Method for Categorization of the Deviations Identified during the Periodic Safety Review (PSR) of Units 5 and 6 at Kozloduy NPP

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Abstract. The purpose of the presented method is to be applied for categorization in terms of safety of the findings (negative as deviations and positive as strengths) identified during the Periodic Safety Review (PSR) of units 5 and 6 at Kozloduy NPP. Such categorization is the main argument of fixing the scope and the deadline of measures to eliminate the deviations. The method consists of an approach as well as steps for categorization of the identified deviations. That includes definition of (1) The significance of the deviation in terms of safety; and (2) A level of the deviations in terms of the requirements for safety, applied technology, basic scientific knowledge and analytical methods, the evaluation of the cumulative effect of accomplished modification and equipment aging, organizational structure of the Licensee (management and operating staff). The method is developed based on the concept of Defence in depth (DiD), which is inherent in the design of the nuclear units.

Keywords: Deviation – PSR negative findings, Periodic Safety Review (PSR), PSR Safety Factor (SF), Reference basis, Criteria and levels for categorization

1 Introduction

The “Periodic safety review - PSR” is a systematic reassessment of the safety of an operating nuclear power plant (NPP) / unit [1]. The PSR deals with the cumulative effects of ageing, modifications, operating experience and technical and science developments. The PSR is carried out at regular intervals (no-longer than ten years) [1–4]. The PSR is one of the main tools to ensure a high level of safety throughout the lifetime of the equipment (SSC) and the nuclear unit (NPP).

2 Purpose of the Method for Categorization

The purpose of the presented method is to be applied for categorization [5] in terms of safety of the findings (negative as deviations and positive as strengths) identified during the PSR of units 5 and 6 at Kozloduy NPP, as requested in [1–3]. Such categorization is the basis of justification of fixing the scope and the deadline of measures to eliminate the identified deviations.

3 Scope of the Method for Categorization

The method consists of an approach as well as steps for categorization of the identified findings (deviations and strengths) [1–3]. That includes definition of (1) The significance of the findings in terms of safety; and (2) The level of the findings in terms of the requirements for safety, applied technology, basic scientific knowledge and analytical methods, the evaluation of the cumulative effect of accomplished modification and equipment aging, organizational structure of the Licensee (management and operating staff).

4 An approach for the development of the method for categorization

4.1 Input data

The following documents are used as input data for development of this method for categorization:

- Periodic Safety Review for NPPs, Specific Safety Guide SSG-25, IAEA, 2013 [1];
- Periodic Safety Review of the safety of NPPs, PP-18/2016, BgNRA [3];
- Guidelines for Periodic Safety Review for VVER NPPs, Technical Report B7-0320/2000/166020/MAR/C2, March 2001. European Commission [6].

The finding (negative as a deviation and positive as a strength) is identified as a difference between the current status of the specific safety issue of the nuclear units (NPP) and the existing safety requirement (determined as a criteria), valid to the date of the PSR [1–4, 6–11].

The current NPP safety requirements are described in the appropriate documents (acts, regulations, procedures) [4, 7, 8, 12–18]. All these documents are clearly defined and presented in the method, developed for review of the given safety factor (SF) [1, 3]. The list of the documents defines the “referent basis” for identification of the findings (negative as deviations and positive as strengths) [9–11, 19–22].

The existing safety requirements (defined as elements and the criteria) cover all aspects of the given SF. They are described in the method for review of the SF [1–3, 6, 9–11, 21, 22].

4.2 Safety assurance

The safety of nuclear unit (NPP) is ensured through consistently applying the defence in depth (DiD) concept based on the use of a system of [2, 12–15] (Art. 38):

- Physical barriers and several levels of protection to the release pathways of ionising radiation and radioactive substances to the environment, as well as on;
- Technical and organizational measures to protect the barriers and retain their effectiveness and to protect the population, the personnel and the environment.

4.2.1 Physical barriers

The system of physical barriers of any nuclear unit (NPP) includes [2, 12–15]:

- the fuel matrix;
- the fuel cladding;
- the reactor coolant system pressure boundary and
- the reactor containment system (where the reactor coolant system is located).

