potential sources and the nuclear power plant site should be obtained for use in making realistic evaluations.

3.23. Mines and quarries are hazardous because the explosives used in their exploitation can generate pressure waves, projectiles and ground shock; moreover, mining and quarrying entail the possibility of ground collapse and landslides. Information should be obtained on the locations of all past, present and possible future mining and quarrying work and the maximum quantities of explosives that may be stored at each location. Information on geological and geophysical characteristics of the subsurface in the area should also be obtained to ensure that the plant is safe from ground collapse or landslide caused by such activities.

3.24. Particular difficulty may be experienced in collecting and evaluating relevant information on military bases, including standby installations, on the use of training areas and on other military activities. Nevertheless, the collection and evaluation of such information is important for safety. Appropriate liaison should be established between the relevant civil and military authorities to ensure that site selection is facilitated and that the design basis parameters are evaluated in those cases where military activities may present a hazard to the nuclear power plant.

MOBILE SOURCES

3.25. The hazards to a nuclear power plant arising from surface transport (by road, rail, sea, inland waterways and pipelines) are similar to those from industrial plants. On-site transport of hazardous material relevant to other units should also be considered. Air traffic presents a different type of hazard because of the possibility of an aircraft crash on to the nuclear power plant.

3.26. Information on such sources in the region should be collected to determine:

(a) the locations of possible sources of external human induced events associated with transport systems;
(b) the probability of occurrence and the severity of the events.

Surface transport

3.27. Information should be collected on fixed traffic facilities in the region, including ports, harbours, canals, dredged channels, railway marshalling yards, road vehicle loading areas and busy junctions and intersections, and on traffic routes in relation to the site.

3.28. Information should be collected on the characteristics of traffic flows in the region, such as: the nature, type and quantities of material conveyed along a route in a single transport movement; the sizes, numbers and types of the vessels; speeds, control systems and safety devices; and accident statistics including consequences. Similar information should be collected for pipelines: on the nature of the substance transported, the flow capacity, the internal pressure, the distances between valves or pumping stations, safety features, and accident records including consequences.

Air traffic

3.29. The information collected on air traffic should include the locations of airports and air traffic corridors in the region, the airports' takeoff, landing and holding patterns, the types of warning and control devices available, the types and characteristics of aircraft and their flight frequencies. Information on aircraft accidents for the region and for similar types of airport and air traffic should be collected. Information should be collected for both civil and military air traffic. Of particular interest are military aircraft training areas which may show a comparatively high frequency of crashes in their vicinity and areas where low flying is practised.

SOURCE DISPLAY MAP

3.30. Source display maps should be prepared showing the locations and distances from the nuclear power plant of all sources identified in the data collection stage which may potentially affect the site, such as chemical plants, refineries, storage facilities, construction yards, mines and quarries, military facilities, means of transport (by air, land and water), transport facilities (docks, moorings, loading areas, marshalling yards, airports), pipelines for hazardous liquids and gases, drilling installations and wells. Any other facilities that may need to be considered for potential adverse effects on the nuclear power plant because of the products manufactured, handled or stored in them or transported to them should be identified and located on the maps. After the evaluation of the potential sources and the establishment of the design basis events, a final version of the source display map should be prepared that includes all the data for the sources corresponding to the adopted interacting events.

3.31. These maps should reflect any foreseeable developments in human activities that may potentially affect safety over the projected lifetime of the nuclear power plant. Relevant information should be obtained by examining development plans for the region.

4. SCREENING AND EVALUATION PROCEDURES

GENERAL PROCEDURE

4.1. The information collected is initially used in a two step screening stage to eliminate those sources which should not be considered further, on the basis of distance or probability. This preliminary screening may be carried out by the use of a ‘screening distance value’ and/or, where the available data permit, by evaluating the probability of occurrence of the event.

4.2. For some sources a simple deterministic study, based on information on the distance and characteristics of the source, may be sufficient to show that no significant interacting event can occur. By means of such an analysis it is therefore often possible to select a screening distance value for a particular type of source beyond which the effects of such sources may be ignored.

4.3. A second screening criterion is based on the probability of occurrence. In this Safety Guide the limiting value of the annual probability of occurrence of events with potential radiological consequences is called the screening probability level (SPL)[4]. Such a value should be defined by the regulatory body coherently with the policy for risk management in the region for nuclear and industrial facilities. Initiating events with a probability of occurrence lower than this screening probability level should not be given further consideration, regardless of their consequences.

4.4. In general the design procedures for nuclear power plants are deterministic and therefore the design basis is assumed to provide the designer with a single point evaluation of the true probabilistic distribution of interacting effects on the plant. However, sometimes a lack of confidence in the quality of the data — that is, in their accuracy, applicability, completeness or quantity — may preclude the use of a quantitative probabilistic criterion in deciding whether to establish a design basis for a particular event or sequence of events or to eliminate them from consideration (by screening). In such cases, a pragmatic approach on the basis of expert judgement should be taken in deciding which events or sequence of events should be considered in a detailed hazard evaluation.

4.5. For each type of source or event not eliminated by the two step screening process, a more detailed evaluation should be made. Sufficiently detailed information to demonstrate the acceptability of the site in respect of external human induced events and to determine the relevant hazards should be collected. Figure 1 shows a flow diagram of the steps in the procedures for preliminary screening and detailed evaluation.

PRELIMINARY SCREENING

4.6. Relatively simple procedures may be used in a preliminary screening of sources and interacting events. The starting point is the identification of all stationary and mobile sources of potential external human induced events in the region and all possible initiating events for each source, as indicated in Section 3 (see boxes 1 and 2 in Fig. 1).

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[4] In some States, a value for the probability of 10^{-7} per reactor-year is used in *the design of new facilities* as one acceptable limit on the probability value for interacting events having serious radiological consequences, and this is considered a conservative value for the SPL if applied to all events of the same type (such as all aircraft crashes, all explosions). Some initial events may have very low limits on their acceptable probability and should be considered in isolation.

