METIS

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Summary

The objective of this report is to define a case study site that allows, to the extent possible, the testing and the verification of all METIS developments, scientific and engineering results. In this framework, three potential case studies were selected. An important work concerning technical reviews, evaluation of advantages and disadvantages, industrial contacts and expert opinions were integrated to identify the most appropriate case study site for the METIS project. The three candidate sites analysed are: ZNNP site in Ukraine; KKNPP site in Japan; ZNPP located at an appropriate site in central Italy. The case study site selected is the Ukrainian ZNPP located at an appropriate Italian site. This solution is certainly not ideal to fulfil all the technical requirements of the METIS applications. However, based on all the compiled information and experts? opinion, it was decided that this case study is the best compromise to evaluate all the outputs produced by WPs 4 to 6 that are needed to support the proper implementation of the full and final seismic Probabilistic Safety calculations performed in WP7.

Approval

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Case study for implementation and application of METIS results

Deliverable D3.1

Version N°1

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Abbreviations and Acronyms

Acronym	Description
WP	Work Package
SPSA	Seismic Probabilistic Safety Assessment
KKNPP	Kashiwazaki-Kariwa Nuclear Power Plant
ZNPP	Zaporizhzhya Nuclear Power Plant

Summary

The objective of this report is to define a case study site that allows, to the extent possible, the testing and the verification of all METIS developments, scientific and engineering results. In this framework, three potential case studies were selected. An important work concerning technical reviews, evaluation of advantages and disadvantages, industrial contacts and expert opinions were integrated to identify the most appropriate case study site for the METIS project. The three candidate sites analysed contain the following principal features:

- ZNNP site in Ukraine. All data regarding the fragility curves of structures or equipment, a reference SPSA model and the seismic and site data are available. This site is located in a stable continental region with very low seismicity. This low rate of seismicity presents complications in fully testing the new methods and tools to be developed in METIS.
- KKNPP site in Japan. An earthquake (6.6 Mw) occurred on 16 July 2007 and affected the KKNPP. A valuable ground motion data set and reported damage that would allow verification is available. However, seismic hazard model, fragility curves of structures or equipment and the SPSA model are not available. TEPCO representatives have indicated that they cannot make available any supplementary data to the METIS project. The only information available is what is published in the framework of the benchmark project KARISMA.
- ZNPP located at an appropriate site in central Italy. This case is a combination of the ZNPP for structures and components, and the seismic hazard assessment for a site in central Italy, the definition of the precise site is in progress. The level of seismicity of a region in Italy is higher than that of the region where ZNNP was designed and built. However, the technical WP leaders believe that it would be possible to make all the NPP safety considerations at the same low level of seismicity commensurate to those at the original Ukrainian site but have sufficient empirical seismicity and ground motion data to go beyond generate seismic levels that could be comparable with corresponding levels of ZNPP site.

Hence, the case study site selected is the Ukrainian ZNPP located at an appropriate Italian site. This solution is certainly not ideal to fulfil all the technical requirements of the METIS applications. However, based on all the compiled information and experts' opinion, it was decided that this case study is the best compromise to evaluate all the outputs produced by WPs 4 to 6 that are needed to support the proper implementation of the full and final seismic Probabilistic Safety calculations performed in WP7.

Keywords

Site selection, Case study, Seismic hazard assessment, Fragility curves, Seismic Probabilistic Safety Assessment.

Introduction

Seismic Probabilistic Safety Assessment is a broad subject, involving a number of science and engineering disciplines. The WP3 of the METIS project addresses this complex subject by integrating all factors necessary for the seismic risk assessment. The objective is to assure that all METIS developments, scientific and engineering results are tested and verified in a real case study, which considers the complete chain of analysis, including probabilistic as well as scenario-based analyses.

This report addresses the first step of the WP3 concerning the selection of the METIS case study. In this framework, three preliminary sites were selected and a meticulous work (technical reviews, evaluation of advantages and disadvantages, industrial contacts, discussions, etc.) was carried out to identify the most appropriate case study for the project.

This report presents:

- The process used to select the preliminary sites
- The technical reviews, synthesis of advantages and disadvantages of each potential case
- The final selection of the METIS case study based on both compiled information and opinions of the METIS WPs experts.

1. Work process to select the METIS case study

The selection of the METIS case study was organized on the following steps:

1. Identification of the needs concerning each technical WPs for implementing the results in a real case study. During this step, several meetings took place to identify all final outputs produced by WPs 4 to 6 and discuss their coherency to enable the proper implementation for the final seismic Probabilistic Safety calculations that will be performed in WP7.
2. Identification of potential case studies. An extensive compilation of technical information including industrial contacts and experts' opinions allowed identification of several potential case studies.
3. Evaluation of advantages and disadvantages for each potential site using several defined criteria to obtain a final selection.

Table 1 below gives a summary of the technical meetings that were held to support the selection. For each potential case identified in the Table 1, an indication sends the reader to the appendix or chapter that contains more precise technical information.

