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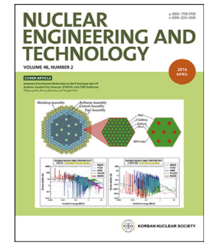

Original Article

An Approach to Improve Romanian Geological Repository Planning

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ABSTRACT

International standards recommend typical phases to be included within any national program for the development of a geological repository dedicated to disposal of the high level radioactive wastes generated in countries using nuclear power. However, these are not universally applicable and the content of each of these phases may need to be adapted for each national situation and regulatory and institutional framework. Several national geological repository programs have faced failures in schedules and have revised their programs to consider an adapted phased management approach. The authors have observed that in the case of those countries in the early phases of a geological repository program where boundary conditions have not been fully defined, international recommendations for handling delays/failures in the national program might not immediately help. This paper considers a case study of the influences of the national context risks on the current planning schedule of the Romanian national geological repository. It proposes an optimum solution for an integrated response to any significant adverse impact arising from these risks, enabling sustainable program planning.

1. Introduction

Recent international reports and standards [1,2] do not give any detail on the management of geological disposal projects in individual countries, nor do they comment on the appropriateness of specific activities within a project from a national context. Moreover, in terms of the characteristics and needs of specific national programs, the results of international peer-reviews cannot be simply transposed to any individual country without a more detailed and adapted analysis.

Several national geological repository programs have faced failures in schedules and have revised their programs to consider an adapted phased management approach. The failures often occurred in the schedules of the siting phase of the geological repository program. In particular, approvals of

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the national environmental regulatory panels have failed or been suspended due to insufficient support from civil society rather than due to technical reasons.

The risks resulting from immature national contexts were seen as one potential reason for early delays in the schedule of an early geological disposal program [3].

International recommendations could potentially help address such problems but the typical implementation phases recommended by international standards to be included within national programs for the development of a geological repository are not universally applicable. Hence, the content of each of these phases often has to be adapted for each national framework to deal with the national context, including the regulatory and institutional frameworks.

There is a great deal of literature on the lessons learned by those countries which have had long-term geological disposal programs e.g., Finland, Sweden, France, USA, UK, Switzerland, and Canada [4]. However, the current national context has changed from that of almost 30 years ago when the first geological disposal programs started. The complexity of the national context varies from country to country and each program will change at different rates of time.

This paper considers the major weaknesses that might arise in the national context which are often beyond the control and responsibility of the implementer. In order to respond to these program deficiencies in an efficient and appropriate manner, government, through state ministries with responsibilities in relation to geological disposal, needs to be involved. In the European Union, the governments through state ministries have the overall responsibility for safe disposal of radioactive waste, in accordance with the European Council Directive 2011/70/EURATOM ("Waste Directive") [5].

A detailed and integrated response to identify those weaknesses in the national context that might cause program failures and how they can be prevented needs the input from individuals experienced in planning geological disposal programs. Often such expertise is not readily available to program managers or the responsible state ministries [3]. This paper outlines a case study of a systematic study on the influences of the national context risks on the current planning schedule of the current Romanian national geological repository. It aims to identify these influences, what their effects are, and proposes an integrated response to addressing these effects in support of sustainable program planning. The study adopted a risk management approach. This was deemed appropriate, since the current tendency in commercial nuclear projects is to use private companies which rely on risk management processes. In addition, key stakeholders are becoming more familiar with risk assessment terminology.

2. Case-study for Romanian geological repository planning

2.1. *The need for a systematic study of the Romanian national context*

Romania, as required by all European Union countries with nuclear power programs, has to provide appropriate national arrangements [5] for safe spent fuel and radioactive waste management to protect workers and the general public from the danger of ionizing radiation. These arrangements include having a national program for radioactive waste management. Geological disposal is one of the components of the national program which is at an early stage of development in Romania.

The first geological disposal strategy for the spent fuel generated by Cernavoda Nuclear Power Plant (the current strategy, hereinafter referred to as the "current Strategy"), was developed by Romanian experts supported by the International Atomic Energy Agency (IAEA) experts in 2008–2009. The current Strategy includes a schedule for the commissioning of a repository by 2055 [6]. The schedule is a living entity that will be updated on a regular basis to provide a sustainable national geological repository (NGR) program.

A PESTEL (Political, Economical, Social, Technical, Environmental, Legal) analysis was used in this study to analyze the NGR program [7]. The aim of the PESTEL analysis was to identify the issues surrounding the NGR program and to identify their origin rather than trying to resolve them. The study focused on those issues that have a relatively significant impact on the development of the NGR program and which were more likely to happen or have already happened.

