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Application of Risk-Informed Approaches in Significance Determination of Armenian NPP Inspection Findings

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Risk-informed decision-making approaches in the field of regulatory inspections performed at the NPPs aim at supporting the regulatory body in better organization of inspections. The paper describes the Armenian national experience of inspection activities by focusing on the process of significance assessment of inspection findings and demonstrates its applicability on practical examples. To demonstrate the applicability of the proposed process, various hypothetic inspection findings are defined for further assessment. Approaches are proposed for the significance determination of single and multiple findings. Several cases of single hypothetic findings and their combinations are considered. The paper summarizes the results for the considered cases, which reveal the applicability of the process by demonstrating the significance of hypothetic findings and the cumulative effects of multiple simultaneous hypothetic findings on plant safety.

Keywords: PSA, inspections, inspection findings, risk-informed, plant safety, Level 1 PSA.

Introduction

One of the main functions of the regulatory body is to ensure safe operation of nuclear power plants. That is partially performed through regular inspections, which are based on the results of the safety assessments [1]. Traditionally deterministic approach has been used, but if the probabilistic safety assessment (PSA) is mature enough to be used along with the deterministic approach, it might be beneficial [2].

The risk-based approaches are solely based on risk metrics. Over time, these approaches have evolved to risk-informed ones. Risk-informed approaches are not solely based on the results of risk analysis, since they may not model everything that is of importance. They take into consideration both deterministic (safety margins, redundancy, diversity) and probabilistic insights (likelihood of accident scenarios and the risk-significant components). The PSA to be used in the risk-informed approaches should be of sufficient scope, level of detail, and technical acceptability for the intended application [3].

The new concept [1] of the International Atomic Energy Agency (IAEA) is to combine probabilistic and deterministic insights in making decisions at the NPP, which requires a structured process to make important decisions that may affect safety of plant personnel, the environment, and the public.

There is no guidance on how to balance the utilization of deterministic and probabilistic insights, therefore in the risk-informed approaches, deterministic and probabilistic insights should be weighted for the issue considered via engineering judgments [4].

Even though there are guides on how to perform risk-informed regulation and decision making [5]-[7], in reality, its practical application may be quite challenging since risk-informed decision-making (RIDM) needs to use the benefits of different approaches in an integrated and well-balanced manner. Examples of how to apply a truly integrated RIDM process are presented in a recent study [8].

An example with an explanation of using an integrated risk-informed decision-making approach in equipment qualifications [9] is one of the good examples of PSA and deterministic safety assessment (DSA) symbiosis. The PSA may identify risk contributions that otherwise could have been omitted [9]. Integrated risk-informed decision-making can be used both to make the right decisions (e.g. in the assessment of inspection findings [10]) and to make the right prioritization (e.g. targeting of system components to be inspected) [9]. PSA provides both qualitative and quantitative insights for the decision-making process. The quantitative outcome is the core damage frequency (CDF) and large early release frequency (LERF) that can be considered as risk-significance measures. The qualitative outcome is of interest due to the same approach to all the nuclear power plant (NPP) systems, which allows assessing the overall consequences of several simultaneous failures of components by making some changes to the PSA model.

The integrated process including the PSA and DSA insights has to be coherent, logical, and well-structured [9]. However, the uncertainties and limitations of PSA have to be addressed. Concerning this, some studies were performed, particularly improving PSA efficiency through applying a genetic algorithm (GA) in the dynamic probabilistic safety assessment (DPSA) is discussed in [11]. Dealing with the residual risks by the means of relocating the classical event trees/fault trees (ETs/FTs), entailing large-scale computation associated with physical models are proposed in [12], which is an attempt to integrate big data, PSA, and DSA.

New measures developed based on the postulated behaviors of the regulated parties and the diversity of interests of the regulators are suggested, and new approaches to setting defaults in regulatory measures are proposed in [13]. The study was performed to streamline the decision-making process on the part of the evaluation of the safety levels likely to result from the regulatory policies or their amendments.

The interest in the use of RIDM approaches is rapidly growing. It is currently used in many countries such as the United States, Finland, France, Spain, Taiwan. Other countries are showing high interest to use RIDM or other RI processes [14].

To streamline RIDM in the frames of regulatory activities, a list of activities where RIDM can be implemented was developed and in terms of periodic inspections, the issues that can be addressed using probabilistic insights are as follows [15]:

Prioritization according to risk-significance,

Determination of significance of inspection findings.

Prioritization according to risk-significance: In the frames of assessment of the feasibility to include the graded approach in the inspection procedure, the corresponding IAEA requirements were outlined in [16], [17], the experience of the United States (the US) was analyzed in a study for Korea [18].

