CONSIDERATIONS ON THE SEISMIC QUALIFICATION OF ELECTRO-ENERGETIC COMMAND AND CONTROL EQUIPMENT FOR THE CERNAVODA NUCLEAR POWER PLANT. PROTECTION OF HUMAN HABITAT AND MAJOR ACCIDENTS PREVENTION

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ABSTRACT

The Chernobyl events of 26 April 1986 and of Fukushima, on March 2011, reinforced the nuclear dimension of the EU energy policy by conducting a comprehensive exercise of resistance tests on nuclear installations in the European Union (and neighboring countries) during the period 2011 and subsequently with the adoption of the Council Directive 2014/87/EURATOM (2014) amending Council Directive 2009/71/ EURATOM (2009) establishing a Community framework for the safety of nuclear installations. This paper addresses some aspects specific to the Seismic Qualification Standards of the Electro-Energetic Command and Control Equipment for the Cernavoda Nuclear Power Plant, the main aspects of which include: a) Defining the seismic class of the equipment, b) Preliminary investigations, c) Seismic qualification, d) Final investigations, e) Conditions of seismic acceptance and qualification.

Keywords: seismic class; acceptability; criteria; qualification.

REZUMAT

Evenimentele de la Cernobîl, din 26 aprilie 1986 şi Fukushima, din martie 2011, au întărit dimensiunea nucleară a politicii energetice a UE, prin derularea unui exerciţiu amplu de testări de rezistenţă la instalaţiile nucleare din Uniunea Europeană (şi din statele învecinate), în perioada 2011-2012 şi, ulterior, prin adoptarea *COUNCIL Directive 2014/87/EURATOM* (2014) de modificare privind *COUNCIL Directive 2009/71/EURATOM (*2009) de instituire a unui cadru comunitar pentru securitatea instalaţiilor nucleare. Prezenta lucrare abordează unele aspecte specifice normelor de Calificare Seismică a echipamentelor electro-energetice de comandă şi de control pentru Centrala Nuclearo-Electrică Cernavodă, aspecte care cuprind, în principal: a) definirea clasei seismice a echipamentului, b) investigaţii preliminare, c) efectuarea calificării seismice, d) investigaţii finale, e) condiţii de acceptabilitate şi de calificare seismică.

Cuvinte cheie: clasă seismică; acceptabilitate; criterii; calificare.

1. INTRODUCTION

The Chernobyl events of 26 April 1986 and of Fukushima, on March 2011, reinforced the nuclear dimension of the EU energy policy by conducting a comprehensive exercise of resistance tests on nuclear installations in the European Union (and neighboring countries) during the period 2011-2012 and subsequently, with the adoption of *Council Directive 2014/87/ EURATOM (2014)* amending *Council Directive 2009/71/ EURATOM (2009)* and establishing a Community framework for the nuclear safety of nuclear installations.

Consequently, physical test confirmation of the functioning of the sistems, control or fault signaling of any equipment in any extreme operating conditions, confirmation called "Seismic Qualification", it is necessarily required. This paper addresses some aspects specific to the Seismic Qualification Standards of the electro - energetic control and control equipments for the Cernavodă nuclear power plant, aspects that mainly include:

- a) Defining the Seismic Equipment Class
- b) Preliminary investigations
- c) Performing the Seismic Qualification
- d) Final investigations
- e) Conditions of Seismic Qualification.

Some names of articles a, b, c, d and e may differ depending on the reference

standard, but the essence of the specified activity is the same.

2. DEFINING THE SEISMIC CLASS OF THE EQUIPMENT

Defining the seismic class of equipment is recommended and selectively exposed in to the following standards:

• SR EN 60068-3-3: 1994 (1994), Enviromental tests. Part 3: Guidance. Seismic test methods for equipments: 5. specifies:
- Section 2: "GENERALITIES. Have two seismic classes were defined: General Seismic Class and Specific Seismic Class. ... If a very high security reliability is required for a specified environment, such as the safety of nuclear power plants, ... the specific seismic class must be applied ... "
o The standard holds the mentioned specification.

• SR EN 60068-3-8: 2004 (2004), Environmental testing. Part 3-8: Supporting documentation and guidance - selecting between vibration tests.
o The standard does not hold the mentioned specification.

• SR EN 60068-2-64: 2010 (2010), Environmental testing - Part 2-64: Tests - Test Fh: - Tests Fc: Vibration, broadband random and guidance.
o The standard does not hold the mentioned specification.

• SR EN 60068-2-6-2008 (2008), Environmental testing. Part 2: Tests - Fc: Vibration (sinusoidal) tests.
o The standard does not hold the mentioned specification.

• IEEE 344 (2013), IEEE Standard for the Seismic Qualification of Equipment for Nuclear Power Generating Stations: 1. specifies:
- Section 1.1: "1.1 Scope. This document describes qualitative seismic qualification procedures that will yield quantitative data to demonstrate that Class 1E equipment can meet its performance requirements during and/or after a safe shutdown earthquake (SSE) event preceded by a number of operational earthquake (OBE) events."
o The standard holds the mentioned specification.