The overall results from the PESTEL analysis have identified several reasons for studying the national context when developing a detailed NGR program [8]. It was not in the scope of this work to examine any internal issues within the organization responsible for planning and implementing the NGR program. It is believed that the latter omission is not as important as taking the national context into account when a state ministry is considering geological disposal.

The PESTEL analysis identified those issues which represent the major risks to the developer of the NGR program. It is evident that:

- solutions to solve high and medium risks should be identified very early in the planning of the NGR program; and
- solutions which address, as far as possible, all issues identified as risks should be considered.

A Guide to the Project Management Body of Knowledge - PMBok [9] recognizes that the development of a project plan depends on the accuracy of estimating the duration of the individual activities in the project, and recommends that the uncertainties of those duration timescales be taken into account.

The PESTEL analysis showed that if the development of a repository program did not take into account the national context, and was not acknowledged by the Government/state ministries, then the NGR program was likely to fail at an early stage. If we take into account that the analysis of risks influence on schedule is typically ignored in any cost evaluation of the projects [10], then a potential failure of the repository program may not easily recognized.

Ward and Chapman [11] argued that the term "risk" has become associated with "events" rather than more general sources of significant uncertainty, and project risk management processes had a limited focus which restricted

Fig. 1 – Staged systematic study of risks influence on the current Strategy.

contributions to improve project management practice. They suggested that modification of the project risk management processes to facilitate an uncertainty management perspective could enhance project risk management.

This paper provides a systematic case-study of the Romanian national context using an improved risk management process approach.

2.2. *Study of the national context risks' influences on the current Strategy*

The PESTEL analysis has enabled us to start to address the questions: what the risks of the national context are, how they can be prioritized, how they can be treated and how these solutions can be integrated in a rational manner in future planning of the NGR program. In order to develop a more robust set of solutions, a further systematic study based on expert judgment and reliable methods and tools was adopted in a staged approach, as illustrated in Fig. 1 [12].

The PESTEL analysis showed that risks can influence the current Strategy schedule over the 20.5 year period covering the duration of the siting and site licensing process (see Table 1). The scope of the study was split into three distinct processes up to the point of commissioning of the NGR, as shown in Fig. 2 [13].

The major activities of the Siting and Site Licensing Process from the consideration of main activities in the current Strategy are shown in Table 1.

Analysis of the influence of the risks on the duration of the current Strategy enabled a work breakdown structure of the strategy to be estimated by expert judgment [13]. This led to the identification of the activities that are influenced by the risks as well as required responses to those risks if they were to occur.

2.3. *Methodology used for a staged study*

The methodology used in each step of the staged systematic study on the risks is set out in a suite of documents containing: comprehensive information on the study, important outputs from the extensive analysis, and details of the methods and tools used in the study. A summary of this methodology covering each step of the study is presented in the following sections.

2.3.1. *PESTEL analysis on geological disposal in Romania [7]*

The analysis consisted of:

- Documents: PESTEL Analysis on geological disposal of radioactive waste
- Methods, tools:
  - Screening the PESTEL analyses factors recommended for large projects/business.
  - Observation of a PEST (Political, Economical, Social, Technical) analysis made for US nuclear industry, questionnaires on geological disposal issued under the IAEA GEOSAF II project [14], as well as the state-of-the-art in geological disposal planning at international level by using international standards and reports published by IAEA, Organization for Economic Co-operation and Development/ Nuclear Energy Agency (OECD/NEA) or the European Commission (EC).
  - Overview of the specific issues and lessons learned from promotion and implementation of previous Romanian nuclear projects.
  - Risk identification in accordance with risk management standards.
- Main outputs:
  - Comprehensive information on the aspects characterizing the current national environment for initiating the

Table 1 – Major activities in the Siting and Site Licensing Process [6].