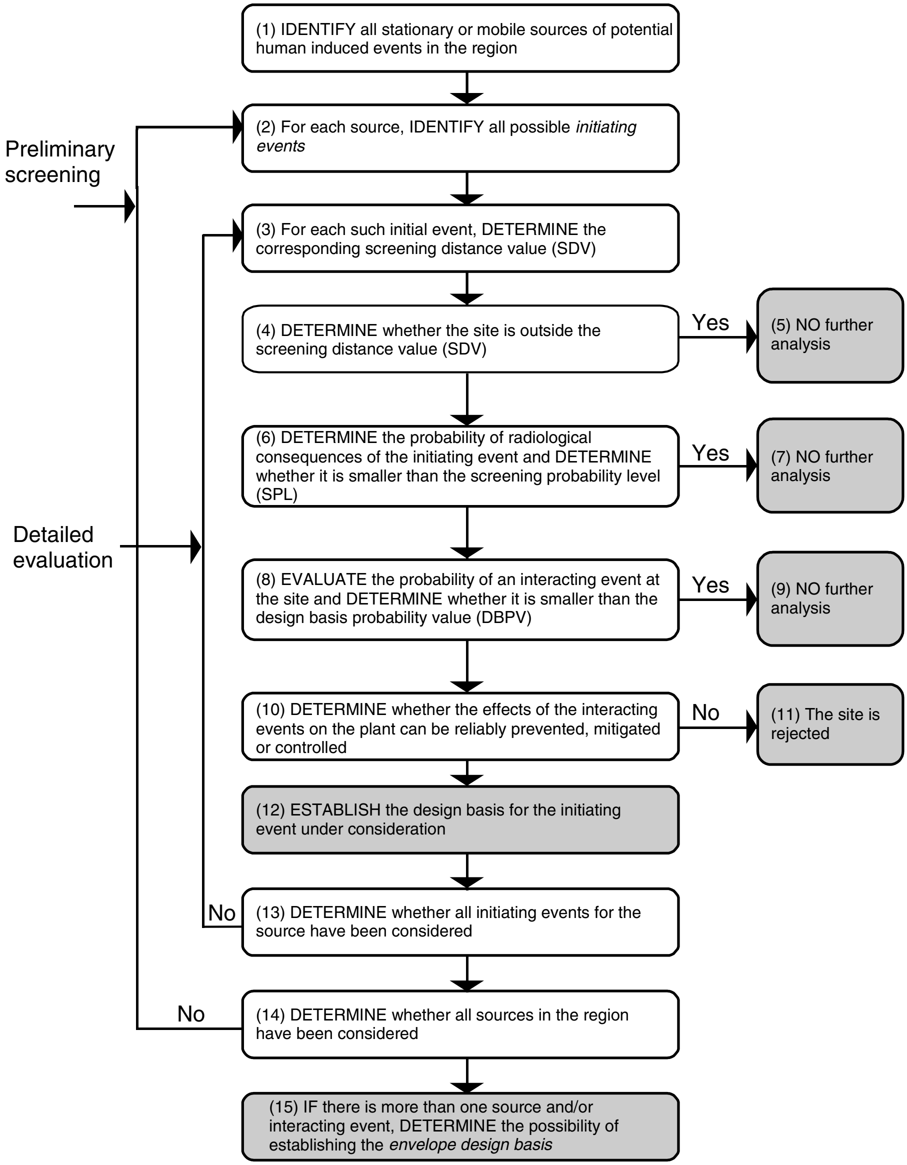

FIG. 1. General flow diagram for the screening and evaluation procedure (shaded boxes represent completed sequences).

4.7. After the step mentioned in para. 4.6, a screening distance value (SDV) should be determined for each particular type of source (stationary and mobile) using a conservative approach such that the effects of interacting events beyond this distance should not be considered further (see box 3 in Fig. 1). The determination of the SDV 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. These characteristics may be assumed for the early stages of siting to be those corresponding to the standard plant design. If the site is outside the SDV for the initiating event under consideration, no further action is necessary (see boxes 4 and 5 in Fig. 1). For sources generating effects of the same nature, a further screening could be performed which would depend upon an enveloping criterion and which should exclude those sources that generate interacting events that are enveloped by those for other selected sources, even if the site is inside the SDVs for these sources.

4.8. If the site is not outside the SDV for the initiating event under consideration, the probability of occurrence of such an event should be determined and compared with the specified SPL (see box 6 in Fig. 1). If the probability of occurrence of the event under consideration is smaller than the SPL, no further analysis should be made (see box 7 in Fig. 1).

4.9. The SPL should be chosen with due consideration, given that the radiological risk associated with external human induced events should not exceed the range of radiological risks associated with accidents of internal origin or with other external causes.

4.10. It is emphasized that the validity of the SPL approach depends on the assumption that a sufficiently low probability of occurrence for an interacting event adequately compensates for the hazard arising from that event. Events associated with major, possibly catastrophic, hazards should not be screened out unless their probability is shown to be significantly below the SPL.

4.11. In this respect, owing essentially to the high uncertainties usually associated with the probabilistic evaluation itself or because of particular concern on the part of the population, some States have selected a two step approach for such events with major hazards associated. In the first step, events with major consequences are evaluated (kept or screened out) on a probabilistic basis. In the second step, independently of the result of the first step and in a purely deterministic way, design parameter values that are lower than the maximum conceivable and are based on good engineering practice are included in the design basis to provide the plant with protection against such generic events. A detailed probabilistic evaluation of the risks associated with the lower deterministic level is not carried out and the scenario is directly included in the design basis.[5]

4.12. In practice, the recommended approach should be followed cautiously, with account taken of the following:

— The uncertainties in the estimation of the load intensity–probability curve. The reliability of this basic tool is affected mainly by uncertainties in the extrapolation of historical data to very low probability levels, such as those usually associated with the SPL. Appropriate statistical approaches should be taken, and comparisons should be made with analogous statistics used for other events and for other kinds of facilities in the region with similar levels of risk.
— The differences between the probability of the onset of the initiating event and the probability of interacting effects on the plant, after propagation of the effects from the source to the site.
— The number of various possible sources of external human induced events whose individual estimated probability (for each source) for the same kind of interacting event may be less than the SPL but whose total estimated probability (for all sources) may exceed it.

DETAILED EVALUATION

4.13. If the probability of occurrence of the initiating event under consideration is greater than the specified SPL value, a detailed evaluation should be made. This implies that the associated interacting events should be determined as well as their corresponding probabilities of occurrence.

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[5] Typical examples:

— In the aircraft crash scenario, a load–time function generically related to a small commercial aircraft is selected, without any reference to the probability of a crash, the fuel content or the impact direction. This would provide for protection in the design against flying objects of similar mass and velocity (such as missiles induced by winds, crashes of upper structural components and human actions).
— In the explosion scenario, a ‘plane wave’ is often selected without any reference to the source. It should be applied as an additional external pressure on the structures, in order to provide for protection against any accidental low level explosions in the neighbourhood of the plant not explicitly accounted for in a dedicated event analysis.