Meetings	Potential case studies
WPs leaders and Project leader.	1. Kashiwaski-Kariwa site – Japan (KKNPP)

Evaluation of two potential case studies. Three meetings were held on this subject Jun 25, 2020 Sep 22, 2020	2. Zaporizhzhya Site – Ukraine (ZNPP) **Appendix 1** presents the technical review elaborated for these two sites and analyses on advantages & disadvantages of these two sites.
External Advisory board, WPs leaders, Project leader. Review of KKNPP and ZNPP and proposal to evaluate new possible case studies Nov 05, 2020	3. Hybrid site: ZNNP for the structures and components and an appropriate site located in central Italy for seismic hazard assessment. The selection of the specific site in Italy is in progress. 4. Plants under decommissioning in France, USA, Switzerland. Several contacts have been made by EAB representatives with individuals responsible for the respective NPPs. However, no plant under decommissioning accepted to participate in the METIS case study. Hence, these sites were not included into the analyses of the potential case studies.
WPs leaders and Project leader Three meetings were held to select the final case study Feb 03, 2021 April 15, 2021 Jun 23, 2021 Sept 02, 2021	Final selection based on technical reviews, data availability, partnerships, experts' opinions, etc. **Chapter 2** gives a synthesis on advantages and disadvantages of each potential site considered for the final selection.

Table 1: Summary of technical meetings and potential case studies

2. Synthesis

This chapter presents a synthesis of advantages and disadvantages of the potential case studies identified in Table 1 and the final selection made by the METIS WPs experts..

2.1. Advantages & Disadvantages of the potential case studies

4. KKNPP Site in Japan

Advantages:

- KKNPP has experienced an earthquake that damaged the nuclear station and a valuable ground motion data set was recorded. This seismic data set is available through the published KARISMA benchmarking (appendix 1 for more details)
- Geometry of the basin, soil columns, geotechnical model are available
- Complete numerical mechanical model of one unit impacted by the earthquake (using code Aster EDF) and propagation model (using Code CAST3M – IRSN) have been elaborated by METIS partners

Disadvantages:

- KKNPP is not representative of the tectonic setting or seismicity of the European region
- Seismic hazard model, fragility curves of structures or equipment and SPSA model are not available
- No METIS partner is closely related to KKNPP
- TEPCO representatives have indicated that they cannot make available any supplementary data to the METIS project

5. ZNPP site in Ukraine

Advantages:

- Good representation of the tectonic setting and seismicity of the intraplate area of the European region
- Geometry of the basin, soil columns, geotechnical model are available
- Seismic Hazard models and results at different return periods for ZNPP are available
- Fragility curves of structures or equipment and SPSA model are available
- METIS partner (SSTC) is related to the ZNPP site

Disadvantages:

- ZNPP is located in a stable continental region with a very low seismicity level.
- The low rate of seismicity is not conducive to testing the new methods and tools to be developed in METIS
- Seismic ground motions recorded in the NPP area are very low, they are not useful for verification

6. Hybrid realistic site: ZNPP at a site in central Italy

Advantages:

- Good representation of the tectonic setting or seismicity of the European context.
- Geometry of the basin, soil columns, geotechnical model and seismic ground motion records are available for the Italian region under consideration.
- Seismic Hazard models and corresponding hazard estimates at relevant returns periods for ZNPP can be provided by a METIS partner for the Italian region.
- Possible to test the adequacy of new methods developed for seismic hazard assessment (vector-based hazard, seismicity clustering, etc) until the end of the chain.
- Fragility curves of structures or equipment and SPSA model are available (from ZNPP)

- METIS partner (SSTC) is related to the ZNPP and WP4/WP5 leaders are related to the Italian site.

Disadvantages:

- It is a hybrid and realistic case but not a real NPP structure-site combination

2.2. Final selection

Following the preceding analyses and the WPs expert opinions, the combination of the ZNPP (for structures and components) combined with an appropriate site in central Italy (for seismic hazard assessments) is considered as the best compromise for the METIS case study. ZNPP mechanical model and Seismic PSA will constitute the reference to evaluate the impact of all METIS developments and proposed improvements.

Time and budget permitting, a second option will be developed concerning a simplified ZNPP model for an application that uses KKNPP data. The interest stems from the opportunity to compare some of the results of METIS with the real data recorded at KKNPP site during the earthquake of 2007.

3. Conclusions

An extensive work including technical reviews, industrial contacts and experts' opinions was carried out to select the case study for METIS project.

The case study selected is the Ukrainian ZNPP but located at an appropriate site in central Italy.

This proposed hybrid case study is certainly not ideal to fulfil all the technical requirements of the METIS project. However, based on all compiled information, this case study was considered to be the best compromise to evaluate all the outputs produced by WPs 4 to 6 to support the implementation of the full and final seismic Probabilistic Safety calculations performed in WP7.

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[8] Results of Seismic Analysis. Development of Seismic Probabilistic Safety Assessment (PSA) for ZNPP Unit 1 – Synthesis of final report.

Appendix

General and technical information:

1 - Kashiwaski-Kariwa site – Japan

2 - Zaporizhzhya Site – Ukraine

1 - Kashiwaski-Kariwa site – Japan

Niigataken-chuetsu-oki (NCO) earthquake (6.6 Mw) occurred on 16 July 2007 and affected the Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP) in Japan. A significant number of sensors measured the accelerations at different locations in the soil (boreholes) and in structures at the KK NPP during the main shock and the aftershocks. All these instrumental data were available for an international benchmarking exercise known as the KAshiwazaki-Kariwa Research Initiative for Seismic Margin Assessment (KARISMA) under the coordination of the IAEA.