• Document Code 8403 / 2016-6.1- 50099785-C1 (2018), Guidelines for the Seismic Qualification of Equipments Installed in Emergency Facilities Building - Nuclear Power Plant - Cernavoda: 5, 18. specifies:
- Section 1: "1 INTRODUCTION. ... The ultimate goal of this document is to establish the performance criteria and requirements for the seismic qualification of SSC at Cernavoda
"4.2 Categories of equipment. Equipment in seismic category "A":
- Equipment included in the seismic category "A" must be able to maintain its structural integrity and pressurization capacity during and after the earthquake, to ensure and maintain the functioning of the safety systems
- Equipment included in the in seismic category "B" shall be capable of maintaining structural, mechanical and / or electrical operation during and / or after the earthquake in order to ensure and maintain the operation of the SSCs included in the "B" and must also meet the requirements for category "A".
o The standard holds the mentioned specification.

• Technical Specification (2001), Safety Systems Equipment Cabinets, Cernavoda 2, code 82-68000-TS-003, Revision 0: 1. Specifies:
- Section 1: "1. Scope. This Specification establishes the technical requirements for the design, fabrication, testing, supply and guarantee of Safety Systems Equipment Cabinets to be installed in the Control Equipment Room and the Secondary Control Area in a Nuclear Generating Station."
o The standard holds the mentioned specification only for Safety Systems Equipment Cabinets.
• Addendum to Technical Specification (2001), Safety Systems Equipment Cabinets,

code 82-68000-TS-003-01, Rev. 0.
o The standard holds the mentioned specification only for Safety Systems Equipment Cabinets.

- Summary of the specifications of the above mentioned standards:

Standard SR EN 60068-3-3: 1994 (1994) provides for a different and specific fitting of test equipment in seismic classes as a general recommendation. The other references relate strictly to the particular equipment of operation in Nuclear Power Generating Stations, Nuclear Power Plant - Cernavoda.

Therefore, in defining the seismic class of test the equipment, first of all, the technical specifications issued by the beneficiary will be considered. It is recommended, as an alternative to any other type of electro-energetic control and/or control equipment, to use the specifications of SR EN 60068-3-3: 1994 (1994).

3. PRELIMINARY INVESTIGATIONS. DETERMINING THE (RESONANT) CRITICAL FREQUENCIES OF THE TESTED EQUIPMENT

Determination of the (resonant) critical frequencies of the tested equipment is recommended and exposed, selectively, as falows:

• SR EN 60068-3-3: 1994 (1994), Enviromental tests. Part 3: Guidance. Seismic test methods for equipments: 15. specifies:

- Section 10.1: "10.1 Investigating vibration response provides data on critical frequencies. Typically, a sinusoidal excitation occurs after a single axis and consists of a logarithmic scanning cycle in the frequency range from 1 Hz to 35 Hz with a scanning speed of 1octave/minute. The most usual scrolling acceleration is 0.2g and can be reduced to 0.1g".
o The standard holds the mentioned specification.
• SR EN 60068-3-8: 2004 (2004) Environmental testing. Part 3-8: Supporting documentation and guidance - selecting between vibration tests: 35-43. specifies:

- Section 8 and Section 8.1: "8 Vibration response of the specimen. - 8.1 General. Useful information about the specimen will be obtained by measuring the vibration characteristics of the whole specimen (see 8.7, Table 2. Recommended method for response investigation (selection)"

"8.7 Table 2. Recommended method for response investigation (selection)"

Properties	Precise investigation
Resonance frequency	Sine
Damping ratio	Sine
Non – linearity of the specimen	Sine
Survival pass/fail, general case	Random

Observation: The value of the normal scanning speed is not specified, but reference is made to SR EN 60068-2-6-2008, which specifies:
• SR EN 60068 – 2 – 6 - 2008 (2008) Environmental testing. Part 2: Tests - Tests Fc:
- Section 4.1.6: "4.1.6 The sweeping shall be continuous and the frequency shall change exponentially with time. The sweep rate shall be one octave per minute with a tolerance of ±10%".
o The standard holds the mentioned specification.

- SR EN 60068-2-64:2010 (2010), *Environmental testing - Part 2-64: Tests - Test Fh: – Tests Fc: Vibration, broadband random and guidance*: 19. specifies:

- Section 8.2: "8.2 If not expressly prescribed in the specific specification, it is not necessary to investigate and study the critical frequencies. However, the particular specification may study the critical frequencies forward on each axis, or before and after trying with random vibrations. ...

When using a sinusoidal excitation, at least one scanning cycle in the frequency range prescribed by the specific specification

must be performed with an acceleration of an 10m/sec^2 amplitude.

