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Meteorological Hazards Evaluation for Nuclear Installations

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Outline

- General Considerations
- Met Data; On-site meteorological program & Off-site Sources, Rare Phenomena
- Meteorological Hazards Assessment
- Meteorological Extreme Events
- Meteorological Rare Events
- Changes of the Hazard with Time
- Monitoring and Warning
- Grading Approach for Meteorological Hazards

General Considerations

- Meteorological phenomena may affect:
  - SSCs and lead to the risk of common cause failure.
  - Communication and transport networks around the site.
- Meteorological hazards include extreme values of meteorological parameters, as well as rarely occurring hazardous meteorological phenomena.

SSR-1, Site Evaluation for Nuclear Installations

Requirement 18: Evaluation of extreme meteorological hazards

Extreme meteorological hazards and their possible combinations that have the potential to affect the safety of the nuclear installation shall be evaluated.

5.11. Meteorological phenomena such as wind, precipitation, snow and ice, air and water temperature, humidity, storm surges and sand or dust storms, as well as their credible combinations, shall be evaluated for their extreme values based on available records. If necessary, efforts shall be made to extend the database on meteorological hazards (e.g. by incorporating historical climate data, numerical models and simulations).

5.12. Appropriate methods shall be applied for the evaluation of meteorological hazards, taking into account the amount of data available (both measured data and historical data) and known past changes in relevant characteristics of the region.


Dust Storms and Sandstorms


Tornadoes


Hail


Waterspouts


High Wind Speed Missiles


Freezing Precipitation - Ice Storm

SSR-1, Site Evaluation for Nuclear Installations

Requirement 19: Evaluation of rare meteorological events

The potential for the occurrence of rare meteorological events such as lightning, tornadoes and cyclones, including information on their severity and frequency, shall be evaluated

Lightning

5.13. The potential for the occurrence and the frequency and severity of lightning shall be evaluated for the site vicinity.

Tornadoes and cyclones

5.14. The potential for the occurrence and the frequency and severity of tornadoes, cyclones and associated missiles shall be evaluated for the site. The hazards associated with tornadoes and cyclones shall be derived and expressed in terms of parameters such as rotational wind speed, translational wind speed, radius of maximum rotational wind speed, pressure differentials and rate of change of pressure.


Dust Storms and Sandstorms


Tornadoes


Hail


Waterspouts


High Wind Speed Missiles


Freezing Precipitation - Ice Storm

General Considerations

- Meteorological variables (2.6)
  — Air temperature;
  — Wind speed;
  — Precipitation (liquid equivalent);
  — Snowpack.
- Rarely occurring meteorological phenomena (2.7)
  — Lightning;
  — Tropical cyclones, typhoons and hurricanes;
  — Tornadoes;
  — Waterspouts.
- Other possible phenomena (2.8)
  — Dust storms and sandstorms;
  — Hail;
  — Freezing precipitation and frost related phenomena.
- High intensity winds (tropical storms, tornadoes) may produce flying debris and projectiles (2.10)

General Considerations

- Extreme values of meteorological parameters are identified by means of statistical analysis of recorded parameters that are measured periodically on an ongoing basis (e.g. extreme temperature).
- Rarely occurring phenomena are unlikely to be measured at any specific location because of their very low frequency of occurrence at any single place and the destructive effects of the phenomena, which may result in damage to standard measuring instruments.

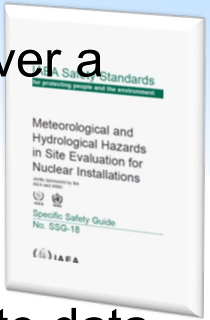
General Considerations

- Changes of the Hazard with Time (2.18, 2.26)
  - Climate variability and change may affect the occurrence of extreme meteorological conditions
- Methods for Assessment of Hazards (2.19 – 2.27)
  - Two broad categories:
    - Deterministic methods
    - Statistical and probabilistic methods
      - Generalized Extreme Value (GEV) approach
      - Peak-Over-Threshold (POT) method
      - An estimate should be made of the annual frequency of exceedance associated with the design basis scenarios