No.	Major activity (the current Strategy)	Duration (yr)
1	Define general framework ("state of art")	0.5
2	Define and document siting process and select up to 10 potential areas	1
3	Field investigations, selection of up to three areas, peer-review	6
4	Sites characterization, selection of one area, peer-review	6
5	Site Licensing Process (including approval of siting in Parliament)	2
6	Complete site characterization	5

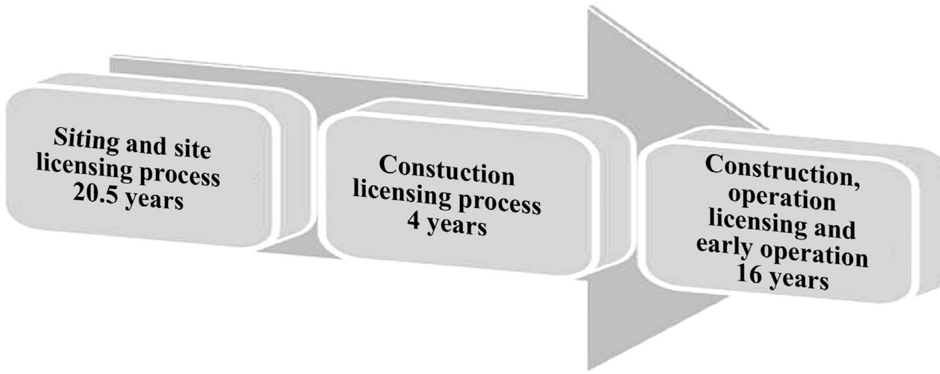

Fig. 2 – Main processes for the national geological repository's commissioning in the current Strategy.

NGR program and broad implications of each issue that might evolve in a certain risk for developing the program.
- A list of 24 risk factors for the current Strategy.

2.3.2. *Study of a national context risk management process [8]*

The national context risk management process (NCRMP) study consisted of:

- Documents:
  - Risks identification, risks likelihood, and evaluation of the impact.
  - Risk Register.
- Method, tools:
  - NCRMP Scheme in accordance with risk management standards.
  - Qualitative risk assessment in accordance with risk management standards.
  - Extrapolation based on relevant historical data from Romanian nuclear projects and/or other national geological disposal programs.
  - Judgments, observations, check lists, lessons learned, and consultation of experts.
  - Risk Register format.
- Main outputs:
  - A list of 21 significant risks that impact on the NGR program and their description.
  - Trigger points & potential outcomes of the risks including triggering in proximity and medium term.
  - Risk treatment strategies, risk treatment options and the "*de facto*" owners of the risks.
  - A prioritization of the risks in function of their impact on the technical activities of the Siting and Site Licensing Process of the program and their treatment strategies.
  - Observations on some risks' threats acting in the medium term.

2.3.3. *Study of the risks' influences on the duration of the current Strategy schedule-risk schedule analysis [13]*

The study consisted of:

- Documents:
  - Definition and description of three scenarios (optimistic, pessimistic, and most likely) for estimating the risks' influences on the duration of the major activities in the current Strategy (by expert judgment).
  - Analysis fiches on the risks impacting on the duration of the major activities through their critical path (by expert judgment).
- Methods, tools:
  - Process of analyzing potential risks' impact on the duration of each major activity of the NGR program, as presented in Fig. 3 (by expert judgment).
  - Quantitative risk analysis by assessing the risks as uncertainties to the current Strategy's schedule.
  - The "Programme Evaluation and Review Technique" (PERT) mathematical formula for calculation of probable duration of each major activity using three points time estimates (minimum time = duration from current Strategy, maximum time, and most likely time) obtained following the three scenarios mentioned above.
- Main outputs (pessimistic and most likely scenarios):
  - Work breakdown structures for the major activities including additional actions through their critical path in response to the triggered risks.
  - Recommendations for NGR planning improvement.
  - Comprehensive valuable information on the way the predominant risks influencing critical path should be responded to.

2.4. *Assumptions and work method used in the risk schedule analysis*

Assessment of the influence of risks on the duration of the major activities in the current Strategy is not simple since there is the need to identify, with a degree of certainty, what effects the risks might trigger and to integrate the mitigating actions in response to the risks in the future planning of the NGR program.

Three scenarios were used for estimating the influence of risk influences:

- Optimistic scenario—the events which might significantly delay the current Strategy do not take place or, an event might occur that is similar to that in another program/project. This late situation could be resolved by the organization responsible for the NGR program implementation through good administration of the program schedule and