Over one hundred NPPs in the world (among them 30 in Europe) have implemented varieties of risk-informed methods. While several countries like Sweden, the USA, Spain, Finland, Mexico widely utilize PSA information to plan NPP ISI programs, other countries either prefer using the traditional deterministic method or consider making the use of PSA information possible in the future. The analysis of the international experience of risk-informed inspections [19] has revealed that the allocation of resources is mainly more efficient compared to the deterministic inspections. Pilot risk-informed inservice inspections (RI-ISIs) were carried out in several European countries including Bulgaria, the Czech Republic, Lithuania, Sweden, Switzerland, and Ukraine. These pilot studies have several objectives which include making comparisons of the effectiveness of different RI-ISI methodologies, choosing the most applicable RI-ISI method for the plant, and checking whether shifting from deterministic ISI to RI-ISI is worthwhile. Even though RI-ISI improves plant safety, as it turns out from the experience gained, it does not always have the desired results in terms of reductions of personnel radiation exposure and the number of the items to be inspected. Further improvements are necessary to solve these problems and make the implementation of RI-ISI more

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beneficial [16], [17], [19]-[28]. The inspections that are based on deterministic techniques require a large amount of time and manpower [18]. Some countries have requirements for pre-service inspections. The introduction of such inspections globally can prevent the construction delays of new NPP Units. To address that issue, the study [29] suggests creating authorized inspection agencies with a highly competent staff. Human resources can be used efficiently provided a thorough and well-structured inspection process.

Determination of significance of inspection findings: Methods used to evaluate the importance of the inspection findings vary from country to country. Some countries either use deterministic information or perform probabilistic recalculations, while others combine these approaches [16], [17], [19]-[28].

The main objective of this paper is to substantiate the practical applicability of the proposed process, which is developed based on the best international practices and IAEA requirements, integrates PSA and DSA insights, and is designed for the right prioritization of the inspection findings utilizing the assessment of their risk-significance. To develop the inputs for the analysis, the inspections performed at the ANPP by the Armenian Nuclear Regulatory Authority (ANRA) during the last decade were used.

1. International experience of PSA utilization in the process of risk-significance assessment of inspection findings

To develop an approach for the evaluation of the significance of inspection findings in line with the international best practice, international experience IAEA recommendations and requirements, namely the procedures for identification of findings were studied. Practices in the field of evaluation of the significance of inspection findings are summarized below.

The U.S. Nuclear Regulatory Comission (US NRC) has enormous experience in the field of inspection activities and its Significance Determination Process (SDP) has been in use for several decades now. The process has undergone an audit and its shortcomings have been revealed. Some countries have adjusted the SDP to their regulatory framework.

The significance of inspection findings is determined based on the qualitative or quantitative evaluation of their risk-significance [30]. According to the report of the PSA working group of VVER regulators' forum, this regulatory PSA application is [30]:

under consideration in Finland, Ukraine and India.

not used in Armenia, Bulgaria, Hungary, Czech Republic, Russia, and the Slovak Republic.

Methods used to evaluate the significance of the inspection findings vary from country to country. Some countries either use deterministic information or perform probabilistic recalculations, while others combine these approaches.

The list of countries that use PSA in the evaluation of the risk significance of the inspection findings is presented in Table 1 [30]-[42].

Some countries generally use deterministic information while evaluating the significance of inspection findings. There is no official rule or system requiring probabilistic information for the regulatory inspections in Korea [32].

Table 1 – List of countries that use PSA in the evaluation of risk significance of the inspection findings [30]-[42]

Country	Description
Finland	PSA and deterministic insights have been combined on a case-by-case basis in evaluating the significance of inspection findings.
France	In specific cases, CDF is evaluated.
Mexico	Mexico has adopted the Significance Determination Process (SDP) methodology of the US NRC.
South African Republic	In the South African Republic, grading of non-compliances is performed in accordance with the impact they have on nuclear safety. The findings of inspections shall be graded and categorized in terms of a new process taking into consideration severity and impact on safety. The Inspector will grade the non-compliance and the Chief Inspector will review the grading presented.
Spain	The evaluation of the significance of inspection findings is deterministic except for the risk-informed inspections performed by the Spanish regulatory body (CSN).
Switzerland	PSA information is used on a case-by-case basis to evaluate the significance of inspection findings.
Ukraine	It is assumed that the evaluation of the importance of the inspection findings will include qualitative and quantitative (PRA) evaluations.
USA	Site-specific SDP notebooks that replicate a simplified version of the licensee's PSA model are used by inspectors as a fundamental tool to determine the risk significance of inspection issues. The Senior reactor analysts (SRAs) in the regional offices are most directly involved with evaluating the risk significance of inspection findings. The numerical results are used as an indicator, but not as a sole determiner, of risk significance.

In the Slovak Republic, analyses of inspection activities contain the statistical evaluation of findings. The purpose of the statistical evaluation is to determine the distribution and frequency of findings from the inspection activities [34]. In France, repetition of findings can be a criterion for significance [32].

Many countries are willing to integrate risk insights in the evaluation processes of inspection findings. In the Czech Republic, development is underway to make the use of the probabilistic approach in evaluating the inspection results comparable to the deterministic one [32]. Japan has intentions to study concrete techniques for risk evaluation and types of information to be collected to structure a system to collect reliability information for every single reactor facility and to evaluate the findings of inspections based on the risk evaluation [32].

1.1. Overview of the IAEA corresponding documents

To develop an approach that is in line with the international requirements and recommendations, the recommendations of the IAEA relevant documents on how to identify findings, the requirements for evaluation of inspection findings were studied.