4.14. Once an interacting event has been identified, an upper bound should be established for the conditional probability that this event will cause unacceptable radiological consequences. This upper bound, denoted herein as the conditional probability value (CPV), should be conservatively evaluated for the specific type of nuclear power plant under consideration.[6]

4.15. In the selection of a single point value on the general probabilistic distribution for the event, due attention should be paid to the generation of consistent recommendations in the design and construction stage. For example, the material capacities should be selected consistently with the assumptions for the probability of the event's being exceeded, since the global design reliability is strongly dependent on the combination of both assumptions: on the definitions of the event and of the material capacities.

4.16. A design basis probability value (DBPV) for the interacting event under consideration should then be determined by dividing the SPL by the CPV.

4.17. The probability of occurrence of each interacting event should then be compared with the DBPV obtained as indicated for the interacting event under consideration. Either of the following two situations may arise (see box 8 in Fig. 1):

(1) If the probability is less than the DBPV, no further consideration should be given to that event (see box 9 in Fig. 1).
(2) If the probability is greater than the DBPV, it should be evaluated to establish whether or not the effects of the interacting event on the plant can be reliably limited by preventing or mitigating them or by taking engineering or administrative measures (see box 10 in Fig. 1). If so, a detailed hazard evaluation for the interacting event should be carried out and the event should be considered a postulated initiating event for the plant safety analysis; otherwise the site should be rejected (see box 11 in Fig. 1).

The primary causes of postulated initiating events may be credible equipment failures and operator errors (both within and external to the facility), human induced events or natural events. The specification of the postulated initiating events should be acceptable to the regulatory body for the nuclear power plant.

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[6] In some States this upper bound has been globally taken as 0.10. The issue should be carefully considered, however, to ensure that the value adopted is indeed an upper bound and is consistent with the limit of the probability value associated with the occurrence of an initiating event having radiological consequences (often taken as 10^{-7} per year).

DESIGN BASIS EVENTS AND PARAMETERS

4.18. In the event that a probabilistic approach is applied to hazard evaluation, the design basis parameters for a particular interacting event should be those corresponding to a probability of occurrence equal to the DBPV.[7]

4.19. For two or more external human induced interacting events of a given type whose probabilities are similar (to within about an order of magnitude) and for which the plant should be protected, the design basis event should be based on the event having the most severe radiological consequences.

4.20. Events within the following categories are discussed in greater detail in the subsequent sections because of their relevance to many possible nuclear power plant sites:

- aircraft crashes;
- chemical explosions (detonation and deflagration);
- moving fluids and drifting clouds of explosive, flammable, corrosive, toxic, asphyxiant or radioactive material.

4.21. Certain other events specific to a particular site should also be considered, for which a similar methodology should be adopted.

5. AIRCRAFT CRASHES

GENERAL

5.1. The potential for aircraft crashes[8] that may affect the plant site should be considered in the early stages of the site evaluation process and it should be assessed over the entire lifetime of the plant [4]. The potential will result from the

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[7] In general this step necessitates the determination of a hazard curve which correlates with the design parameter under consideration; for example, the peak overpressure associated with an incident blast wave in relation to the probability that such a parameter will not be exceeded.

[8] Wilful actions that may potentially affect the nuclear power plant site are excluded from consideration here.

contributions to the probability of occurrence of an aircraft crash of one or more of the following events[9]:

Type 1 event: A crash occurs at the site deriving from the general air traffic in the region. To evaluate the probability of occurrence of such crashes, the site is considered as a tract or circular area of 0.1–1 km^2 and the region as a circular area of 100–200 km in radius.

Type 2 event: A crash occurs at the site as a result of a takeoff or a landing operation at a nearby airport.

Type 3 event: A crash occurs at the site owing to air traffic in the main civil traffic corridors and the military flight zones.

PRELIMINARY SCREENING

Screening distance value approach

5.2. In a preliminary evaluation, consideration should be given to potential sources for crashes in the site region within defined distances from the site. The SDV, which is determined on the premise that any potential hazard beyond the screening distance is minor enough to be ignored, is developed from a deterministic and a probabilistic evaluation of a spectrum of aircraft hazards.

5.3. The information to be collected for evaluating the SDV includes:

- distance from the nearest major airport to the site and the locations of landing strips in relation to the location of the plant;
- the types and frequency of air traffic;
- the routes of air traffic corridors and the locations of air route crossings;
- the distances from the plant to military installations such as military airports and bombing and firing practice ranges.

[9] In general this probability might be calculated either in relation to the statistics for crash initiating events or in relation to the statistics of crash rates. However, the latter approach relies on data more easily available and therefore it is more widely applied in States. In the following discussion, reference is made only to the crash rate approach.

The SDV may be estimated for Type 2 and Type 3 events only[10].

5.4. Aircraft hazards may be dismissed in the initial screening if the proposed site does not lie within the SDVs determined for all types of potential events of this kind,[11] provided that the probability of occurrence of a Type 1 event is smaller than the SPL.

Screening probability level approach

5.5. If the site is not located outside the SDV estimated as indicated earlier, the probabilistic approach should be used for screening purposes. Thus, if the probability of occurrence of interacting events for all types of aircraft is less than the specified SPL, no detailed evaluation is necessary and a presentation of verifying information is sufficient. However, if the probability is equal to or greater than the SPL, a detailed evaluation should proceed.

5.6. In the application of the SPL screening criterion, the following should be borne in mind:

— The probability of Type 1 events should be carefully evaluated, in particular in densely populated regions with several civil airports and thus more flights. Appropriate zoning of the area considered should be carried out to avoid non-conservative averaging.
— The probability of aircraft crashes is usually higher in the vicinity of airports, both civil and military (Type 2 events). A separate check should be carried out for areas in the vicinity of airports.

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[10] If the probability of a commercial aircraft crashing during a takeoff or a landing operation is assumed to be in the range 10^{-5}–10^{-6}, which may be taken as a starting point in the evaluation of the probability of occurrence associated with Type 2 events, it may be taken that crashes tend to occur within approximately semicircular areas of 7.5 km in radius centred at the ends of the runways.

[11] One State adopts the following criteria for estimating the SDV. The potential hazards arising from aircraft crashes are taken into account if: airways or airport approaches pass within 4 km of the site; airports are located within 10 km of the site for all but the biggest airports; for large airports, if the distance d in kilometres to the proposed site is less than 16 km and the number of projected yearly flight operations is greater than $500d^2$. Where the distance d is greater than 16 km, the hazard will be considered if the number of projected yearly flight operations is greater than $1000d^2$. For military installations or air space usage such as practice bombing or firing ranges, which might pose a hazard to the site, the hazard will be considered if there are such installations within 30 km of the proposed site.