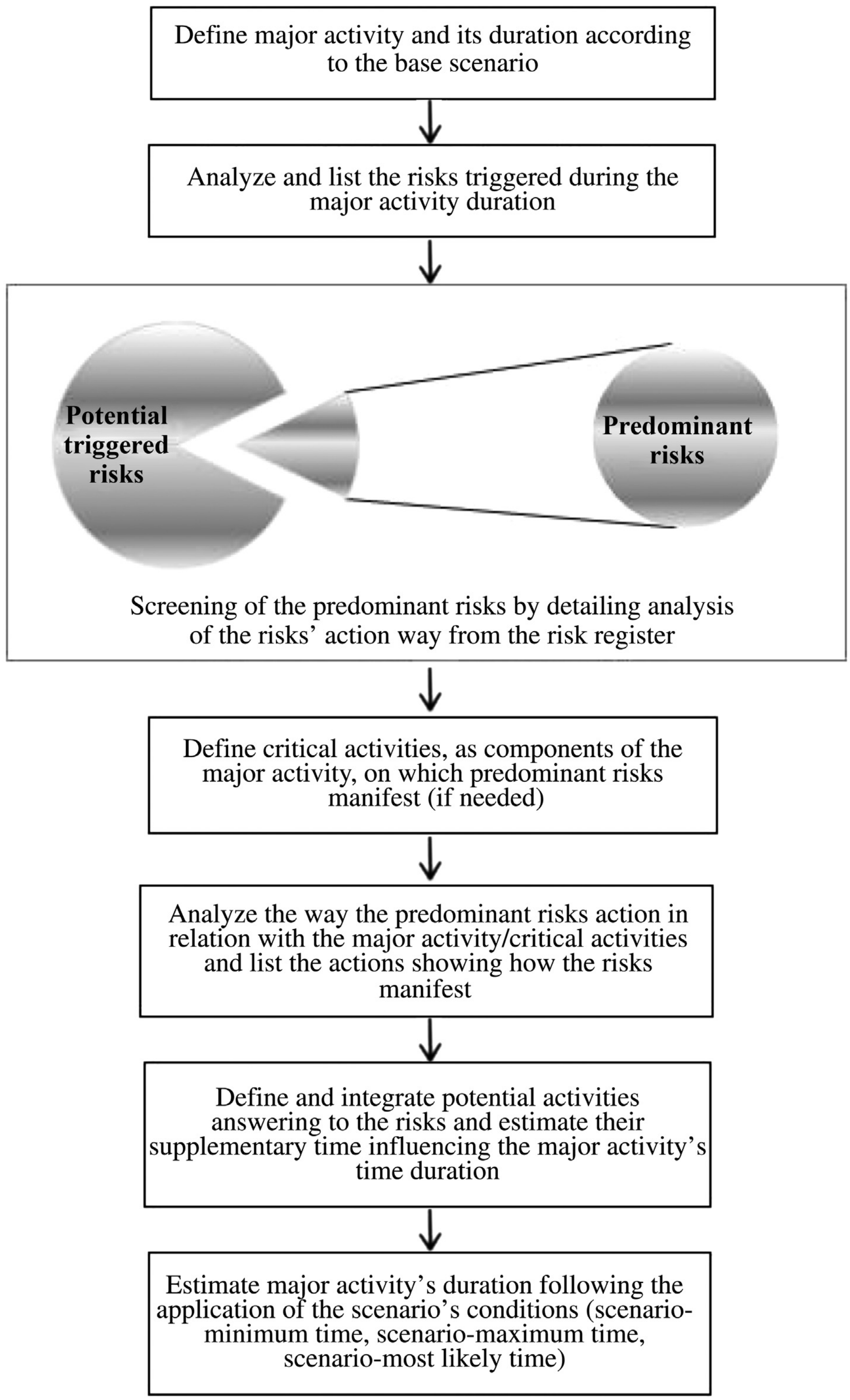

Fig. 3 – Process of analyzing the potential impact of risks on the duration of each major activity.

having constructive and open interaction with stakeholders. This scenario corresponds to the duration timescales in Table 1.

- Pessimistic scenario—assumes that risks are recognized by managers of the NGR program and a "see and do" strategy is used to respond to these risks
- Most likely scenario—any gaps in planning the current Strategy schedule due to the omission of key activities in the critical path are not accepted as risk. Planning should be revised in order to include those key activities. Risks identified through international standards and expert opinion, and the recognized 'best practice' responses to

those risks have not been considered and integrated in an appropriate way in the planning of the NGR program.

To manage the uncertainties due to the risks in the NGR program planning, a combination of two project management methods was used: the stochastic PERT technique and the deterministic "Critical path method" (CPM) technique. In particular, these were applied to a project within NGR which planned to utilize new and untested technologies [15].

PERT is a method for analyzing the tasks involved in completing a given project, especially the time needed to complete each task, and to identify the minimum time needed to complete the total project. CPM analysis tools allow a user to select a logical end point in a project and quickly identify its longest series of dependent activities (the longest path).

