Class I Guidances

Guideline on the evaluation of the seismic hazards for new class I nuclear installations

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1. Introduction

Earthquakes are part of the natural external events that should be taken into account in the design of nuclear installations according to site specific conditions.

The designs for nuclear installations constructed a few decades ago applied a deterministic approach to seismic design based on site-specific investigations to determine the *maximum credible earthquake* (MCE) from a single source/fault. This approach considers only the earthquakes for which sufficient data are available (+- 1000 years) and uses the characteristics of a single earthquake to determine both the *peak ground acceleration* (PGA) and the spectral accelerations used for the design basis. The resulting accelerations do not, in general, represent a uniform[1] hazard risk level.

it is recognized that the use of exclusively deterministic approaches lead to a number of shortcomings including the short period for which there are records, the difficulty of assessing the characteristics of earthquakes that occurred prior to the use of seismometers, the difficulty of identifying the existence of all earthquakes that pre-date the historic record, and ultimately the reliance on one single earthquake. In the deterministic approach, often, a single earthquake determines the spectral accelerations for all considered frequencies.

In Belgium, extensive work has been done already a few decades ago by the operator of NPPs and the nuclear power plants were designed according to a US NRC regulatory guidance applicable at that time. For existing nuclear power plants in Belgium, the PGA is determined on the basis of a deterministic seismic hazard analysis taking into account the maximum possible earthquake considering different area sources. Once the PGA determined, the Design Ground Motion *Response Spectrum* (GMRS) is based

- on the RG 1.60 pre-determined large band spectral shape calculated as the 84 % percentile of several (33) natural earthquake recordings (e.g. Doel 3, Doel 4 and the initial Tihange 2 and 3 GMRSs)
- on a site specific large band spectra calculated as the 84% of several natural earthquake recordings selected from sites with similar soil profiles characteristics than the considered site (e.g. Tihange Seismic Revaluation)

More recently, many standards and regulatory documents refer to Probabilistic Seismic Hazard Analysis (PSHA) studies in support to the determination of the design basis earthquake.

The PSHA estimates the *frequency of exceedance* of various levels of earthquakes-caused motion (depending on the return period considered) at a given location in a given future time period (e.g. per year or for the lifetime of the installation). The result of such a PSHA is a *uniform hazard response spectrum* (UHRS) that would apply to all considered equipment (safety equipment) regardless of their resonance frequency. Defining a uniform hazard is the main advantage of a PSHA approach.

In the context of civil work constructions, conventional seismic codes (IBC, Eurocode) contain the minimal requirement aimed primarily to safeguard against major structural failure (buildings, bridges, tanks, stacks, ..) and loss of life and not to maintain function (No-collapse requirement). The return period of used acceleration to anchor the design spectra in conventional standards like the Eurocode 8 is based on an exceedance frequency of 10% in 50 years i.e. 475 years return period.

Due to the risk associated with such hazards, it is desirable that the exceedance frequency of an earthquake induced structural damage for nuclear installations is lower than for conventional installations. Nuclear seismic rules require that structures, systems and components important to safety to withstand the effects of earthquakes. This means that for equipment important to safety integrity should be ascertained; if this equipment is relied upon for a seismic event, its functionality should also be ascertained.

[1] The uniform hazard risk level is defined through the Uniform Hazard Response Spectra (UHRS)

2. Scope

This guideline applies (i.e. it should be used as an *applicable document*[2]) to new class I nuclear installations except disposal installations. A new class I nuclear installation means a nuclear installation that is the subject of a new license application and for which the license application is introduced to the regulatory authority after the date of approval of this document.

It is outside to the scope of this guideline to address aspects related to multi-installation sites (for example the fact that several installations on the site may be challenged at the same time).

The applicant is free to propose an approach that differs from this guideline provided it is fulfilling the regulatory requirements. The quantitative data related to the hazard levels (i.e. the hazard exceedance frequency defined in §5.3 and the minimum hazard levels defined in §5.6.2) should however always be respected. The nuclear regulator will evaluate the proposed approach and its justification against the background of this guideline.

3. Content and approach

This guideline provides recommendations with regards to the seismic hazard levels to be considered for the design of installations referred to in §2.

Section 4 provides a short review of the Belgian regulatory framework and a description of the main conclusions arising from the EU, IAEA and WENRA. Section 5 covers the guidance and detailed expectations. Section 5.1 presents the hazards to consider in the design and the associated safety objectives. Section 5.2 presents how a graded approach can be implemented in the context of the safety assessment. Section 5.3 presents the recommendations for the elaboration of an Earthquake Level 1 (EL-1) on the *rock outcrop* and justifies this level through a historical check. Section 5.4 presents the recommendations on how to perform a margin assessment of the EL-1 earthquake. Section 5.5 presents an approach to define an Earthquake Level 2 (EL-2) on the rock outcrop which goes beyond the EL-1. Section 5.6 provides recommendations for the elaboration of a site specific transfer function, and a *free field ground motion* response spectrum. References are provided in section 6.