A scanning speed of 1 octave per minute must be applied to determine the resonance frequencies and the amplitudes."

o The standard holds the mentioned specification.

- IEEE 344 (2013), *IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations:* 15. specifies:

- Section 8.1.4.1: "8.1.4.1. Resonance search by base excitation.... The resonance search is generally performed just before the qualification seismic vibration test, as the information gathered may be useful in performing it. ... Generally, a slow swept low-level sinusoidal vibration should be employed. The sweep rate should be two octaves per minute, or less, to ensure resonance buildup. A 0.2g peak input is the conventional input level ... It is recommended that the resonance search be carried beyond 33 Hz ... "

o The standard holds the mentioned specification.

- Document 8403 / 2016-6.1- 50099785-C1 (2018), *Guidelines for the Seismic Qualification of Equipment Installed in Emergency Facilities Building (Unit 5 Integrated Building) - Nuclear Power Plant Cernavoda*: 31. specifies:

- Section 5.6.1: "5.6.1 Exploratory tests. In some situations, exploratory tests may be performed, requiring equipment at low intensities to allow the selection of a suitable method for the real scale test. Exploratory tests will be performed at a rate of less than 2 octaves per minute for a certain frequency range. All resonances will be recorded "

o The standard holds the mentioned specification without specifying the value of the usual sweep acceleration.

- Technical Specification (2001), *Safety Systems Equipment Cabinets, Cernavodă 2, cod 82–68000–TS - 003, Revision 0, Appendix A*: A-2. specifies:

- Section A-2-3: "A.2.3. Resonance Search. Prior to the qualification test and after the qualification test, two sine sweep resonance searches at 0.2 g, one sweeping up and one sweeping down, shall be conducted in each of the three directions. The sweep rate shall be one octave per minute starting at 2 Hz and ending at 33 Hz."

o The standard holds the mentioned specification.

- Addendum to Technical Specification (2001), *Safety Systems Equipment Cabinets, code 82-68000-TS-003-01, Rev. 0*: 2. specifies:

- Section 2.1: "2.1 Before the qualification test and after the qualification test, two sine sweep resonance searches at 0.4 g, one sweeping up and one sweeping down, shall be conducted in each of the three directions. The sweep rate will be one octave per minute, starting at 2 Hz and ending at 33 Hz" and thus change the value of the usual scanning acceleration size from 0.2g to 0.4g.

o The standard holds the mentioned specification.

- Summary of the specifications of the above mentioned standards:

It is recommended that the determination of the critical frequencies (resonance) be done by sinusoidal vibration with increasing frequency and then decreasing in the three directions. The exploration frequency range is 2 to 33 Hz, the sweep rate is one octave per minute, and the acceleration of the vibrating mass is 0.2g ... 0.4g, depending on the accepted standard.

4. PERFORMING THE SEISMIC QUALIFICATION

The seismic qualification methods of the test equipment are recommended and exposed, selectively, in the following regulations:

- SR EN 60068-3–3:1994 (1994), *Enviromental testings. Part 3: Guidance. Seismic test methods for equipments*: 10-15. specifies:

- Section 6.1: “6.1 Choice of the test type. In order to verify the equipment's ability to withstand seismic demands, several types of testing may be considered. These are shown in Table 1.”

“6.1 Table 1 - Choosing the type of test”

Test waves	Type of the test	
	Monoaxial test	Poliaxial test
Sine wave	a	c
Modulated sinusoid	a	c
Accelerogram	b	a
Continuous sine	b	c
a = recommended		
b = suitable		
c = not recommended		

- Section 6.2: “6.2 Choice of test method. There are two methods:
a) **conventional testing with standardized amplitude:** this test is applied when the conditions of use of the equipment are not known (see paragraph 7);
b) **calculated amplitude test:** this method is applied when the conditions of use of the equipment are known enough to allow the specification of the different test parameters (see paragraph 8).”

- a) Section 7: “7 Conventional standard amplitude test. 7.1 Application. This test has three levels of performance, often called skill levels (see Table 2) and it is recommended when conditions of the use of the equipment are not known. The equipment user must ensure that the performance level at which the equipment was tested matches the intended application.”

“7.1 Table 2 - Performance level”

Performance level *)	Floor Acceleration (a_f)	
	Horizontally	Vertical
	m/s^2	m/s^2
I	6	3.0
II	9	4.5
III	15	7.5
*) These levels can be used above the 1.6 Hz transfer frequency.		

- Section 7.2: 7.2 Test conditions. The conventional amplitude standard test is monoaxial only. The different axes are excited successively. The test acceleration value is defined starting from the performance level (see paragraph 7.2.1), the wave factor (see paragraph 9.2.1) and the geometric factor (see section 9.2.2).”
These last sections will be further discussed.

- Section 7.2.1: “ 7.2.1 Performance level ... In the conventional standard amplitude test, the acceleration (*af*) is chosen directly from the levels shown in Table 2.”