Requirement 27 of GSR Part 1 (Rev. 1) states that the primary purpose of regulatory inspections [35] is:

"The regulatory body shall carry out inspections of facilities and activities to verify that the authorized party is in compliance with the regulatory requirements and with the conditions specified in the authorization [36]."

"When inspections find that the facility or activity is not in compliance with regulations or authorization conditions, the inspector or regulatory body needs to consider enforcement actions to ensure that compliance is re-established [35]."

"The regulatory body should establish periodical evaluating the findings of inspections, identifying generic safety issues and making arrangements to enable inspectors from various locations or projects to meet to exchange views and discuss the findings and issues [36]."

Among other things related to inspection activities, IAEA-TECDOC-1867 also addresses concepts and methods on how to evaluate the safety significance of inspection findings and document the inspection results and findings.

An individual regulatory inspection can be viewed as having four phases: planning, performance, evaluation, and reporting. In the evaluation phase, the inspector determines if the observations are violations of regulatory requirements and if some immediate action is required. In the reporting phase, the inspector documents the results of the inspection including the regulatory body's assessment of the licensee's activities concerning safety and any necessary follow-up actions, including enforcement actions.

During an inspection or a walkthrough, the inspector may identify one or more observations (gaps/issues/concerns/problems) that should be evaluated to determine if the issue is a potentially safety-significant concern. For each observation, the inspector needs to determine the presence or absence of an immediate threat to public health and safety, the need for regulatory actions or enforcements, violations of laws, regulations, and other requirements, etc.

Regulatory inspection programs normally guide the inspectors to evaluate observations and findings in accordance with their regulatory framework, and the initial screening tool of IAEA can be used at the early stages. The table is merely an auxiliary tool and cannot replace the local guidance of the regulatory body [35]. Inspection findings should be discussed at regular meetings attended by groups of inspectors, which in many states includes the part of the regulatory body staff involved in review and assessment activities or authorization activities [36].

Inspection findings should be forwarded to the authorized party so that it is informed on the identified issues and will take corrective actions if needed. Providing there is a necessity for corrective actions to be taken, formal communication including the findings from inspection reports is mandatory. In some IAEA member states, the full inspection report is forwarded to the authorized party [39].

There are two parts of the formal reporting phase of an inspection. The first is the presentation of the results at an exit meeting with the licensee. The results may be subject to the inspector's supervisor review or final. The second part is the documentation of the results in an official inspection report [35].

A program to organize the analysis and follow-up actions on inspection findings should be established. It should include provisions for periodic review and surveillance of the follow-up actions to verify that the authorized party is taking the necessary actions in response to the findings. Following the satisfactory completion of the actions, the inspection findings should be formally documented and corresponding records should be maintained [36].

1.2. Overview of the US NRC SDP and the workflow

The US NRC SDP requires a response to violations in a consistent manner, taking into account their impact on safety. The performance is monitored in three "Strategic performance" areas, which, in their turn are divided into seven "cornerstones". Performance indicators (PI) are used to compare the performance to the safety-related thresholds. The SDP provides a mechanism to determine the safety significance of inspection findings identified within the seven “cornerstones” and correlates the results to the performance indicators via color coding (green, white, yellow, or red in ascending order of significance) [37-40]. The SDP estimates the increase in CDF (or LERF) as a result of conditions contributing to risk increase due to deficient licensee performance. This estimation considers all IE and the time during which the equipment or the function was degraded [37]. To determine whether the deficiency is minor or more-than-minor in terms of significance, it should pass a screening process. This is important to eliminate the minor deficiencies from further significance evaluation. The findings of more-than-minor significance are formally documented [37], [40]. A meeting called SDP/enforcement panel (SERP) is scheduled to discuss more-than-minor findings [37].

An audit of significance determination process was carried out to assess the consistency of NRC to evaluate the inspection findings using SDP [40]. The audit identified the following:

Inspectors confront difficulties because of unclear screening questions [40]. As a result, inspectors might needlessly spend time or resources formally documenting minor issues and miss opportunities to document more significant ones [40];

Independent audits performed were not always documented [40].

1.3. Comparison of inspection finding identification approaches of the US NRC and the IAEA

The IAEA suggests a table to help the inspectors identify the observations needing an assessment [35]. To identify inspection findings, the SDP provides a list of questions. Answering the questions, the inspector can identify the findings and screen out the minor issues [41].

The two approaches have a lot in common. Both questionnaires have questions regarding the potential negative effects of the observation both on public health, safety, and the environment. They also require the inspector to answer whether the observation is of media interest and to decide whether left uncorrected it has the potential to lead to a more significant safety concern. In addition to that, the IAEA questionnaire also requires to decide whether immediate corrective enforcement actions are required and to mention if the licensee has already taken any [35], [41], [42].

Despite the similarities of the two approaches, they also have some differences. While the US NRC SDP approach requires checking whether performance deficiency adversely affects the cornerstones, the IAEA recommends checking its compliance with the regulations, license conditions, and/or radiological or industrial issues [35], [41].