Appendix A recalls some definitions specific to seismic hazard analysis. All terms written in this guide and defined in Appendix A are written in *italic* the first time they appear. Appendix B presents a historical check of the EL-1 spectrum for 4 Belgian nuclear sites. Appendix C presents correspondence between this guideline and relevant documentation issued by IAEA and WENRA.

4. Background

4.1. The Belgian regulatory framework

Article 7.4 of the Royal Decree of 30 November 2011 [1] which applies to all Belgian class I nuclear installations sets forth that the list of design basis accidents (internal and external) shall be subject to approval by the regulatory authority.

Article 20.3 of the Royal Decree of 30 November 2011 [1] (for existing NPPs) which applies to design basis events, states that:

[2] This means that for new class I nuclear installations, it is expected by the regulatory authority that all applicable recommendations of this guideline are implemented in the design. If this is not the case, the regulatory authority will likely ask the applicant to provide justifications for the recommendations that are not implemented.

"Among those events of an external origin that need to be taken into account, are at the minimum the site characteristic events of natural origin such as:

- ...
- Earthquakes"

This quoted article requires that earthquakes are considered in the design basis.

4.2. European directives

The council of the European Union published a Council Directive amending Directive 2009/71/EURATOM establishing a Community framework for the nuclear safety of nuclear installations [17]. The proposed amendment of 2014 was published in response to lessons-learned from the accident in Fukushima Daiichi NPP in 2011 and aims at enhancing the regulatory framework for nuclear safety in the EU.

Of particular interest is section 2 with specific obligations for the nuclear safety objective for nuclear installations (article 8a, see [13]) and the implementation of the nuclear safety objective for nuclear installations (article 8b):

Article 8b indicates that in order to achieve the nuclear safety objective set out in Article 8a, Member States shall ensure that the national framework requires that where defence-in-depth applies, it shall be applied to ensure that:

- "the impact of extreme external natural and unintended man-made hazards is minimized"
- ...

4.3. IAEA publications

4.3.1. IAEA, GSR Part 4, Safety Assessment for Facilities and Activities

In this IAEA standard [14], the Requirement 8 "Assessment of site characteristics" indicates that "*an assessment of the site characteristics relating to the safety of the facility or activity shall be carried out and has to cover : (...) Identification of natural and human induced external events in the region that have the potential to affect the safety of facilities and activities. This could include natural external events (such as ...earthquakes) and human induced events (...), depending on the possible radiation risks associated with the facilities and activities"*.

4.3.2. IAEA, SSR-2/1, Safety of Nuclear Power Plants: Design

In this IAEA standard [2], the Requirement 17 "Internal and external hazards" indicates that:

"All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered for determination of the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant."

Further to this general statement, requirement 5.17 to 5.22 of [2] address External hazards and shall all be considered by the applicant. In relation to the seismic hazard level to be considered, the requirement 5.17 states *"The design shall include due consideration of those natural and human induced external events (i.e. events of origin external to the plant) that have been identified in the site evaluation process …."* and refers further to IAEA Site Evaluation standard [3], discussed below.

The design objective with regards to external hazards is recalled in §5.20 [2] *"The design shall be such as to ensure that items important to safety are capable of withstanding the effects of external events* *considered in the design, and if not, other features such as passive barriers shall be provided to protect the plant and to ensure that the required safety function will be performed"*.

In addition, the seismic design of the plant shall provide for a sufficient safety margin to protect against seismic events and to avoid cliff edge effects (§5.21 [2]).

4.3.3. IAEA, NS-R-4, Safety of research reactors

In this IAEA safety requirement standard [15], requirements 15 and 16 refer to "earthquakes".

"5.15. The hazard for the site due to earthquake induced ground motion shall be assessed, with account taken of the seismotectonic characteristics of the region and specific site conditions. The uncertainties in the methods shall be taken into consideration in deriving ground motion parameters for the design basis."

"5.16. The extent and the level of detail of site investigations to determine the ground motion parameters for the design basis will depend on the installation under consideration. For smaller installations with minimal potential for radiological consequences for people, it may be preferable (and cost-effective) to limit the site investigations and instead to use conservative values for the design basis parameters. The conservatism is necessary because in general more uncertainties will persist when the investigations are not as detailed."

4.3.4. IAEA, NS-R-5, Safety of Nuclear Fuel Cycle Facilities

In this IAEA standard [16], §5.5 on "site evaluation" indicates that:
"Site characteristics (e.g. soil properties, geology, hydrogeology) that may affect safety aspects of the facility shall be assessed, in particular the likelihood and the potential severity of natural phenomena (e.g. earthquakes, ….)"