— For Type 3 events, the probability of crashes of civil aircraft near air traffic control corridors should be carefully examined, but in general for areas outside air traffic control corridors this probability decreases markedly and it is usually smaller than the specified SPL (for example, 10^{-7}/a). This is not necessarily true for military aircraft which may not follow programmed flight plans or flight regulations.

DETAILED EVALUATION

5.7. When a detailed evaluation is necessary, the probability of an aircraft crashing in the region should be determined for each class of aircraft considered (small, medium and large civil and military aircraft) by using the aircraft crash statistics called for in Section 3. The results should be expressed in the form of crashes per year per unit area. This probability will be a function of site location in relation to the airport runways. Crashes are more likely to occur within the last three or four kilometres before the extreme landing perimeter of the runway, and in sectors oriented within about 30° either side of the runway axis.

5.8. The estimated probability of an aircraft crash affecting the plant may be determined in terms of crashes per year per unit area multiplied by an effective area for damage to items important to safety.

5.9. The size of the effective area depends on: the average angle of the trajectory relative to the horizontal; the plan areas of the relevant structures and their heights; other areas relating to items important to safety; and allowances to be made for the size of the aircraft.[12] In calculating target areas, allowance should be made for skidding. A skid length of several hundred metres is possible though the aircraft's momentum would be significantly reduced. Skidding impacts are only possible at low descent angles; they are unlikely to occur for angles of above 15°.

5.10. The steps to be taken after this detailed evaluation are described in Section 4.

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[12] Some States have decided to design all nuclear power plants against aircraft crashes, having found a probability of about 10^{-6} per year for aircraft crashing on an area of 10 000 m^2 anywhere in the country. Consequently, a single idealized load function for a certain type of aircraft has been derived that is accepted as representative of aircraft crashes for design purposes in those States. In other States, figures of 10 000 m^2 to 40 000 m^2 have been used for the effective area. In the calculation of these values, trajectory angles of 10°–45° to the horizontal have been assumed.

HAZARD EVALUATION

Design basis events

5.11. For several types of aircraft the probability of a crash at any given site may be equal to or greater than the DBPV. The plant should be protected against crashes of aircraft of any type. General assurance is provided if the plant is protected against the aircraft crash that would be expected to produce the most severe consequences for the plant.

5.12. The plant layout — and particularly the physical separation and the redundancy of items important to safety, especially for vulnerable parts of the plant — should also be taken into consideration. This contributes to the basis for deciding whether or not an acceptable engineering solution is possible.

5.13. When the probability of an aircraft crash is equal to or exceeds the DBPV, the severity of the effects should be determined. In addition, for the deterministic assumption of a reference aircraft crash that envelops a set of possible scenarios (see para. 4.11), a detailed analysis of the effects induced should be carried out, with consideration given to local structural effects, direct damage by primary and secondary missiles, induced vibrations and effects caused by the fuel. Examples of effects that should be considered and included in the design basis are set out below.

Primary impact and secondary projectiles

5.14. The evaluation of the effects of an aircraft crash should include analyses of the potential for structural failure due to shearing and bending forces, for perforation of the structure, for spalling of concrete within structures and for the propagation of shock waves that could affect items important to safety.

5.15. A crashing aircraft may break up into parts which become separate projectiles with their own trajectories. An analysis should be made on the basis of engineering judgement of the projectiles that could be produced and their significance, with due regard for the possibility of simultaneous impacts on separate redundant systems. In special circumstances the effects of secondary projectiles should be considered.

Effects caused by aircraft fuel

5.16. The following possible consequences of the release of fuel from a crashing aircraft should be taken into account:

— burning of aircraft fuel outdoors causing damage to exterior plant components important to safety;
— the explosion of part or all of the fuel outside buildings;
— entry of combustion products into ventilation or air supply systems;
— entry of fuel into buildings through normal openings, through holes caused by the crash or as vapour or an aerosol through air intake ducts, leading to subsequent fires, explosions or side effects.

Design basis parameters

5.17. The design basis parameters for the direct impact of an aircraft on the plant's structures may be defined to different levels of detail depending on the level necessary for the final evaluation. This will depend on the importance of this event for the design of the specific plant and for the degree of conservatism assumed in the entire design process. Two examples are as follows:

— Distribution of mass and stiffness along the aircraft concerned (one or more), nose shape, area of impact, velocity and angle of incidence — when the structural evaluation includes detailed local analyses of the potential for structural failure due to shearing and bending forces, for spalling and scabbing of concrete within the structures, and for perforation of the structures.
— A load–time function, which may be independent of the specific aircraft and representative of a class of aircraft, with associated mass, velocity and application area when the structural evaluation includes only a preliminary screening of local effects in comparison with other design events, or for a generic evaluation of the induced vibration effects on structures and components.

5.18. The type of fuel and the maximum amount of fuel potentially involved in an accident should always be evaluated in order to quantify the fire interaction effects and correlate them with the potential structural damage. The amount of fuel should be evaluated for this purpose on the basis of the type of aircraft and typical flight plans.

5.19. Estimation of the same quantities may be necessary also for parts of an aircraft that have become separated to form secondary projectiles.

5.20. Load–time functions developed for some types of aircraft may be useful in the site selection process or for assessment of the design. For examples of standard load–time functions, see Ref. [2].

6. RELEASE OF HAZARDOUS FLUIDS

GENERAL

6.1. Section 6 deals with hazardous fluids (explosive, flammable, corrosive and toxic, including liquefied gases) which are normally kept in closed containers but which upon release could cause a hazard to items important to safety and to human life. This subject should be given particular attention in view of the potential release of the following substances:

— Flammable gases and vapours which can form explosive clouds and can enter ventilation system intakes and burn or explode,
— Asphyxiant and toxic gases which can threaten human life and impair crucial safety functions,
— Corrosive and radioactive gases and liquids which can threaten human life and impair the functionality of equipment.

6.2. Initiating events and dispersion mechanisms are discussed in Section 6. Explosive effects (if they are a concern) are then discussed in Section 7. The mechanisms of interaction with the nuclear power plant differ greatly from one event to another (see Table I), but the propagation phenomena can be discussed for the entire range of hazardous substances. Toxic, corrosive and asphyxiant effects are considered in the design stage and are covered in other Safety Guides.

PRELIMINARY SCREENING FOR HAZARDOUS LIQUIDS

6.3. Activities and facilities involving the processing, handling, storage or transport of flammable, toxic or corrosive liquids within the SDV should be identified. The SDV selected will depend on a number of factors such as the physical properties of the substance, the regional topography and the type and extent of industrialization. It is usually close to the SDV used for the fixed sources of explosions (see Section 7).