The mathematical method used to calculate the estimated duration of each major activity considered in the NGR program following the study of NC risks' influence was based (as per PERT) on the formula:

$$T = \frac{t_{min} + 4t_{ml} + t_{max}}{6} \qquad \text{Eq. (1)}$$

Where:

- t_{min} is the minimum time from the optimistic scenario;
- t_{ml} is the most likely time from the most likely scenario; and
- t_{max} is the maximum time from the pessimistic scenario.

Setting up and implementation of the work method for estimating the maximum time (t_{max}) and most likely time (t_{ml}), relied on expert knowledge and experience gained from the management of previous Romanian nuclear projects, and the research and development program on disposal of the spent fuel and radioactive waste generated by the Romanian nuclear power plant. That expertise helped the authors to overcome the lack of historical data which could have been used for verification of the methodology described above.

In the case of major projects such as the NGR program, the stochastic method for scheduling gives more realistic estimates [16]. However, many of the distributions used in these techniques have complicated mathematical forms and are difficult to understand and to interpret the results from. Program managers might feel more comfortable using a less complicated mathematical method, and stakeholders might be more confident in the estimated durations if they understand the methodology that was used to derive them.

The authors used Monte Carlo simulation using a triangular distribution of the probability to verify the results obtained using the PERT formula for the duration of each of the major activities [17]. This Monte Carlo simulation used 10,000 runs to estimate the duration of each activity.

The quantities of interest in the triangular distribution are [17]:

Probability distribution function (PDF) or p(t), which is the probability of the task completing by time t and its function:

$$p(t) = \frac{2(t - t_{min})}{(t_{ml} - t_{min})(t_{max} - t_{min})} \quad \text{for } t_{min} < t < t_{ml} \qquad \text{Eq. (2)}$$

$$p(t) = \frac{2(t_{max} - t)}{(t_{max} - t_{ml})(t_{max} - t_{min})} \quad \text{for } t_{ml} < t < t_{max} \qquad \text{Eq. (3)}$$

Cumulative distribution function (CDF) or P(t), which is the probability of the task finishing at time t and its function:

$$P(t) = \frac{(t - t_{min})^2}{(t_{ml} - t_{min})(t_{max} - t_{min})} \quad \text{for } t_{min} < t < t_{ml} \qquad \text{Eq. (4)}$$

$$P(t) = 1 - \frac{(t_{max} - t)^2}{(t_{max} - t_{ml})(t_{max} - t_{min})} \quad \text{for } t_{ml} < t < t_{max} \qquad \text{Eq. (5)}$$

The time corresponding to this cumulative probability is obtained by solving Eqs. (4) and (5) numerically for P(t).

The authors used Excel functions in the simulation procedure and the calculations were made using the parameters t_{min}, t_{ml}, and t_{max} obtained for the three example scenarios.

3. Results and discussion

3.1. *Improved risk management process*

The case-study on the Romanian national context provides a systematic and effective solution for improving future planning of the NGR program based on an improved approach of a risk management process that includes:

- Development of a methodology relying on: risk registration, identification and review of estimates and analyses in a readily available format; understanding the sources of the issues raised by bodies external to the organization in charge of the NGR program; and delineating what issues should remain the responsibility of the managers of the NGR program and what issues should be solved by external bodies who are normally responsible for solving those issues.
- Design of a process that facilitates quantitative analysis and allows a mechanism for analyzing the effect of risk on individual activities of the NGR program.
- Identification of a solution that allows risk management within the national context to be integrated in the early planning of the NGR program, rather than using a reactive based approach.

The systematic study described above is cited in an EC guide to be in support of the planning of the less-advanced research, development and demonstration (RD&D) programs in geological disposal [18]. The current study is referenced as part of the discussion of the boundary conditions that need to be established as a basis for setting the RD&D drivers, priorities, and timescales of a geological disposal program.

Table 2 – Estimated durations of the major activities of the Siting and Licensing Process.

No.[a]	t_{min}, yr (Optimistic scenario)	t_{max}, yr (Pessimistic scenario)	t_{ml}, yr (Most likely scenario)	T(yr) $\frac{t_{min}+4t_{ml}+t_{max}}{6}$
1	0.5 [b]	0.5 [b]	0.5 [b]	0.5 [b]
2	1	6	3	3.16
2a	–	–	3 [c]	3 [c]
3	6	11	8	8.16
4	6	12	9	9
5	2	3.5	3.5	3.25
6	5 [d]	5 [d]	5 [d]	5 [d]
	Total: 20.5	Total: 38	Total: 32	Total: 32.32

[a] The numbers correspond to the major activities in Table 1.
[b] The duration of this major activity remains unchanged from the duration of the current Strategy because even though the risks exist they are not triggered.
[c] 2a is a new major activity "Strategic Environmental Assessment Procedure" which arose from the analysis of the pessimistic scenario as a required correction in the planning of the current Strategy schedule.
[d] The duration of this major activity is not considered to be influenced by the risks.