2. Overview of the Armenian national experience of inspection activities

Regulatory inspections is one of the main functions of the Armenian Nuclear Regulatory Authority (ANRA). Regulatory inspections aim to ensure that safety regulations and rules, the licenses provided by the ANRA, and the obligations mentioned in the orders are properly addressed. The ANRA under the government of the Republic of Armenia plans and carries out inspections in the field of atomic energy utilization in accordance with the legislation of the Republic of Armenia. The legislation of the field describes the rights and the obligations of state inspectors. It allows the involvement of representatives of public administration bodies, local and international organizations [43].

The ANRA has internal documents for organization, implementation, and quality assurance of inspections. The documents are listed below [43]:

Temporary guidance on organizing and performing inspections;

The directive of the quality assurance plan;

Periodic plan;

The list of the planned inspections through the ongoing year [43].

According to the temporary guidance, ANRA inspections regarding planning are classified as planned and unplanned; concerning notifications: declared and not declared; concerning the scope of inspections: special or complex.

The directive of the quality assurance plan is developed to make sure in the effective implementation and continuous improvement of the inspections.

The periodic plan of inspections includes inspection topics and their periodicity.

The inspections are not limited to the ones planned according to the periodic plan. Besides these inspections, there are also daily inspections of the on-site inspector.

Currently, the PSA information is not used in the inspection planning and implementation process.

As a result of the inspections, inspection findings are identified and corresponding orders are prepared in which the time limits to address these issues are established. Whether the issues have been addressed is checked either during the next inspections or the upcoming refueling outage [43].

To identify the shortcomings of the above-described approach of inspections, the internal documents of inspections, inspections carried out by the regulatory body during the last decade, their periodicity, topics considered, orders prepared in correspondence with the identified inspection findings, and other documents are checked. Based on checking, the problems associated with the inspections and relevant for the ANRA are identified [43].

3. Proposed regulatory inspection framework for ANRA

An improved procedure is developed to eliminate the problems associated with the current inspection procedure (Figure 1). Parts that are subject to change are colored orange.

The Armenian legislation is in the heart of the ANRA inspections. There are internal documents to organize and carry out inspections. It is suggested to make changes in the "Temporary guidance on how to organize and carry out inspections" for including the description of the suggested improvements. It is also suggested to describe the possible utilization of PSA information in different phases of the inspection procedure. The periodic plan can also be changed because of the possible utilization of PSA information. If the risk-significance of the system components is considered, the inspection routes will undertake some changes [44].

Inspections are carried out according to the internal documents. The ones carried out according to the cyclic plan will be subjected to some changes in case of implementing the suggested updates. Daily inspections of the on-site assistant will be changed in compliance with the suggested changes of routes and checklists. In case of overlapping topics in various types of regulatory inspections, it is proposed to consider them as carried out periodic planned inspections. Hence, in the suggested framework, the number of inspections performed according to the periodic plan will be reduced by considering the overlaps in the inspection topics.

During the preparation of the inspection finding order, it is suggested to use tables classifying the system components according to their risk-significance. The importance and urgency to implement the orders currently are determined based on deterministic information and expert judgment, it is proposed to supplement this process with the use of PSA information if applicable. The implementation of the orders is checked during the forthcoming inspections.

To make inspections more efficient it is suggested to develop specific guidance for each topic. This is the approach of the USA and Finland. The guidance will contain the main points, inspection steps, regulatory and technical documentation associated with the topic, etc. [43].

The utilization of PSA information to consider the importance of the system components has several benefits, which include the improvement of overall plant safety, efficient use of human resources, and possible reduction of the number of inspections.

Pilot routes for regulatory inspections are developed. In the report [45], the system components are classified according to their importance based on FC (fractional contribution) and RIF (risk increase factor) factors. Then the components with a high or medium level of importance are classified according to their compartments. These importance measures of components and the locations of the compartments were used to develop pilot inspection routes. In addition, existing inspection routes were studied, which were developed based on expert judgment.

To sum up, in order to achieve higher efficiency with the current human resources of the ANRA in [43] it is proposed to:

revise the periodic plan to avoid excessive inspections,

use risk-informed approaches in the inspection procedure,

involve the technical support organization personnel in the inspection activities. This approach is applied in France and Belgium [30],

develop a guide for each inspection topic.

