Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

Seismological quickscan for Borssele

Available data and recommendations for approach

P.P. Kruiver, J. Spetzler

De Bilt, 2023| KNMI-Publicatie 23-02

Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

Seismological quickscan for Borssele
Available data and recommendations for approach

Date 24 August 2023
Status final

Colophon

Version	1
Contact	Dr. P.P. Kruiver
Appendices	3
Authors	Dr. P.P. Kruiver Dr. J. Spetzler

Content

1 Introduction

At the end of 2022, the Dutch government has approved the Borssele site, the Netherlands, as the location for two new nuclear power plants (NPP). The Ministry of Economic Affairs and Climate (EZK) has commissioned several preparatory studies in order to assess what is required to build these NPP. As part of this preparation, Deltares has requested advice from KNMI on seismological topics.

In this stage, the two relevant seismological topics are:

1) Background data:
   a. List of available seismological data at KNMI
   b. Summary of relevant Probabilistic Seismic Hazard Analysis (PSHA) studies
2) International standards for Nuclear Power Plants in relation to the general PSHA framework.

The available seismological and other background data relevant to PSHA are described in chapter 2. The overview of available PSHA for the site, for the Netherlands, for neighbouring countries and for the EU is included in chapter 3. The international standards for conducting a PSHA for NPP are described in chapter 4.

We recommend performing a PSHA using state-of-the art knowledge about seismic hazard assessment for the new NPPs in Borssele conform SSHAC. The SSHAC Level can be determined in collaboration with the nuclear regulator ANVS.

2 Background information

2.1 Seismological observations of earthquakes

One of the inputs for a PHSA is the earthquake catalogue within ~ 200 km of the site. Since the founding of KNMI in 1854, seismology has been part of the tasks. Instrumentation with seismometers for the registration of earthquakes started in 1910. The first seismometers were analogue instruments recording on e.g. smoke paper. Events were analysed manually. Arrival times of phases (picks) were manually added to the earthquake database. In the early days, only seismic events were stored.

Nowadays, digital seismological data is stored on the Web Services of the International Federation of Digital Seismograph Networks (FDSN). The KNMI event catalogue of Dutch earthquakes on the FDSN web services starts in 1911. For pre-digital seismometer times, event data, such as picks, location and magnitude were manually added to the FDSN. The network started relatively sparse. Therefore, additional stations from Europe were used for the determination earthquake locations and magnitudes.

The development of the seismometer network is documented in Dost and Haak (2002) in terms of expansion phases of the network and types of sensors. The network is referenced as KNMI (1993). Seismometers developed through the years and became digital. Digital seismometers were installed in the Netherlands from 1993 on. These seismometers were recording continuous data. However, not all data were stored continually for all stations. For several stations, only triggered data was digitally stored. This means that after a trigger, 1 or 2 minutes of data was stored. This was the amplitude of the X, Y and Z components with a defined sample frequency. During that period, earthquake locations were analysed using stations in the Netherlands, Belgium and Germany. When data telecommunication improved the switch was made from storing triggered data to storing continuous data for all Dutch stations. This was around 2009-2010. The network has expanded considerably since then, notably in Groningen, Drenthe, Friesland, Twente, North Holland and South Holland. The station configuration in the south remained rather constant. Individual equipment was upgraded, but station locations were stable.

All event data, triggered data and continuous data is made available through http://rdsa.knmi.nl/ with links to ORFEUS and the FDSN Web Services. Queries can be made on http://rdsa.knmi.nl/dataportal/. Data availability can be checked per station using http://www.orfeus-eu.org/data/eida/quality/availability/.

The earthquake catalogue is relevant for the seismic hazard. The earthquake catalogues for tectonic events and for induced events since 1911 are updated after each new event in csv, json, xml and pdf format on
https://www.knmi.nl/kennis-en-datacentrum/dataset/aardbevingscatalogus
and via the KNMI Data Platform in nc format:
https://dataplatform.knmi.nl/dataset/aardbevingen-catalogus-1.

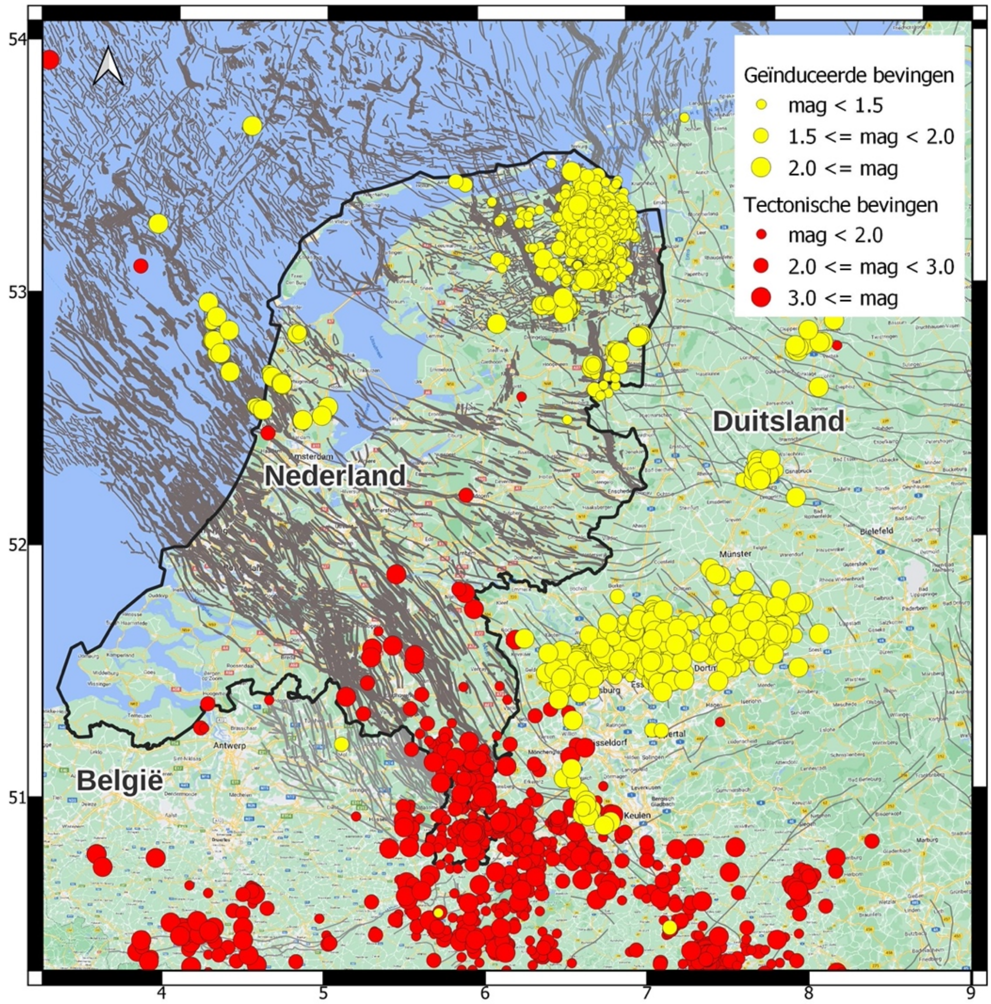

Figure 1. Tectonic (red) and induced (yellow) earthquakes in the earthquake KNMI catalogue (date: 17 April 2023).

The earthquake locations from the KNMI catalogue are shown in Figure 1. Especially the earthquakes near Antwerpen are relevant for the seismic hazard in Borssele. These are listed in Table 1.

Table 1. Earthquakes in the KNMI catalogue within ~ 85 km from Borssele. M is given in local magnitude.

Date YYYYMMDD	Time	Location	Lat (N)	Lon (E)	Depth (km)	M
19210519	24100.00	Galmaarden (Belgium)	50.77	3.95	15	4
19330323	184813.14	Middelkerke (Belgium)	51.122	2.863	10	4.7
19380611	105737	Ronse (Belgium)	50.73	3.62	19	5.6
19380611	130906.79	Maarkedal (Belgium)	50.78	3.58	10	4
19380612	132540.00	Maarkedal (Belgium)	50.78	3.58	10	4.5
19880615	30243.06	Rilland (Netherlands)	51.384	4.26	3.1	2.1
20010801	10805.90	Wuustwezel (Belgium)	51.402	4.648	5.4	1.8
20080214	92935.01	Beveren (Belgium)	51.287	4.24	1.9	1.9
20080214	95146.17	Beveren (Belgium)	51.288	4.218	3.4	2.3

Earthquakes from before instrumentation started are documented in Houtgast (1991). In this report, however, several described events appeared not to be an earthquake. The events listed in Houtgast (1991) were reviewed as part of a project commissioned by EBN in 2021. The reviewed list is included in Appendix 2. Events that were interpreted as true earthquakes are indicated in red. The last entries of this table with events from 1911 are also included in the earthquake catalogue.

Catalogues of neighbouring countries were reassessed as part of the national PSHA maps. The earthquake catalogue of BGS (United Kingdom) is described in Mosca et al (2020) and up-to-date information is available on the BGS website.

The earthquake catalogue used in the PSHA of Germany is documented in Grünthal et al (2018a) and references therein. The administration of Flanders, Belgium, had commissioned a reassessment of the Flanders catalogue and the surrounding area. Different earthquake catalogues were combined and double entries were removed. The Flanders catalogue and extended catalogue are documented in Qcon (2021). The public dataset can be requested from Departement Omgeving Vlaanderen, Afdeling Vlaams Planbureau voor Omgeving. This dataset, however, is not kept up-to-date.

2.2 Other background information

Information about site characterization is important input for PSHA. This includes the geological composition of the subsurface and parameters such as V_{S30} (the time-averaged shear-wave velocity over the top 30 m). There is a Seismic Cone Penetration Test (SCPT) with a V_{S30} profile available from EPZ, the operator of the current NPP in Borssele. The SCPT and possibly other subsurface information can be requested at EPZ as classified information.

On a regional scale, a V_{S30} map has been derived for the part of the Netherlands which is covered by the geological model GeoTOP (Stafleu et al, 2022). This map is included in Figure 2. This map shows low values for V_{S30} for the province of Zeeland in general.