3.2. *Improved approach of updating the current Strategy*

From the risk schedule analysis, as presented earlier in this paper, the estimates for the duration of the Siting and Site Licensing Process for the three example scenarios, summed over the major activities shown in Table 1, are given in Table 2.

The value of 38 years estimated for the maximum time (t_{max}) is believed to be credible because it is consistent with those durations for suspensions/reconsiderations of the siting process for a geological disposal facility experienced in other countries.

The estimated value of the most likely time (t_{ml}) was closer to the maximum time (t_{max}) than to the minimum time (t_{min}). This was due to the fact that even though there was an improvement in the current Strategy planning following the integration of responses to the several key risks in the pessimistic scenario, other risks became dominant which increased the duration of the schedule [13].

The reliability of the analysis for estimating the durations for the three scenarios in Table 2 is supported by:

- Knowledge of the influence of the risks on the duration of the major activities (risks leading to small durations have been discounted in the analysis).
- The information gained from the development and analysis of the pessimistic and most likely scenarios. This leads to a better approach to managing risk by improving the risk response. It allows a review of the current Strategy by integrating improved response activities in the early planning stages.

Using Monte Carlo simulation, the distributions obtained for the durations of the major activities (numbered 2, 3, and 4 in Table 1) supports the results of the combined deterministic/stochastic method for risk analysis. For Major Activity 4 in Table 1, Fig. 4 shows the profile of the cumulative probability calculated using Eqs. (4) and (5). The histogram representing the distribution of the cumulative probabilities is obtained by grouping the probabilities in periods of 0.25 years.

Assuming that the NGR program stakeholders have agreed to an acceptable level of confidence of the 80th percentile, the Monte Carlo simulations indicated that Major Activity 4, with all of its risks, would be completed in 10 years or less. This time duration is 1 year more than the time duration obtained from the combined method used by the authors, as seen for the expected time T for Activity 4 in Table 2, but the difference should not affect the credibility of that result since the

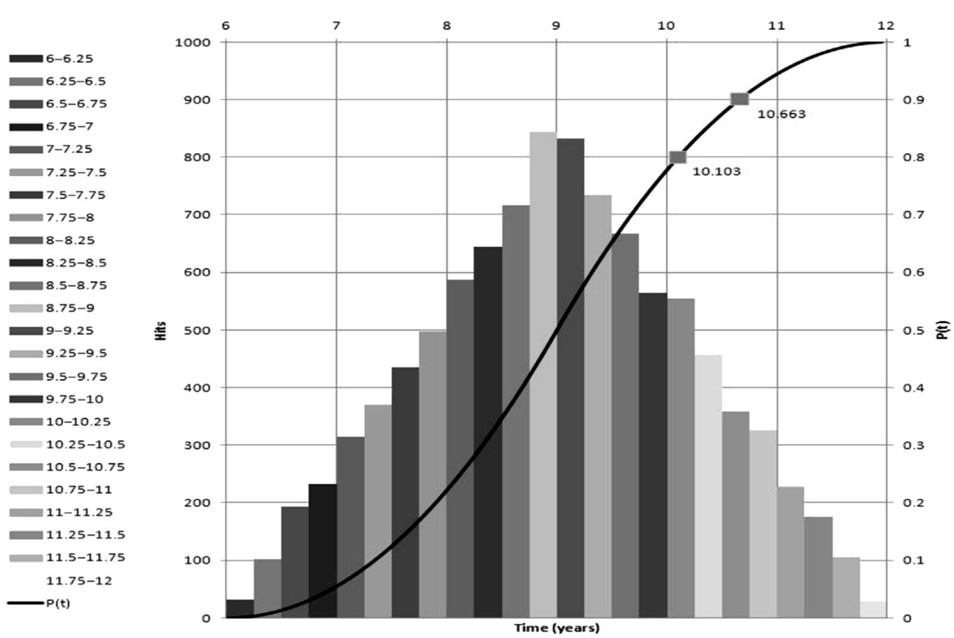

Fig. 4 – Major Activity 4 (Table 1). Histogram with cumulative distribution for completion date ($t_{min}=6$, $t_{ml}=9$, $t_{max}=12$).

assumptions and results of the risk schedule analysis indicated that further work to improve the current Strategy schedule by integrating detailed risk responses is needed. Similar indications provided the profiles of the distributions for completion dates of Activities 2 and 3 from Table 1. Thus, the study provides a methodology that allows program managers and owners of risks to respond to those risks in order to avoid slippage or blockage in the NGR program. It is the responsibility of managers to identify the right expertise and knowledge to integrate risk management within the national context in the early planning of the NGR program.