- Section 7.2.2: “7.2.2 Choice of test wave. The recommended waveform is the sinusoid modulated by five cycles or the sinusoidal sweep. The maximum excitation acceleration value for the chosen qualification shall be corrected by the wave factor (see paragraph 9.2.1) and by the geometric factor (see paragraph 9.2.2).”
These last sections will be discussed further.

- b) Section 8: “8 Amplitude calculated. 8.1 Application. The calculated amplitude test method is recommended when sufficient information on the conditions of use and characteristics of the equipment is available to allow an estimation of the better test level than that of the standardized amplitude test method (see paragraph 7).”

- Section 8.2: “8.2 Test conditions. In principle, this test is of the monoaxial type in which the different axes are excited successively. This corresponds when, for example, there is only a weak coupling between the different axes or if this coupling can be justified by applying a geometric factor.”

- Section 8.2.1: “8.2.1 Performance level. The degree of severity of the test is determined by the values assigned to the following parameters, which define the particular feature of the equipment:
a) the test string (section 8.2.2);
b) material depreciation (section 8.2.3);
c) amplification factor (section 8.2.5);
d) steering factor (section 8.2.6);
e) the duration of the test (section 9.1);
f) wave amplitude (section 9.2).

- Section 8.2.2: "8.2.2 Choice the test wave. The choice of the test wave has an influence that is not negligible on the response of the equipment when the value of its damping coefficient is sensibly different from 5% ..."

- Section 8.2.3: "8.2.3 Coefficient damping. A damping coefficient offten of 5% is recommended."

- Section 8.2.4: "8.2.4 Ground acceleration (a_g). Ground acceleration (a_g) depends on the seismic conditions of the place where the equipment must be located. If known, that must be indicated in the particular specification. Otherwise, it must be chosen from the ones recommended in Table 3."

- Section 8.2.5: "8.2.5 Factor amplification (K). The amplification factor (K) allows maintaining the gain of the acceleration of the soil acceleration resulting in the vibration behavior of the buildings and structures. Recommended values are those shown in Table 4, but when site conditions are known, the specific specification may prescribes other values."

- Section 8.2.6: "8.2.6 Direction factor (D).
... If the equipment mounting conditions are specified, the test for the preferential horizontal test axes X and Y at 100% of the test plane, but only at 50% of the vertical Z axis, shall be performed. Direction factors (D) are indicated in Table 5."

- Section 8.2.7: "8.2.7 The slab acceleration. In the calculated amplitude test method ... Soil acceleration (a_g) is known or is given by the individual specification. The slab acceleration is determined by the formula:

$$a_f = a_g * K * D \qquad (1)$$

in which:
- a_g = acceleration of the soil (section 8.2.4);
- K = amplification factor (section 8.2.5);
- D = correction factor (section 8.2.6).

"8.2.4 Table 3 - Ground acceleration levels (selection)"

Reference acceleration to the ground	Features of the earthquake			
	Overview	a_g [m/s^2]	Informative	
			Richter Magnitude	MSK Intensity [2)]
AG 2	Low to medium intensity erthquake	22	< 5.5	< VIII
AG 3	Medium to height intensity earthquake	3 5 33	5.5 to 7.0	VIII to IX
AG 4	Height to very high intensity arthquake	55	>7.0	> IX

[2)] MSK (Medvedev - Sponheuer - Karnik corresponding to the modified Mercali scale)

"8.2.5 Table 4 - Recommended amplification factors (K) (selection)"

K Factors	Application
1.0	Equipment mounted on rigid foundations or on rigid structures
1.5	Equipment rigidly linked to buildings
2.0	Equipment mounted on rigid structures, rigidly linked to buildings
3.0	Equipment mounted on small rigid structures linked to buildings

" 8.2.6 Table 5. Steering factors (D)"

Axis of vibration	D Factor	Restrictions
Horizontal, D_x	$D_x = 1.0$	-
Horizontal, D_y	$D_y = 1.0$	-
Verical, D_z	$D_z = 0.5$	Only if vertical orientation is specified *)
Verical, D_z	$D_z = 1.0$	
*) If the effect of gravity has no influence on the behavior of the equipment, these tests are performed successively with each of the three main axis of the equipment in the vertical plane and Dx = 1.0, Dy = 1.0 and Dz = 0.5.		

- Section 9: "9 Test Parameters. 9.1 Duration of the test. The seismic test time must correspond to the one in the force of the earthquake accelerogram ..."

- Section 9.2: "9.2 Acceleration of test. ... The value a_t represents the level of acceleration to be applied to the equipment, calculated with the formula:

$$a_t = a_f * \alpha * G \qquad (2)$$

in which:
- a_f = slab acceleration (7.2.1 or 8.2.7);
- α = wave factor (section 9.2.1);
- G = geometric factor (section 9.2.2).