The number of the necessary physical barriers are specified on the basis of an assessment of quantities and isotope composition of radionuclides that might be released into the environment, the efficiency of the different barriers, their vulnerability to internal and external impacts, as well as the potential consequences in case of a failed barrier [2, 12–15] (Art. 39).

4.2.2 Levels of the Defence in Depth (DiD)

Five levels of defence in depth (DiD) are established to prevent the following to the extent practicable [2, 12–15] (Art. 40):

- Conditions leading to breaking the integrity of the physical barriers;
- Failure of a physical barrier when challenged;
- Failure of a physical barrier as a consequence of a failure of another physical barrier;
- Possibility of unfavorable consequences resulting from errors in the operation and servicing of structures, systems and components (SSCs).

The purpose of the first level of DiD is to prevent abnormal operation, failures of SSCs important to safety. It necessitates a conservative layout, design, construction, maintenance and operation of the NPP in compliance with a management system and proven engineering practices. This objective of the fist level of the DiD is accomplished with [2] (Art. 40):

- Selection of appropriate design standards and materials;
- Quality control during component manufacturing, construction and commissioning;
- Decreasing the risk of internal hazards;
- Application of processes and procedures for NPP design, manufacturing of components, construction of the NPP, maintenance, surveillance and testing of important to safety SSCs;
- The method of operation and consideration of operating experience;
- Detailed analyses of the operation, maintenance and management system.

The purpose of the second level of the DiD is to detect and control deviations from normal operation to prevent anticipated operating occurrences escalating into accident conditions. The second level of defence requires [2] (Art. 40):

- The design to provide systems and design features that control and limit the reactor facility operation;
- Efficiency of design systems and features to be verified by safety analyses;
- Development of operating procedures to prevent deviations from normal operation and anticipated operational occurrences, to mitigate their consequences and return the NPP to a safe state.

The objective of the third level of the DiD is to prevent nuclear fuel damage and off-site release of radioactive substances; to bring the reactor installation to a safe state in case of anticipated operational occurrences and accident sequences, through the use of the inherent safety features, and safety systems and emergency procedures envisaged for that purpose [2] (Art. 40).

The purpose of the fourth level of the DiD is to control and manage accidents that have occurred at precedent levels of defence or were caused by extreme external events in order to return the nuclear reactor to a stable safe state and postpone in time the consequences of severe accidents. At this level, the most important task is to ensure the function for retaining radioactive substances within the containment, thus decreasing radioactive releases into the environment to a level as low as reasonably achievable (ALARA) [2] (Art. 40).

The purpose of the fifth level of the DiD is to mitigate the radiological consequences to the public caused by radioactive releases as a result of possible accident conditions. This requires that an adequately equipped emergency response centre, emergency plan and emergency procedures, and an off-site emergency response should be in place [2] (Art. 40).

The implementation of the DiD shall ensure that each level of defence is independent and efficient at all times so that the loss or inefficiency of one of the defence levels shall not affect the functionality of the other levels [2] (Art. 41).

4.2.3 Safety functions (SFs)

The design of units 5 and 6 at Kozloduy NPP is based on the application of the DiD concept [6,8,9]. The main goal is to eliminate to the practically achievable level (ALARA) [23]:

- The conditions leading to a violation of the integrity of physical barriers;
- Failure of a physical barrier if there are conditions leading to a violation of the integrity of physical barriers;
- Failure of a physical barrier as a consequence of a failure of another physical barrier.

For all operating and emergency conditions, the nuclear unit of the NPP must be able to perform the following fundamental safety functions (SFs) [12–15] (functions, the successful performance of which ensures the integrity of the barriers):

- Control of the reactivity;
- Heat removal from the core;
- Retention of the radioactive materials into the predefined areas within the established limits.

The design technical solutions, technologies and procedures are defined and justified in accordance with the achievements of science and technology and of internationally recognised operating experience.

The integrity of the fuel matrix (first barrier) is ensured by the successful performance of the following SFs:

- Reactivity control during normal operating conditions;
- Reactivity control during transients and accident conditions;
- Ensuring and control of the subcriticality during the shutdown reactor and refuelling.