If further indicates in its appendix I that selected postulated initiating events include …earthquakes and ….

4.3.5. IAEA, NS-R-3, Site Evaluation for Nuclear Installations

This IAEA standard [3] addresses the evaluation of the suitability of a site for a nuclear installation, through the following aspects:

- The effects of external events occurring in the region of the particular site (these events could be of natural origin or human induced);
- The characteristics of the site and its environment that could influence the transfer to persons and the environment of radioactive material that has been released;
- The population density and population distribution and other characteristics of the external zone in so far as they may affect the possibility of implementing emergency measures and the need to evaluate the risks to individuals and the population.

As indicated under §2.2 [3], if the site evaluation for the three aspects cited indicates that the site is unacceptable and the deficiencies cannot be compensated for by means of design features, measures for site protection or administrative procedures, the site shall be deemed unsuitable.

The level of the seismic hazard to be considered in the design of the installation is addressed through bullet a. The assessment of the likely effects of an earthquake will be conducted considering bullets b & c.

More specific requirements for evaluation of earthquakes and surface faulting are provided in paragraphs §3.1 to §3.7 of [3].

4.3.6. IAEA, SSG-9, Seismic Hazards in Site Evaluation for Nuclear Installations

This IAEA standard [5] addressing the seismic hazard evaluation provides guideline for the data to collect, for the construction of a regional *seismotectonic model*, for the evaluation of the ground motion hazard, for the conduct of a probabilistic and a deterministic seismic hazard analysis and finally for the design basis ground motion, fault displacement and other hazards associated to earthquakes.

This IAEA guideline document should be considered for all those organizations developing one or more of the topics mentioned above.

In §2.1 [5], it indicated that *"The hazards associated with earthquakes shall be determined by means of seismotectonic evaluation of the region with the use to the greatest possible extent of the information collected."*, leaving out the possibility of using other type of models such as the "historical models": the seismic hazard evaluation should be based on a seismotectonic model.

Another important message is provided through §2.10 and §2.11 [5], where it is indicated that "regardless of any lower apparent exposure to seismic hazard, a minimum level should be recognized as the lower limit to any seismic hazard study". This minimum level should be represented by a horizontal free field standardized response spectrum anchored to a peak ground acceleration value of 0.1g. It is further indicated that this value of 0.1g will not represent a sufficiently conservative estimate of the hazard if the database used for the seismic hazard evaluation shows deficiencies in comparison with the recommendation of the IAEA standard.
Guideline on the combined use of a deterministic and a probabilistic hazard evaluation is also provided in §5.1 [5] where it is indicated that "The ground motion hazard should preferably be evaluated by using both probabilistic and deterministic methods of seismic hazard analysis.

4.4. WENRA

The Western European Nuclear Regulators Association, WENRA, has determined ´reference levels` [6] for existing NPPs which have been incorporated in a Belgian Royal Decree [1]. A specific section of [1] applies to all class I facilities and future extensions specific to certain types of facilities are foreseen.

The WENRA reference levels were revised [7] following the accident at Fukushima and are published. In particular, WENRA has added reference levels for natural hazards (issue T) and is developing guidance on them. The current concepts of these reference levels and the additional guidance have been used as part of this guideline.

5. Guidance and expectations

5.1. Hazard levels and radiological safety objectives

The guideline on the safety demonstration of new class I nuclear installations [13] provides guidance on the safety demonstration, defence in depth, quantified safety objectives and the application of the graded approach for external hazards.

Consistently, this guideline defines three levels of earthquakes:

- EL-1: level 1 seismic hazard (see §5.3);
- EL-1*: level 1* seismic hazard resulting from a margin assessment (see §5.4);
- EL-2: level 2 seismic hazard (see §5.5).

Referring to [13]:

- **The EL-1 hazard has to be treated as a C3a event and the associated safety objective is therefore SO2. The safety analysis should use conservative methods, assumptions and data;**

- **The EL-1* hazard has to be treated as a C3b event and the associated safety objective is therefore SO2. The safety analysis can use less conservative methods, assumptions and data than in the EL-1 safety analysis;**

- **When considered in the safety assessment (see §5.2), the EL-2 hazard has to be treated as a C4a event and the associated safety objective is therefore SO3. The safety analysis can use less conservative methods, assumptions and data than in the EL-1 safety analysis.**

5.2. Safety assessment and graded approach

The hazard-specific worst-case consequences (see [13] for details and definitions) will allow categorizing the installation into one of four graded approach (GA) categories. Depending on this categorization, the scope of the safety assessment for earthquakes can be determined:

1. Radiological consequences on-site below the SO2 limits;
2. Radiological consequences on-site larger than SO2 but radiological consequences off-site below the SO2 limits;
3. Radiological consequences off-site larger than SO2 but not larger than SO3 limits;
4. Radiological consequences off-site larger than SO3 limits.