- Section 9.2.1: "9.2.1 Wave factor. Wave factor value (α) is normally determined by a damping factor of 5% for a continuous sinusoid or a sinusoidal sweep, and for different damping coefficients. Table 6 indicates proposed values for these cases."

"9.2.1 Table 6. Waveform factor (α)"

Critical damping coefficient	Wave Factor (α)	
	Sine wave modulated by 5 cycles	Continuous sinusoid or sinusoidal sweep (1 oct./min)
$\xi \leq 2\%$	1	0.30
$2\% < \xi \leq 10\%$	1	0.55
$\xi > 10\%$	1	0.80

- Section 9.2.2: "9.2.2. Geometric Factor (G). If there is insufficient information about the excitement conditions at the installation site of the equipment, the geometric factor is equal to:
- 1.0, in the case of a single axial excitation without coupling between the axis;
- 1.5 in the case of a single axial excitation with axis coupling."
o The standard holds the mentioned specification.

- SR EN 60068-3-8:2004 (2004), *Environmental testing. Part 3-8: Supporting documentation and guidance – selecting amongst vibration tests*: 31, 21. specifies:

- Section 7.1: "7.1 General. For making a decision on the appropriate test method, the following information is needed:
- description of vibration environment (Pct. 5);
- definiton of environment type (Pct.5.3);
- estimation of dynamic conditions (Pct. 6)."

- Clause 5 (Pct. 5) specifies: "5.3 Definition of dynamic condition. ... one of the dynamic conditions given in Table 1 may be chosen. If none of these classes are appropriate, the type of environmental condition must be estimated - see Clause 6 (Pct. 6)."

"5.3 Table 1 – Examples of vibration environment and recommended test method (selection)"

Method IEC 60068	Mixed mode Part 2-80	Random Part. 2-64	Sine Part. 2-6
Type of vibation signal for testing	Random+ Sine	Random	Sine
Vibration environment of the specimen		*	
Specimen installed in different locations	*	*	*
Estimated dynamic condition, type of signal	*	*	*

- Clause 6 specifies: "6. Estimation of "real-life" dynamic conditions for the specimen. 6.1 General. If the actual environment does not fit into the classes listed in 5.3 and Table 1, the type of vibration environment must be determined in some other ways. There are different methods for obtaining these typ of informations about dynamic conditions:
- measuring real life vibration;
- using experience and an engineering judgment;
- using an appropriate standard, such as IEC 60721-3 series. "

o The standard holds the mentioned specification without specifying the value of the usual seismic qualification acceleration and the duration of the test excitation.

- SR EN 60068-2-64:2010 (2010), *Environmental testing - Part 2-64: Tests - Test Fh: – Tests Fc:Vibration, broadband random and guidance*: 17, 18. specifies:

- Section 5: "5 Severity degree. The test severity degree is determined by combining the following parameters:
- the frequency domain of the test;
- actual acceleration value;
- duration of the test.

The values of each parameter must be prescribed in the particular specification."

- Section 5.1: "5.1 Frequency range of the test can be selected from the following values:
a) f1: 1; 2, 5; 10; 20; 50; 100 (Hz);
b) f2: 20 50; 100; 200; 500; 1000; 2000; 5000 (Hz)."

- Section 5.2: "5.2 The effective acceleration magnitude can be chosen from the following values:
- 1; 1.4; 2; 2.8; 3.5; 5; 7; 10; 14; 20; 28; 35; 50; 70; 100; 140; 200; 280. (m/sec^2)."

- Section 5.4: "5.4 Trial duration. The duration of the test shall be indicated in the particular specification or may be chosen from the following series: 1; 2; 5; 10; 20; 30; 45; 60 minutes or 2; 5; 8; 12; 24 hours, with ± 5% tolerance."

- Section 8: "8 Attempts. 8.1 Generalities. The test follows the sequence prescribed by the specific specification. "

o The standard holds the mentioned specification.

SR EN 60068-2-6-2008 (2008), *Environmental testing. Part 2: Tests – Tests Fc:Vibration (sinusoidal)*: 33, 35. specifies:

- Section 8: "8. Testing. Unless otherwise stated in the relevant specification, the specimen shall be vibrated in three mutually perpendicular axes, in turn, wich should be so chosen that faults are most likely to be revealed."

- Section 6.1: " 6.1 Vibration response investigation. ... Normally, the vibration response investigation shall be carried out over a sweep cycle under the same conditions as for the endurance (see 8.2) ... "

- Section 8.2: "8.2 Endurance procedure. The relevant specification shall be prescribed which of the following endurance procedures shall be employed:

- 8.2.1 Endurance by sweeping;
- 8.2.2 Endurance at fixed frequencies."

o The standard holds the mentioned specification without specifying the value of the usual seismic qualification acceleration and the duration of the test excitation.