The main objective of the KARISMA benchmark exercise was to study the comparison between an analytical seismic response versus the real responses of selected structures, systems and components (SSCs) of KK NPP Unit 7. The KARISMA benchmark exercise included benchmarking on the analytical tools and numerical simulation techniques used for predicting the seismic response of NPP structures (in linear and non-linear ranges), site response, soil–structure interaction phenomena, seismic response of piping systems, 'sloshing' in the spent fuel pool and buckling of tanks. The benchmark was based on data provided by the Tokyo Electric Power Company (TEPCO).

Results of this benchmarking study were published by IAEA in 2013 [1]. The publication includes a CD-ROM summarizing the analyses of the main results: the KK NPP reactor building (static and modal analyses of the fixed base model, soil column analyses, soil–structure models, margin assessment, etc.); the residual heat removal piping system; the spent fuel pool and the pure water tank. Analyses of the main results include comparison between different computational models, variability of results among participants, and comparison of analysis results with recorded ones. See reference [1] for more precise information.

At the moment of the earthquake, four reactors were in operation: Units 2, 3 and 4 (Boiling Water Reactor - BWRs) and Unit 7 (Advanced Boiling Water Reactor - ABWR), the other three reactors were shut down for planned works (figure 1).

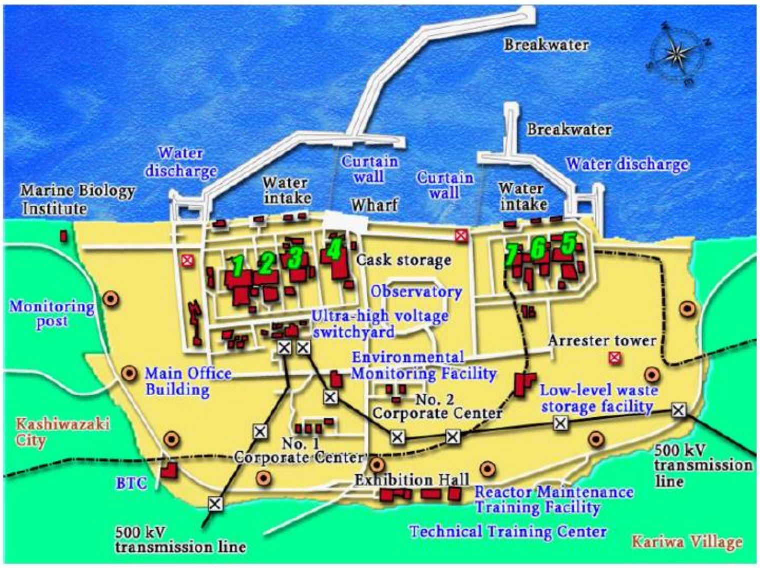


Figure 1: View of the KK NPP site with units 2,3,4,7 in operation at the moment of NCO earthquake (from IAEA rapport [1]).

Geotechnical context and model available

The KK Unit 7 Reactor Building (RB7) was selected for the benchmark. This reactor is embedded in a soil with very low shear wave velocity (Vs_{30}= 250 *m/s*) near the surface. The bedrock was found at 167 *m* of depth, with Vs_{30}=720 *m/s*. Full geotechnical properties are reported in [2].

The reference [3] describes the numerical models available:

The unit 7 has been implemented, by the CEA, in a finite elements code (Code CAST3M) and then made available to the project by IRSN.

The 3D FEM elastic structural model of the reactor building of Unit 7 was performed by EDF using code Aster

The reference [4] describes the three phases of the benchmark and data available for each phase:

- Phase I: Modeling, static and modal analyses, soil column analyses,
- Phase II: Response analyses of the structure and equipment during the NCOE earthquake,
- Phase III: Assessment of the seismic margin by multiplying the seismic level.

Seismic records - soils and structure data

Seismic records of the NCOE earthquake from KK NPP benchmarking have been collected and are currently available. The table 1 below, which lists the available records (main shock and aftershocks), identifies also the position of the main shock and aftershocks that struck the unit. Guidance documents are also available with precise information on soil and structure models [4]

INPUT	IDENTIFICATION	Number of record (signals) with three components (X,Y,Z)
Main shock	5G1 Free field	1 record
	RB7 3rd Basement	1 record
	RB7 3rd Floor	1 record
Aftershock 1	Borehole 5	5 records
	Free Field 5G1	1 record
	RB7 3rd Basement	1 record
	RB7 3rd Floor	1 record
Aftershock 2	Borehole 5	5 records
	Free Field 5G1	1 record
	RB7 3rd Basement	2 record
	RB7 3rd Floor	Not find in the data set available

Table 1: Seismic records concerning the main shock and the aftershocks used in the benchmark and available for METIS case study.