The integrity of the fuel cladding (second barrier) is ensured by the successful performance of the following SFs:

- Fuel heat removal during normal operating conditions and accident conditions without loss of coolant (LOCA);
- Fuel heat removal during accident conditions with loss of coolant (LOCA);
- Fuel heat removal during shutdown reactor and refuelling.

The integrity of the primary circuit (third barrier) is ensured by the successful performance of the following SFs:

- Ensuring the integrity of the reactor pressure vessel (RPV);
- Ensuring the integrity of the primary circuit under the high pressure in hot condition;
- Ensuring the integrity of the primary circuit under the high pressure in cold condition.

The integrity of the containment (fourth barrier) is ensured by the successful performance of the following SFs:

- Ensuring the integrity of the containment during normal operating conditions;
- Ensuring the integrity of the containment during transients and accident conditions;
- Reduction of radioactive releases during an accident.

The SFs are ensuring by the successful performance of the following functions:

- Operation and control;
- Provision of cooling water;
- Ventilation and conditioning;
- Heat removal by the secondary side.

Protection against internal and external hazards includes:

- Resistance against internal fires;
- Resistance against internal floods;
- Resistance against dependent failures (including dynamic effects of high energy pipe break; damages caused by heavy load drop and missiles, steaming, gassing, blast in case of damage/failure of equipment on the site);
- Resistance against earthquakes;
- Resistance against external hazards (external floods, strong winds; sudden changes in ambient temperature; fall of an aircraft; external effects due to human activity, including gassing, explosion in case of damage to off-site equipment).

The general requirements and criteria used as a basis for evaluation of the integrity of barriers and the successful performance of the SFs include:

- Requirements referred to evaluation of the integrity of barriers;
- Requirements not referred to evaluation of the integrity of barriers;
  - Management;
  - Operation;
  - Technical support and tests;
  - Training;
  - Emergency planning;

- Feedback from operating experience;
- Management of beyond design basis accidents (BDBA);

- Analysis of accidents;
- Radiation protection (RP);
- Management of the spent nuclear fuel (SNF);
- Radioactive waste management (RAW);
- Management of decommissioning.

4.3 Levels of categorizations

In order to take into account dynamics in the development of the safety requirements, the findings shall be evaluated both in terms of safety and by the degree of compliance to the regulatory requirements.

The criteria for categorization of the deviations therefore take into account:

- the impact of the identified deviation (high, medium, low, negligible) on the integrity of barriers and/or the successful performance of SFs ensuring the integrity of barriers [1–3, 5];
- the evaluation of the identified deviation in terms of the degree of compliance (complete, partial, insignificant) to the regulatory requirements for:
  - Safety, technologies, basic scientific knowledge, analytical methods;