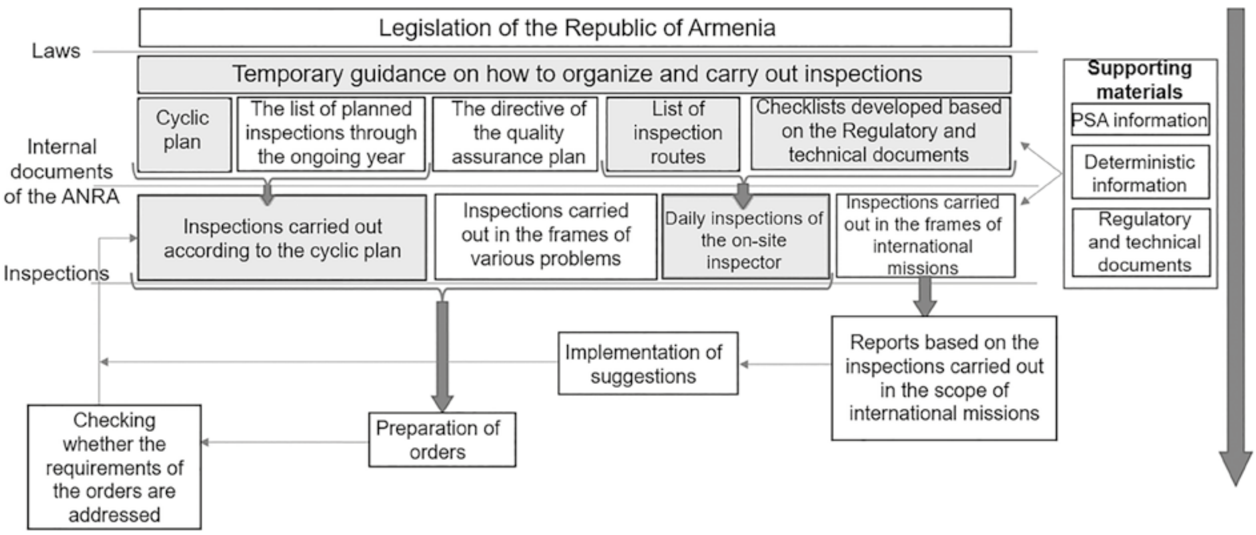

Figure 1 – The suggested inspection framework

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4. Development of a procedure for the ANRA to estimate the risk-significance of the inspection findings identified

The inspection findings are identified according to the non-compliance with the regulatory documents. There is no procedure to differentiate the findings from the observations. Moreover, there is no system to determine the risk-significance of the inspection findings. If the significance determination is a necessity, the findings are evaluated based on expert judgment. However, the significance of several findings could have been evaluated with a uniform procedure that would have reduced the unnecessary burden on the experts. Furthermore, the system would have eradicated all the possible subjectivity.

To resolve the problems associated with the absence of procedures to evaluate risk-significances of the inspection findings, a new approach is developed. The approach integrates local and international experience and international regulations.

The workflow of the evaluation process starts with inspections. The outcomes of the inspections are the observations and findings. The findings should be distinguished from the observations. An observation can be considered a finding if it has an essential effect on safety. If the impact of the observation on safety is of minor significance it should not be evaluated but the licensee should be informed and is obliged to take the necessary corrective actions on time. For each identified finding, the inspector has to evaluate the significance or submit the corresponding information to the expert responsible for the evaluation. After the evaluation, orders are prepared in which time limits to address the issues are specified. The licensee can appeal the orders by presenting its solid justifications. The evaluation is reviewed and new orders are prepared. The process is finalized by the ANRA which should check the completion of the required corrective actions and formally document the results. The simplified workflow of the process is presented in Figure 2.

Perform inspections (Task 1). One of the main responsibilities of the regulatory body is to perform inspections. The outcomes of inspections are the observations or/and findings.

Identification of inspection findings (Task 2). To help the inspectors perform the identification of findings, lists of questions should be developed based on the national experience, best practices (including finding identification processes), and the recommended list of questions presented in the IAEA-TECDOC-1867.

Evaluation of the significance of inspection findings (Task 3). To evaluate the risk-significance of the finding, suggested method distinguishes 3 possible paths: single finding reflected in the PSA model, multiple findings reflected in the PSA model, and findings not reflected in the PSA model.

For the findings reflected in the PSA model, the inspector uses the SSC risk-significance list, which is developed based on the PSA indicators, and proceeds with the evaluation (Task 3a) unless the lists are not applicable for the evaluation process.