- IEEE 344 (2013), *IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations*: 19, 27. specifies:

- Section 8.6: "8.6 Test methods. 8.6.1 Introduction. Present test methods generally fall into three major categories. They are proof or generic testing and fragility testing. The types of motion available to best simulate the postulated seismic environment fall into two categories: single frequency and multiple frequency. The method chosen will depend upon the nature of the expected vibration

environment and also somewhat on the nature of the equipment.

In general, the proof or generic test seismic simulation waveforms, or both, should:

a) Produce a TRS that closely envelops the RRS using single - or multiple-frequency input as required to provide a conservative (but not overly so) test-table motion.

b) Have a peak acceleration equal to or greater than the RRS ZPA.

c) Not include frequency content above the RRS ZPA asymptote.

d) Have a duration in accordance with the requirements of 8.6.5."

Definitions:

- TRS: test response spectrum. The response spectrum that is developed from the actual time history of the motion of the shake table.

- RRS: required response spectrum. The response spectrum issued by the user or the user's agent as part of the specifications for qualification or artificially created to cover future applications. The RRS constitutes a requirement to be met.

- **ZPA: zero period acceleration.** The acceleration level of the high-frequency, nonamplified portion of the response spectrum. This acceleration corresponds to the maximum peak acceleration of the time history used to derive the spectrum.

- Section 8.6.5: "8.6.5 Test duration and low-cycle fatigue potential. ... The duration of the strong motion portion of each test should at least be equal to the strong motion portion of the original time history used to obtain the RRS, with a minimum of 15 s. For multiple-frequency tests, the stationary part of the test defines the strong motion portion of one multiple-frequency waveform employed."

o The standard holds the mentioned specification without specifying the value of the usual seismic qualification acceleration and the explicit duration of the test excitation. The standard refers in particular to the use of TRS and RRS as input and experimental response values.

- Document 8403 / 2016-6.1- 50099785-C1 (2018), *Guidelines for the Seismic Qualification of Equipment Installed in Emergency Facilities Building (Unit 5 Integrated Building) - Nuclear Power Plant Cernavoda*: 28. specifies:

- Section 5.6: "5.6 Qualification by Testing. If the analysis of the capability to maintain the functionality of an equipment in a seismic hypothesis can not be performed by a reasonable degree of confidence, dynamic testing is required to prove this capability. For this purpose, real-scale or small-scale testing models can be used."

o The standard holds the mentioned specification without specifying the value of the usual seismic qualification acceleration level, the test frequency range and the duration of the test excitation.

- Technical Specification (2001), *Safety Systems Equipment Cabinets, Cernavodă 2, cod 82–68000–TS - 003, Revision 0*: A-2. specifies:

- Section A.3: "A.3 Qualification Methods. The manufacturer shall provide documented evidence that the fully loaded safety cabinet will remain structurally sound and meet the performance requirements during and after the vibration input conditions defined as: the cabinet may be qualified by performing a sinusoidal sweep test in each of the three directions for uni – directional testing, with the sweep rate to be used shall be as follows:

a) 0.2g at 1Hz to 1.0g at 5Hz linearly;
b) 1.0g, from (5-33)Hz
and:
c) 1 Hz to 4 Hz: 1 Hz/min + 0%, -15%
d) 4 Hz to 33 Hz, with the sweep ratio:

$$\left(\frac{f^2}{1000}\right) Hz/\sec, +0\%, -15\% \qquad (2)$$

where "f" is the frequency."

o The standard holds the mentioned specification.

- Addendum to Technical Specification (2001), *Safety Systems Equipment Cabinets, code 82-68000-TS-003-01,Rev. 0*: 2. additional specification:

- Section 2.2: "Appendix A.3 "Qualification Methods", the first paragraph is modified as follows:

- The supplier shall provide documented proof that fully loaded safety system cabinets will remain structurally sound and meet performance requirements during and after the vibration input conditions defined as:
a) 0.4g at 1Hz to 2.0g at 5Hz linearly;
b) 2.0g, from (5-33)Hz
o The standard holds the mentioned specification.

- Summary of the specifications of the above mentioned standards:

Standards SR EN 60068-3-3: 1994 (1994), SR EN 60068-2-64: 2010 (2010), Technical Specification (2001) and Addendum to Technical Specification (2001), hold the specifications mentioned in the field. Standards SR EN 60068-3-8: 2004 (2004), SR EN 60068-2-6-2008 (2008), IEEE 344 (2013) and Document Code 8403/2016-6.1-50099785-C1(2018), don't holds the specific values regarding both the test acceleration level and the test frequency range or the duration of the test action.

5. FINAL INVESTIGATIONS

Seismic testing of electro-energetic equipment may require postcalculation and quantitative evaluation of the functional and structural integrity of the test specimen.

Some norms recommend performing a final experimental sweep cycle with the same waveform and the same frequency range used to identify the initial critical characterization.

The provisions of these rules are selectively displayed in the following regulations:

- **SR EN 60068-3–3:1994 (1994),** *Enviromental testings. Part 3: Guidance. Seismic test methods for equipments*.
o The standard does not hold the mentioned specification.