Met Data, General Considerations

- WMO maintains standards and best practices for instruments, siting, and measurements (3.11, 3.12)
- Available data sources include national meteorological services as well as international, local, and private organizations (3.11, 3.13)
- Climatic normal and extreme values to be collected include (3.11)
  - Annual exceedance frequencies (# hours per year)
    - Dry-bulb temperature, wet-bulb temperature
  - Annual extreme values
    - Wind speed, precipitation (liquid equivalent), snow pack
  - Historic worse case (UHS)
    - Maximum evaporation, minimal water cooling
- Long term periods of record (e.g., 30 years) should be used (3.7)

Met Data, General Considerations



- Data should be collected at appropriate intervals uninterrupted over a long period of time (3.14)
- An assessment should be made of the data available from meteorological stations in the region (3.14)
  - Ensure representativeness by making comparisons with onsite data
- Field measurements made by organizations other than the National Meteorological Services may not follow WMO standards (3.16)
  - Wind data recorded at other than 10-m elevation
  - Maximum wind speed recorded for different averaging times (3-sec gusts, 60-sec gusts, 10-min averages)
  - Air temperatures recorded continuously, at frequent intervals (hourly), or daily maximum and minimum values
  - Precipitation recorded daily or for shorter averaging times

Met Data, Off-site Sources

- A report of the results of any analyses using off-site data sources should include a description of the monitoring program (3.17)
  - Types of instruments
  - Calibration history
  - Geographical location
  - Instrument exposure and altitude
  - Data record periods
  - Data quality

Met Data, On-site meteorological program

- An on-site meteorological program should be established as early as possible after selecting the site (air temperature, precipitation, wind speed and direction and humidity).
- Instrumentation, data collection and monitoring should be coordinated with the National Meteorological Service.

- On-site collected data in general cover a short period of time. Therefore, these data should be verified and compared with the long-time regional data series and the similarity should be determined. (3.19-3.21)

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Met Data, Rare Phenomena

- Rare hazardous meteorological phenomena are unlikely to be recorded at any single location or by a standard instrumented network (3.22)
  - Low frequency of occurrence
  - Small affected area
  - Damage standard instruments or produce unreliable measurements

- Two types of data sources are available for rare phenomena (3.9, 3.23, 3.24)
  - Historical data
  - Data collected, processed and analyzed in recent years, soon after the occurrence of an event
- Specific data catalogues should be compiled (3.25)

Assessment of meteorological hazards

General Procedure

Obtain representative data series available for the region and evaluate of its quality (representativeness, completeness, QA/QC)

↓

Select the most appropriate statistical distribution for the data set (Gumbell, Frechet, Weibull)

↓

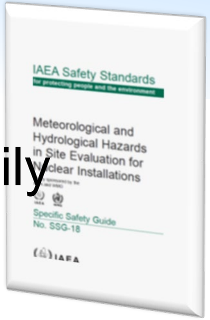
Process the data to evaluate the Mean Recurrence Interval (MRI)

Assessment of Meteorological Hazards

- IAEA Safety Series No. 50-SG-S11A Annex I provides examples of methods to be used in the statistical evaluation of the extreme values of meteorological parameters important to the safety of NPPs. It presents practical procedures without any attempt to demonstrate the underlying theories.

Meteorological Extreme Event - Extreme Air Temperature

- Identify stations for which the meteorological conditions are similar for the site
  - ✓ Compare existing off-site station data with on-site data
- Extreme annual values typically derived from the data set of daily maximum and minimum values
- Annual percentiles values that are exceeded by the indicated percentage of the total number of hours in a year are derived from hourly data sets.
- For NPPs that utilize evaporation-based ultimate heat sink designs, identify the following using hourly data sets:
  - ✓ Maximum evaporation potential (for evaluating sufficient water supply)
  - ✓ Minimum water cooling (for evaluating sufficient cooling supply)



Meteorological Extreme Event - Extreme Air Temperature

Extreme Air Temperature - Design Basis Parameters

Site Parameter	Criterion	Use
Extreme Air Temperature		
Maximum dry-bulb & Coincident wet-bulb	Exceeded for 1% of the time annually*	Cooling / AC
	100-yr MRI	(a)
Maximum non-coincident wet-bulb	Exceeded for 1% of the time annually**	Cooling towers, evaporative coolers and fresh air ventilation systems.
	100-yr MRI	
Minimum dry-bulb	Exceeded for 99% of the time annually	Heating
	100-yr MRI	(a)

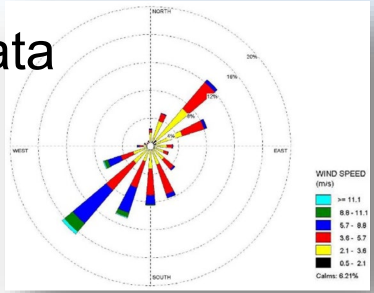
(a) Maximum and minimum 100-yr MRI criteria can be used for the operational design of equipment to ensure continuous operation and serviceability, structural analysis of thermal loads on building and structures, etc.