6.4. If the potential hazard within the SDV to items important to safety arising from these activities and facilities is less than that due to similar materials to be stored on the site and against which protection has been provided, then no further investigation should be carried out. Otherwise the potential hazards due to off-site activities should be evaluated using in the first instance a conservative and simple deterministic approach.

DETAILED EVALUATION FOR HAZARDOUS LIQUIDS

6.5. If there are sources of hazardous liquids that have not been eliminated in the preliminary evaluation, a more detailed evaluation of the potential hazard from these sources should be made.

6.6. The locations of the sources of liquid should be identified and the maximum inventory, quantity in store or amount otherwise contained should be determined for each facility.

6.7. The probability of rupture of a container or of any leak from the facility store should be evaluated.

6.8. The maximum quantities of hazardous liquids that could be released, the rate of release and the related probability of release should be evaluated as a worst possible case.

6.9. The probability of release of a hazardous liquid from a mobile source in transit within the SDV should be evaluated on the assumption that the maximum quantity being transported is released. If a more precise evaluation is necessary, the quantity to be assumed should be assessed on the basis of the probabilities of the different quantities being present at the same time in the release. Mobile sources, such as barges and ships carrying large amounts of hazardous liquids within the SDV, should be assumed to become stranded at the point of approach to the nuclear power plant for which the most unfavourable effects would result.

6.10. An important route for hazardous interaction with the nuclear power plant is provided by the water intake; danger may arise owing to spillage at an adjacent plant or tanker accidents, often after an uncontrolled drifting. Parameters for the dilution and dispersion of the liquid and its entry into the water intake should be evaluated and the nuclear power plant should be adequately protected. Consideration should be given to the fact that spillage of explosive or highly flammable liquids on water may produce floating pools, which may approach a nuclear power plant on the shore or along a river bank. A conservative estimate should be made and dispersion characteristics should be considered. Consideration should also be given to the possibility that liquids with low flash points may be extracted from contaminated sources of intake water.

6.11. The nearest point to the nuclear power plant where hazardous liquids may collect in pools should be determined, with account taken of the topography of the land and the layout of the plant.

6.12. The probabilities of hazardous interactions with items important to safety and with personnel should then be evaluated.

HAZARD EVALUATION FOR HAZARDOUS LIQUIDS

Design basis event

6.13. The location and size of, and the flow paths to and from, any pool formed by hazardous liquids should be determined and the associated hazards to the nuclear power plant should be assessed.

6.14. It may be possible to prevent the flow of liquid towards the nuclear power plant by means of engineered structures such as earthworks. For a fixed source such a barrier may be constructed in its immediate vicinity and the hazard to the nuclear power plant would thereby be reduced.

Design basis parameters

6.15. The important parameters and properties that should be established for inclusion in the design basis for protection of the nuclear power plant against hazardous liquids are as follows:

- — amount of liquid,
- — surface area of the pool,
- — chemical composition,
- — concentration (corrosion potential),
- — partial pressure of vapours,
- — boiling temperature,
- — ignition temperature,
- — toxicity.

GENERAL REMARKS FOR GASES, VAPOURS AND AEROSOLS

6.16. Gases, vapours and aerosols from volatile liquids or liquefied gases may, upon release, form a cloud and drift. The drifting cloud may affect the nuclear power plant in the following two ways:

- — When the cloud remains external to the plant (either near the source or after drifting) it is a potential hazard similar to some of the other external human

induced events considered in this Safety Guide (fires, explosions and related effects).
— The cloud can permeate plant buildings, posing a hazard to personnel and items important to safety, particularly for a cloud of toxic, asphyxiant or explosive gas. It can also affect the habitability of the control room and other important plant areas.

6.17. The most practical method of defence against a hazard of this type is to ensure protection from the potential source by means of distance.

6.18. Clouds of toxic or asphyxiant gases can have severe effects on the personnel of a nuclear power plant. Corrosive gases can damage safety systems and may, for example, cause loss of insulation in electrical systems. These matters should be given careful consideration.

6.19. Meteorological information should be taken into account in estimating the danger due to a drifting cloud as local meteorological conditions will affect dispersion. In particular, dispersion studies based on probability distributions of wind direction, wind speed and atmospheric stability class should be made.

6.20. For the postulated event of an underground release of hazardous gases or vapours, consideration should be given to escape routes and to seepage effects which may result in high concentrations of hazardous gases in buildings or the formation of hazardous gas clouds within the SDV.

PRELIMINARY SCREENING FOR GASES, VAPOURS AND AEROSOLS

6.21. The surroundings of the nuclear power plant should be examined for the purpose of identifying all possible sources of hazardous clouds within the SDV.[13] Particular attention should be paid to the following sources:

— chemical plants,
— refineries,
— above ground and underground storage systems,
— pipelines for volatile liquids, gases and liquefied gases,
— transport routes and their associated potential sources external to the SDV on which hazardous clouds may be generated.

[13] In some States an SDV in the range of 8–10 km is used for the sources of hazardous clouds.

6.22. The preliminary evaluation is intended to screen out those facilities and activities to which no further consideration should be given. The criteria should be conservative and simple in their application; for example, by taking account of the existence of similar, larger potential sources closer to the site and the quantities of materials to be stored on the site. The first step in this evaluation should be based on the assumption that the maximum inventories of the plant and the storage area are involved.

6.23. A conservative and simple method should be adopted in the first step of the preliminary evaluation for mobile sources within the SDV also. The maximum amount of hazardous material that may reach the point of the greatest potential hazard to the nuclear power plant for a given transport system should be determined, and this amount should be assumed to be present for any incident that may occur. The effects of interacting events on the plant should be evaluated and if they are not significant they should be given no further consideration. Particular care should be exercised in the consideration of explosive clouds since theory concerning the behaviour of such clouds is still developing.

6.24. If further consideration is necessary, the evaluation should be progressively refined to yield the probability of occurrence of an interacting event, with account taken of the frequency of passage of hazardous shipments and the probability of an accident during such a passage. If the resultant probability of occurrence of the interacting event is greater than the SPL, a more detailed evaluation should be made.

6.25. The potential sources that are not eliminated by this initial screening process should be given consideration in the detailed evaluation.