- **SR EN 60068-3-8:2004 (2004),** *Environmental testing. Part 3-8: Supporting documentation and guidance – selecting amongst vibration tests*:35. specifies:

- Section 8: "8 Vibration response of the specimen. 8.1 General. If specified in the relevant specification, the vibration response of a specimen will need to be measured before and after the endurance test to see if the specimen shows changes in dynamic response due to some form of mechanical degradation."
o The standard holds the mentioned specification.

- SR EN 60068-2-6-2008 (2008), *Environmental testing. Part 2: Tests – Tests Fc:Vibration (sinusoidal)*: 49, 69. specifies:

- Section A.3.1: "A.3.1 Vibration response investigation ... A vibration response test applied before and after the endurance test may be used to identify changes in the frequency at which resonance or some other responses occur. A change in frequency may indicate that some fatigue has occurred and the specimen may therefore be unsuitable for the operational environment. "
o The standard holds the mentioned specification.

- SR EN 60068-2-64:2010 (2010), *Environmental testing - Part 2-64: Tests - Test Fh: – Tests Fc: Vibration, broadband random and guidance*: 19. specifies:

- Section 8.2: "8.2 If not expressly prescribed in the specific specification, it is not necessary to investigate and study the critical frequencies. However, the particular

specification may study the critical frequencies forward on each axis, or before and after trying, with random vibrations of $a_g \leq 10$ m/s^2.

A scanning speed of 1 octave per minute must be applied to determine resonance frequencies and amplitudes. "

o The standard holds the mentioned specification.

- IEEE 344 (2013), *IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations*.

o The standard does not hold the mentioned specification.

- Document 8403 / 2016-6.1- 50099785-C1 (2018), *Guidelines for the Seismic Qualification of Equipment Installed in Emergency Facilities Building (Unit 5 Integrated Building) - Nuclear Power Plant Cernavoda*: 28. specifies:

o The standard does not hold the mentioned specification.

- Technical Specification (2001), *Safety Systems Equipment Cabinets, Cernavodă 2, cod 82–68000–TS - 003, Revision 0, Appendix A*: A-2. specifies:

- Section A-2-3: "A.2.3. Resonance Search. Before the qualification test as well as after the qualification test, two sine sweep resonance search at 0.2 g, one sweeping up and one sweeping down, shall be conducted in each of the three directions. The sweep rate shall be one octave per minute, starting at 2 Hz and ending at 33 Hz."

o The standard holds the mentioned specification.

- Addendum to Technical Specification (2001), *Safety Systems Equipment Cabinets, cod 82–68000–TS–003-01, Rev. 0*: 2. specifies:

- Section 2.1 "2.1 Before the qualification test as well as after the qualification test, two sine sweep resonance search at 0.4 g, one sweeping up and one sweeping down, shall be conducted in each of the three directions.

The sweep rate shall be one octave per minute, starting at 2 Hz and ending at 33 Hz." and thus modifies the value of the usual scanning acceleration size from 0.2g to 0.4g.

o The standard holds the mentioned specification.

- Summary of the specifications of the above mentioned standards:

Standards SR EN 60068-3-8: 2004 (2004), SR EN 60068-2-64: 2010 (2010), SR EN 60068-2-6-2008(2008), Technical Specification (2001) and Addendum to Technical Specification (2001) hold the mentioned specification.

Standards SR EN 60068-3-3: 1994 (1994), IEEE 344 (2013) and Document Code 8403/ 2016-6.1-50099785-C1 (2018) do not hold these specifications.

6. QUALIFICATION CONDITIONS. ACCEPTANCE

The equipment seismic qualification after the test is recommended and exposed, selectively, in the following rules:

- SR EN 60068-3–3:1994 (1994), *Enviromental testings. Part 3: Guidance. Seismic test methods for equipments*.

o The standard does not hold the mentioned specification.

- SR EN 60068-3-8:2004 (2004), *Environmental testing. Part 3-8: Supporting documentation and guidance – selecting amongst vibration tests*: 39,41. specifies:

- Section 8.6: "8.6 Survival pass/fail criterion. Changes in critical frequencies before and after endurance testers, may be used for pass/ fail criteria purposes.

... One of the following maximum allowable variations (feasibility decreases) for those modes shall be prescribed by the relevant specifications: 2 - 5 - 10 - 20% change in critical frequency."

o The standard holds the mentioned specification.

- SR EN 60068-2-64:2010 (2010), *Environmental testing - Part 2-64: Tests - Test Fh: – Tests Fc:Vibration, broadband random and guidance*:

o The standard does not hold the mentioned specification.

SR EN 60068-2-6-2008 (2008), *Environmental testing. Part 2: Tests – Tests Fc:Vibration (sinusoidal)*: 69. specifies:

- Section A.8: " A.8 Performance evaluation. ... If the test is to demonstrate survival only, the functional performance of the specimen should be assessed after the completion of vibration endurance (see clause 11)."