Observation point				Maximum acceleration value observed (Gal) NS	EW	UD	Recording time: Recording start time	Recording period (Sec)	Remark
Service hall	Free field	SG1	T.M.S.L.+65.1m	347	437	590	10:12:57:00	600.00	The seismometer of the basic system
Service hall	Free field	SG2	T.M.S.L.+16.7m	340	411	179	10:12:57:00	600.00	The seismometer of the basic system
Service hall	Free field	SG3	T.M.S.L.-31.9m	403	647	174	10:12:57:00	600.00	The seismometer of the basic system
Service hall	Free field	SG4	T.M.S.L.-182.3m	430	728	160	10:12:57:00	600.00	The seismometer of the basic system
Ground surface	Unit 1	1-G1	Seismic observation shed for Reactor No.1	890	890	715	10:12:46.00	600.00	
Ground surface	Unit 5	5-G1	Seismic observation shed for Reactor No.5	964	1223	539	10:12:45.00	600.00	
Unit 1	Reactor building	1-R1	2nd floor	599	884	394	10:12:45:00	493.26	
Unit 1	Reactor building	1-R2	Basement 5 (on foundation)	311	680	408	10:12:46:00	498.20	
Unit 1	Turbine building	1-T2	1st floor (pedestal)	1862	1459	741	10:12:46:00	186.29	
Unit 2	Reactor building	2-R1	2nd floor	517	718	412	10:12:45:00	493.92	
Unit 2	Reactor building	2-R2	Basement 5 (on foundation)	304	606	282	10:12:45:00	498.79	
Unit 2	Turbine building	2-T1	1st floor	431	764	594	10:12:45:00	493.17	
Unit 2	Turbine building	2-T2	1st floor (pedestal)	642	1159	650	10:12:46:00	181.75	
Unit 2	Turbine building	2-T3	Basement 3 (on foundation)	387	681	470	10:12:45:00	497.95	
Unit 3	Reactor building	3-R1	2nd floor	525	650	518	10:12:44:00	494.84	
Unit 3	Reactor building	3-R2	Basement 5 (on foundation)	308	384	311	10:12:46:00	498.15	
Unit 3	Turbine building	3-T2	1st floor (pedestal)	1350	2058	619	10:12:46:00	183.01	
Unit 3	Turbine building	3-T3	Basement 3 (on foundation)	581	549	513	10:12:44:00	600.00	The new additional seismometer
Unit 4	Reactor building	4-R1	2nd floor	606	713	548	10:12:45:00	492.74	
Unit 4	Reactor building	4-R2	Basement 5 (on foundation)	310	492	337	10:12:45:00	494.02	
Unit 4	Turbine building	4-T1	1st floor	411	560	549	10:12:46:00	492.61	
Unit 4	Turbine building	4-T2	1st floor (pedestal)	614	763	526	10:12:45:00	326.96	
Unit 4	Turbine building	4-T3	Basement 3 (on foundation)	348	442	443	10:12:45:00	600.00	
Unit 5	Reactor building	5-R1	3rd floor	472	697	331	10:12:45:00	493.21	
Unit 5	Reactor building	5-R2	Basement 4 (on foundation)	277	442	205	10:12:45:00	493.69	
Unit 5	Turbine building	5-T2	2nd floor (pedestal)	1166	1157	533	10:12:45:00	187.26	
Unit 6	Reactor building	6-R1	3rd floor	554	545	578	10:12:45:00	498.67	
Unit 6	Reactor building	6-R2	Basement 3 (on foundation)	271	322	488	10:12:45:00	600.00	
Unit 7	Reactor building	7-R1	3rd floor	367	435	464	10:12:45:00	493.92	
Unit 7	Reactor building	7-R2	Basement 3 (on foundation)	267	356	355	10:12:44:00	600.00	
Unit 7	Turbine building	7-T1	2nd floor	418	506	342	10:12:44:00	600.00	
Unit 7	Turbine building	7-T2	2nd floor (pedestal)	673	1007	362	10:12:45:00	266.77	
Unit 7	Turbine building	7-T3	Basement 2 (on foundation)	318	322	336	10:12:45:00	600.00	

Table 2: with available seismic records, in red the units 5 (free field records for main shock and aftershocks) and unit 7 for records in structure (3rd floor and basement on foundation), from [1].

There are available files with soils proprieties near RB unit 7 and unit 5 (properties of soils and strain dependent soil properties) and a database with all dimensions (Floor plan: Crane Floor…) and precise guidance documents [4]. As indicated in the previous table, the available ground motions were recorded in the structure of unit 7 and in the free field close to unit 5.

WHAT IS NOT AVAILABLE?

- Seismic hazard model of the KK NPP site
- Fragility curves for any structure or equipment
- PSA model

2 - Zaporizhzhya Site – Ukraine

The Zaporizhzhya Nuclear Power Plant (ZNPP) is located in southeastern Ukraine near the city of Enerhodar. It is the largest nuclear power plant in Europe and the fifth largest in the world. There are six units. The Plant is operated by the National Nuclear Energy Generating Company Energoatom.

For the ZNPP site, data are not directly available. METIS partner SSTC (State Scientific and Technical Center for Nuclear and Radiation Safety) is the contact between the ZNPP and METIS. SSTC has gotten the official permission from ZNPP to share data within the METIS project. Below is a summary of data and reports currently received.

Probabilistic Seismic Hazard Analysis (PSHA)

A site specific PSHA was performed at the ZNPP site. The PSHA is very well described [5]. All elements of the PSHA are clear: geology and tectonic, seismic source models, seismic catalogue, activity rates, ground motion models, etc. A synthesis of some PSHA components and final results are presented in the following paragraphs.

Tectonic and Seismicity

A declustered catalog of earthquakes for a region within the 500 km radius of the ZNPP was compiled. The size of the earthquakes in the catalog is measured in moment magnitude (MW). The final catalogue includes 348 events with moment magnitude between 2.5 and 5.2 and spanning the time period from 2500 B.C. to July 2011, see figure 1 below.

The seismicity in most parts of Ukraine is sparse. The most seismically active regions are outside of the 500 km distance of the ZNPP site. Around ZNPP the seismicity is very scarce, the closest significant event is located at 320 km from the site.