DETAILED EVALUATION FOR GASES, VAPOURS AND AEROSOLS

6.26. In the detailed evaluation the probability of occurrence of an interacting event due to gas clouds — that is, the probability that flammability or toxicity limits are exceeded — should be assessed and the following factors should be taken into consideration:

- — the probability of occurrence of the initiating event (for example, pipe rupture);
- — the quantity of material released and the release rate;
- — the probability that a cloud will drift towards the nuclear power plant;
- — the dilution due to atmospheric dispersion;
- — the probability of ignition for explosive clouds.

For factors (3) and (4), the probability distributions of wind direction, wind speed and atmospheric stability classes should be considered, unless conservative values are assumed for these parameters. For underground releases, seepage effects should be taken into account.

6.27. The steps to be followed after the detailed evaluation of the probability that toxicity or flammability concentration limits may be exceeded at the nuclear power plant are set out in Section 4.

HAZARD EVALUATION FOR GASES, VAPOURS AND AEROSOLS

6.28. In evaluating the hazard associated with drifting clouds of hazardous gases, vapours or aerosols, the probability of occurrence and the characteristics of the interacting event should be considered. The interaction could consist of the generation of significant levels of airborne toxic substances in the nuclear power plant or of flammable or explosive substances inside or outside the plant. The associated effects of clouds of these types on the safety of the plant should be evaluated in each case and a design basis event for each type should be established.

Generation of drifting clouds of hazardous gases, vapours or aerosols

6.29. For evaluating the generation of a drifting cloud of hazardous gases, vapours or aerosols and its interaction with items important to safety, distinctions should be drawn between the following:

— subcooled liquefied gases; and
— gases liquefied by pressure and non-condensable compressed gases.

Gases in group (1) are kept, generally, in insulated containers at very low temperatures, while gases in group (2) are maintained at ambient temperatures.

Subcooled liquefied gases

6.30. Usually the release of a subcooled liquefied gas will occur as a steady leak over a considerable period of time (at a given leak rate), but the possibility of an effectively instantaneous release (a total sudden release) should also be considered, depending on the following conditions associated with the release:

— the type of storage container and its associated piping;
— the maximum size of the opening from which the material may leak;

— the maximum amount of material that may be involved;
— the relevant circumstances and mode of failure of the container.

6.31. The starting point for the detailed analysis is the evaluation of a range of leak rates and related failure probabilities or the total amount of material released and the related failure probability. If a large amount of subcooled liquefied gas is released, much of it may remain in the liquid phase for a long time. It should be treated as a liquid throughout this period, although a fraction will vaporize almost instantaneously.

6.32. The characteristics of the pool formed by the liquid, such as its location, surface area and evaporation rate, should be evaluated, with account taken of the wind speed and the permeability and thermal conductivity of the soil (if the spillage occurs on soil). Where applicable, any ponds or catchment areas should be surfaced with low conductivity materials to confine spilled liquids.

6.33. To evaluate the maximum concentration at the site, the models presented in Ref. [12] may be used. They should be used with caution, since often the gases released are at a very low temperature and the models are not strictly applicable to a gas–air mixture of negative or positive buoyancy.

Gases liquefied by pressure and non-condensable compressed gases

6.34. The formation of a large cloud is more likely for gases liquefied by pressure and non-condensable compressed gases than it is for subcooled liquefied gases. The detailed analysis is easier because the source is more easily defined and in some cases dispersion of the cloud is governed by simpler phenomena.

6.35. As with subcooled liquefied gases, the release should be characterized by a leak rate or by a sudden total release, and a similar evaluation should be carried out. The assumptions to be used will depend on the type of storage tank, the process vessels, their associated piping and the associated failure probability.

6.36. In making an appropriate assumption for the amount of material available to be released in the event of an accident, account should be taken of the time interval before action is taken to stop the leak. For example, pipeline valves may close automatically, thus isolating the ruptured section.

6.37. With buried pipes, the soil cover is usually insufficient to prevent the escape of gases released from the pipes. Seepage may occur or gas may escape through fractures or discontinuities. In all cases, when the characteristics of the gaseous release to the atmosphere have been established, a model should be selected to determine the dispersion of the gas towards the nuclear power plant site. Attention should be given to the meteorological conditions assumed at the time of formation of the cloud and during its dispersion in the atmosphere. Owing to the uncertainty in other factors, such as the amount and the rate of the release, it may be sufficient to use a simplified dispersion model derived for an average site.

Design basis parameters

6.38. The calculated concentrations should be compared with reference concentrations that depend on the characteristics of the material and of the hazard. For flammable or explosive clouds the reference concentration is the lower limit of flammability. For toxic material the toxicity limits are the reference concentrations.

6.39. For a toxic, corrosive or flammable cloud the following are important characteristics relevant to the design:

— chemical composition,
— concentration with time and distance,
— toxicity limit and asphyxiant properties,
— flammability limit.

7. EXPLOSIONS

GENERAL CONSIDERATIONS

7.1. Section 7 deals with explosions of explosive solid, liquid or gaseous substances at or near the source. For the purposes of evaluating the dispersion, as mentioned earlier, moving clouds of explosive gases and vapours are also considered.

7.2. The word explosion is used in this Safety Guide broadly to mean any chemical reaction between solids, liquids, vapours or gases which may cause a substantial rise in pressure, possibly owing to impulse loads, drag loads, fire or heat. An explosion can take the form of a deflagration, which generates moderate pressures, heat or fire, or a detonation, which generates high near field pressures and associated drag loading but usually without significant thermal effects. Whether or not the ignition of a particular chemical vapour or gas causes a deflagration or a detonation in air depends primarily on the concentration of the chemical vapour or gas. At concentrations two to three times the deflagration limit, detonation can occur. The deflagration limit and therefore the related effects are in general related to the burning velocity.

7.3. For a gas cloud, there is evidence that the maximum burning velocity (relative to the non-burning gases) increases with the size of the gas cloud and that there is an upper limit for the burning velocity for homogeneous mixtures. This limit seems to be a function of the power of ignition and the turbulence induced by different obstacles. For deflagrations in free air and in the absence of significant turbulence, the burn velocity will probably not exceed some tens of metres per second. The chemical reaction will form a pressure wave travelling with a velocity close to the speed of sound, creating a peak overpressure of a few tenths of a bar (up to approximately 0.3 bar or 30 kPa) in the incident wave. With a moderate amount of confinement and for a saturated hydrocarbon such as butane, the burn velocity will be higher and deflagration overpressures of 1 bar are obtainable. If more reactive fuels such as ethylene are present in the maximum free field conditions — that is, where the pressure wave may propagate without interactions with structures — pressures may rise to 5 bar or more. It is also possible that ignition of a gas cloud initiates a deflagration, which owing to turbulence or partial confinement (for example, multiple reflection) becomes a detonation affecting only a limited volume. In this case, an overpressure of between a few tenths of a bar (a few tens of kilopascals) and 20 bar (about 2 MPa) may be generated in the surrounding space.