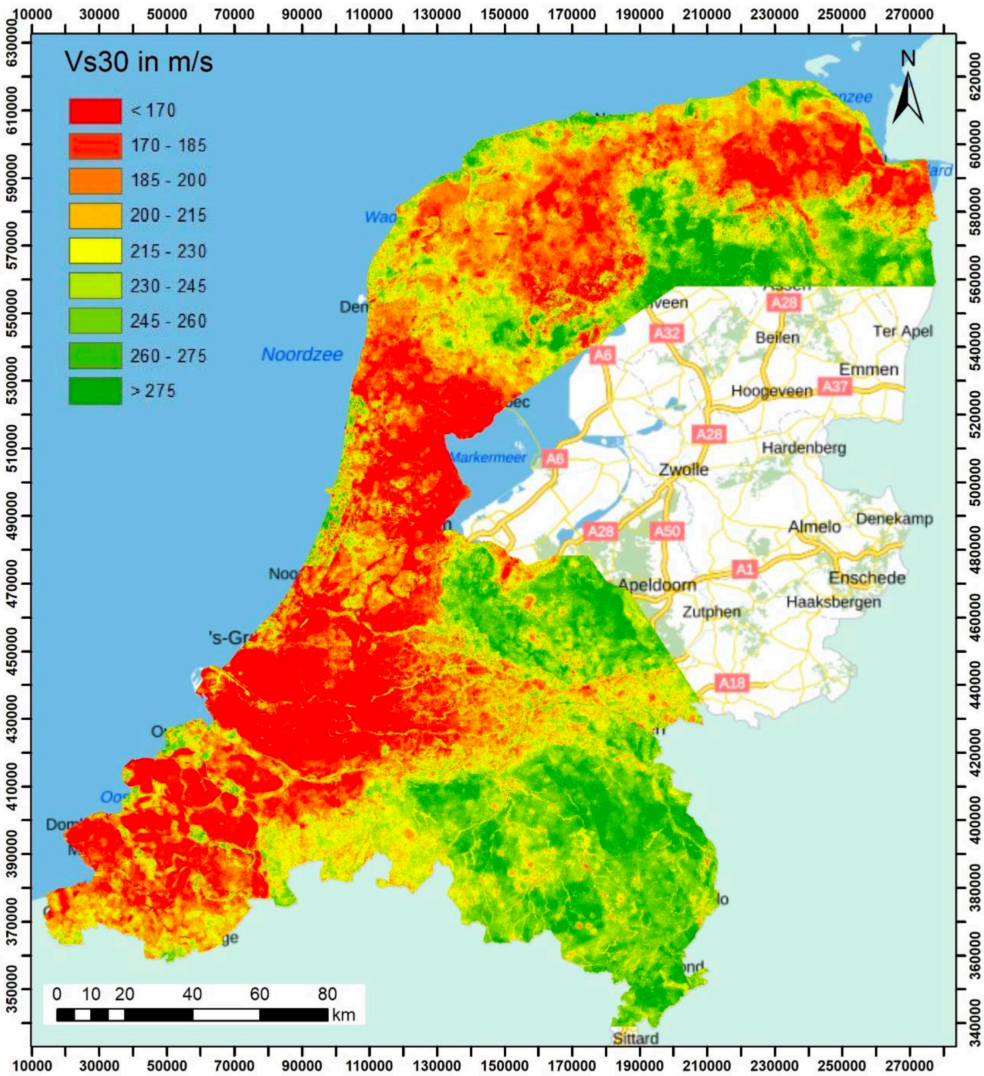

Figure 2. Mean V_{S30} map of the on-shore part of the Netherlands with GeoTOP coverage (Stafleu et al, 2022).

3 PSHA studies

3.1 Modern PSHA approaches

Probabilistic Seismic Hazard Analysis aims at quantifying the rate (or probability) of exceeding defined ground-motion levels, such as PGA or spectral acceleration, at a site or on a map given all possible earthquakes. During the last decades, the use of logic trees in PSHA has become common practice. Each branch of the tree reflects a choice in models and parameters. Instead of looking at one preferred model, the ensemble of all possible models is investigated. The main purpose is to capture the center, body and range of defensible technical interpretations of ground motions (USNRC 2012). Two types of uncertainty need to be considered in PSHA:

1. Epistemic uncertainty, describing the uncertainty in modelling the processes due to lack of sufficient data and knowledge. This results in uncertainty in the correct value of the median.
2. Aleatory variability referring to the natural randomness of a process. This results in variation around the median.

The logic tree has two parts: one part with branches for the seismic source characterization (SSC) and one part with branches for the ground-motion characterization (GMC). The SSC includes different source zones models, earthquake locations, magnitude frequency distributions and maximum magnitudes. The GMC part is populated by Ground Motion Prediction Equations (GMPE's). The GMPE compendium by Douglas (Douglas and Edwards 2016; Douglas 2021) is a useful resource for GMPE's and contains all modern GMPE's with information about their application range.

Logic trees are applied to capture epistemic uncertainty. Each GMPE has an uncertainty model representing aleatory variability. The complete logic tree with its branches and appropriate weights is intended to represent the underlying continuous distribution of possible ground motions. The design of logic trees and the choice of weights is specialist work (e.g. Bommer 2012), as is the selection of suitable GMPE's (Bommer et al. 2010; Bommer and Stafford 2020).

For site-specific PSHA, the backbone GMPE approach is becoming more widely used (Douglas, 2018; Bommer and Stafford, 2020). Instead of populating the logic tree with different GMPE's, one backbone GMPE is chosen. This backbone GMPE is adjusted and re-scaled to describe a range of median ground motions that captures the epistemic uncertainty. The scaling factors are intended to represent the influence of uncertainties in the seismological properties of the ground motion in the target region such as, for example, local characteristics of stress-drop and attenuation. A recent example of a backbone GMPE for Europe is developed by Weatherill et al (2020).

3.2 Available PSHA for Borssele

The national seismic hazard map of the Netherlands based on macroseismic intensity dates from 1996 (de Crook, 1996). A seismic hazard map for Peak ground Acceleration (PGA) was calculated by de Vos (2010). These maps are shown in Figure 3. For specific sites, such as the Delft reactor or the Pallas reactor in Petten site specific seismic hazard analyses were carried out. As described in the previous section, there have been large advancements in PSHA approaches during the last decade. KNMI is currently updating the seismic hazard map for tectonic earthquakes.

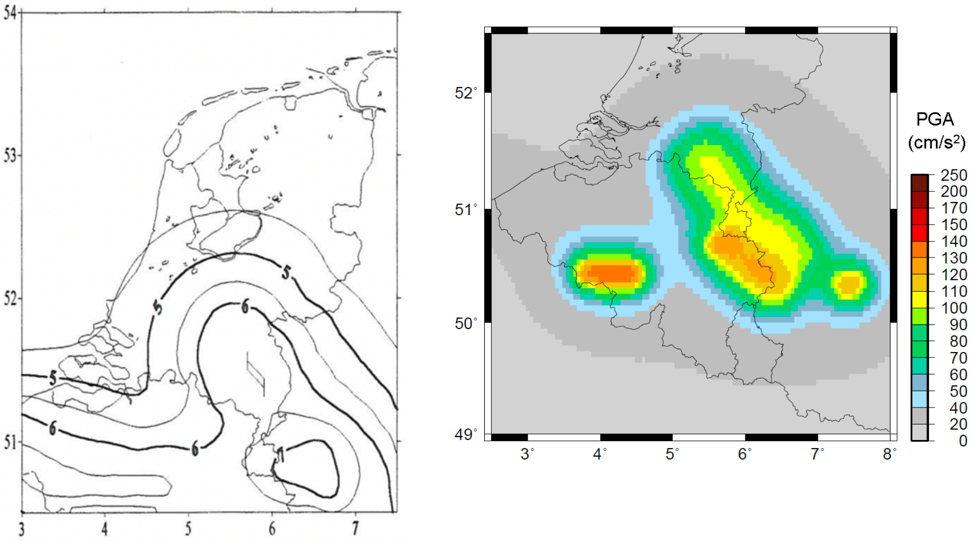

Figure 3. Seismic hazard maps a return period of 475 years for the Netherlands. Left for European Macroseismic Scale, de Crook (1996). Right for PGA, showing one of the possible hazard outcomes from de Vos (2000), based on M3C and the GMPE of Campbell and Bozorgnia (2008).

In response to the damage to nuclear facilities in Fukushima in March 2011, all European nuclear facilities were required to perform a stress test. The stress test for Borssele is reported by the Ministry of Economic Affairs, Agriculture & Innovation (2011). A summary in Dutch for the general public is provided by EPZ (EPZ, 2011). In these documents, the design PGA is compared to the seismic hazard for PGA. The assessment is based on the strongest earthquake reported in the region. This is the earthquake near Tournai, Belgium that occurred on June 11 1938 with a magnitude of 5.6 on the Richter scale and a macroseismic intensity of V½. The macroseismic intensity unit for the assessment was increased by 1 to VI½ conform the then valid guidelines of the International Atomic Energy Agency (IAEA) and Kerntechnische Ausschuss (KTA). The macroseismic intensity was converted to a PGA value of 0.075 g. The strongest earthquake has a lower PGA value than the design value for PGA of 0.1 g. This means that the facility is stronger than the design earthquake. The national stress test was assessed during a European review round. The National Report was judged as being of very good quality (ENSREG, 2012). The facility complies with the safety requirements (Kamerbrief, 2012). One of the recommendations of the European review regarding earthquakes was to perform an additional seismic hazard analysis.

The owner of the Borssele power plant EPZ commissioned KNMI to carry out a recommendation study for seismic hazard in context of IAEA for the site of the Borssele nuclear reactor. KNMI performed a preliminary PSHA (van Eck et al, 2013). This analysis was carried out without an in-depth analysis of all aspects such as choice of source zones, the earthquake catalogue, magnitude-frequency distributions and the minimum and maximum magnitude to be considered. For the 10-yearly update in 2022, KNMI reviewed the then available information. Based on the scientific progress and the available information, KNMI recommended performing a thorough PSHA in accordance with modern standards. This recommendation was discussed between EPZ and the regulator ANVS. For the currently existing NPP, ANVS assessed that the available seismic hazard information was sufficient and no full PSHA was required. The seismic hazard information can be requested from EPZ or ANVS.

For a new nuclear facility, the return period to be considered is 10,000 years. De Crook (1993) provides a seismic hazard map in terms of macroseismic intensity for this return period. His figure 5f shows a macroseismic intensity for Borssele of VI. This roughly agrees with the macroseismic intensity of the strongest earthquake in the region. A more recent probabilistic seismic hazard study resulted in a macroseismic intensity of 6,4 for a return period of 10,000 years (EPZ, 2015). The determination of the seismic hazard, however, has undergone significant scientific improvements. Hazard maps based on macroseismic intensity are considered to be outdated.

3.3 PSHA for neighbouring countries

The earthquake hazard map of Europe has been developed by the European Facilities for Earthquake Hazard and Risk (EFEHR). This is a non-profit network of organisations and community resources aimed at advancing earthquake hazard and risk assessment in the European-Mediterranean area. The current earthquake hazard model of Europe is the 2020 European Seismic Hazard Model (ESHM20) (Danciu et al, 2021). The map in Figure 4 shows the expected level of ground shaking at a specific location due to future potential earthquakes that might occur locally or at a greater distance. In general, seismic hazard is high in Turkey, Greece, Albania, Italy and Romania. Considerable seismic hazard is present in the other Balkan countries and in some regions of Austria, Belgium, France, Germany, Iceland, Norway, Portugal, Slovenia, Spain and Switzerland. But even in regions with low or moderate seismic hazard, earthquakes can occur at any time. The European seismic hazard map shows the information on a coarse scale. Countries have often derived more dedicated seismic hazard maps for their territory.