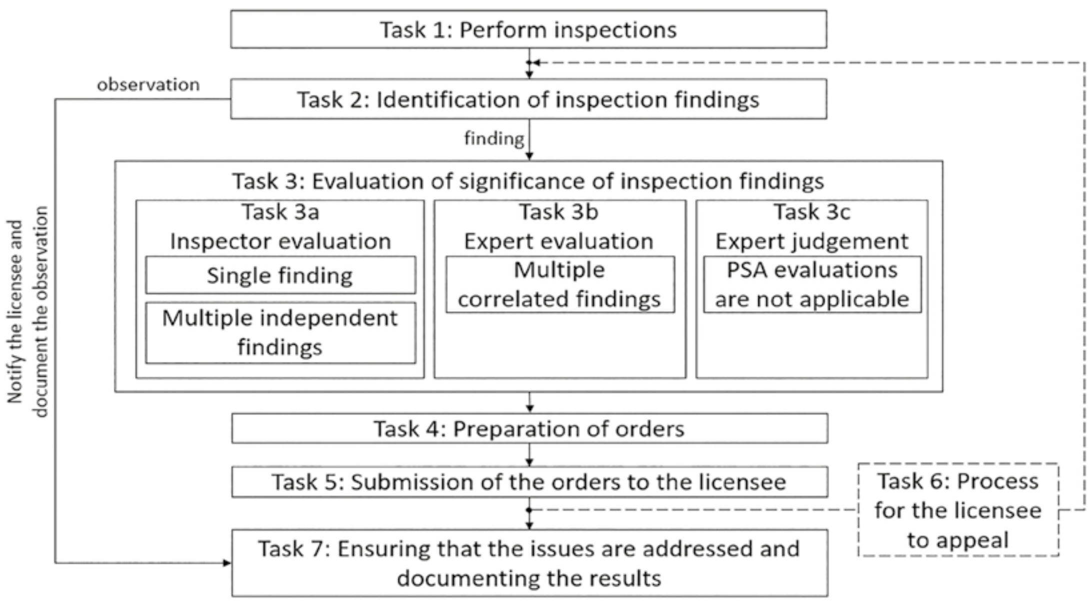

Figure 2 – Workflow of the evaluation process of inspection findings

If several findings are identified, the inspector needs to check whether the findings affect each other. If they are not linked to each other, they are treated as separate single findings. If several findings are linked to each other the cumulative impact on safety should be addressed (Task 3b). If the findings are not reflected in the PSA model, the inspector should submit the information related to the finding to the corresponding expert/s for analysis (Task 3c).

Inspector evaluation (Task 3a). The risk-significance of a single finding or multiple unrelated findings is determined according to the risk-significance metrics presented in the risk-significance lists of system components.

To determine the risk-significance of the systems, components, and human errors, the risk achievement worth (RAW) and fractional contribution (FC) values are used as follows [30]:

– High safety importance:
  RAW(E)>2 and FC(E)>0.005
  RAW(E)>100
  FC(E)>0.1
– Medium safety importance:
  2<RAW(E)<100 and FC(X)<0.005
  RAW(E)<2, FC(E)>0.005;
– Low safety importance:
  RAW(E)<2 and FC(E)<0.005.

An extract of risk-significance lists is presented as an example in Table 2 [46].

If the component is of safety class 1 or 2, then the priority to address the issue is increased despite the associated risk metrics.

Expert evaluation (Task 3b). Risk-significances of multiple correlated findings cannot be determined based on the risk-significance lists of system components. To address the cumulative impact on the safety of the several findings, the expert evaluates the risk-significances carrying out recalculations by making corresponding changes to the PSA model.

Expert judgment (Task 3c). The risk-significance of some findings can neither be determined using risk-significance lists nor it can be evaluated by making changes to the PSA models since they are not reflected in them. Therefore, these findings require expert judgment. Experts ascribe risk-significances based on many different factors.

The evaluations should meet the timeliness requirements. The evaluation time can be extended by the permission of the regulatory body, if the recalculations require more time to finish.

Preparation of orders (Task 4). Orders are formal documents that oblige the licensee to take corrective actions during the specified time limits.

Submission of the orders to the licensee (Task 5). Once the orders are prepared they are submitted to the licensee.

Process for the licensee to appeal (Task 6). Having received the orders from the ANRA, the licensee has 5 working days to appeal by presenting its justifications. Providing the arguments of the licensee are pertinent and valuable, the inspector or the expert has to review the identification and evaluation of the finding. Then the experts or the inspectors determine the final safety-significance of the finding and final orders are prepared. The final orders cannot be appealed. The licensee and the regulator can request a meeting if needed.

Ensuring that the issues are addressed and documenting the results (Task 7). When the time limit is over, the ANRA should ensure that the licensee has completed all the necessary corrective actions. The completion of the corrective actions associated with the finding should be formally documented.

Based on the proposed process, the importance of inspection findings is evaluated to prioritize them in terms of urgency. Some issues (finding) should be resolved right away to keep the safety of the plant at an appropriate level, meanwhile, the time limits

Table 2 – Risk-significances of the components of the emergency core cooling system

ID	Description	FC	RAW
Risk-significances: **High**			
EM-PC-2APN-1	ECCS pump 2APN-1	3.36E-02	5.90E+02
EM-PC-2APN-2	ECCS pump 2APN -2	3.36E-02	5.90E+02
EM-PC-2APN-3	ECCS pump 2APN -3	3.36E-02	5.90E+02
Risk-significances: **Medium**			
EM-VI-2R-9-2	Valve 2P-9/2	1.23E-05	5.31E+00
EM-VI-2R-9-4	Valve 2P-9/4	1.23E-05	5.31E+00
EM-VI-2R-9-6	Valve 2P-9/6	1.23E-05	5.31E+00

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to address the other ones can be negotiated if they have a minor impact on safety. The time limits to address the issues should be commensurate with their importance. It should be noted that in some cases, the plant safety is degraded because of the urgent measures taken to eliminate a finding that was of low risk-significance. Meanwhile, the problem associated with the finding could have been resolved at a convenient time without negative effect on the plant safety.

The resulting outcomes of all tasks should have mandatory formal documentation. The inspectors will benefit from using this approach since it is a simple tool of evaluation and requires only to act following the steps described in the process. The process is free of subjectivity and is entirely correspondent to the international requirements and national regulations.

5. Practical application of the evaluation process of inspection findings

To demonstrate the applicability of the proposed process for the significance assessment of inspection findings, the ones identified at the ANPP during the last decade were analyzed. However, the actual findings could not be used in the article, since it is prohibited to reveal sensitive information regarding plant safety. Moreover, the findings identified were mainly common to the system components of minor importance, which are not convenient to demonstrate the applicability of the proposed process (no tangible results during CDF calculation).