Depending on this categorization, the scope of the safety assessment for earthquakes can be determined:

	Include in safety assessment?		
GA category	EL-1	Margin assessment	EL-2
4	yes	yes	yes
3	yes	yes	no
2	yes	no	no
1	yes, but adapted	no	no

For graded approach category 1 the installation should be designed for at least the severity retained in conventional design standards, when existing, according to the national codes for industrial facilities. In addition, the EL-1 event should be defined and analyzed with a severity set such that the exceedance frequency of the external natural hazard corresponds to a few percent's exceedance frequency during the lifetime of the installation rather than the value provided in §5.3.

5.3. Earthquake Level 1 (EL-1) at the outcropping rock

Horizontal motion:

A uniform hazard response spectrum (UHRS) for the *outcropping rock* (see appendix A for the definitions of *bedrock motion* and *rock outcropping motion*) which is specific to the nuclear site should be conducted through a PSHA[3]. This guideline recommends that the UHRS for the horizontal motion on the rock outcrop is derived for the **10^{-4} mean annual hazard exceedance frequency**.

Appendix B/Figure 1 presents, as an example only, the UHRS as obtained by the Royal Observatory of Belgium (ROB) [9]. In this figure, the 10^{-4} mean annual hazard exceedance frequency hazards correspond to the curves "UHS(1E+04 yr)". This hazard exceedance frequency is associated with reasonable uncertainties. Since Belgium is considered as consisting of low and moderate seismic areas, for much lower annual exceedance frequencies (10^{-5} and below), the uncertainties become

[3] The value of a cut-off magnitude, if any, used in the PSHA should be justified by the applicant

unreasonably high. In addition, this 10^{-4} annual exceedance frequency is consistent with the frequency of postulated internal single initiating events considered in traditional conservative safety demonstrations.

For installations that pose a very low threat (graded approach category 1), the annual hazard exceedance frequency may be reduced; see §5.2.

Vertical motion:
A uniform hazard response spectrum (UHRS) for the outcropping rock which is specific to the nuclear site should be conducted through a PSHA preferably also for the vertical motion. This guideline recommends that this UHRS is derived for the **10^{-4} mean annual hazard exceedance frequency**. Alternatively, the vertical motion should be derived from the horizontal motion according to the RG 1.60 [11].

Historical earthquake ground motion check (HGMC):
The horizontal UHRS on the rock outcrop as derived from above should be compared to rock outcrop response spectra from historical earthquakes that may have affected the site and show that the EL-1 is conservative compared to historical earthquakes (i.e. without incorporating additional conservatisms). This means in particular that all earthquakes considered in the study should be characterized by best-estimate parameters (with uncertainties if available) in terms of *epicentre*, depth, fault rupture extent and *magnitude*. The distance between the nuclear site and the source should also be calculated in a best estimate manner. In particular, the earthquakes source positions are not moved within any particular zone. From all the rock outcrop response spectra obtained, an enveloping spectrum is calculated, for each site.

Since the historical earthquake spectra depend on models, data and assumptions which might not stay up to date with time, this historical spectra might themselves change in time and the check should be repeated.

Appendix B/Figure 1 presents, as an example only, historical earthquake response spectra in comparison with different mean Uniform Hazard Spectra (UHS) [10], for the 4 nuclear sites of Doel, Tihange, Mol/Dessel and Fleurus. In this figure, all attenuations laws used in the ROB PSHA study [9] are presented with and without taking into account the uncertainty on the data. The figures show that the EL-1 response spectra envelope the response spectra of the historical earthquakes.

Although this historical earthquake ground motion check can be considered as included in any PSHA of good quality, the applicant is asked to explicitly do this check and to show it (as for example it is done in Appendix B/Figure 1).

5.4. Consideration for the margin assessment

Consistently with [13], the safety analysis should demonstrate the sufficiency of conservatism for accidents induced by the EL-1 hazard. This is demonstrated if the margin defined below is sufficiently large and acceptable to the regulatory authority.

The margin is defined as the gap between the EL-1 hazard, and a hazard (named EL-1*) for which the radiological safety objective SO2 can still be ensured with the use of less conservative methods, assumptions and data (see [13] for more details). The acceptance criteria will be established by the regulatory authority on a case by case basis.

This gap can be measured in several ways:

- As a gap in exceedance frequency between the EL-1 hazard and the EL-1* hazard.
- As a gap in the severity between the EL-1 hazard and the EL-1* hazard (i.e. response spectrum).

5.5. Earthquake Level 2 (EL-2) at the outcropping rock

As indicated in [13], severe accidents from external hazards which would lead to early or large releases should be practically eliminated. For this reason, a rare and severe earthquake, which may be additional to the general design basis, needs to be addressed in the overall safety analysis.