3.3. *An optimum solution for integrating risks' responses*

The authors believe that the above methodology, in accordance with the PMBoK Guide recommendations [9], represents a practical means of identifying and establishing the processes which contribute to planning of the NGR program. The processes identified for reviewing the current Strategy are presented in Fig. 5. This shows that the risk management process and the risk response planning are key elements in the planning process.

The above approach represents an optimum solution to risk management in the national context. Detailed risk response activities should be integrated in a planning program during any update of a work breakdown structure of the NGR program following a process similar to that shown in Fig. 3.

3.4. *An effective solution for integrating responses to the environmental risks*

In order to build confidence in the solution identified for an integrated response to the risks in the planning of the future NGR program, the authors reviewed the activities for the Environmental Licensing and Approvals (ELA) Process, since this process lends itself to review by expert judgment. This is due to the fact that the Romanian environmental legislation and regulations which transposed the European Union

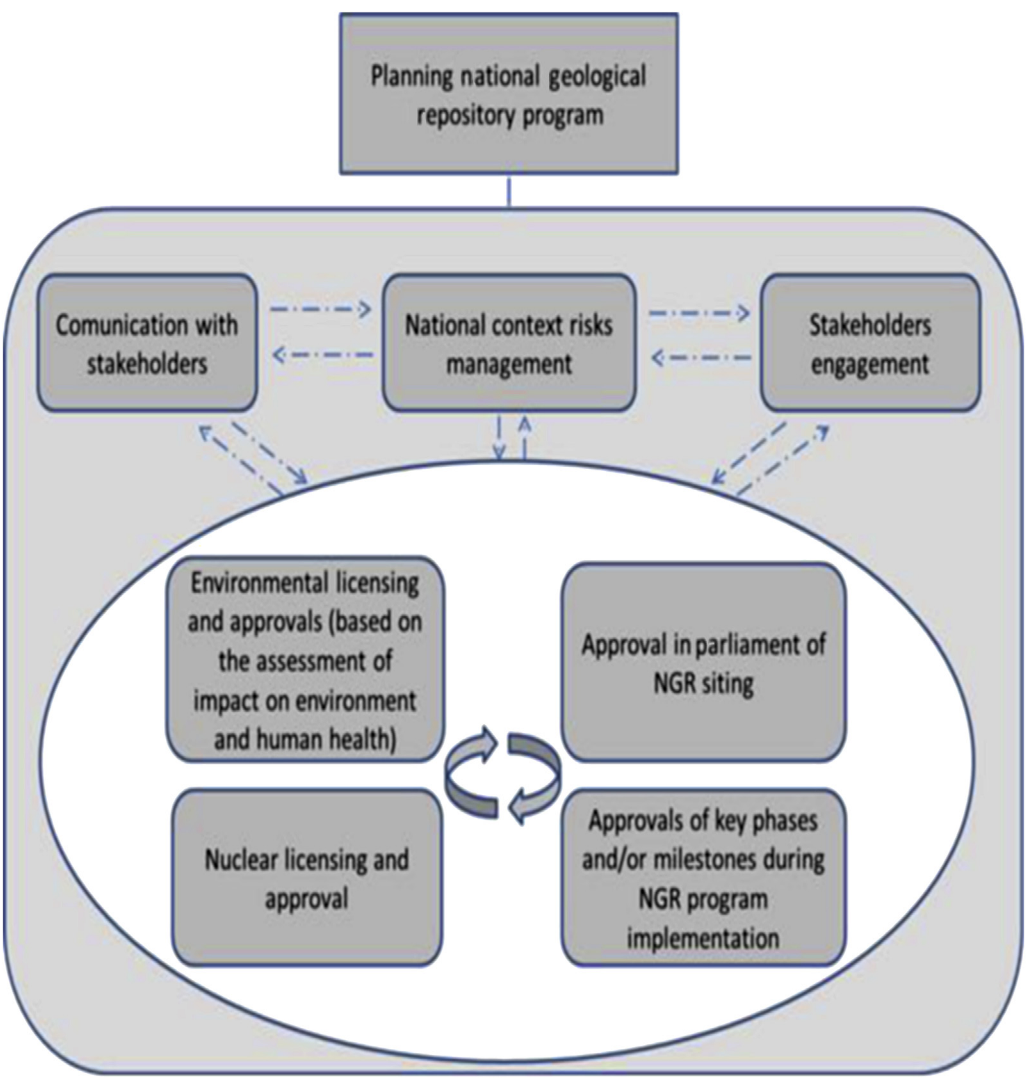

Fig. 5 – Processes ensuring an integrated response to the risks in the current Strategy. NGR, national geological repository.

Table 3 – List of the risks considered in the Environmental Licensing and Approvals Process.

Risk ID [a]	Short risk description
E1	Absence of expertise/technical support to authorities issuing the environmental permit, in the field of geological disposal. (Note: expertise is concentrated at the national nuclear authority)
E2	Presentation of technical information in EIA at the level of technical design.
L3	No specific legal requirement to apply SEA procedure to NGR program. (Note: the law stipulates SEA procedure on the national strategy for radioactive waste management)
L4	The certificate for urban planning allowing NGR's construction is a condition to obtain environmental permit based on EIA.

EIA, environmental impact assessment; NGR, national geological repository; SEA, strategic environmental assessment.
[a] Risk ID is according to the Risk Register obtained in the study of the national context risk management process [8].

specific legislation was sufficiently prescriptive and well documented. This allowed both the activities needed for planning environmental licensing procedures to be put into place, and the identification of the most relevant activities in response to risk for integration into the NGR program planning. The risks which were considered in the ELA Process are presented in Table 3.

In order to identify how the activities that make up the ELA Process influence the current Strategy in how they would be included in planning a future NGR program, the authors relied on the following resources:

- Expert knowledge of the current national and EU environmental legislation.
- Expert experience of the environmental licensing and approval process in other national nuclear projects (e.g., environmental agreements for a dry spent fuel storage facility and new nuclear power units).