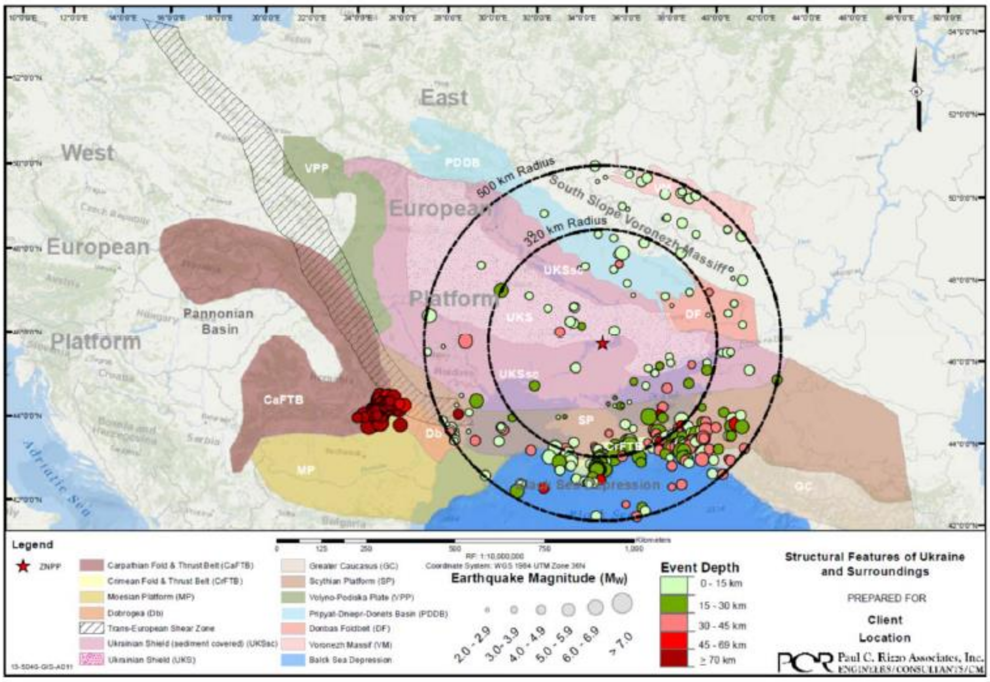


Figure 1: Seismicity distribution from the final homogenized declustered catalog. The red star identifies the ZNPP site. Figure excerpted from [5].

Ground motion model

Available geological, geophysical, and seismological data were evaluated to define the Stable Continental Region (SCR) containing the ZNPP Site. The deep crustal seismic profiles show that the ZNPP is situated in a platform setting of the East European Craton, south of the Ukrainian Shield. More precisely, ZNPP is located in a platform sediments which overlie the basement (figure 2). The thickness of the sedimentary layer is around 78 meters overlying a hard rock level characterized by a time averaged shear-wave velocity over the upper 30 meters (VS30) of 2830 m/s.

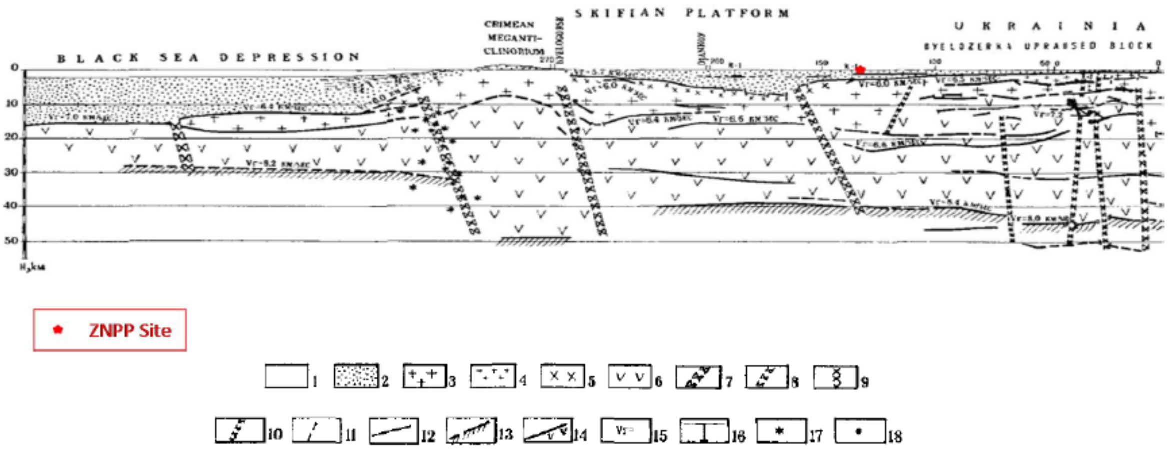


FIGURE 4-3
CRUSTAL CROSS SECTION ALONG PROFILE I OF FIGURE 4-2 (THE BLACK SEA TO THE VORONEZH MASSIF)

Notes:
1 = Water
2 = Sedimentary layer
3 = Granitic layer
4 = Metamorphic rocks of the belozerka series within the granitic layer.

Figure 2: Crustal cross section with sedimentary layer overlapping the basement and location of ZNPP site [5].