- Clause 11: "11 Final measurements. The specimen shall be submitted to the visual, dimensional and functional checks prescribed by the relevant specification. The relevant specification shall provide the criteria upon which the acceptance or rejection of the specimen is to be based (see A.9)."

- Clause A.9: "A.9 Initial and final measurements. The purpose of the initial and final measurements is to compare particular parameters in order to assess the effect of vibration on the specimen. The measurements may include, as well as visual requirements, electrical and mechanical operational and structural characteristics. ..."

o The standard holds the mentioned specification.

- IEEE 344 (2013), *IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations*: 7. specifies:

- Section 5: " 5. Seismic qualification approach. The seismic qualification of equipment should be demonstrate an equipment's ability to perform its safety function during or/after the time it is subjected to the forces resulting from one SSE (Safe Shutdown Earthquake). In addition, the equipment must withstand the number of OBEs (Operating Basis Earthquake)."

o The standard holds the mentioned specification.

- Document 8403 / 2016-6.1- 50099785-C1 (2018), *Guidelines for the Seismic Qualification of Equipment Installed in Emergency Facilities Building (Unit 5 Integrated Building) - Nuclear Power Plant Cernavoda*: 18. specifies:

- Section 4.2: "4.2 Categories of equipment.

o Equipment in seismic category "A" Equipment included in the seismic category "A" must be able to maintain its structural integrity and pressurization capacity during and after the earthquake, to ensure and maintain the functioning of the safety systems.

o Equipment in seismic category "B" Equipment included in the seismic category "B" must be capable of maintaining the operability and structural, mechanical and / or electrical functioning during and / or after the earthquake, in order to ensure and maintain the functioning of the safety systems. SSCs included in the "B" category must also meet the requirements for category "A"."

o The standard holds the mentioned specification.

- Technical Specification (2001), *Safety Systems Equipment Cabinets, Cernavodă 2, cod 82–68000–TS - 003, Revision 0, Appendix A*: A-2. specifies:

- Section A-5: "A-5 Acceptance Criteria. The cabinet will be deemed to have passed the qualification test if the following conditions are satisfied:

a) The cabined remains mechanically and structurally sound without any visual deformities after being subjected to the acceleration levels ...

b) The resonance frequency search test of the cabinet in each of the three axes at 0.2g table input remains unchanged before and after test.

c) The minimum resonant frequency of the fully loaded test cabinet shall not be less than 15 Hz."
o The standard holds the mentioned specification.

- Addendum to Technical Specification (2001), *Safety Systems Equipment Cabinets*, *cod 82–68000–TS–003-01, Rev. 0*: 2. specifies:

- Section 2.3: "2.3 ... b). The resonance frequency search test of the cabinet in each of the three axes at 0.4g table input remains unchanged before and after the tests."
o The standard holds the mentioned specification.

- Summary of the specifications of the above mentioned standards:

Standards SR EN 60068-3-8: 2004 (2004), SR EN 60068-2-6-2008 (2008), IEEE 344 (2013), Document 8403 / 2016-6.1-50099785-C1 (2018), Technical Specification (2001) and Addendum to Technical Specification (2001) hold the mentioned specification.

Standards SR EN 60068-3-3: 1994 (1994), and SR EN 60068-2-64: 2010 (2010) do not hold the mentioned specification.

7. CONCLUSIONS

The main purpose of this documentary investigation was mainly to perform a comparative analysis of the Seismic Qualification fundamentals concerning all the equipments types, both for the Cernavoda Nuclear Power Plant as well as the other critical equipments disposed at any other location. The provisions of these standards and technical specifications are compared and discussed. Thus, some conclusions can be drawn:

- The general Seismic Qualification Requirements of Electro - Energetic Equipments or of any type of the other equipments are fully covered by SR EN 60068-3-3: 1994 (1994), *Enviromental testings. Part 3: Guidance. Seismic test methods for equipments* and IEEE 344 (2013), *IEEE Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations.*

- Standard SR EN 60068-3-3: 1994 operates with measurable measurements, such as the type and the values of the input and of the output response actions, in terms of acceleration.

- IEEE 344 (2013) standard operates with indirect measurable sizes, such as RRS: Required Response Spectrum and TRS: Test Response Spectrum, sizes resulting from the application of The Seismic Qualification Action and which, through the expressed values, confirms or not confirms the qualification experiment accomplishment.

- Both rules are applying with general character for equipments that does not have a technical specification explicitly provided by the beneficiary.

- If the beneficiary has the own rules concerning the Seismic Qualification of Equipments, according to its own technical specification (eg: *Technical Specification (2001), Safety Systems Equipment Cabinets, Cernavoda 2, Code 82-68000-TS-003, Revision 0*), this requirements will be of first order and will be analyzed comparatively with the provisions of the related standards explained in the paper.

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