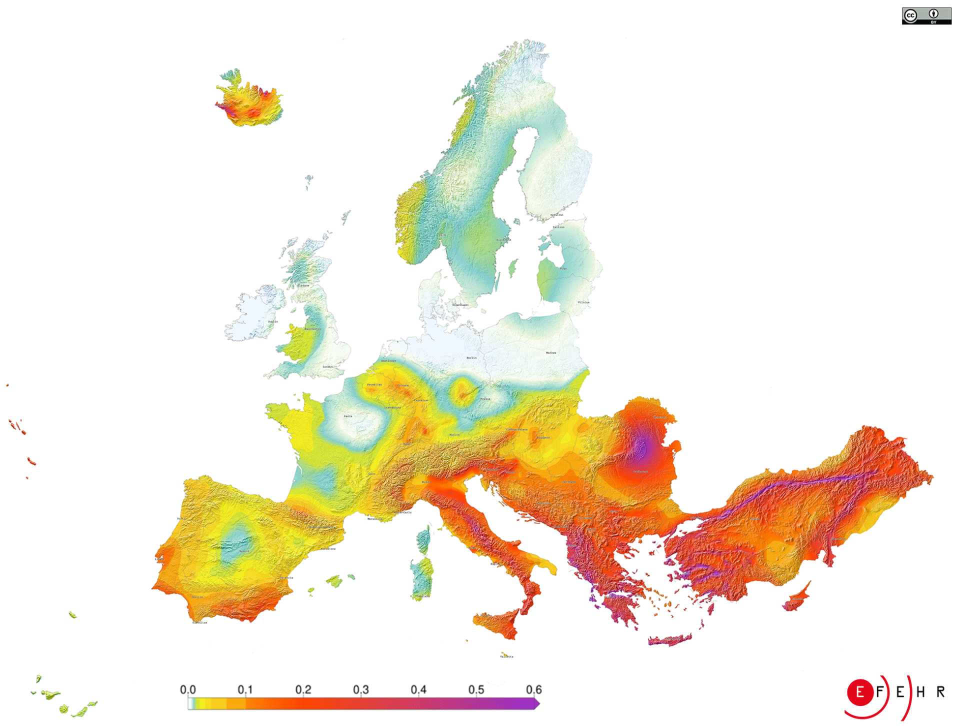

Figure 4. European seismic hazard map (ESHM20, Danciu et al, 2021). Ground shaking is expressed as Peak Ground Acceleration (PGA), normally given in the percentage of "g", the Earth's gravitational acceleration for a return period of 475 years.

Recently, countries neighbouring the Netherlands have developed nation-wide or regional seismic hazard maps. In Germany, the conversion has been made from macroseismic intensities to spectral accelerations. Grünthal et al (2018a, b) developed the well documented German seismic hazard maps (Figure 5). This PSHA is also disseminated by an interactive hazard map (GFZ, 2016).

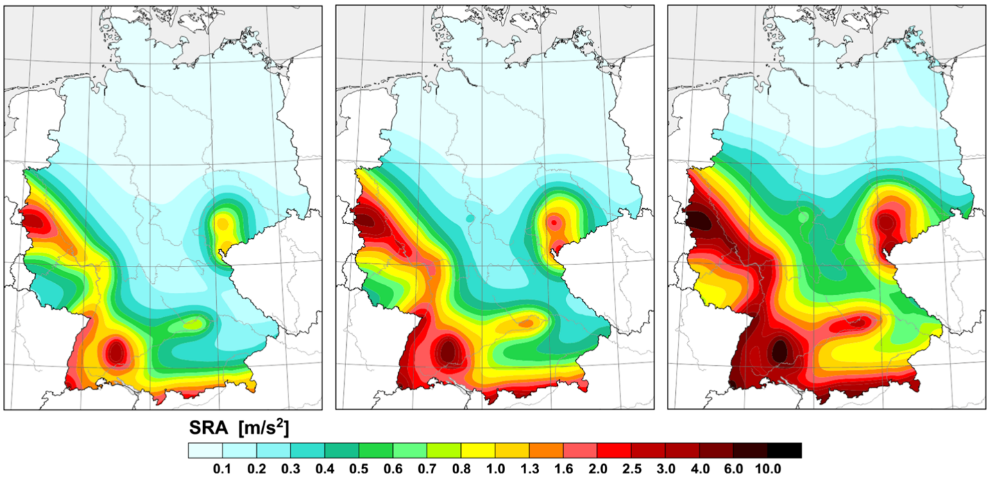

Figure 5. Spectral accelerations (SRA) for Germany, averaged over the periods from 0.1 to 0.2s (plateau) for the return periods of 475, 975 and 2475 years (left to right). From Grünthal et al (2018a).

The seismic hazard map for Belgium within the Eurocode 8 framework is based on the seismic hazard assessment by Leynaud et al (2000), who considered only one source model and one ground-motion model. The seismic zonation map for PGA and a return period of 475 years is shown in Figure 6. This seismic zonation map is available on the geo.be data portal.

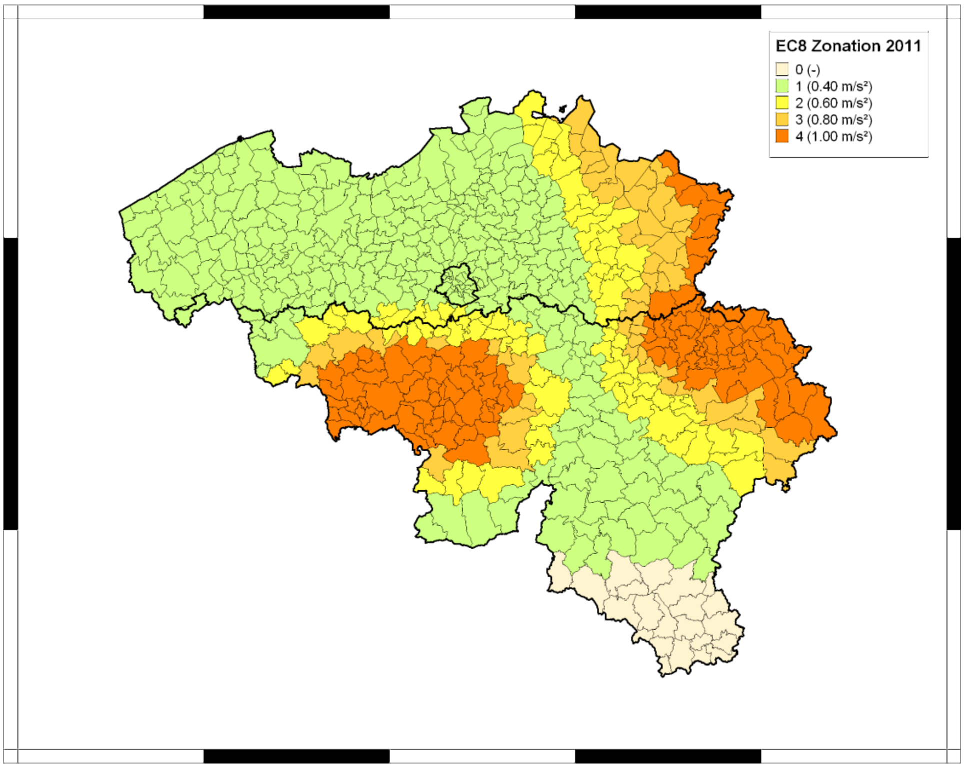

Figure 6. Seismic zonation of Belgium, national annex of Eurocode 8, for PGA and a return period of 475 years (NBN, 2011; map from data portal geo.be).

Later, two updates were made: one for Flanders (Vanneste et al, 2009) and one for Wallonia (Vanneste et al, 2017). For Flanders, two additional seismic source zone models were used and the same ground-motion model as in Leynaud et al. (2000). One of these source models, the "Seismotectonic" source model, was documented in detail in this study. The resulting hazard maps for the two seismic source models, for PGA and a return period of 475 years are shown in Figure 7.

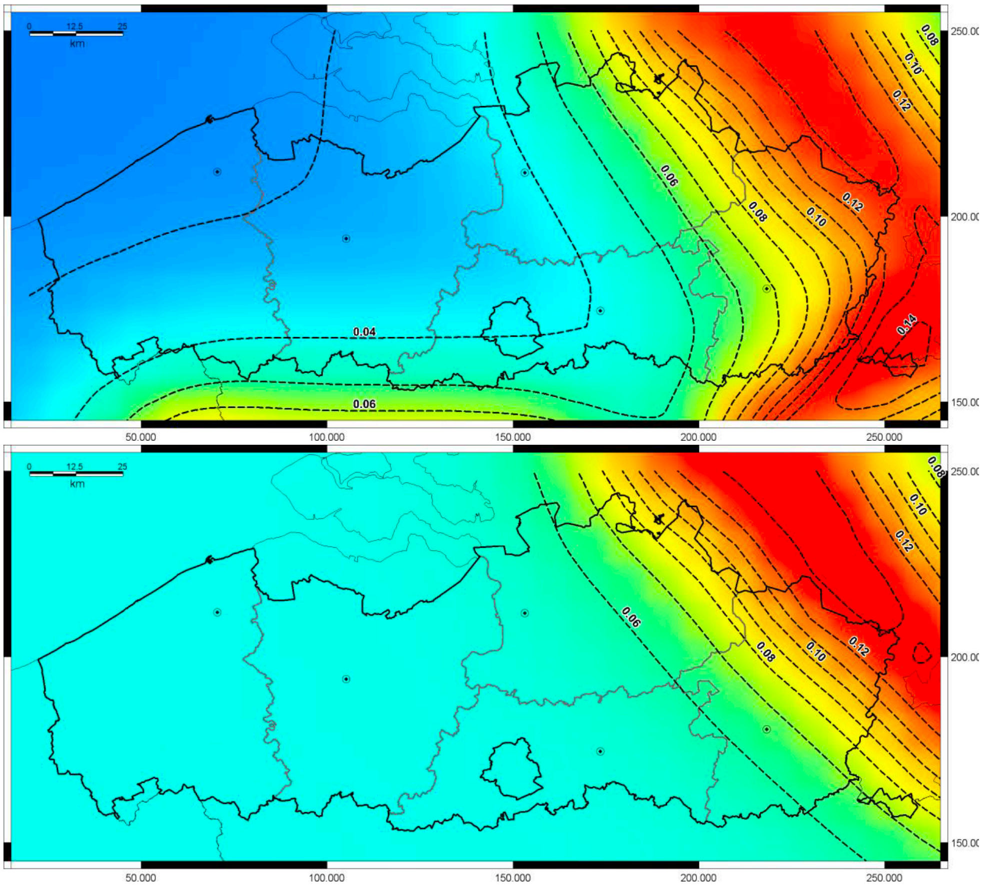

Figure 7. Updated seismic hazard maps for Flanders for PGA and a return period of 475 years for the seismotectonic source model (top) and the two-zone model (bottom). From Vanneste et al (2009, chapter 5).