Seismic monitoring of the ZNPP site is performing from 2012 by temporary seismic monitoring system and from 2018 by onsite permanent seismic monitoring system (Results are available). Six events were recorded at KIEV seismic station which is located at 600 km from ZNPP with magnitude of around 4.8 to 5.1 Mw. The site condition at Kiev station is undetermined. The hard rock site was supposed for KIEV station to compare with selected GMPEs. The final result show that all selected GMPEs from several tectonics environments overestimate the hazard compared with observations. Following expert opinion a group of models representing continental stables and actives regions were selected and adjusted for very hard rock conditions, tableau 1 below.

GMPE
Campbell (2003)
Toro et al., (1997)
Chiou and Youngs (2008) - Adjusted to very hard rock condition
Cauzzi and Faccioli (2008) - Adjusted to very hard rock condition
Akkar and Bommer (2010) - Adjusted to very hard rock condition
Youngs et al., (1997) – For Vrancea intermediate-depth earthquake source zone

Table 1 with final selected GMPEs for ZNPP site [5]

Seismic hazard curves and Uniform Hazard Response Spectra on rock

A lower-bound magnitude of 5.0 Mw is used in the hazard calculations. Seismic hazard curves were calculated for a hard-rock site conditions characterized by a time averaged shear-wave velocity over the upper 30 meters (VS30) of 2830 m/s. Hazard was determined for discrete spectral acceleration levels ranging from 0.002 to 4 g. Figure 3 shows an example of the seismic hazard curve for PGA.

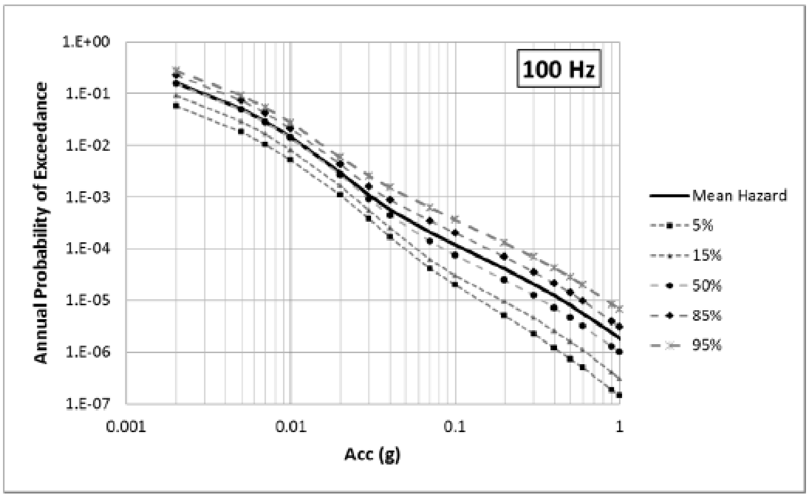


Figure 3: Seismic hazard curve for PGA at rock level [5]

Uniform Hazard Response Spectra (UHRS) are determined for annual probabilities of exceedance of 1E-03 and 1E-4, figure 4.

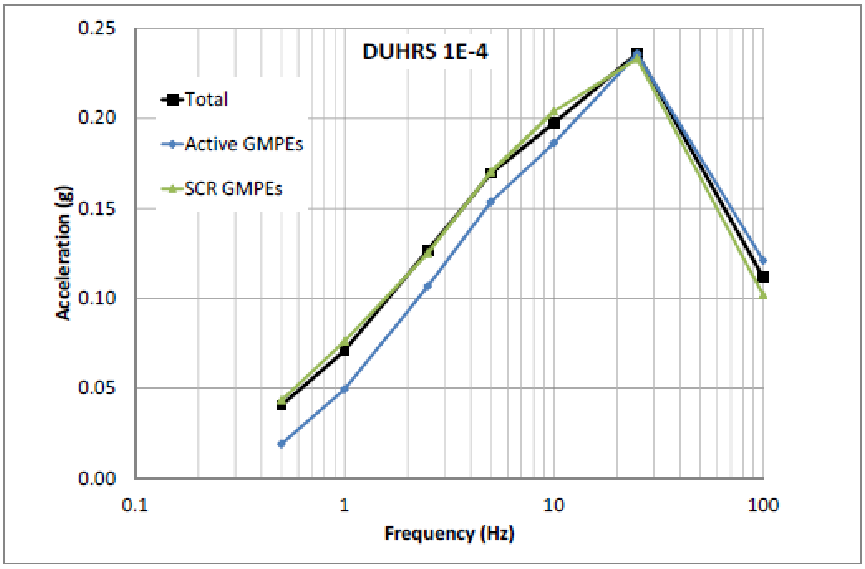


Figure 4: Uniform hazard response spectra for 1E-04 for total hazard and for the hazard associated with active region and SCR at rock level [5].

Figures below show an example of the mean hazard disaggregation of UHRS carried out for two spectral frequency ranges: low (1 and 2.5) Hz and high (5 and 10 Hz) and two exceedance probabilities (1E-03 and 1E-04).