This guideline recommends that the EL-2 is derived following a **deterministic seismic hazard analysis** (DSHA). This choice is deliberate in order to rely on an approach that is different from the one used to derive the EL-1 and hence prevent common cause shortcomings. The EL-2 is the **maximum credible earthquake (MCE)** affecting the site and this has to be demonstration by the applicant to the regulatory authority. The two approaches described below may help the applicant in doing this demonstration.

Approach 1: In this approach, an attenuation law for the rock outcrop motion is proposed and justified by the applicant to the regulatory authority. Usually, *magnitude* and distance from fault to site are input parameters. This attenuation law should be used to derive the PGA of the EL-2 and the following should be considered:

- The magnitude of the earthquake is at least equal to the maximum observed magnitude of all earthquakes considered at present by the Royal Observatory of Belgium in their source-zone models;
- The selected attenuation law is applied for the 84th percentile values of the accelerations (i.e. the median value + 1 standard deviation 'sigma')
- The earthquake is assumed to be located below the site (zero epicentral distance).

The applicant can propose a standardized response spectra representative for the rock outcrop or alternatively use the RG 1.60 [11] or the chosen attenuation law for the selected frequencies of interest.

Approach 2: In this approach, an earthquake intensity versus PGA correlation is proposed and justified by the applicant to the regulatory authority. The maximum credible earthquake intensity relevant for the site location should be proposed and justified by the applicant to the regulatory authority. This will allow the derivation of the PGA. The applicant can then propose a standardized response spectra representative for the rock outcrop or alternatively use the RG 1.60 [11] for the selected frequencies of interest.

Any alternative DSHA approach is also acceptable to the regulatory authority as long as the applicant justifies that the EL-2 is the maximum credible earthquake affecting the site location.

In all cases, the EL-2 should be significantly more severe than the EL-1 but not screened out[4] (otherwise another EL-2 should be proposed). Depending on the potential consequences posed by an installation, the EL-2 may or may not need to be defined and assessed. See the application of the graded approach provided in §5.2.

5.6. Site transfer function and free field ground motion response spectra

5.6.1. Site transfer function

As part of the quantification of earthquake ground motions at an installation site, a site specific analysis of soil response effects on ground motions should be done (unless the site is directly on the bedrock). In this context, the stiffness of the soil and bedrock as well as the depth of soil deposit should be carefully evaluated. The results of the *site response* analysis should show the input motion (derived from the rock outcrop response spectrum which is obtained from §5.3 or §5.4 or §5.5), the associated output motion (free field ground motion), and the site transfer function (spectral

[4] If a candidate EL-2 is excessively severe making it not credible or equivalently, if its corresponding annual exceedance frequency is too low, then this candidate earthquake could be screened out coherently with "Position 6: External hazards" of the WENRA Ref [8]

amplification function). Unless a non-linear model is validated by tests, experience and supported by references to published documents, only linear elastic soil behavior can be considered. If non-linear effects of the soil are taken into account than a comparison with a linear elastic soil behavior should be done and the respective responses to the input ground motion should be provided.

In order to compute the site response, the following model is acceptable [4]:
- A viscoelastic soil system overlying a viscoelastic half-space;
- A horizontally layered system;
- Materials that dissipate energy by internal damping;
- Vertically propagating body waves (shear and compression waves).

In addition, uncertainties in the mechanical properties of the site materials should be taken into account through parametric studies.

5.6.2. Free field ground motion response spectra

The earthquake acceleration time history at the ground is obtained by the convolution of the earthquake acceleration time history at the rock with the site specific transfer function. The free field ground motion response spectra can then be calculated easily.

For any new class I nuclear installations of graded approach category 4, 3 or 2, a minimum level is recognized as the lower limit to any seismic hazard study performed. This minimum level is represented by a standardized horizontal free field ground motion response spectrum anchored to a peak ground acceleration value of 0.1g (where ‘g’ is the acceleration due to gravity). This standardized free-field ground motion response spectrum is the one defined in RG 1.60 [11]. In case the free field ground motion response spectrum of the EL-1 does not envelop this minimum response spectrum then, this minimum response spectrum should be used. This minimum level does not apply for new class I nuclear installations of graded approach category 1 (see §5.2). For all free field ground motion response spectra, credit can be given to the site effects (amplification factor < 1).

6. References

[1] Moniteur Belge-21.12.2011, Arrêté Royal portant prescriptions de sûreté des installations nucléaires, 30 novembre 2011

[2] IAEA, Specific Safety Requirements, No. SSR-2/1, Safety of Nuclear Power Plants: Design, 2012.

[3] IAEA, Safety Standards Series No. NS-R-3, Site Evaluation for Nuclear Installations, 2003.