Vanneste et al (2017) developed a seismic hazard map for the Walloon region in Belgium. The motivation for this update was to assist the Walloon Government with the development of new regulation specific for the Seveso industry (hazardous substances) in Wallonia. Because of this industry, longer return periods than used in Eurocode 8 were considered. This study benefited from the experience gained by the Royal Observatory of Belgium in several site-specific hazard studies for the nuclear industry in the years before (e.g. site study for disposal of category-A nuclear waste, European stress tests and follow-up study for the Belgian NPPs). Consequently, the level of sophistication of this study is much higher than in the older regional studies. The most important improvements are the use of a logic tree to capture epistemic uncertainties at the level of source geometry (2 source models), magnitude-frequency distribution in each source (25 models), GMPE's. For the latter, a distinction was made between active crust (Lower Rhine Graben area with known active faults) and stable crust (the area outside the Lower Rhine Graben). A further distinction was made between standard rock (V_S ~800 m/s) and hard rock (V_S > 1500 m/s) for the stable crust.

For each of the 3 cases, a selection of 4 to 5 recent GMPE's was made. The Walloon maps were calculated return periods of 475 years, 1000 years, 3000 years and 5000 years for PGA and 1 s spectral period, for standard rock and for hard rock. The PGA maps for 475 and for 5000 years and standard rock are shown in Figure 8 as examples.

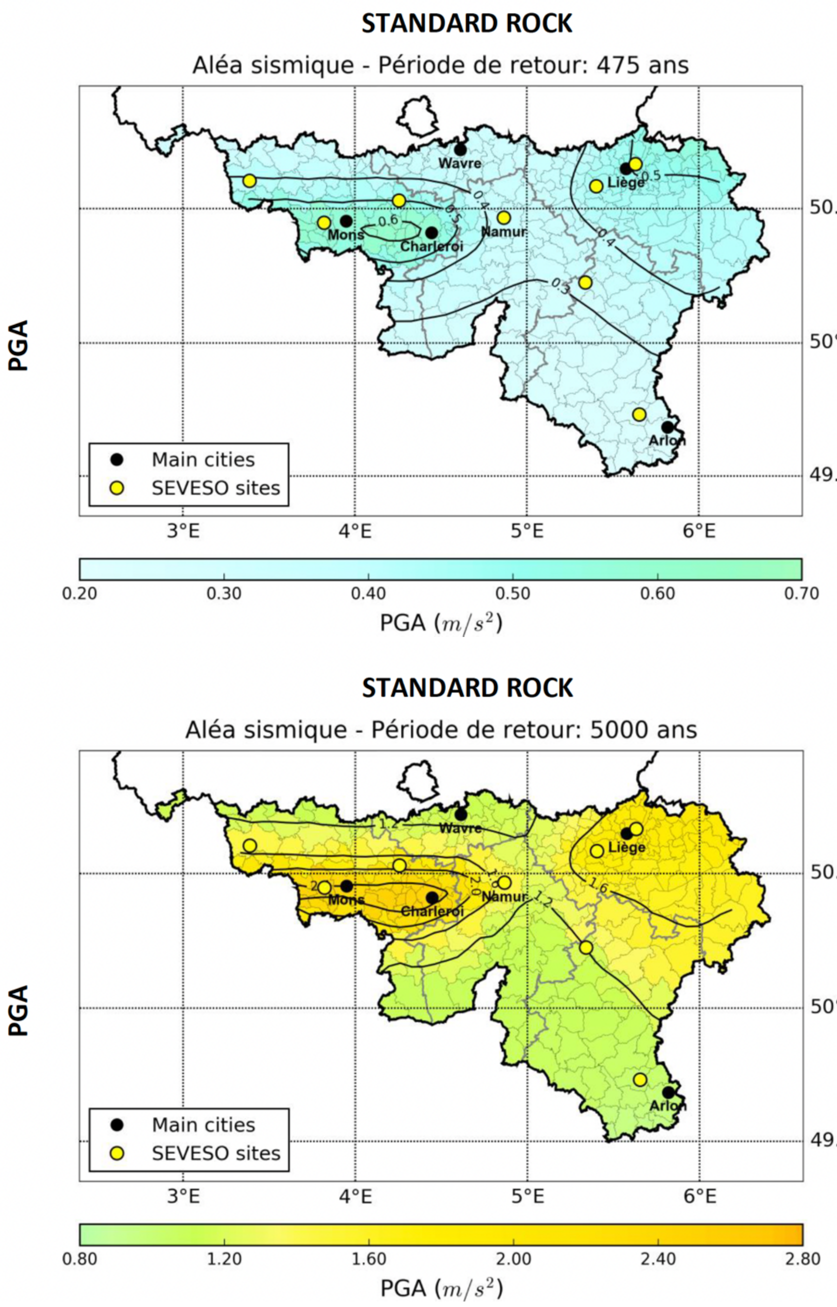

Figure 8. PGA for the Walloon region for a return period of 475 years (top) and 5000 years (bottom). From Vanneste et al (2017).

The British Geological Survey developed the seismic hazard map for the United Kingdom using Monte Carlo sampling of the logic tree (Mosca et al. 2020; Mosca et al, 2022). The seismic hazard maps were calculated for PGA and spectral acceleration for periods of 0.2 s and 1.0 s, for return periods of 475 years and 2475 years. The hazard maps for a return period of 475 years are shown in Figure 9 as an example. The maps can be downloaded from the BGS website (n.d.).

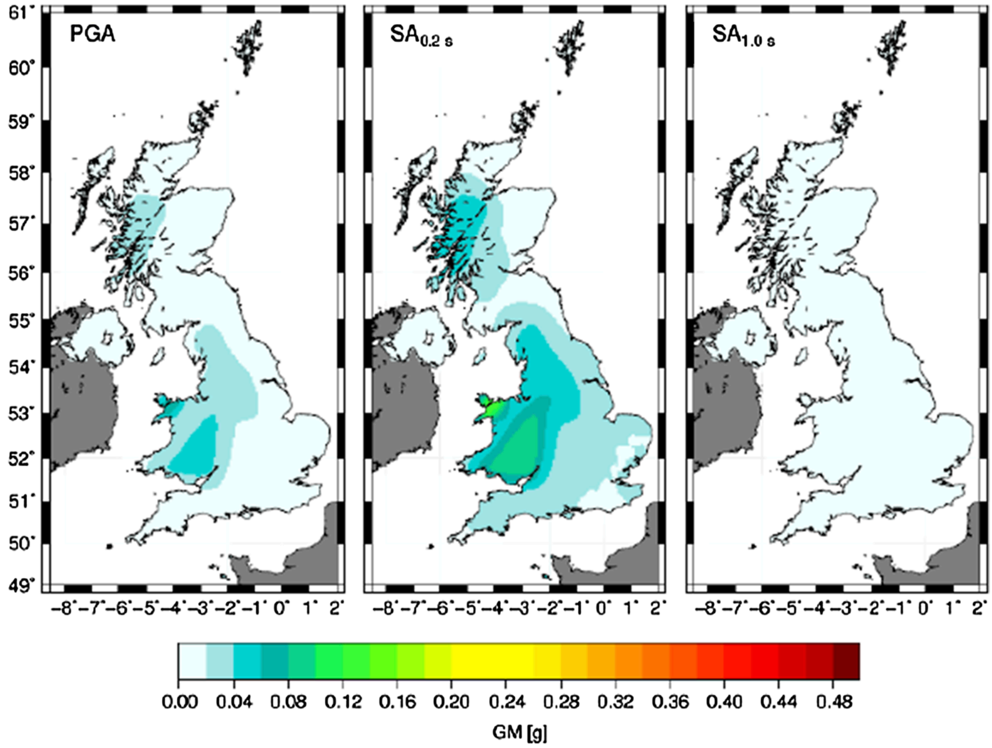

Figure 9. Seismic hazard maps for PGA, 0.2 s and 1.0 s peak spectral accelerations, for a return period of 475 years. From Mosca et al (2022).

4 PSHA according to international standards

There are two frameworks for conducting a PSHA for a nuclear facility. The first is the IAEA- SSG-9 guideline (2022). This document provides recommendations about the components and the type of information that should be included in the PSHA. The second is the guideline from the United Stated Nuclear Regulatory Commission (USNRC, 2018). This document describes the SSHAC process to be followed to achieve a well-documented hazard study that captures the center, body and range of technically defensible interpretations. Whereas the IAEA- SSG-9 describes the *what*, the SSHAC describes the *how*. In the next sections, both frameworks are summarised.

4.1 What: IAEA-SSG-9 guideline

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste pose a radiation risk and must therefore be subject to standards of safety. The International Atomic Energy Agency (IAEA) has published several safety standards. The IAEA safety standards are based on the practical experience of its Member States. They reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. Two IAEA Safety standards are relevant for seismic hazard: the IAEA-SSR1 (2019) and the IAEA-SSG-9 guideline (2022). The IAEA-SSR1 (2019) is a Specific Safety Requirements document for nuclear installations. The IAEA-SSG-9 is a Specific Safety Guide and deals with seismic hazards in site evaluation for Nuclear Installations. It describes all components of a PSHA.

The safety requirements for nuclear installations are described in IAEA-SSR-1 (2019). The objectives of IAEA SSR-1 are:

- Defining the information to be used in the site evaluation process;
- Evaluating a site such that the site specific hazards and the safety related site characteristics are adequately taken into account, in order to derive appropriate site specific design parameters;
- Analysing the characteristics of the population and the region surrounding the site to determine whether there would be significant difficulties in implementing emergency response actions effectively.

To meet these objectives, 27 requirements are given, which fall into several groups:

- 1 requirement for the safety objective in site evaluation for nuclear installations
- 1 requirement for the application of the management system for site evaluation
- 12 general requirements for site evaluation
- 2 requirements specific for seismic hazards
- 1 requirement specific for volcanic hazards
- 2 requirements specific for meteorological hazards
- 3 requirements specific for flooding hazards
- 2 requirements for other natural hazards
- 3 requirements for the evaluation of the potential effects of the nuclear installation on the region
- 2 requirements for monitoring and periodic review of the site

The two requirements specific for seismic hazards are about fault capabilities and ground motion hazards.

The objective of IAEA-SSG-9 is to provide recommendations on how to meet the requirements established in SSR-1 (IAEA, 2019) in relation to the evaluation of hazards generated by earthquakes that might affect a nuclear installation site and on how to determine the following:

- The vibratory ground motion hazards necessary to establish the design basis ground motions and other relevant parameters for the design and safety assessment of both new and existing nuclear installations;
- The potential for, and the rate of, fault displacement phenomena that could affect the feasibility of a site for a new nuclear installation or the safe operation of an existing installation at a site;
- The earthquake parameters necessary for assessing the associated geological and geotechnical hazards (e.g. soil liquefaction, landslides, differential settlements, collapse due to cavities and subsidence phenomena) and concomitant events (e.g. external flooding phenomena such as tsunamis and fires).

A useful flowchart showing all the components of the seismic hazard assessment is given in Figure 10.