The inspection findings were categorized into groups and based on the several types of findings, hypothetic findings are introduced. To have noticeable results, some of the hypothetic findings are purposely developed for safety systems, shifted from the minor ones, exaggerated, and made more severe than they were.

In order to present separate and cumulative impacts of multiple simultaneous findings on the plant safety and have more room for various assumptions regarding their combinations, they were assumed to be identified in the course of a single inspection.

In order not to go into details on what are the functions of different components in the considered systems, and to draw attention to the implementation of the risk-significance assessment of findings, the findings of several types were assumed to be identified for the manually driven valves mounted on the pressure head of the pumps of different systems.

The first type of findings (hypothetic findings No. 1, 2) contains findings resulting from type A human errors.

Hypothetic finding No. 1. Throughout the inspections, components of ECCS (emergency core cooling system) were checked. It was identified that following testing or repair, the manually driven valve on the pressure head of an ECCS (emergency core cooling system) pump had been left closed as a result of a human error.

Hypothetic finding No. 2. During the inspections, components of the primary water makeup system were checked. It was identified that the manually driven valve on the pressure head of a makeup pump had been left closed following testing or repair.

The next type of inspection findings (hypothetic findings No. 3) includes findings resulting from wrong labels and inscriptions.

Hypothetic finding No. 3. During inspections, it was identified that because of the wrong indication of the direction in which the manually driven valve on the pressure head of an emergency feedwater pump closes, it had been left closed following testing or repair.

Another type of findings includes inconsistencies between documents or wrong instructions (hypothetic findings No. 4).

Hypothetic finding No. 4. During document inspections, inconsistencies were identified between the description of the essential service water system and job instructions of the operating personnel. The requirement for changing the position of the interlock switch of the pump of the essential service water system into the right position following the testing completion was omitted in the job instruction of the main control room (MCR) operator.

According to the proposed process of significance assessment of inspection findings, at first, it was checked whether the findings could be assessed by the inspectors based on risk-significance lists of components. According to the proposed significance assessment, the findings that were not screened out are submitted to the PSA experts for further significance assessment. If the quantity of the findings identified that could be integrated into the PSA model is insufficient to assess their cumulative impact, they are addressed separately. If several findings that could be integrated into the models were identified, their cumulative impact on the plant safety is assessed.

Several cases for various combinations of the identified findings are analyzed. The cases are presented below:

Case No. 1. This case includes three subcases. While in the first two subcases (subcase No. 1a, No. 1b), hypothetic findings No. 1 and No. 4 are analyzed separately as single findings, in the third one (subcase No. 2c) the effects of their simultaneous occurrence are demonstrated. In the last subcase it is considered that the essential service water system provides the ECCS with cooling water. The ECCS consists of two trains with three pumps each.

Normally, the manually driven valves on the pressure head of the ECCS pumps are open so that they do not prevent water to be pumped to the primary side in case of a LOCA (loss of coolant accident). The valves are closed during tests, so that water is recirculated through the tank. The valves are also closed when the pump is taken out for repair. During full power operation, it is allowed to have an outage of no more than one ECCS pump from the same group (train) for an emergency repair or maintenance. At the same time, no limitation is imposed on the power level of the NPP unit. To sum up, in the first two subcases, the effects of a single finding in ECCS and essential service water systems are analyzed separately and then compared to the results of the third subcase, which considers their simultaneous effects, taking into account the fact that essential service water system serves as a providing system for ECCS. The subcases are described below:

Subcase No. 1a. One of the ECCS pumps was left inoperable following the completion of testing or repair as a result of leaving the valve on the pressure head closed.

Subcase No. 1b. Depending on the type of inconsistencies identified between the system description and job instructions, some operator actions could have been overlooked or erroneous actions might have been taken. In this case, human error occurred following the completion of tests in the essential service water system. The interlock switch of one of the pumps was left in a wrong position following a test, thus making it inoperable.

Subcase No. 1c. In this subcase the effects of simultaneous occurrence of inoperabilities described in the previous two subcases are analyzed. It was assumed that the inoperable pump of the essential service water system belongs to the train which supplies cooling water to the ECCS train containing the pump left inoperable.

Case No. 2. This case consists of two subcases. In the first subcase (Subcase №3a) the effects of concurrent Hypothetic findings №2 and №3 are analyzed and then the results are compared with the results of the subcase (Subcase №3b) with simultaneous Hypothetic findings №2-4.