* 1.0% value that are exceeded on average for 88 hours per year for the period of record analysed are typical design conditions.

**The maximum dry bulb temperature that has a 1% annual frequency of exceedance (100 year mean recurrence interval)

Meteorological Extreme Event - Extreme Wind Speeds

- Identify stations for which the meteorological conditions are similar for the site
  - ✓ Compare existing off-site station data with on-site data
- Processing of the data should be standardized to:
  - ✓ Uniform averaging times
  - ✓ Uniform heights and surface roughness
  - ✓ Corrected for local topographic effects
- Design basis parameter



Wind Rose : A graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location

Wind speed		
3-sec gust[(a)]	100-yr MRI	Wind loads

(a) This site parameter should account for the occurrence of tropical cyclones for those sites that are susceptible to such phenomena

Meteorological Extreme Event - Extreme Precipitation

- Identify stations for which the meteorological conditions are similar for the site by reviewing micrometeorological characteristics, mesoscale systems, and topographic influences
- Prefer data from those off-site stations equipped with continuing recording rain gauge
- Similarity concepts may be employed to extrapolate data to different averaging periods for those climatically similar off-site stations where precipitation totals exist for fixed intervals
- Design basis parameter

Precipitation		
Local Intense Precipitation[a]	PMP	Water drainage system design and flooding evaluations
	100-yr MRI	

(a) The depth of rainfall for a specified duration and surface area (e.g., cm/hr-km2)

Meteorological Extreme Event - Extreme Snowpack

- Structural loads are a function of both snow depth and packing density; therefore, snow depth is expressed in term of a water equivalent depth in order to convert to a snowpack weight
- Variables to be consider include:
  - ✓ Snowfall and its density
  - ✓ Snow cover (snowpack)
- Identify stations for which the meteorological conditions are similar for the site
  - ✓ Altitude
  - ✓ Topographic position (south facing versus north facing slope)
  - ✓ Neighboring structures
- Design basis parameter

Snowpack		
Ground snowpack weight	100-yr MRI	Roof loads

Meteorological Rare Events - Lightning

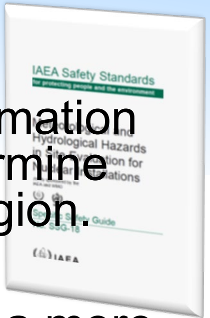
- Unpredictable transient phenomenon with characteristics that vary widely from flash to flash and whose measurement is difficult.
- Lightning strike frequency is the product of:
  - Equivalent collection area of the structure or object
    - Function of structure length, width, height
  - Flash density of the area where the structure is located
- Two methods for determining flash density
  - Isokeraunic map showing number of thunderstorm days per month/year
  - Lightning flash density map (preferred method)
- Design basis parameter

Lightning		
Lightning Strike Frequency	Lightning strikes per year	Design of lightning protection systems

Meteorological Rare Events - Tornadoes

- Tornadoes are violent rotating columns of air, usually associated with a thunderstorm.
- Damage caused by tornadoes include:
  - Severe wind loading
  - Sudden air pressure drop
  - Impact of wind-driven missiles
  - Floods (caused by indirect damage)

Meteorological Rare Events - Tornadoes



Hazard assessment

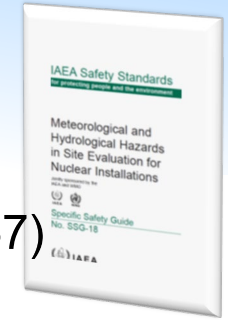
- Tornado phenomena have been documented around the world. Information over as long a period of time as possible should be collected to determine whether there is a potential for the occurrence of tornadoes in the region. (4.53)
- If the possibility that tornadoes may occur in the region is confirmed, a more detailed investigation should be performed to obtain suitable data for the evaluation of a design basis tornado. (4.54)
- An intensity classification scheme similar to that developed by Fujita–Pearson or the more recently implemented enhanced Fujita scale should be selected. This system is a combination of the Fujita scale rating for wind speed, the Pearson scale for path length and the Pearson scale for path width. The classification for each tornado is based on the type and extent of damage. Descriptions and photographs of areas of damage provide additional guidance for the classification of the tornado. Typically, tornado databases archived by national meteorological services include an intensity classification scheme similar to the Fujita–Pearson and enhanced Fujita scales.(4.55)