Article [2.9] of the IAEA-SSG-9 (2022) states that structured expert interactions should be employed to avoid artificial influence of uncertainty estimates on the results. Reference is made to NRC (2018) in order to capture the centre, body and range of the technically defensible interpretations.

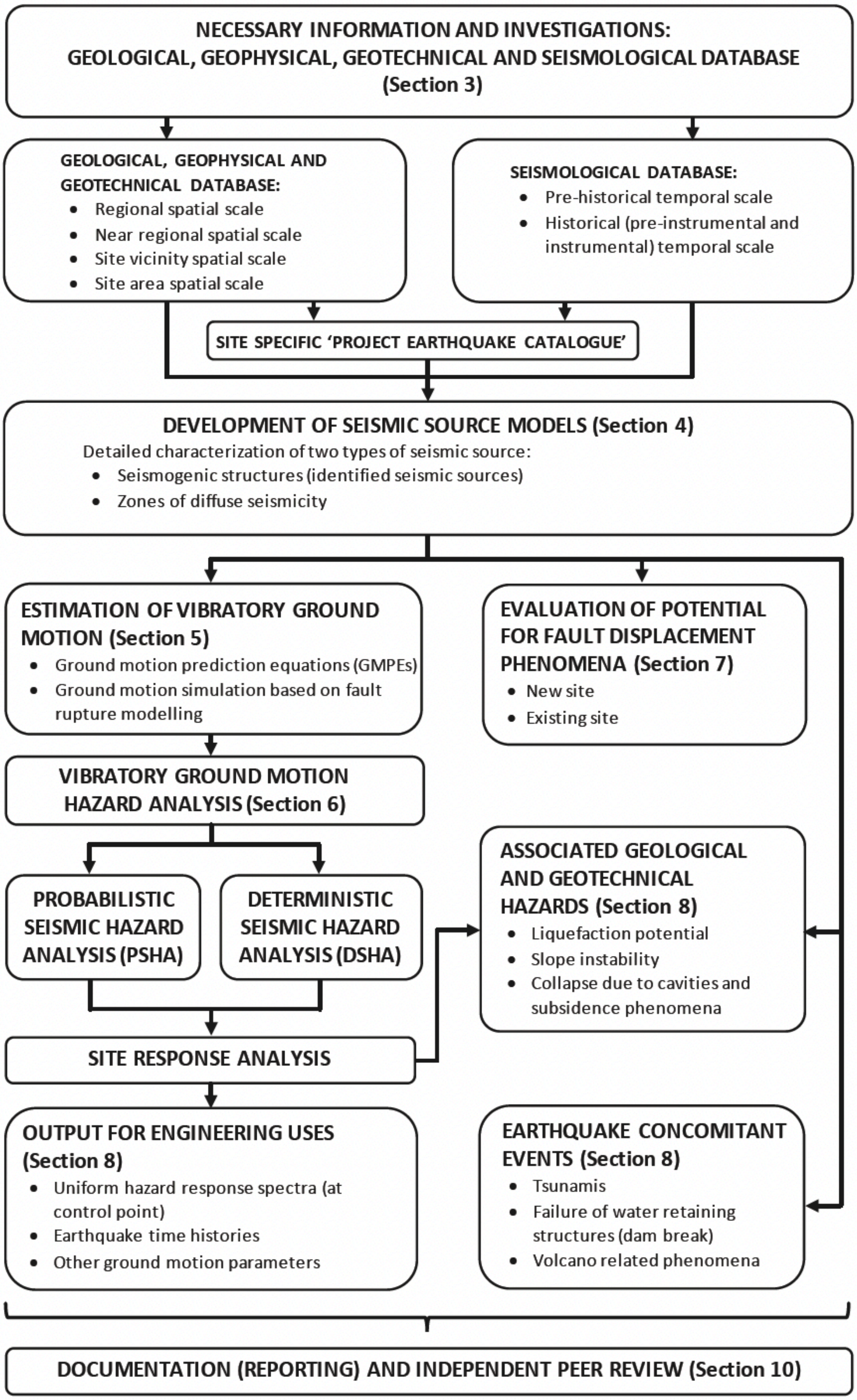

Figure 10. Flow chart showing the seismic hazard assessment process for nuclear installations (IAEA, 2022).

4.2 How: SSHAC

The United States Nuclear Regulatory Commission issued the NUREG/CR-6372, entitled "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts" in 1997 (USNRC, 1997). This document was the result of four years of deliberations of the Senior Seismic Hazard Analysis Committee (SSHAC) regarding the way uncertainties in probabilistic seismic hazard analysis should be addressed using expert judgment. The NUREG/CR-6372 describes the formal process for structuring and conducting expert assessments that has come to be known as a "SSHAC process". There are four levels defined at which seismic hazard assessment studies can be conducted. The SSHAC guidelines were updated in 2012 with practical implementation guidelines for SSHAC Level 3 and 4 studies (USNRC, 2012). In 2018, the updated implementation guidelines were published (USNRC, 2018). This latest document provides the most complete and practical application of the SSHAC guidance to date and is summarised in this section.

The aim of the SSHAC process is the structured interaction among experts to achieve a well-documented hazard study that captures the center, body, and range of technically defensible interpretations (commonly referred to as the CBR of TDI). There are five key elements to the SSHAC process. If one of them is missing or incomplete, the PSHA does not qualify as a SSHAC study. The five key elements are:

1. Clearly defined roles for all participants
2. Objective evaluation of all available data, models and methods that could be relevant to the characterisation of the hazard at the site.
3. Integration of the outcome of the evaluation process into models that reflect the best estimate of the hazard input and its associated uncertainty.
4. Documentation of the study with sufficient detail to allow reproduction of the hazard analyses.
5. Independent participatory peer review during all stages of the process.

During the evaluation, one should be aware of cognitive bias, such as overconfidence, anchoring, availability, coherence/vividness, ignoring conditioning events. These biases are inherent to all expert judgment and are not deliberate. The most effective way of countering these cognitive biases is simply to make experts aware that they exist and to encourage the experts to counter them.

There are 4 levels of SSHAC, from the simplest (Level 1) to the most complicated and demanding (Level 4). An important criterium in selecting the SSHAC Level for a hazard study is the degree to which regulatory assurance is required. The characteristics of each SSHAC Level are described in chapter 3 of NRC, 2018.

All SSHAC Levels must include the 5 key elements. The SSHAC Level defines the level of detail and the number of experts involved. The characteristics of and the differences between the SSHAC Levels are listed below. The key features of the different SSHAC Levels are visualised in the figures in section 3.1 of NRC, 2018. These figures are included in Appendix 3.

SSHAC Level 1:

- Evaluation and Integration are undertaken by a Technical Integration Team (TI) rather than by an individual.
- More than one Technical Interrogator.
- Participatory Peer Review Panel (PPRP) consists of more than one person and reviews during the entire process, not only at the end.

SSHAC Level 2:

- Additional steps relative to SSHAC Level 1:
  - Outreach to external experts.
  - Preliminary hazard model is developed and calculated in order to assess which elements of the total uncertainty are exerting the greatest influence on the hazard results.
  - Cycle of review and feedback regarding the preliminary seismic source characterization (SSC) and ground motion characterization (GMC) models.
- TI team is required to document discussion and obtain written concurrence from the experts.

SSHAC Level 3:

- Larger group of key participants with more roles.
- Process is built around three major workshops: two in the Evaluation phase and one in the Integration phase.
- Including formal working meetings
- Technical experts produce a single logic tree that captures the overall distribution agreed by the evaluators through the process of technical challenge and defence.

SSHC Level 4:

- Almost the same as SSHAC Level 3, apart from how the logic tree is built:
  - Each expert or expert team is charged with producing a logic-tree reflecting their view of the distribution that captures the center, body, and range of technically defensible interpretations. The Technical Facilitator Integrator is then charged with aggregating these individual logic trees into the final integrated distribution.

The level of effort increases from Level 1 to Level 2 to Level 3/4. The effort level for Level 3 and 4 is similar. The largest increase in effort is between Level 2 to Level 3/4.

An important consideration in the selection process is whether or not there is an existing PSHA. If so, that study might be subject to revision, refinement, or replacement. This depends on whether the existing PSHA is a regional or site-specific study and the availability of new data, models, and methods. For Borssele, only a preliminary PSHA has been conducted (Section 3.2). This earlier study was not performed as a SSHAC study nor as a full PSHA.

The decision factors regarding the choice of SSHAC level include the scope and the need for the hazard study and the risk profile of the facilities. Factors to consider are:

- the significance of the issue to the final results of the PSHA
- the issue's technical complexity and level of uncertainty
- the degree of technical contention about the issue in the technical community
- the degree to which regulatory assurance is required
- available resources
- public perception

We recommend performing a PSHA using state-of-the art knowledge about seismic hazard assessment for the new NPPs in Borssele conform SSHAC. The SSHAC Level can be determined in collaboration with the nuclear regulator ANVS.

Appendix 1 - References

BGS website (n.d.) for earthquakes: http://www.earthquakes.bgs.ac.uk/earthquakes/dataSearch.html. Last visited on 16 June 2023.

BGS website (n.d.). for seismic hazard of UK: http://www.earthquakes.bgs.ac.uk/hazard/UKhazard.html . Last visited on 17 June 2023.

Bommer J.J. (2012). Challenges of Building Logic Trees for Probabilistic Seismic Hazard Analysis: Earthquake Spectra 28:1723–1735. https://doi.org/10.1193/1.4000079

Bommer J.J., Douglas J., Scherbaum F., et al (2010). On the selection of ground-motion prediction equations for seismic Hazard analysis. Seismol Res Lett 81:783. https://doi.org/10.1785/gssrl.81.5.783

Bommer J.J., Stafford P.J. (2020). Selecting Ground-Motion Models for Site-Specific PSHA: Adaptability versus Applicability. Bull Seismol Soc Am 110:2801–2815. https://doi.org/10.1785/0120200171

Campbell K.W. and Bozorgnia Y. (2008). NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s. Earthquake spectra, 24(1), 139-171.

de Crook T. (1993). Probabilistic seismic hazard assessment for The Netherlands. Geologie en Mijnbouw, 72(1): 1-13.

de Crook T. (1996). A seismic zoning map conforming to Eurocode 8, and practical earthquake parameter relations for the Netherlands. Geologie en Mijnbouw 75: 11-18, 1996.

de Vos D. (2010). Probabilisitic Seismic Hazard Assessment for the Southern part of the Netherlands. De Bilt, the Netherlands

Dost B., Haak H. (2002). A comprehensive description of the KNMI seismological instrumentation. KNMI report TR-245. Link: https://cdn.knmi.nl/knmi/pdf/bibliotheek/knmipubTR/TR245.pdf

Douglas J. (2018). Calibrating the backbone approach for the development of earthquake ground motion models. Best Practice in Physics-based Fault Rupture Models for Seismic Hazard Assessment of Nuclear Installations: Issues and Challenges Towards Full Seismic Risk Analysis.