7.4. In a detonation of solid substances and/or a partial detonation of a fuel–air gas or vapour mixture, the reaction is shock induced, will travel at velocities higher than the speed of sound and will produce high peak overpressures. With high explosives (such as trinitrotoluene (TNT)) the pressure peaks in the near field may be of the order of 1000 bar (100 MPa). However, at standoff ranges of interest, the overpressure will probably be less than 0.5 bar. Engineering relationships should be used for determining the correlation between the pressure peak, the explosive yield and the distance from the explosion.

7.5. In evaluating the potential for explosions, all potential sources lying within the SDV should be taken into consideration, as described in Section 3. This process should permit the evaluation, for each identified source, of the following parameters:

— The nature and maximum amount of the material that may simultaneously explode,
— The distance and orientation from the explosion centre to the site,

where the explosive mass is usually expressed in terms of TNT equivalent mass for generic explosive substances.

7.6. An explosion will cause a pressure wave to propagate away from the source, in which the shock front moves with supersonic velocity. The evolution in time of the overpressure, that is, the pressure above the initial atmospheric pressure, should be determined using standard procedures. The pressure at any fixed point in the free field — that is, the pressure that would be registered if the pressure wave were free to propagate without the presence of interacting structures — is designated as side-on or incident overpressure. Upon reflection of the pressure wave by interacting obstacles, the overpressure may increase several times and is designated as reflected overpressure.[14]

PRELIMINARY EVALUATION FOR STATIONARY SOURCES OF EXPLOSIONS

7.7. If on the basis of past experience or available information it is established that the nuclear power plant under consideration could safely withstand a sudden incident overpressure, then the SDV for any initiating event should be determined by calculating the scaled distance corresponding to that overpressure.[14]

7.8. The SDV associated with explosions should be estimated by means of a simplified conservative approach based on the engineering relationship between the TNT equivalent mass and the distance.

7.9. After identification and evaluation of the basic parameters of the explosion, the potential sources of explosions should be preliminarily assessed by simple deterministic methods applied conservatively with the aim of deciding whether further consideration should be given. Detailed analyses should be made of the potential hazards due to the sources not screened out in order to arrive at a design basis event or to exclude explosions from further consideration.

7.10. It is usually enough to determine the potential hazard from the dominant source of a given type in the vicinity of the nuclear power plant and to demonstrate that it provides an envelope for all sources of the same type. The analysis of the potential for effects on items important to safety should proceed in stages with increasing levels of detail.

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[14] In one State it is assumed that a typical plant does not need any analysis for reflected overpressures of less that 0.07 bar, for which SDV = $18W^{1/3}$ (W in kg, SDV in m). Other States simply adopt an SDV for explosions in the range of 5–10 km.

7.11. If the site is located within the SDV, an evaluation of the probability of occurrence of the explosion should be undertaken. The probability of an explosion occurring at hazardous industrial plants, refineries and storage depots is usually higher than the SPL. Unless there is adequate justification, a conservative assumption should be made that the maximum amount of explosive material usually stored at the source will explode, and an analysis should then be made of the effects of interacting events (incidence of pressure waves, ground shock and projectiles) on items important to safety. The secondary effects of fires resulting from explosions should also be considered, as discussed in Section 8.

7.12. The evaluation of the probability of occurrence of an explosion necessitates data on the relative frequency of explosions in industrial and military installations or transport routes in the site vicinity. If such information is not available, reference should be made to global statistics and/or to expert opinion after technical inspections of the potential sources in the vicinity of the site.

DETAILED EVALUATION FOR STATIONARY SOURCES OF EXPLOSIONS

7.13. If facilities exist or activities take place within the SDV in which the amount of explosive material is large enough to affect safety and the probability of occurrence of an explosion is higher than the SPL value, then a more detailed evaluation should be made in order to establish a design basis event. If as a result of the detailed evaluation using more specific data the calculated probability of occurrence of a postulated explosion exceeds the DBPV, a design basis explosion should be determined.

7.14. For the purposes of evaluating the importance of the interacting event, the protection necessary against the design basis explosion should be compared with that already provided against overpressures from other external events such as extreme winds and tornadoes.

PRELIMINARY EVALUATION FOR MOBILE SOURCES OF EXPLOSIONS

7.15. If there is a potential for explosions within the SDV on transport routes, the potential effects should be estimated. If these effects are significant, the frequency of shipments of explosive cargoes should be determined. The probability of occurrence of an explosion within the SDV should be derived from this, and if it is less than the SPL no further consideration should be given. Particular attention should be paid to the potential hazards associated with large explosive loads such as those transported on railway freight trains or in ships.

7.16. Appropriate methods for calculating the probability of an explosion should be used. If there are not enough statistical data available for the region to permit an adequate analysis, reference should be made to global statistics, to pertinent data from similar regions and/or to expert opinion, after technical inspections of the potential sources in the site region.

DETAILED EVALUATION FOR MOBILE SOURCES OF EXPLOSIONS

7.17. If the probability of an explosion within the SDV is greater than the SPL, a detailed evaluation should be made using specific and detailed data from the potential sources in the vicinity of the site. The consequences of an explosion should first be evaluated for a simplified case on the basis of the assumption that, for a given transport route, the total amount of explosive material that is transportable in one shipment explodes at the point of approach for which the most adverse effects on items important to safety are produced. If the consequences for this simplified case have an unacceptable impact on items important to safety, more information should be collected and improved assumptions should be made concerning the quantity of explosive as well as the probability of its exploding at any specific point along the route.

HAZARD EVALUATION

7.18. The pressure waves, drag level and local thermal effects at the plant would differ according to the nature and amount of the explosive material, the configuration of the explosive, meteorological conditions, the plant layout and the topography. Certain assumptions are usually made to develop the design basis for explosions, with data on the amounts and properties of the chemicals involved taken into account. TNT equivalents are commonly used to estimate safe distances for given amounts of explosive chemicals and for a given pressure resistance of the structures concerned. For certain explosive chemicals, the pressure–distance relationship has been determined experimentally and should be used directly.

7.19. Projectiles that may be generated by an explosion should be identified by using engineering judgement and taking into account the source of these projectiles. In particular, the properties of the explosive material concerned and the characteristics of the facility in which the explosion is assumed to occur should be considered.

7.20. Consideration should also be given to possible ground motion and to other secondary effects such as the outbreak of fire, the release or production of toxic gases and the generation of dust.