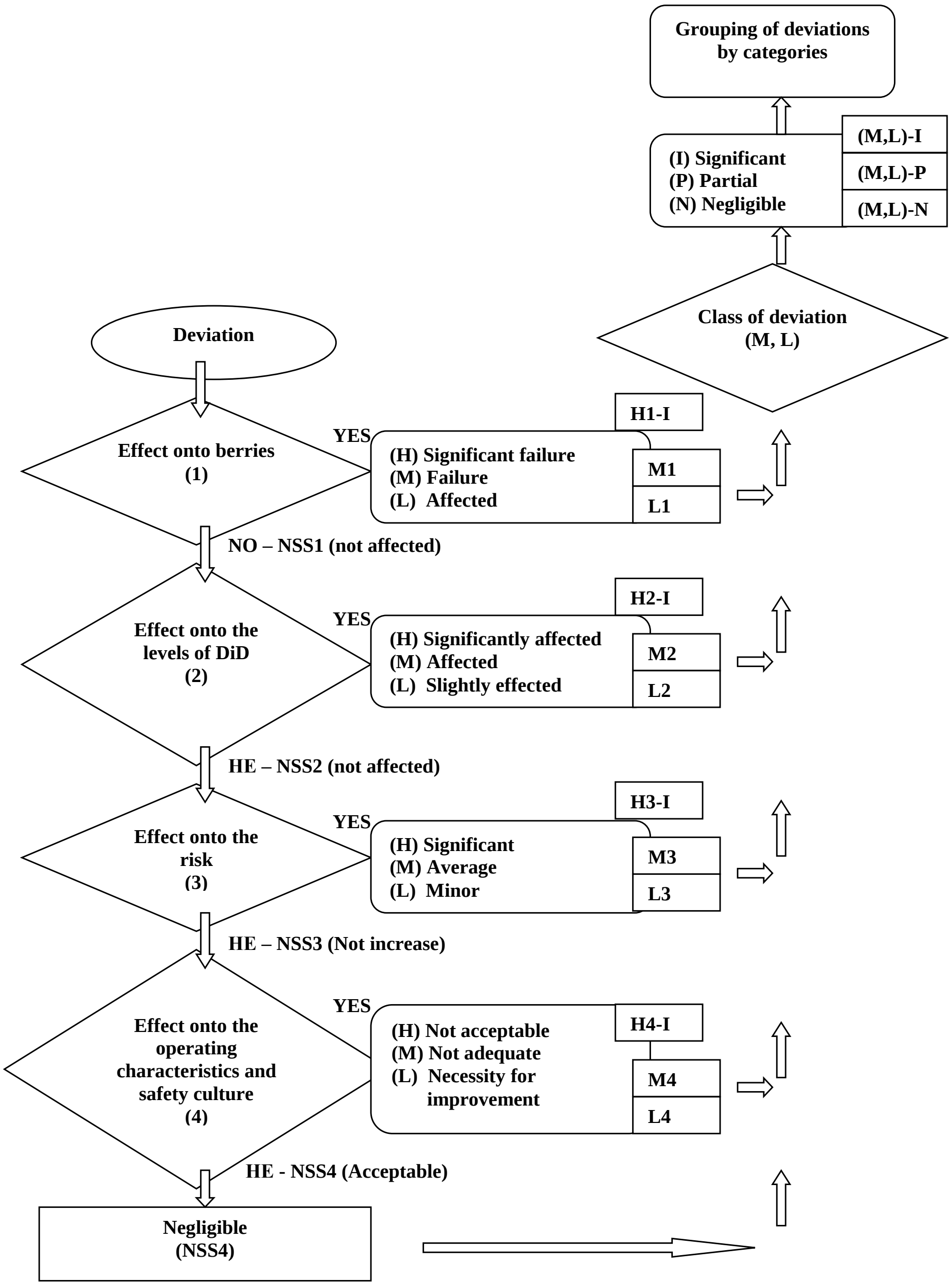

Figure 1. Logic diagram for categorization of the deviations.

– The evaluation of the accumulated effect of the modifications made and the ageing of the equipment;
– Organizational structure of the operating organization (management and executive staff).

The regulatory requirements are taken into account by compiling a complete list of regulatory documents, so-called "reference basis" [19,20], in which all safety requirements for the safety factors (SF) are presented. All existing national and international standards governing the safety of NPPs and containing specific SF requirements shall be used. This list shall be applied to determine the elements and criteria for evaluation of the current status of the all aspects of each SF.

The good practices are taken into consideration by examining the reports of the safety review missions (WANO, OSART, IPSART, etc.) [23–25].

The categorization of identified deviations in terms of both safety requirements and good practices shall be carried out in the same way following the logic of the diagram, presented in Figure 1.

4.3.1 Categorization in terms of safety (affecting the barriers)

The definition of the category in terms of safety is based on the evaluation of the potential impact on the barriers and the levels of the DiD. It means that the potential effect of the deviation on the integrity of each barrier, or successful performance of the SFs, which ensures the integrity of the barriers has to be defined [1–3, 5, 6, 10, 11, 14, 15, 17, 18, 21, 22, 24–26].

The following four categories are defined for the categorization of the deviations in terms of safety (affecting the barriers):

- Category **H (HIGH)** – for deviations which have significant impact on the safety;
- Category **M (MEDIUM)** – for deviations which have medium impact on the safety;
- Category **L (LOW)** – for deviations which have small impact on the safety;
- Category **NSS (NOT SAFETY SIGNIFICANT)** – for deviations which have negligible impact on the safety for the corresponding category: (1) – Barriers; (2) Levels of defence in depth; (3) Risk, (4) Operational characteristics and safety culture.