Douglas J. (2021). GMPE compendium. http://www.gmpe.org.uk/. Accessed 5 July 2023.

Douglas J., Edwards B. (2016). Recent and future developments in earthquake ground motion estimation. Earth-Science Rev 160:203–219. https://doi.org/10.1016/J.EARSCIREV.2016.07.005

Danciu L., Nandan S., Reyes C., Basili R., Weatherill G., Beauval C., Rovida A., Vilanova S., Sesetyan K., Bard P-Y., Cotton F., Wiemer S., Giardini D. (2021). The

2020 update of the European Seismic Hazard Model: Model Overview. EFEHR Technical Report 001, v1.0.0, https://doi.org/10.12686/a15

ENSREG (2012) Peer review country report – Netherlands - Stress tests performed on European nuclear power plants. Available from: https://www.autoriteitnvs.nl/onderwerpen/stresstest/documenten/rapporten/2015/1/7/peer-review-country-rapport-nederland

EPZ (2011). Europees robuustheidsonderzoek voor kerncentrales - Complementary Safety margin Assessment (CSA) - publieksversie 1.0 - 31 oktober 2011

EPZ (2015). Veiligheidsrapport. Kernenergiecentrale Borssele. Report no. VR15-KCB, version 1, November 2015

geo.be (n.d.) Data portal for Eurocode 8 zonation map for Belgium: https://www.geo.be/catalog/details/26926de1-5ef4-47ee-b59d-bee0d9e6acee?l=nl Last accessed 27 June 2023.

GFZ (2016). Plattform zur Abfrage von gefährdungskonsistenten Antwortspektren (UHS) für beliebige Punkte in Deutschland sowie von nationalen Erdbebengefährdungskarten nach dem Berechnungsmodell von Grünthal et al. (2018). GFZ Helmholtz-Zentrum Potsdam http://www-app5.gfz-potsdam.de Last accessed 16 June 2023.

Grünthal G., Stromeyer D. Bosse C., Cotton F. & Bindi D. (2018a). The probabilistic seismic hazard assessment of Germany – version 2016, considering the range of epistemic uncertainties and aleatory variability, Bull. Earthquake Eng. 16: 4339-4395. https://doi.org/10.1007/s10518-018-0315-y

Grünthal G, Stromeyer D, Bosse C, Cotton F. & Bindi D. (2018b). Plattform zur Abfrage von gefährdungskonsistenten Antwortspektren (UHS) für beliebige Punkte in Deutschland sowie von nationalen Erdbebengefährdungskarten nach dem Berechnungsmodell von Grünthal et al. (2018). http://www-app5.gfz-potsdam.de. Last accessed 6 Dec 2021.

Houtgast (1991). Aardbevingen in Nederland - Catalogus van aardbevingen t/m 1990. KNMI-publication 179, KNMI.

IAEA (2019). Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSR-1, IAEA, Vienna

IAEA (2022). Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9 (Rev. 1), IAEA, Vienna

Kamerbrief (2012). Europese peer review van het Nationaal Rapport stresstest kerncentrale Borssele. 8 May 2012, reference DGETM/PDNIV / 12048861.

KNMI (1993). Netherlands Seismic and Acoustic Network. Royal Netherlands Meteorological Institute (KNMI). https://doi.org/10.21944/E970FD34-23B9-3411-B366-E4F72877D2C5

Leynaud, D., Jongmans, D., Teerlynck, H., and Camelbeeck, T. (2000), Seismic hazard assessment in Belgium, Geologica Belgica, 3(1-2), 67-86.

Ministry of Economic Affairs, Agriculture & Innovation (2011). Netherlands' National Fukushima Stress Test for the Borssele Nuclear Power Plant.

Mosca I., Sargeant S., Baptie B., Musson R.M.W., Pharaoh T. (2020). National seismic hazard maps for the UK: 2020 update. British Geological Survey Open Report, OR/20/053. 138pp.

Mosca I., Sargeant S., Baptie B., Musson R. M. W. and Pharaoh T. C. (2022). The 2020 national seismic hazard model for the United Kingdom. Bull Earthquake Eng 20, 633–675. https://doi.org/10.1007/s10518-021-01281-z

NBN (2011). Bureau de Normalisation (NBN), 2011, Eurocode 8 - Calcul des structures pour leur résistance aux séismes - Partie 1: Règles générales, actions sismiques et règles pour les bâtiments – Annexe nationale: NBN EN 1998-1-ANB:2011(F).

Qcon (2021) Seismicity in Flanders. Link: https://www.friscris.be/en/publications/seismicity-in-flanders(a94f7d1a-3fbf-4bb3-b654-d5e56d2a3621).html

SHARE: http://www.share-eu.org/ Last visited on 17 June 2023.

Stafleu J., Kraaijpoel D.A., Osinga S. (2022). Ideation Challenge 2020: RHINOCEROS - Regional sHear-wave velocIty modelliNg fOr seismiC sitE RespOnSe - Final scientific report. TNO report TNO 2022 R10324.

USNRC (1997). Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts: Main Report. NUREG/CR-6372, Volume 1.

USNRC (2012). Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies. NUREG-2117, Rev. 1

USNRC (2018). Updated Implementation Guidelines for SSHAC Hazard Studies. NUREG-2213.

Vanneste K. and Van Dyck J. (2009). Project VLA07-4.2 - Compilatiestudie betreffende de seismiciteit in Vlaanderen –Hoofdstuk 5 Kaart van de seismische gevarenkans op het niveau van de harde sokkel (WP3). Publication from Vlaanderen. Summary of compilation study on https://publicaties.vlaanderen.be/view-file/15028

Vanneste K., Vleminckx B. and Camelbeeck T. (2017). Seismic hazard assessment for SEVESO industries in the Walloon region, ROB-SPW 2017-01, 31 March, 2017.

van Eck T., Dost B. & Caccavale M. (2013) Recommendation study "Seismic hazard in context IAEA", KNMI report.

Weatherill G., Kotha S.R. and Cotton F. (2020). A regionally-adaptable "scaled backbone" ground motion logic tree for shallow seismicity in Europe: application to the 2020 European seismic hazard model. Bull Earthquake Eng 18, 5087–5117. https://doi.org/10.1007/s10518-020-00899-9

Appendix 2 - Revision of Houtgast (1991) earthquake catalogue

Events that were interpreted as true earthquakes are indicated in red.

LOCATION	Land	ID	YYMMDD	Time	Lat (N)	Lon (E)	Intensity	Magnitude	Depth (km)	Comments
Maastricht	NL	10070000000000.000	10070000	000000.00	50.9	5.7				Fake event. Ref to Sieberg (1940), but not in his catalog
Brabant (B)	NL	10810327180000.000	10810327	180000.00	0	0		0.00	0.00	
Luik (B)/ Aken (D)	B	11120103000000.000	11120103	000000.00	0	0		0.00	0.00	
Aken (D)/Luik (B)	NL	11120420000000.000	11120420	000000.00	0	0		0.00	0.00	
Luik (B)	B	11170502000000.000	11170502	000000.00	50.6	5.5		0.00	0.00	probably same event as jan 3 in Italy
Aken (D)	D	11211210040000.000	11211210	040000.00	50.8	6.1		0.00	0.00	
Aken/Herzogenrath (D)	D	11410424000000.000	11410424	000000.00	50.8	6.1		0.00	0.00	
Northsea	NL	11421102000000.000	11421102	000000.00						Felt in Utrecht, but also in Holland. Possible Northsea event
Maastricht	NL	11740000000000.000	11740000	000000.00	50.9	5.7		0.00	0.00	No original sources, fake event
Wierum	NL	12251027060000.000	12251027	060000.00	53.4	6		0.00	0.00	No earthquake, presumably wind related damage
Nederland (Noord-)	NL	12620128000000.000	12620128	000000.00	53.3	6.8		0.00	0.00	No earthquake, presumably wind related damage
Northsea	NL	13420103000000.000	13420103	000000.00	52.1	5.2		0.00	0.00	Felt in Holland, Zeeland and Gent (B), most probable Northsea event
Holland	NL	13460102000000.000	13460102	000000.00	0	0		0.00	0.00	same event as 1342, wrong date
Nederland/ Duitsland	NL	13500000000000.000	13500000	000000.00	0	0		0.00	0.00	probably related to large Swiss event (Villach)
Street of Dover (North sea)	GB	13820521130000.000	13820521	130000.00	51.3	2.0	VII	6.00	5.00	Street of Dover, North sea (Melville et al., 1996)
Maastricht	NL	13850000000000.000	13850000	000000.00	50.9	5.7	VI-VII	0.00	0.00	Alexandre (1994): wrong copy of event in Liege
Maastricht	NL	13930611000000.000	13930611	000000.00	50.9	5.7	VI-VII	0.00	0.00	Alexandre (1994): refers to 1395 event
Julich (D)	D	13950611030000.000	13950611	030000.00	50.9	6.4	IV-V	0.00	0.00	Felt in Koln & Liege (Alexandre, 1994)
Nederland	NL	14120000000000.000	14120000	000000.00	0	0		0.00	0.00	No sources, only mentioned by Lorie, fake event
North sea	B	14490423040000.000	14490423	040000.00	51.6	2.5		5.50	0.00	North sea (Melville (1996)
Luik (B)	B	14560826020000.000	14560826	020000.00	50.6	5.6		0.00	0.00	small event, felt around Liege (Alexandre, 1994)
Maastricht	NL	15040514000000.000	15040514	000000.00	50.9	5.7	IV	0.00	0.00	Only one unreliable source (Eversen- see Alexandre, 1994)
Aken (D)	D	15040823233000.000	15040823	233000.00	50.8	6.2	VII	5.00	0.00	
Maastricht	NL	15050601000000.000	15050601	000000.00	50.9	5.7	IV	0.00	0.00	Only one unreliable source (Eversen- see Alexandre, 1994)
Venlo	NL	15310712000000.000	15310712	000000.00	51.3	6.2	VII	0.00	0.00	1531/32; date unsure, location also unsure
Weert	NL	15540322000000.000	15540321	000000.00	51.3	5.7	VII	5.00	0.00	Felt in Weert, Geleen, Erkelenz, Liege, Antwerp; location?
Weert	NL	15540430000000.000	15540321	170000.00	0	0	VII	0.00	0.00	Felt in Weert
Weert	NL	15540514150000.000	15540514	150000.00						Felt in Weert
Weert	NL	15630228140000.000	15630228	140000.00	51.3	5.7	II	0.00	0.00	?
Boxmeer	NL	15630321000000.000	15630321	000000.00	51.65	5.95		0.00	0.00	same as 1554
Weert, Hoofdschok	NL	15630322000100.000	15630322	000100.00	51.3	5.7	VI	0.00	0.00	Same event as 1554
Weert	NL	15630430000000.000	15630430	000000.00	51.3	5.7		0.00	0.00	1554
Weert	NL	15630515000000.000	15630515	000000.00	51.3	5.7		0.00	0.00	source not specific
Weert	NL	15660000000000.000	15660000	000000.00	51.3	5.7		0.00	0.00	source not specific
Montfort (??)	B	15660000000000.000	15660000	000000.00	51.1	5.6		0.00	0.00	source not specific
Weert	NL	15680900000000.000	15680900	000000.00	51.3	5.7		0.00	0.00	?
Belgie	NL	15690514000000.000	15690514	000000.00	0	0		0.00	0.00	felt in Weert, Geleen, Erkelenz, Liege, same date as 1554?
Street of Dover (North sea)	GB	15800406180000.000	15800406	180000.00	51	1.5	VIII	6.00	10.00	Melville et al. (1996)
Canterbury (GB)	GB	15800501000000.000	15800501	000000.00	51.2	1.1	VI	5.00	0.00	
Boxmeer	NL	15810310000000.000	15810310	000000.00	51.6	5.9	VI	0.00	0.00	
Maastricht	NL	15830000000000.000	15830000	000000.00	50.9	5.7	II	0.00	0.00	
Zwitserland	CH	16010908010000.000	16010908	010000.00	0	0	VIII	0.00	0.00	
Nederland	NL	16020102114500.000	16020102	114500.00	0	0		0.00	0.00	