[4] IAEA, Safety Standards Series No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, 2004.

[5] IAEA, Specific Safety Guide N° SSG-9, Seismic hazards in site evaluation for nuclear installations, 2010.

[6] Western European Nuclear Regulators´ Association, Reactor Harmonization Working Group, WENRA Reactor Safety Reference Levels, January 2008

[7] Western European Nuclear Regulators´ Association, Reactor Harmonization Working Group, WENRA Safety Reference Levels for existing Reactors, 24 September 2014

[8] Western European Nuclear Regulator´s Association, Reactor Harmonization Working Group, Report “Safety of new NPP designs”, March 2013

[9] Royal Observatory of Belgium, Probabilistic Seismic-Hazard Assessment (PSHA) of the Belgian nuclear sites, 5 June 2012.

[10] Royal Observatory of Belgium, ROB-FANC 2012-02, Historical earthquake ground-motion check for the Belgian nuclear sites, final report, October 2012

[11] Regulatory guide 1.60, Design response spectra for seismic design of nuclear power plants, July 2014, Revision 2.

[12] http://classes.engr.oregonstate.edu/cce/winter2011/ce570001/Class%20Slides/06a20Slides%20-%20Codes.pdf, Earthquake Definitions, Oregon State University

[13] FANC, Guideline - Safety demonstration of new class I nuclear installations - Approach to Defence-in-Depth, radiological safety objectives and application of a graded approach to external hazards, 2013-05-15-NH-5-4-3-EN, revision 0, 27 February 2015

[14] IAEA, General Safety Requirements Part 4 (GSR Part 4), Safety Assessment for Facilities and Activities,2009

[15] IAEA, Safety Requirements NS-R-4, Safety of research reactors, 2005

[16] IAEA, Safety Requirements NS-R-5, Safety of Nuclear Fuel Cycle Facilities, 2008

[17] Council Directive 2014/87/EURATOM of 8 July 2014 amending Directive 2009/71/EURATOM establishing a Community framework for the nuclear safety of nuclear installations.

[18] Kramer Steven L., Geotechnical earthquake engineering, ISBN 0-13-374943-6, Prentice Hall, 1996

Appendix A: Glossary

rock outcrop [18]: location where bedrock is exposed at the ground surface

bedrock motion [18]: the motion at the base of the soil deposit (also the top of bedrock)

epicentre [5]: The point on the Earth's surface directly above the focus (i.e. *hypocentre*) of an earthquake.

free field ground motion [5]: Motion that would occur at a given point on the ground owing to an earthquake if vibratory characteristics were not affected by structures and installations.

frequency of exceedance [5]: The frequency at which a specified level of seismic hazard will be exceeded at a site or in a region within a specified time interval. In probabilistic seismic hazard analysis (PSHA), generally a one year time interval (i.e. annual frequency) is assumed. When the frequency is very small and it cannot exceed unity (in the prescribed interval), this number approaches the probability of the same event when the random process is assumed to be Poissonian.

hypocentre [5]: The point (focus) within the Earth at which an earthquake is initiated.

magnitude (of an earthquake) [5]: Measure of the size of an earthquake relating to the energy released in the form of seismic waves. Seismic magnitude means the numerical value on a standardized scale such as, but not limited to, moment magnitude, surface wave magnitude, body wave magnitude, local magnitude or duration magnitude.

maximum credible earthquake (MCE) [12]: The largest earthquake that appears capable of occurring under the known tectonic framework for a specific fault or seismic source, as based on geologic and seismologic data. Based on the maximum earthquake from deterministic analyses (DSHA). There may be multiple MCEs for a site, each from a different fault or seismic source.

outcropping rock: same as *rock outcrop*

peak ground acceleration (PGA) [5]: The maximum absolute value of ground acceleration displayed on an accelerogram; the greatest ground acceleration produced by an earthquake at a site.

response spectrum [5]: A curve calculated from an accelerogram that gives the value of peak response in terms of the acceleration, velocity or displacement of a damped single-degree-of-freedom linear oscillator (with a given damping ratio) as a function of its natural frequency or period of vibration.

rock outcropping motion [18]: the motion at a location where bedrock is exposed at the ground surface

seismotectonic model [5]: The model that defines the characterization of seismic sources in the region around a site of interest, including the aleatory and epistemic uncertainties in the seismic source characteristics.

site response [5]: The behavior of a rock or soil column at a site under a prescribed ground motion load.

uniform hazard response spectrum (UHRS) [5]: Response spectrum with an equal frequency of exceedance for each of its spectral ordinates.