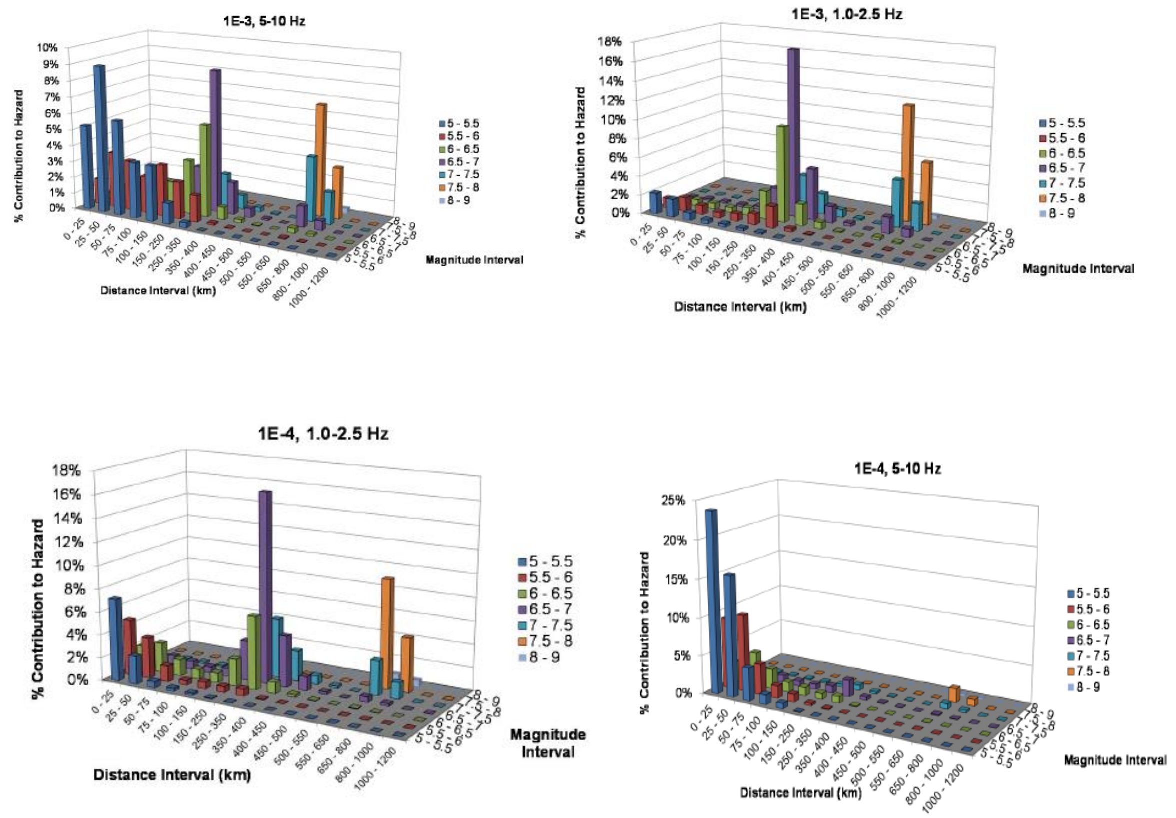


Figure 5: Mean hazard disaggregation [5].

Following figure 5, the main results are:

- ► Exceedance probability of 1E-03:

- for low-frequency spectral accelerations there is a bimodal distribution combination: 6.5 to 7.0 Mw at distances of 250 to 350 km, and 7.5 to 8.0 Mw at distances of 550 to 800 km.
- for high-frequency spectral accelerations there is a trimodal distribution: 5 to 5.5 Mw at distances of 25 to 50 km; 6.5 to 7.0 Mw at distances of 250 to 350 km, with a lesser contribution from 7.5 to 8.0 Mw at distances of 550 to 800 km.

- ► Exceedance probability of 1E-4:

- for low-frequency spectral accelerations there is a trimodal distribution combination: 5.0 to 5.5 Mw at distances < 25 km; 6.5 to 7.0 Mw at distances of 250 to 350 km, with a lesser contribution from 7.5 to 8.0 Mw at distances of 550 to 800 km
- for high-frequency spectral accelerations there is a single dominant magnitude/distance combination: 5 to 6.0 Mw at distances of 0 to 50 km.

Site response analyses

The hard rock hazard was calculated at free field using PSHA. To achieve this objective, a calculation of site amplification functions was performed. The methodology is well described in [5]. We concentrate the next paragraphs on the available data regarding site geotechnical model. A very important experimental work was done to perform the geotechnical model. Figure 6 presents the best estimate share wave velocity profile. The table below illustrates the characteristics of the wave velocity profile.

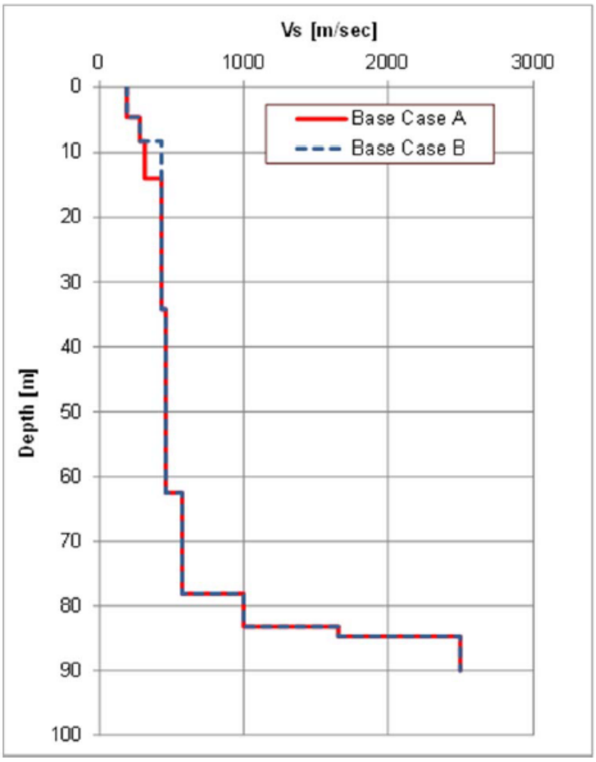


Figure 6: Proposed best-estimate (be) shear wave velocity profile [6]