7.21. For the established design basis explosion the following parameters should be determined:

- — the properties of the exploding substance;
- — the properties of the pressure waves (maximum side-on or incident and reflected overpressures and evolution with time of the pressure wave);
- — the properties of the projectiles generated (material, size, impact velocity);
- — the ground shock, especially for buried items.

It should be noted that the layout of structures at the site can result in substantial superposition of reflected pressure waves with a resultant increase in the pressure. Some knowledge of the conceptual or preliminary design of the proposed plant should be acquired for the purpose of establishing the design basis. The design basis will then be reviewed in the design stage or in the design assessment stage.

8. OTHER EXTERNAL HUMAN INDUCED EVENTS

GENERAL

8.1. In addition to the three main types of external human induced events, namely those due to aircraft crashes, explosions and hazardous fluids, there may be other types of interacting event which can result from external human induced events. Fires are one such type which may be common to a number of external human induced events. In particular, fires may be caused by an event such as an aircraft crash or a chemical explosion.

FIRES

8.2. A survey should be made at and around the site to identify potential sources of fire, such as forests, peat, storage areas for low volatility flammable materials (especially hydrocarbon storage tanks), wood or plastics, factories that produce or store such materials, their transport lines, and vegetation.

8.3. The area to be examined for the possible occurrence of fires that may affect items important to safety should have a radius equal to the SDV for this type of hazard.[15]

[15] This radius is some 1–2 km from the nuclear power plant.

8.4. The precautions taken to protect the nuclear power plant against internal fires also offer some protection against external fires and should be taken into account in evaluating the effects of external fires on the plant.

8.5. The protection provided against fire hazards at the source of the fire should also be taken into account. For example, automatic sprinkler systems or the presence of permanent local fire fighters can reduce the probability of a serious fire.

8.6. The main fire related hazard to the nuclear power plant site is the burning of parts of the plant and the resulting damage. Local structural collapse may occur. Smoke and toxic gases may affect plant operators and certain plant systems. Particular attention should be paid to sources causing possible common mode failures. For instance, the off-site emergency power supply could be interrupted by fire, while the emergency diesel generators may fail to function owing to smoke being drawn into their air intakes.

8.7. The possibility should be considered that emergency access may be prevented and escape routes may be cut off by a large fire.

8.8. Parameters and properties that define the magnitude of a fire are:

— the maximum heat flux,
— the magnitude of hazards from burning fragments and smoke,
— the duration of the fire.

8.9. It should be taken into consideration that the heat flux is inversely proportional to the distance from the fire, although other factors may affect this relationship.

SHIP COLLISION

8.10. Ship collision may constitute a particular hazard to the water intake structures of a nuclear power plant.

8.11. If the ship collision probability is found to be greater than the SPL, a detailed analysis should be conducted to assess the consequences of such an impact. In such an analysis, the simulation of uncontrolled drifting of ships and recreational boats (especially sailing vessels) should be conducted, according to the direction of dominant winds and currents. The collision of large ships in normal cruising can usually be screened out by the implementation of administrative measures and safeguards.

8.12. Important parameters that should be analysed are:

— impact velocity,
— impact area,
— mass and stiffness of the ship,
— substances transported,
— potential secondary effects such as oil spills and explosions.

ELECTROMAGNETIC INTERFERENCE

8.13. Electromagnetic interference can affect the functionality of electronic devices. It can be initiated by both on-site (high voltage switchgear, portable telephones, portable electronic devices, computers) and off-site sources (radio interference, the telephone network).

8.14. The presence of central telephone installations close to the site could give rise to specific provisions for the design stage, but usually such high frequency waves do not represent exclusion criteria for sites since specific engineering measures for the qualification of equipment should be taken in the design stage and administrative procedures should be adopted on site to avoid local interference.

8.15. In the site evaluation stage, potential sources of interference should be identified and quantified (for example, intensity, frequency). They should be monitored over the lifetime of the plant for the purpose of ensuring the proper qualification of plant components.

9. ADMINISTRATIVE ASPECTS

9.1. In compliance with the current requirements in some States, the competent national authority should give due consideration to the present and future development of activities in the region that may give rise to external human induced events, taking into account the required degree of protection of the nuclear power plant.

9.2. The means of effecting controls on development and the extent to which they are exercised are still under consideration in the States concerned, but it is envisaged that where they are to be used they may be necessary from the time a site is selected.

9.3. When the source of an induced external event is found to be within the SDV or to have a higher probability of occurrence than the SPL, and in cases for which it is not practicable to regard the event as a design basis event for the nuclear power plant, consideration may be given to controlling the distance and/or the size of the source in such a way that it will always be outside the SDV or always have a probability of occurrence lower than the SPL. This entails administrative control by a competent authority. The effectiveness of the administrative control should be monitored over the lifetime of the plant and periodically reassessed [4, 5, 10].

9.4. Dedicated monitoring systems should be designed and operated at the site to confirm the site evaluation and design assumptions and to prevent the evolution of initiating events into nuclear accidents. To this extent, specific operational procedures should be set up for real time monitoring and operator action following an accident caused by an external human induced event.

9.5. Public acceptance issues may strongly affect the site evaluation phase and should be given due consideration.

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[a] A revision of this publication is in preparation.

GLOSSARY

conditional probability value (CPV). The upper bound for the conditional probability that a particular type of event will cause unacceptable radiological consequences. The term is used in the detailed event screening process for site evaluation.

design basis probability value (DBPV). A value of the annual probability for a particular type of event to cause unacceptable radiological consequences. It is the ratio between the SPL and the CPV. The term is used in the detailed event screening process for site evaluation.

initiating event. An identified event that leads to anticipated operational occurrences or accident conditions and challenges safety functions.

interacting event. An event or a sequence of associated events that, interacting with a facility, affect site personnel or items important to safety in a manner which could adversely influence safety.

postulated initiating events. An event identified during design as capable of leading to anticipated operational occurrences or accident conditions. The primary causes of postulated initiating events may be credible equipment failures and operator errors (both within and external to the facility), human induced or natural events.

screening distance value (SDV). The distance from a facility beyond which, for screening purposes, potential sources of a particular type of external event can be ignored.

screening probability level (SPL). A value of the annual probability of occurrence of a particular type of event below which, for screening purposes, such an event can be ignored

site evaluation. The analysis of the sources of external events for a site that could give rise to hazards with potential consequences for the safety of a nuclear power plant constructed on that site.

siting. The process of selecting a suitable site for a facility, including appropriate assessment and definition of the related design bases.

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