Meteorological Rare Events - Tornadoes

Hazard assessment

- The annual frequency of exceedance at which a particular plant site will experience tornado wind speeds in excess of a specified value should be derived from a study of the tornado inventory. A homogeneous region centred at the site should be considered for developing the tornado inventory. Generally, an area of about 100000 km^2 is appropriate. (4.56)

Meteorological Rare Events - Tornadoes



Values of parameters deriving from the hazard assessment

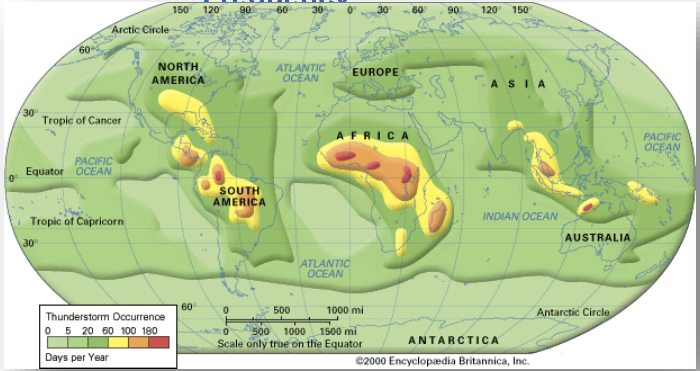
- The results of a hazard assessment for tornadoes should be the annual frequency of exceedance at which a particular site will experience tornado wind speeds in excess of a specified value. (4.57)
- After determination of the design basis tornado, which is scaled by wind speed, a tornado model should be selected to develop the maximum expected pressure drop and the maximum rate of pressure drop. Tornado generated projectiles should also be specified in terms of their mass and velocity. (4.58)

Meteorological Rare Events - Dust Storms and Sandstorms

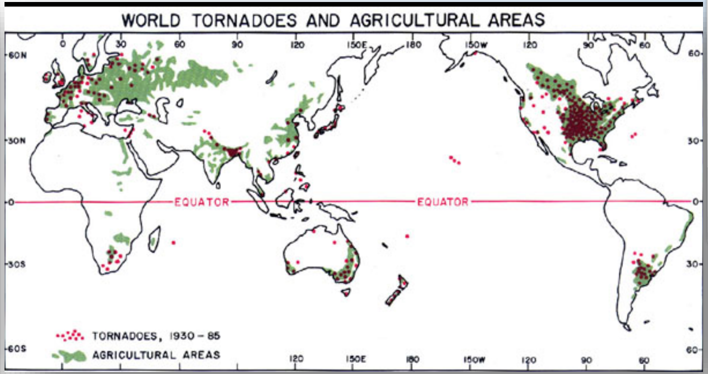
- Loose sand and dust are removed from a dry surface and become airborne because wind forces exceed threshold values (4.64)
- Frequency can be compiled based on hourly weather observations (4.65)
- Hazard assessment based on historic dust storm with largest calculated time-integrated dust/sand loading (mg-hr/m^3) (4.66)
  - Duration (hr)
  - Average dust/sand loading (mg/m^3)