Following the concept of the DiD, the categorization of the identified deviations takes into account:

(1) The impact on the physical barriers;

(2) The impact on the levels of defence in depth;

(3) The impact on the risk; (initiating a new Initiating event (IE), or increasing the frequency of certain initiating events and demand for start-up of safety systems);

(4) The impact on the operational characteristics and safety culture.

The following qualitative indicators are used:

- Significant failure, failure, affected, not affected – in terms of (1) The impact on physical barriers;
- Significantly affected, affected, slightly affected, not affected – in terms of (2) The impact on levels of defence in depth (DiD);
- Significant, average, minor, does not increase – in terms of (3) the impact on risk; (inducing a new initiating event, or increasing the frequency of certain initiating events and demand to start-up a safety system);
- Not acceptable, not adequate, need for improvement, acceptable – in terms of (4) the impact on the operational characteristics and safety culture.

The impact of a given deviation on the levels of the DiD is presented in Table 1.

Table 1. Matrix with the criteria and the levels for categorization of the deviations in terms of safety

Category of safety (Code)	**Impact on the barriers (1)**	**Impact on one or several levels of the defence in depth (2)**	**Impact on the risk (3)**	**Impact on the operational characteristics and safety culture (4)**
High **(H)**	Significant failure **H1**	Significantly affected **H2**	Significant **H3**	Not acceptable **H4**
Medium **(M)**	Failure **M1**	Affected **M2**	Average **M3**	Not adequate **M4**
Low **(L)**	Affected **L1**	Slightly affected **L2**	Minor **L3**	Need for improvement **L4**
Negligible **(NSS)**	Not affected **NSS1**	Not affected **NSS2**	Does not increase **NSS3**	Acceptable **NSS4**

Based on these order of impact of the deviations on each level of the DiD, the following criteria are defined for categorization:

Category H (HIGH) – deviation with significant impact on the safety such as:

H1 – significant failure of one of the barriers;
OR

H2 – significantly affect one or more levels of the DiD in such a way, that the SF cannot ensure the integrity of the barrier for some design basis accidents (DBA);
OR

H3 – inducing a new Initiating event (IE) OR increases the frequency of certain IEs AND demands the start-up of a safety system (SS) and requests operator action, which increases the risk significantly (by more than 60%);
OR

H4 – not acceptable level of the operational characteristics and safety culture.

Necessary actions – immediate corrective measures must be carried out to reduce the risk. If these measures do not reduce the risk, the nuclear unit (NPP) must be shutdown. Temporary corrective measures for a given period or long term corrective measures must be carried out to reduce the risk corresponding at least to category M (MEDIUM).

Category M (MEDIUM) – deviation with medium impact on the safety such as:

M1 – failure of one of the barriers;
OR

M2 – affect one or more levels of the DiD in such a way, that the safety SF cannot ensure or there is doubt to ensure the integrity of the barrier for some design basis accidents (DBA);
OR

M3 – inducing a new Initiating event (IE) OR increases the frequency of certain IEs AND demands the start-up of a safety system (SS) and requests operator action, which increases the risk in the range of average (by 10% to 60%);
OR

M4 – not adequate level of the operational characteristics and safety culture.

Necessary actions – the safe operation of the nuclear unit (NPP) is ensured for a given period of time through already implemented measures. For this period, additional measures must be implemented to reduce the risk for a long-term period and in cost-effective manner.

Category L (LOW) – deviations with low impact on the safety such as:

L1 – affects one of the barriers;
OR

L2 – minor impacts on one or more levels of the DiD in such a way, that the SF is with reduced capability or there is doubt to ensure the integrity of the barrier for some beyond design basis accidents (BDBA);
OR

L3 – inducing a new Initiating event (IE) OR increases the frequency of certain IEs AND demands the start-up of a safety system (SS) AND requests operator actions, which increases the risk in low range (by less than 10%);
OR

L4 – acceptable level of the operational characteristics and safety culture.

Necessary actions – the safe operation of the nuclear unit (NPP) is provided for a long period of time, without the need to carry out any intermediate actions. Corrective actions are considered and implemented on a defined schedule only if their benefits are demonstrated.