LOCATION	Land	ID	YYMMDD	Time	Lat (N)	Lon (E)	Intensity	Magnitude	Depth (km)	Comments
Aken (D)	D	16400404033000.000	16400404	033000.00	50.8	6.2	VII	5.50	0.00	ORB-solution
Holland	NL	16420400000000.000	16420400	000000.00	0	0		0.00	0.00	Perrey, wsch 1640 event
Nederland	NL	16520000000000.000	16520000	000000.00	0	0		0.00	0.00	Genoemd door Lorie, geen bronnen. Vermeld bij Mobachius (1756)
Maastricht	NL	16630519180000.000	16630519	180000.00	50.9	5.7	V	0.00	0.00	Sieberg (1940), no reliable sources
Nederland	NL	16650000000000.000	16650000	000000.00	0	0		0.00	0.00	Lorie (1903), no sources
Zeeland	NL	16870519000000.000	16870519	000000.00	51.5	4	III	0.00	0.00	Rummelen, no sources in Nethrlands
Verviers (B)	B	16920918143000.000	16920918	143000.00	50.59	5.86	VIII	6.30	0.00	Alexandre et al (2008)+pers. comm ORB
Vlaanderen (B), Hoofdschok	B	16930109000000.000	16930109	000000.00	51	3.5		0.00	0.00	fake, maybe 1692 event
Aix-la-chapelle (D)	D	16901218173000.000	16901218	173000.00	#####	6.1	VI	4.60	n	AHEAD
Maastricht	NL	16940322140000.000	16940322	140000.00	50.9	5.7	III	0.00	0.00	
Roermond/ Maastricht	NL	16990422000000.000	16990422	000000.00	51.1	5.9	VI-VII	4.00	0.00	?
Roermond, Hoofdschok	NL	16990622000000.000	16990622	000000.00	51.1	5.9	III	0.00	0.00	
Maastricht, Hoofdschok	NL	16990624000000.000	16990624	000000.00	50.9	5.7	II	0.00	0.00	
Maastricht	NL	16990724000000.000	16990724	000000.00	50.9	5.7	II	0.00	0.00	
Bergen op Zoom	NL	17110517000000.000	17110517	000000.00	51.5	4.3	II	0.00	0.00	
Tienen (B)	B	17140113220000.000	17140113	220000.00	50.8	4.8	VII	4.50	5.00	
Maastricht	NL	17140528000000.000	17140528	000000.00	50.9	5.7	II	0.00	0.00	
Keulen (D)	D	17550218070000.000	17550218	070000.00	50.9	6.9		0.00	0.00	
Helmond, Hoofdschok	NL	17550400000000.000	17550400	000000.00	51.5	5.7	III	0.00	0.00	
Maastricht	NL	17551218000000.000	17551218	000000.00	50.9	5.7	VII	0.00	0.00	
Aken (D)	D	17551227003000.000	17551226	003000.00	50.86	6.311	VII	5.10	n	Meidow (1995), AHEAD
Aken (D)	D	17551226160000.000	17551226	160000.00	50.8	6.3	VI-VII	4.80	n	Meidow (1995), AHEAD
Utrecht (prov.)	NL	17560115000000.000	17560115	000000.00	52.1	5.2	III	0.00	0.00	fake event
Duren (D), Hoofdschok	D	17560218074500.000	17560218	080000.00	50.76	6.311	VIII	5.70	n	Meidow (1995), AHEAD
Aix-la-chapelle	D	17600120221500.000	17600120	221500.00	50.74	6.42	VII	5.20	n	AHEAD
Harderwik	NL	17810923000000.000	17810923	000000.00	52.3	5.6	II	0.00	0.00	acoustic?
Aken (D)	D	17950308035700.000	17950308	035700.00	50.8	6.1		0.00	0.00	?
Brussel (B)	B	18001109000000.000	18001109	000000.00				0.00	0.00	fake event, severe storm instead
Nederland (West-)	B	18021218000000.000	18021218	000000.00				0.00	0.00	fake event, maybe reference to 1803? No contemp. Messages
Rotterdam	NL	18031213000000.000	18031213	000000.00				0.00	0.00	fake event, same as 18040113, watermovements detected -large event?
Nederland (West-)	NL	18040113000000.000	18040113	000000.00				0.00	0.00	fake event, watermovement due to M6.7 event in Spain (Alboran sea)
Schiedam	NL	18040825100000.000	18040825	100000.00				0.00	0.00	fake event, watermovement due to M6.4 Spain (Almeria)
Aken (D)	D	18181104000000.000	18181104	000000.00	50.8	6.1	VI	4.50		AHEAD
Harderwijk	NL	18240818000000.000	18240818	000000.00			II	0.00	0.00	possibly acoustic
Maastricht	NL	18270223000000.000	18270223	000000.00			II	0.00	0.00	probably 1828-02-23; felt in Maastricht, more often errors in manuscripts
Hannut (B)	B	18280223083000.000	18280223	083000.00	50.7	5.12	VII	5.10	10.00	Camelbeeck et al. (2021); location uncertainty: 10 km
Hautes-Fagnes (B)	D	18281203183000.000	18281203	183000.00	50.38	6.19	VI-VII	4.20	0.00	Knuts et al (2016), location uncertainty 30 km
Zwolle	NL	18290704010000.000	18290704	010000.00			II	0.00	0.00	tremors coinciding with strong winds?
Utrecht	NL	18320823120000.000	18320823	120000.00	52.1	5.1	II	0.00	0.00	fake? , Kunst en Letterbode 1832
Haarlem	NL	18331202020000.000	18331202	020000.00	52.4	4.6	II	0.00	0.00	zie Lorie; acoustic?
Veghel/Uden	NL	18430406053000.000	18430406	053000.00	51.6	5.6	V-VI	4.50	10.00	further investigation required (27 felt reports)
Nijmegen	NL	18460131020000.000	18460131	020000.00	51.8	5.9	II	0.00	0.00	storm?
Heeswijk Dinther	NL	18481218143000.000	18481218	143000.00	51.6	5.5	III	0.00	0.00	further investigation required, small event
Haarlem	NL	18500909074000.000	18500909	074000.00	52.4	4.6	III	0.00	0.00	acoustic? Many locations report even damage, neigbouring locations not
Haarlem	NL	18501219000000.000	18501219	000000.00	52.4	4.6		0.00	0.00	acoustic? Many locations report even damage, neigbouring locations not

LOCATION	Land	ID	YYMMDD	Time	Lat (N)	Lon (E)	Intensity	Magnitude	Depth (km)	Comments
Roermond	NL	18510121042000.000	18510121	042000.00	51.2	6	II	0.00	0.00	further investigation required
Haarlem	NL	18520524000000.000	18520524	000000.00	52.4	4.6	II	0.00	0.00	acoustic?
Harderwijk	NL	18590821000000.000	18590821	000000.00	52.3	5.5	III	0.00	0.00	acoustic?
Herzogenrath (D)	D	18731022094500.000	18731022	094500.00	50.88	6.158	VII	5.10	4.00	Leydecker 2011) solution, AHEAD
Herzogenrath (D)	D	18740828154500.000	18740828	154500.00	50.9	6.1	II	0.00	0.00	?
Brabant	NL	18760124193000.000	18760124	193000.00			II-III			to be investigated, newspaper reports
Herzogenrath (D)	D	18770624085300.000	18770624	085300.00	50.88	6.083	VIII	4.70	2.00	Leydecker (2011) solution; AHEAD
Tollhausen (D)	D	18780826090000.000	18780826	090000.00	50.93	6.548	VIII	5.50	n	Meidow(1995), AHEAD
Heerlen	D	18791100000000.000	18791100	000000.00	0	0		0.00	0.00	jongeneel, often wrong date
Aken (D)	D	18811118231400.000	18811118	231400.00	50.8	6.1	VI	4.90	13.00	Leydecker solution
Boxmeer	NL	18820811210000.000	18820811	210000.00	51.6	5.9	II	0.00	0.00	van Beurden, often incorrect information - needs extra check
Haarlem	NL	18830317051500.000	18830317	051500.00	52.4	4.6	IV	3.50	0.00	acoustic?
Herzogenrath (D)	D	18920624020000.000	18920624	020000.00	50.9	6.1	II	0.00	0.00	?
Den Haag	NL	19050429061500.000	19050429	061500.00	52.1	4.3	II	2.10	0.00	fake, acoustic??
Harderwijk	NL	19060108203000.000	19060108	203000.00	52.3	5.6	IV	3.50	0.00	acoustic?
Grathem	NL	19060831000000.000	19060831	000000.00	51.2	5.8	V	??	0.00	real event? Check reports. Felt in Grathem
Poulseur (B)	B	19081112091400.000	19081112	091400.00	50.46	5.64	VI	3.7	0.00	ORB solution, not recorded on JEN, HAM, DBN
Eifel (D)	D	19110530194340.000	19110530	194329.71	50.65	6.23		4.20	10.00	recorded on stations UCC,GTT,DBN,HAM,STR,JEN
Eifel (D)	D	19110531020820.000	19110531	020800.24	50.65	6.23		4.00	15.00	recorded on stations DBN, GTT, JEN, STR (HAM X)
Gosselies (B)	B	19110601225200.000	19110601	225248.22	50.45	4.5		4.20	10.00	recorded on stations UCC, DBN, STR, JEN (HAM X)
Gosselies (B)	B	19110603143500.000	19110603	143517.72	50.45	4.5		4.20	15.00	recorded on stations UCC, AAC, STR (HAM X)
Eifel (D)	D	19110906135447.000	19110906	135434.73	50.7	6.32	VI	4.10	15.00	recorded on stations GTT, DBN, HOH, POT, JEN, STR, HAM

Appendix 3 – SSHAC Level schemes

In this appendix, the figures describing the components of the SSHAC Levels are included. They are copied from chapter 3 from USNRC (2018).