Meteorological Rare Events

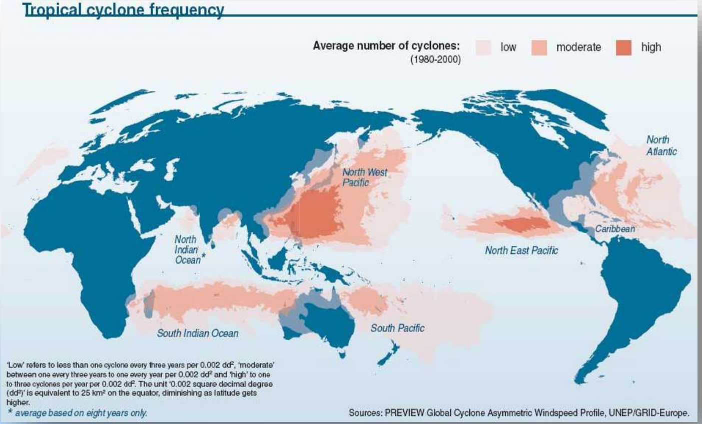
Thunderstorm: Worldwide Frequency



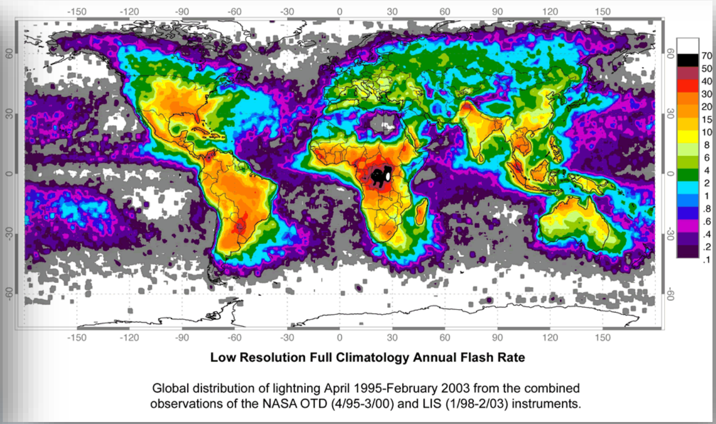
World Map of Tornado Occurrence



Tropical Cyclone Frequency



Lighting Flashes / Km^2 / Year



Changes of the Hazard with Time

- Meteorological hazards may change over time due to:
  - Regional climate change associated with global climate change
  - Changes of land-use in the area around the site
- Major effects:
  - Changes in air and water temperatures
  - Changes in frequency and intensity of phenomenon
- Regional climate variability and change should be considered for the planned life time of an installation (e.g., 100 years)
  - Additional safety margin should be considered in the design
  - Periodic re-evaluation of design parameters should be performed

Monitoring and Warning

- Monitoring of any meteorological event proved to be a significant hazard should be performed continuously from the site selection phase throughout the entire lifetime of the facility (9.1)
  - Validate design basis parameters
  - Support periodic revision of the site hazard
    - consequence of global climate change
  - Provide warnings for operators and emergency managers
- Warning system should be used in connection with forecasting models (9.3-9.10)
  - Arrangements should be made to receive warnings on severe weather from national warning systems reliably and on time

Grading approach for Installations other than NPPs

- For the purpose of the evaluation of meteorological hazards, if a graded approach is applied, installations should be graded on the basis of their complexity, potential radiological hazards and hazards due to other materials present. Meteorological hazards should be evaluated in accordance with this grading. (10.2)

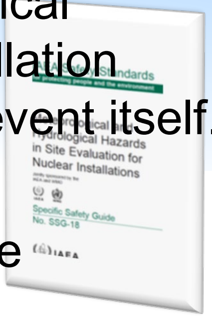
Grading approach for Installations other than NPPs

- Prior to categorizing an installation, a conservative screening process should be applied on the assumption that the complete radioactive inventory of the installation is released in a meteorologically initiated accident.
- If the result of such a release would be that no unacceptable consequences were likely for workers, the public (i.e. doses to workers or the public due to the release of that inventory would be below the acceptable limits established by the regulatory body) or the environment, and no other specific requirements for such an installation are imposed by the regulatory body, the installation may be screened out from the evaluation of specific meteorological hazards.
- In such a case the applicable national maps and codes for commercial and/or industrial facilities may be used. (10.3)

Grading approach for Installations other than NPPs

- If the results of the conservative screening process show that the consequences of potential releases are ‘significant’, an assessment of meteorological hazards for the installation should be carried out, in accordance with the steps indicated in SSG-18 paras (10.5–10.10.). (10.4)

Grading approach for Installations other than NPPs



- The likelihood that a meteorological event would give rise to radiological consequences will depend on the characteristics of the nuclear installation (e.g. its use, design, construction, operation and layout) and on the event itself. Such characteristics include the following factors:

  —The amount, type and status of the radioactive inventory at the site (e.g.solid, fluid, processed or only stored);