TABLE 6-2
BASE CASE SHEAR WAVE VELOCITY PROFILES FOR THE ZNPP SITE

LAYER NO	DESCRIPTION	THICKNESS (m)	Vs (M/S) (CASE A)	Vs (M/S) (CASE B)	COV_{VS}	UNIT WEIGHT (kN/m^3)	MATERIAL TYPE NO	SOURCE OF STRAIN-DEPENDENT PROPERTIES
1	Wet sand above groundwater	4.7	190	190	0.15	15.9	1	EPRI 1993 Sand with depth 0-20'
2	Saturated sand I	3.7	280	280	0.16	19.3	1	EPRI 1993 Sand with depth 0-20'
3	Saturated sand II	5.6	315	430	0.15	19.9	2	EPRI 1993 Sand with depth 20-50'
4	Saturated sand III	20.2	430	430	0.15	20.4	3	EPRI 1993 Sand with depth 50-100'
5	Clay	15.7	460	460	0.15	18.8	4	Vucetic and Dobry 1991 Clay with PI=30
6	Saturated sand IV	12.6	460	460	0.15	18.2	5	EPRI 1993 Sand with depth 100-250'
7	Sandstone	6.4	573	573	0.15	18.1	6	Volume 4 Summary Report Sandstone
8	Kaolin I	9.2	573	573	0.15	17.7	7	Volume 4 Summary Report Kaolin
9	Kaolin II	5.1	1000	1000	0.15	19.6	7	Volume 4 Summary Report Kaolin
10	weaker granite	1.5	1658	1658	0.15	25.4	8	
11	granite		2500	2500	0.15	25.4		

Table with Shear velocity profile for the ZNPP site [6].

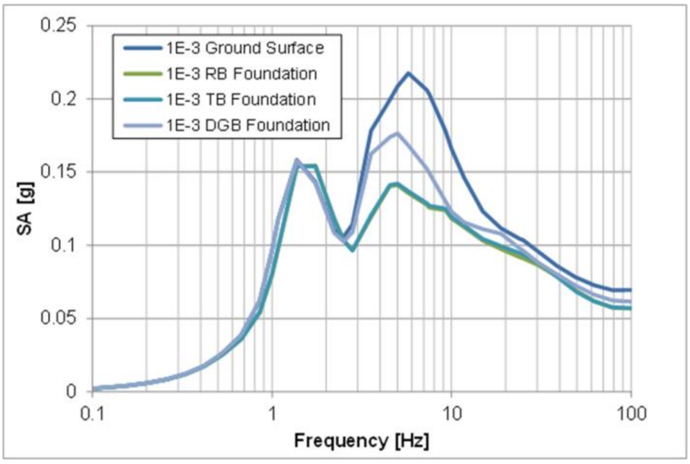
Uniform Hazard Response Spectra at free field and foundations.

Site amplification functions were developed and used to adjust the hard rock uniform hazard response spectra to derive the free field design basis earthquake (DBE) response spectra for 1E-03 and 1E-04.

The amplification functions were obtained at the top of the Layer 1 and the foundation levels for the Reactor Building (RB), Turbine Building (TB), and Diesel Generation Building (DGB). The foundation embedment depths for the RB, TB, and DGB are listed below:

BUILDING	FOUNDATION ELEVATION (m)	EMBEDMENT DEPTH (m)
Reactor Building	15.0	7.0
Turbine Building	15.6	6.4
Diesel Generation Building	14.0	8.0

The PSHA results are used to derive Response Spectra at the foundation level of the RB, TB, and DGB for ZNPP Units 1 and 2. Figure 7 illustrate the sets of Response Spectra provided per building: one set associated with annual probability of 1E-03, and another set consistent with an annual probability of 1E-04.



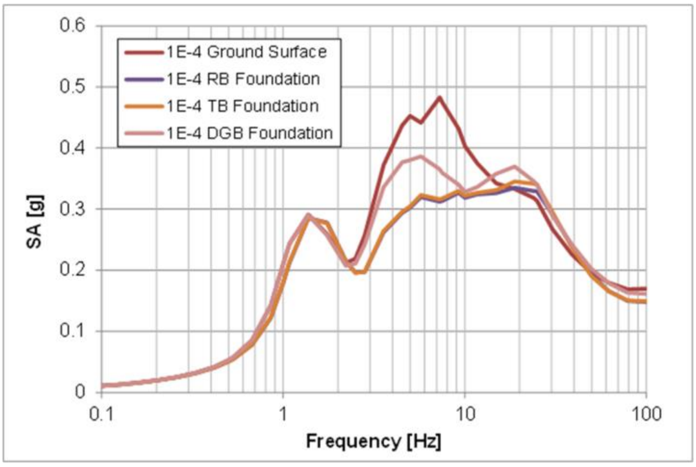


Figure 7: Final UHRS at multiple elevations [5]

Probabilistic Safety Assessment (PSA)

Level 1 PSA and level 2 PSA were performed for ZNPP. A synthesis of these calculations is available [8] as well as all data files of the PSA model.