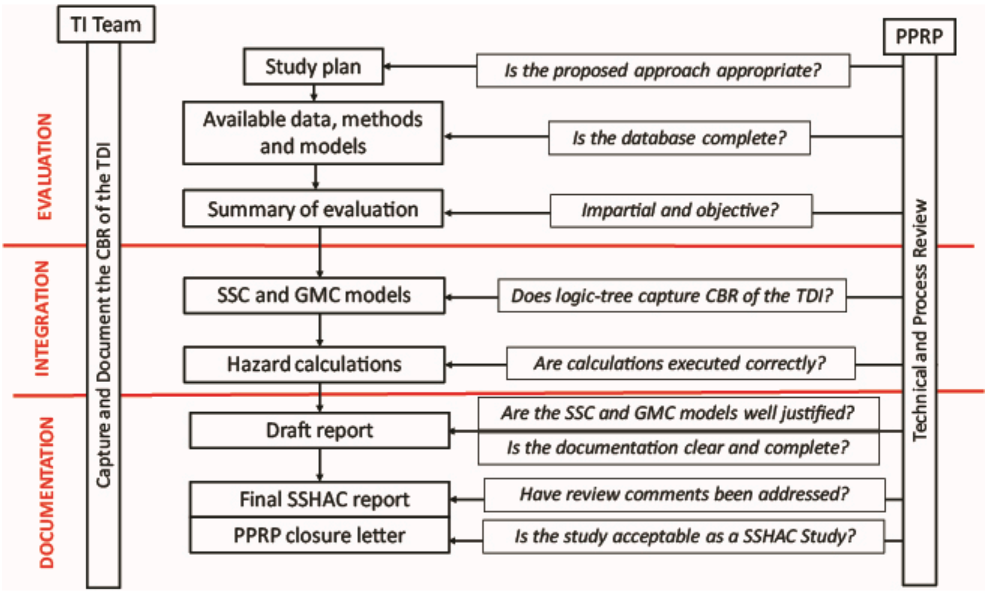

Figure 11. Flowchart for a SSHAC Level 1 Probabilistic Seismic Hazard Analysis (PSHA) study, with order of events running from top to bottom. Also indicating the review criteria and potential questions at each point of engagement by the PPRP (Figure 3-2, USNRC, 2018).

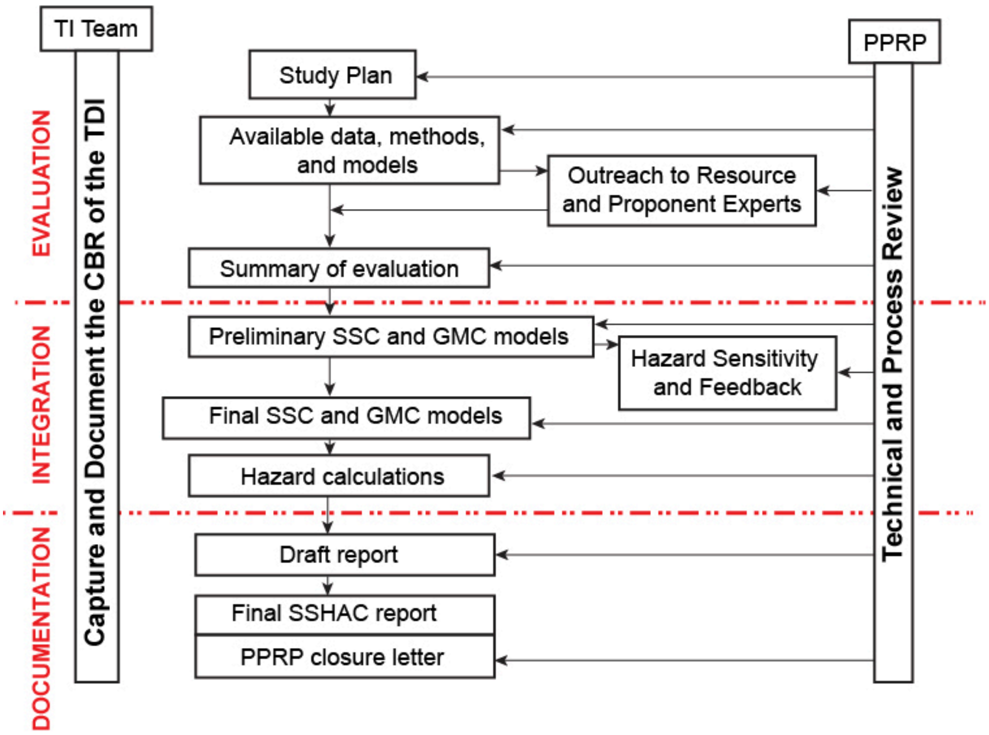

Figure 12. Flowchart for a SSHAC Level 2 PSHA study, with time running from top to bottom. Showing the two additional steps relative to SSHAC Level 1 (Outreach to resource and proponent experts & hazard sensitivity and feedback). (Figure 3-3, USNRC, 2018).

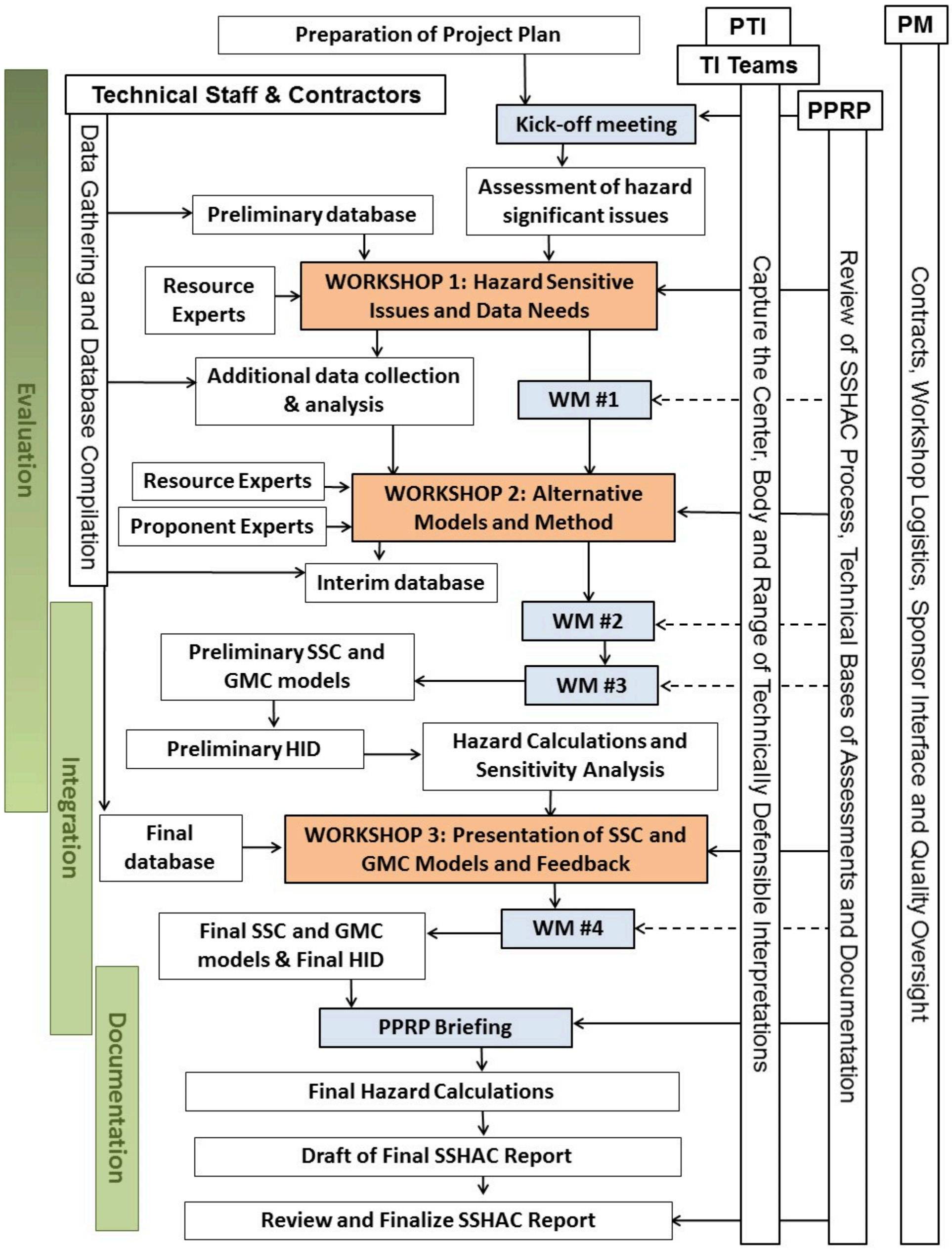

Figure 13. Flowchart illustrating the key features in a SSHAC Level 3 process. The order of activities runs from top to bottom of the diagram. The timing of the working meetings reflects one suggested arrangement and alternative schemes may be used, although one meeting after Workshop #3 is essential. Dashed arrows indicate activities where one (or more) PPRP member(s) is selected to observe and represent the larger panel. (Figure 3-4, USNRC, 2018).

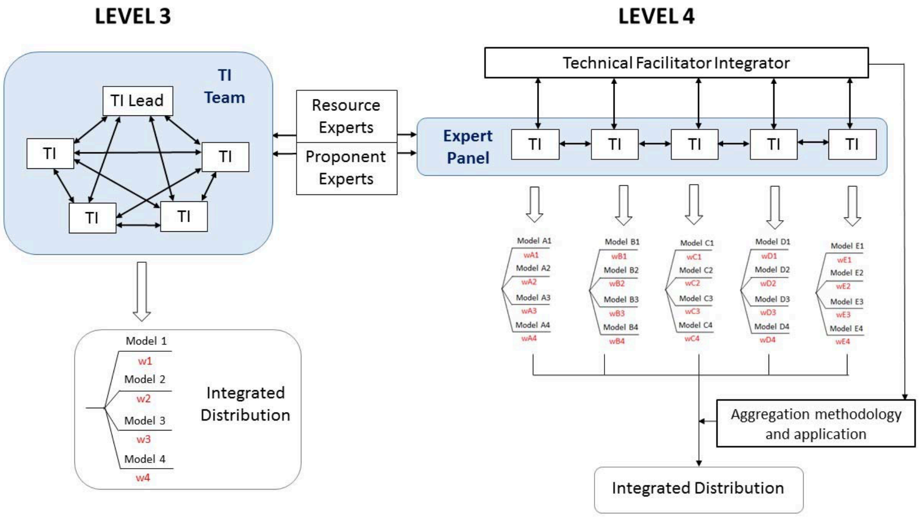

Figure 14. Organizational and structural differences between Level 3 and Level 4 studies. The role of the PPRP is identical in both cases and the same sequence of at least three formal workshops is also followed in both cases. (Figure 3-5, USNRC, 2018).

Koninklijk Nederlands Meteorologisch Instituut

Postbus 201 | 3730 AE De Bilt
T 030 220 69 11 | www.knmi.nl