- Consultations with an environmental expert with large expertise in licensing procedures for major projects at a national level.

By integrating solutions to respond to the risks in Table 3, the structure of the major activities of the current Strategy has changed from environmental position as follows:

- A preparation phase of the NGR program with an estimated duration of about 4 years was introduced before the Siting and Licensing Process. During this phase, planning and arrangements on how the environmental and nuclear requirements should be put in place for licensing procedures based on Strategic Environmental Assessment and Environmental Impact Assessment (EIA).
- A major activity with an estimated duration of 2 years was introduced in the critical path of the Siting and Licensing Process. This consists of the first licensing procedure, namely the strategic environmental assessment (SEA) procedure for obtaining the environmental approval for the NGR program.
- Planning of some technical activities in the current Strategy was revised in order to secure the ELA Process. This means, the second licensing environmental agreement procedure with an estimated duration of 7 years could safely take place during the "Sites characterization, selection of one area, peer-review" major activity with a revised estimated duration of 8 years.

Following the integration of the responses to the environmental risks, the new duration of the Siting and Licensing Process was estimated to be about 25 years. This value was higher than the duration of this process in the current Strategy but even if the 4 years are added on for the preparation phase, the duration of 29 years is still lower than the 32 years which was the duration in the most likely scenario. This was considered to be reasonable since the schedule of the current Strategy did not explicitly take into consideration the environmental licensing process and it was previously treated as an uncertainty.

Based on the registration, the authors believe that the integration of the responses to these risks could be a driver for the new duration of the Siting and Licensing Process which also covers future integration of responses to the other risks of the national context.

In addition, the solution for setting up an acceptable level of environmental risk in the national context might be a good prerequisite, not only for planning of the future NGR program, but could also be considered to be a recommendation of a standardized approach for including an environmental impact assessment in an NGR across Europe (Espoo Convention, 1991) [19], particularly with regards to the timing and content of the documentation for the SEA and EIA procedures.

Setting up a proper national framework for developing an early geological disposal program might require substantial effort from the owners of the risks as well as the managers of the geological disposal program. Managers should use the required expertise and knowledge for integrating an improved risk management process at an early stage of program planning for the national context. This offers a far more robust approach to mitigating risks in the program than through monitoring risks and reacting to them as they happen.

Conflicts of interest

The authors declare no conflicts of interest.

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