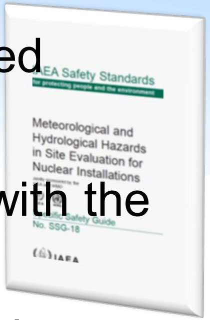
  —The intrinsic hazard associated with the physical processes (e.g. criticality) and chemical processes used at the installation;

  —The thermal power of the nuclear installation, if applicable;

  —The configuration of the installation for activities of different kinds;

  —The concentration of radiation sources in the installation (e.g. for research reactors, most of the radioactive inventory will be in the reactor core and fuel storage pool, while in fuel processing and storage plants the radioactive inventory may be distributed throughout the plant);

Grading approach for Installations other than NPPs



—The changing nature of the configuration and layout for installations designed for conducting experiments (such activities have an associated intrinsic unpredictability);

—The need for active safety systems and/or operator actions to cope with the management of postulated accidents;

—The characteristics of engineered safety features for preventing accidents and for mitigating the consequences of accidents (e.g. the containment and confinement systems);

—The characteristics of the process or of the engineering features that might show a cliff edge effect in the event of an accident;

—The characteristics of the site that are relevant to the consequences of the dispersion of radioactive material to the atmosphere and the hydrosphere (e.g. size, demographics of the region);

—The potential for on-site and off-site contamination. (10.5)

Grading approach for Installations other than NPPs

- Depending on the criteria of the regulatory body, some or all of the above factors should be considered. For example, fuel damage, radioactive releases or doses may be the conditions or metrics of interest. (10.6.)
- The grading process should be based on the following information:

(a) The existing safety analysis report for the installation, which should be the primary source of information;

(b) The results of a probabilistic safety assessment, if one has been performed;

(c) The characteristics specified in SSG-18 para. 10.5. (10.7)

Grading approach for Installations other than NPPs

- For an existing installation, the grading may have been performed in the design stage or later. If so, the assumptions on which this grading was based and the resulting categorization should be reviewed and verified. The results may range from no radiological consequences (associated with conventional installations) to high radiological consequences, i.e. for consequences associated with NPPs. (10.8)

Grading approach for Installations other than NPPs

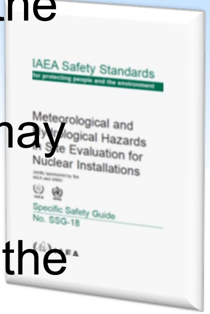
- As a result of this grading process, three or more categories of installation may be defined depending on national practice:
  (a) The least radiologically hazardous installations are similar to conventional facilities (essential facilities, such as hospitals, or hazardous facilities, such as petrochemical plants) such as those that are defined in the national building codes or codes dedicated to hazardous industrial facilities.
  (b) The highest grade of hazardous installation would be installations for which the hazards approach the hazards associated with NPPs.
  (c) There is often one or more intermediate category of hazardous installation specified as being between those defined as equivalent to conventional facilities (essential facilities or hazardous facilities) and the category for NPPs. (10.9)

Grading approach for Installations other than NPPs

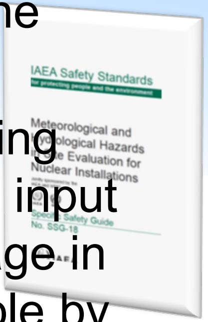
The evaluation of meteorological hazards should be performed using the following guidance:

(a) For the least hazardous installations, the meteorological hazards may be taken from national building codes and maps.

(b) For installations in the highest hazard category, methodologies for the evaluation of meteorological hazards should be used as described in previous sections of this Safety Guide; the recommendations applicable for NPPs should be followed.



Grading approach for Installations other than NPPs



(c) For installations categorized in the intermediate hazard category, the following cases may be applicable:

—If the evaluation of meteorological hazards is typically performed using methodologies similar to those described in SSG-18, a lower stringent input for designing these installations may be adopted during the design stage in accordance with the safety requirements for the installation, for example by decreasing the annual frequency of occurrence of the hazards considered.

—If the database and the methods recommended in SSG-18 are found to be excessively complex and time and effort consuming for the nuclear installation in question, simplified methods for the evaluation of meteorological hazards, based on a more restricted data set, can be used. In such cases, the input parameters finally adopted for designing these installations should be commensurate with the reduced database and the simplification of the methods, with account taken of the fact that both of these factors may tend to increase uncertainties. (10.10).

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Thank you for your kind attention!