Appendix B: Historical earthquake ground motion check (HGMC)

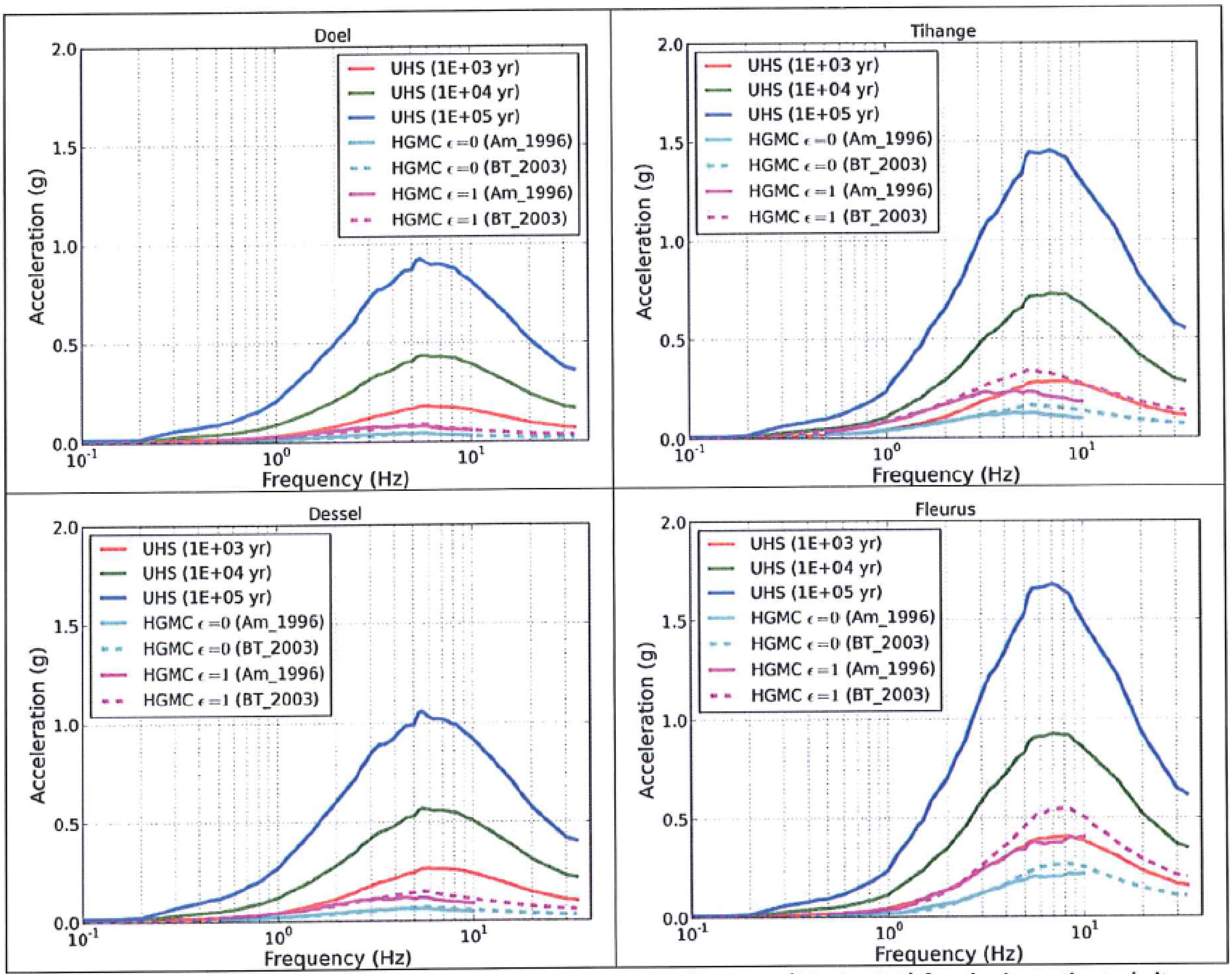

Figure 6 - Comparison of HGMC spectra with uniform hazard spectra (Mmin=3.5) for the investigated sites.
Top left: Doel. Top right: Tihange. Bottom left: Dessel. Bottom right: Fleurus.

Figure 1: Historical earthquake ground motion check (HGMC) from Ref [10]
(EL-1 = UHS (1E+04 yr); AM = Ambraseys (1996); BT=Berge-Thierry (2003)

Appendix C: Correspondence with international documentation

This appendix presents the correspondence between the sections in this guideline and relevant documentation issued by the IAEA and by WENRA. Note that for this correspondence the symbol § is used to indicate a section in this guideline and the abbreviation ´para.` is used to indicate a specific paragraph (text separated from other parts by a space). In case no paragraph is indicated, the entire (sub)section corresponds to the article in question.