Subcase No. 2a. In the subcase, the effects of simultaneous hypothetic findings No. 2 and No. 3 are analyzed. Speaking of hypothetic finding No. 2, the manually driven valves on the pressure head of the make-up pumps are open so that they do not prevent water to be pumped to the primary circuit. The system has four pumps. The valves on the pressure head are closed during tests, so that water is recirculated in the system, or when the pump is taken out for a repair. During full power operation, it is allowed to have an outage of two pumps provided they are supplied with power from two separate panels. Based on water level decrease of in the pressurizer, 1, 2, or 4 pumps are automatically actuated. As a result of leaving the valve on the pressure head closed, in case of a LOCA, when pumps are automatically actuated based on the setpoints of water level decrease in the pressurizer, if the actuation of that pump was required, it would not have been able to pump water to the primary side and replenish water losses. On the topic of hypothetic finding No. 3, if in the course of inspections, system components were identified with missing labels or erased and unreadable inscriptions, it would have been barely possible to differentiate to which train of the system different fittings of the same type belong. When operator actions are required, the likelihood of human errors increases because the operator will have difficulties finding the right gauges or valves. The same problem is with the wrong labels, for example in the case of the wrong indication of the direction in which a manually driven valve closes. As a result, following a test or repair, it is likely that the valve will be left closed. During the inspections, components of the steam generator emergency feedwater system were checked. The system consists of two pumps. The system is in standby mode during NPP normal operation and is actuated by the system of step-start automatics in case of a blackout. Normally, the manually driven valves on the pressure head of the pumps are open in order not to prevent water to be pumped to the steam generators following system actuation. During full power operation, it is allowed to have an outage of no more than one pump for an emergency repair or maintenance. Resulting from the finding identified, in case of a blackout, one of the pumps will not be able to pump water to the steam generators.

Subcase No. 2b. The subcase is the same as subcase No. 2a, but simultaneous hypothetic finding No. 4 is added. When it comes to hypothetic finding No. 4, it indicates that one pump of the essential service water system is left inoperable following testing or repair.

As a result of the significance assessment of the inspection findings, the findings can be addressed systematically in order of significance and in well-substantiated time limits. The implementation of this process will make the regulatory body procedure to address the findings in line with IAEA recommendations.

For the components that are of low risk-significance, the improvement would be setting longer time limits to address the issues. On the contrary, for the components that are of high risk-significance, setting shorter time limits would

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Table 3 – Summary of the calculation results showing the effects of hypothetic findings on the plant safety (increase in CDF)

Case	Hypothetic finding No.	Hypothetic finding No.	Hypothetic finding No.	ΔCDF
1a	1	-	-	2.93E-07
1b	4	-	-	8.31E-07
1c	1	4	-	1.1E-06
2a	2	3	-	1.7E-06
2b	2	3	4	2.51E-06

be considered as an upswing. It should be noted, that the time limits defined without the utilization of PSA do not always reflect the urgency to perform corrective actions in a well-substantiated way.

To perform the recalculations, the attributes related to the applications of level 1 PSA mentioned in IAEA Tecdoc 1804 [47] were taken into account. Calculation results are compared to the ones for the initial case (case 0) in which it is supposed that there are no unresolved issues/findings in the NPP unit. Two options to assess the ΔCDF increase in core damage frequency were considered. The first option was to make changes to the model, and the second one was to use post-processing techniques. For the latter option, the cutoff value should be set low enough to include a sufficient quantity of minimal cutsets to have reliable results following post-processing. It will ensure that only a few cutsets with the present basic event are left below the cutoff value. For the considered cases, recalculations of the plant PSA model were performed and the results are summarized in Table 3.

The findings can be classified based on their risk-significance, using an approach with a classification scale similar to the one used by the US NRC SDP (color-coding the inspection findings based on the ΔCDF increase in core damage frequency) [37].

6. Discussion of the results

The ΔCDF increase in core damage frequency was calculated for various cases. The findings demonstrated impacts commensurate with their risk-significance measures when considered separately. The proposed process proved its applicability on the examples of multiple simultaneous hypothetic findings. Moreover, the process can be useful in the cases with several low-significant findings, when their risk-significance measures may undermine possible negative effects they might have, provided they occur simultaneously. The process enables the prioritization of several cases with multiple concurrent findings. As a scale, it is proposed to use the one used in the US NRC SDP process [37].

Conclusion

The practical applicability of the process developed to support the regulatory body to assess the significances of the inspection findings was demonstrated. The recalculations present the results that can be used to classify the cases with multiple simultaneous findings according to their possible impact on plant safety. To make the decision-making process efficient, a scale to ascribe risk-significance categories to the findings based on ΔCDF should be developed.

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Застосування підходів з урахуванням ризиків у визначенні значущості результатів інспекції Вірменської АЕС

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Підходи до прийняття рішень з урахуванням ризиків у сфері регуляторних перевірок, що здійснюються на АЕС, мають на меті підтримати регуляторний орган у кращій організації перевірок. У статті описано національний досвід інспекційної діяльності Вірменії, акцентуючи увагу на процесі оцінки значущості результатів інспекції та продемонстровано його застосування на практичних прикладах. Щоб продемонструвати застосовність запропонованого процесу, визначено різні гіпотетичні висновки перевірки для подальшої оцінки. Запропоновано підходи для визначення значущості одиничних і множинних результатів. Розглянуто декілька випадків окремих гіпотетичних знахідок та їх комбінацій. У статті узагальнено результати для розглянутих випадків, які розкривають застосовність процесу, демонструючи значущість гіпотетичних висновків та кумулятивний вплив кількох одночасних гіпотетичних висновків на безпеку станції.

Ключові слова: ІАБ, інспекції, висновки інспекції, інформовані про ризики, безпека станції, ІАБ 1 рівня.

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