Category NSS (NOT SAFETY SIGNIFICANT) – deviations with no impact on the safety such as:

NSS1 – does not affect neither of the barriers;
OR

NSS2 – no impacts on neither one of the levels of the DiD in such a way, that the SF is with reduced capability can or there is doubt to ensure the integrity of the barrier for some beyond design basis accidents (BDBA);
OR

NSS3 – does not induce a new Initiating event (IE) OR does not increase the frequency of certain IEs AND does not demand start-up of a safety system (SS) AND does not request operator actions, which does not increase the risk;
OR

NSS4 – acceptable level of the operational characteristics and safety culture.

Necessary actions – usually such deviations are included as a part of deviations categorized with greater importance.

4.3.2 Categorization of the level of deviation in terms of the regulatory safety requirements and goods practices

In accordance with the safety requirements, the periodic safety review (PSR) shall be carried out at least every 10 years [1–4]. Within that accepted period, the following topics shall be taken into account:

- The possibility of significant changes in the regulatory safety requirements, in the used technologies, scientific knowledge and analytical methods;

Table 2. Matrix of criteria and classes for categorization of non-compliances in terms of the regulatory document requirements and good international practices

Class of non-compliance	Level of non-compliance	Area of non-compliance (common for all levels)
Class I	Significant	Compliance been identified in terms of regulatory requirements and good international practices in the following areas:
Class P	Partial	• Applied technologies, basic scientific knowledge and analytical methods;
Class N	Negligible	• The need to evaluate the cumulative effect of modifications made and the ageing of equipment;
		• Organizational structure of the operating organization (management and operating staff).

- The need to evaluation the accumulated effects of the applied modifications and the aging of the equipment;
- Possible significant changes in the organizational structure of the operating organization (management and operating staff).

The following qualitative indicators are used: Important (I), Partial (P), Negligible (N).

For the categorization of the deviations identified by the safety re-evaluation in terms of the regulatory requirements and good international practices, the following grades/classes are defined:

Class I – IMPORTANT – A significant non-compliance has been identified in terms of regulatory requirements and good international practices in the following areas:

- Applied technologies, basic scientific knowledge and analytical methods;
- The need to evaluate the cumulative effect of modifications made and the ageing of equipment;
- Organizational structure of the operating organization (management and operating staff).

All non-compliances classified as Category H in terms of safety shall be of Class I.

Class P – PARTIAL – partial non-compliance been identified in terms of regulatory requirements and good international practices in the following areas:

- Applied technologies, basic scientific knowledge and analytical methods;
- The need to evaluate the cumulative effect of modifications made and the ageing of equipment;
- Organizational structure of the operating organization (management and operating staff).

Class N – NEGLIGIBLE – negligible non-compliance identified in terms of regulatory requirements and good international practices in the following areas:

- Applied technologies, basic scientific knowledge and analytical methods;
- The need to evaluate the cumulative effect of modifications made and the ageing of equipment;
- Organizational structure of the operating organization (management and operating staff).

The levels of the non-compliances in terms of the regulatory safety requirements and good international practices are presented in Table 2.

All issues, for which the current status is in compliance with the safety requirements, shall be categorized as "deviations are not identified" (the findings are positive, (strengths). The compliance (positive findings, strengths) has to be also categorized as "The current status fully meets the requirements" or "The current status exceeds the requirements". The compliance is recorded with the criterion code, its sequence number code (Nxx) and the code of the compliance ND (no deviation) (e.g. F06-E-1-K01-Nxx-ND) [10, 11, 21, 22].

4.4 Advantages

The advantages of the developed method are as following:

- The usage of the IAEA documents which are internationally harmonized, accepted and well known. This provides a common basis for discussion and analysis;
- Minimum but accepted and with sufficient number of documents establishing so-called "reference basis" to determine the findings (negative as deviations and non-compliance and positive/ strengths);
- Completeness of the criteria for categorization (both the impact of the deviations in terms of safety and the level of non-compliance/compliance in terms of safety requirements).

4.5 Limitations

The main limitation of the developed method is as following:

- Deterministic (expert and qualitative) evaluation is used only [7].

To reduce this limitation, the analysis and categorization was carried out on several iterations/steps on several levels (initial categorization by the expert who filled out the form; discussion in the group of specialists in the relevant area, preliminary discussion in the coordinating group with the presence of the team leader of the relevant area, final discussion at a high level in the coordinating group).

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