C.1. NS-R-3

IAEA safety requirements NS-R-3 on site evaluation for nuclear installations form a significant part of this guideline:

Article (subject)	Correspondence (comment)
2.1 (objective)	§5.3 para. 1(limited to 2.1(a) – input to PSHA)
2.4 (site charact.)	§5.3 para. 1(expected input to PSHA)
2.5 (freq. and sev.)	§5.3 para. 1(expected input to PSHA)
2.6 (non-stationary effects)	§5.3 para. 1(expected input to PSHA)
2.7 (hazard parameters)	§5.3 para. 1, §5.4, §5.5
2.12 (potential radiological impacts)	§5.1
2.14 (site characterization)	§5.3 para. 1(expected input to PSHA); 5.5
2.15 (identification)	§5.3 para. 1(expected input to PSHA)
2.17 (data)	§5.3 para. 1(expected input to PSHA)
2.18 (methods)	§5.3 (PSHA)
2.19 (extent of data)	§5.3 para. 1(expected input to PSHA)
2.20(parameters for describing the hazard)	§5.3 para. 1(expected output of PSHA), §5.5, §5.6.2
2.21 (Site specific data)	§5.3 para. 1(expected input to PSHA), §5.5, §5.6.1
3.1 (seismological and geological conditions)	§5.3 para. 1 (expected input to PSHA)
3.2 (recorded earthquakes)	§5.3 para. 1 (expected input to PSHA)
3.3 (seismotectonic evaluation)	§5.3 para. 1 (expected input to PSHA)
3.4 (ground motion)	§5.3 para. 1 (PSHA expected output)
3.5 and 3.6 (the fault capability)	§5.5

C.2. SSR-2/1

IAEA SSR 2/1 with specific safety requirements on safety of nuclear power plants, specifically the design, is not covered by the underlying guideline because the protection concept and design assessment are out of its scope. However, requirement 17 on internal and external hazards states that:

All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered for determination of the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant.

For Earthquakes this entire guideline conforms to this requirement through section 5.

C.3. NS-R-4

IAEA Safety Requirements NS-R-4 on Safety of research reactors is covered by the underlying guideline as follows:

Article (subject)	Correspondence (comment)
5.15 (seismotectonic characteristics)	§5.3 (expected in PSHA)
5.16 (extent of site investigation)	§5.3 (expected in PSHA)
6.21 (external events design basis)	§5.3, §5.5

C.4. NS-R-5

IAEA Safety Requirements NS-R-5 on Safety of Nuclear Fuel Cycle Facilities is covered by the underlying guideline as follows:

Article (subject)	Correspondence (comment)
5.5 (site characteristics)	§5.3 (expected in PSHA)
6.8 (postulated initiating events/Annex I)	§5.3, §5.5

C.5. SSG-9

IAEA Specific Safety Guide SSG-9 on seismic hazards in site evaluation for nuclear installations provides guideline for the data to collect, for the construction of a regional seismotectonic model, for the evaluation of the ground motion hazard, for the conduct of a probabilistic and a deterministic seismic hazard analysis and finally for the design basis ground motion, fault displacement and other hazards associated to earthquakes.

§4.3.6 indicates that this IAEA guide should be considered for all those organizations developing one or more of the topics mentioned above:

Article (subject)	Correspondence (comment)
§2,§3,§4,§4 and §6 (Probabilistic analysis)	§5.3 (PSHA)
§7 (Deterministic analysis)	§5.5
§2.10 and §2.11 (minimum hazard)	§5.6.2

C.6. NS-G-3.6

IAEA Safety Standards Series NS-G-3.6 on Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants is covered by the underlying guideline as follows:

Article (subject)	Correspondence (comment)
§3.11 (site response)	§5.6.1

C.7. Updated WENRA reference levels

The updated WENRA reference levels for existing reactors are considered here [7]. WENRA reference levels under T5 on “protection against design basis events” are not addressed because outside the scope of this guideline. For the other reference levels the correspondence is as follows:

Reference level (subject)	**Correspondence (comment)**
T1.1 (objective)	§1 para. 1, §5.1
T2.1 (identification and justification)	§5.1
T2.2 (list of hazards)	- (suppressed, as guideline is on earthquakes
T3.1 (screening)	§5.3 (expected in PSHA) in particular footnote 3
T3.2 (hazard assessment: det. and prob.)	§5.3 and &5.5
T3.3 (hazard assessment: specific considerations)	§5.3 (expected in PSHA)
T4.1 (DBE)	§5.3 (expected in PSHA)
T4.2 (exceedance freq.)	§5.3 para. 1
T4.3 (historical check)	§5.3 “Historical earthquake ground motion check”
T4.4 (DBE parameters)	§5.3 para. 1 (UHRS)
T6.1 (DEC events)	§5.4 and §5.5 (the margin assessment and the EL-2 address this RL)
T6.2 (DEC events/hazard curves)	§5.3 (expected in PSHA)
T6.3 (DEC events /improvements)	§5.2 (For DEC events, this quideline asks to rach specified safety objectives)