Radioctive Wastes Management - AHP Application

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Abstract: A procedure for radioactive wastes (RW) management in Bulgaria is developed. The analytical hierarchy process (AHP) and Expert Choice are used as basic decision making methods in RW management procedure: for analysis of RW volume, high level RW (HLW) management conception and the scenarios-variants tree as a whole; for technological choice in the case of low and intermediate level RW (LLW,ILW) conditioning; for site selection for RW disposal - as single relative model and in combination with rating model; for final choice of RW repository variant under non-technical criteria - a case of Benefit-Cost analysis.

Key words: Radioactive wastes management; System analysis; Site selection; Decision making; Analytic hierarchy process.

1. INTRODUCTION

1.1. General principles

The problem of formation, analysis and choice of variants for construction of national radioactive wastes (RW) repository as a basic element of the radioactive wastes management (RWM) system will be considered. Its correct elaboration is an integral part of the formation of national RWM concept.

The repository construction concept is built on the basis of several fundamental principles and criteria, proposed by IAEA [1].

1.2. Overlying objectives of underground disposal of high level RW [1]

- RESPONSIBILITY TO FUTURE GENERATION: to isolate high level wastes from the human environment over long time-scales without relying on future generations to maintain the integrity of the disposal system, or imposing upon them significant constraints due to the existence of the repository;
- RADIOLOGICAL SAFETY: to ensure a long term radiological protection of humans and the environment in accordance with current internationally agreed radiation protection principles.

1.3. Basic RWM strategy future priorities

- RW reduction and prevention;
- RW conditioning and recycling;
- optimal site selection and technological choice, for interim storage, conditioning and construction of RW repositories.

2. RESEARCH PROCEDURE FOR FORMATION, ANALYSIS AND CHOICE OF VARIANTS FOR NATIONAL RW REPOSITORY CONSTRUCTION

2.1. Initial principles

The research procedure is based on: the system approach and analysis; the decision making theory; the basic objectives and principles of the national repository construction; the RWM priorities; the underground repository concept and so on [2].

2.1.1. Main criteria

- Minimal environmental impact;
- Maximal economic efficiency.

The first criterion is a reflection of the safety principles and criteria, proposed by IAEA. The second criterion reflects the necessity of taking into account the real possibilities of the RWM (see principles 1 and 7, [1]).

2.1.2. Some basic notions

The RW are characterized by a set of parameters, some of which are new introduced [3].

- RW environment: the RW production and all conversions are realized within a complex environment, which includes 6 basic elements - subenvironments (RWE): the surroundings and natural environment; economic; scientific and technical-technological; socio-psychological; legal; institutional-political.
- RW barriers (RWB): input barriers (INB)(production barriers (PB); conditioning barriers (CB); temporary storage barriers (TSB)) and output barriers (OTB)(natural barriers (NB); artificial barriers (AB) - regime barriers (RB) and engineered barriers (EB); site selection and choice of repository' variant (SRB); RW environment barriers (RWEB)).

2.2 RW' environment identification

The RW environment elements are characterized in the following way:

- the surroundings and natural environment have not siutable conditions for RW disposal but an adequate RW disposal (respective management) is possible coupled with the rest kind of environments;
- the scientific and technical-technological environment - Bulgarian specialists can solve the problems of LLW and ILW storage and will realize a systematic work to solve problems connected with RW, in conjunction with world experience and expected assistance;
- economic environment - severe restrictions determine its central role for RWM; morreover it is very important not to aggrevate the quality of the limited natural resources;
- the backwardness of legal environment imposes significant restriction on an adequate RWM; its improving has to be closely connected with other environments;
- the institutional-political environment is under conditions of unstable connection with scientific and technical-technological environment and of undeveloped state of legal environment; this would result in nuclear technologies and RWM decisions, which are short-sighted and far from rationality;
- the socio-psychological environment is dominated by institutional-political environment - in this case it results in phenomena like NIMBY (Not In My BackYard)

syndrome in connection with RW repository siting.

The expanding of the interpretation of the notion barrier is due to the system approach, applied under consideration of the RW repository construction concept as an element of RWM. The RWM is in the context of RW environment. Input barriers, economic, scientific and technical-technological, socio-psychological, legal and institutional-political barriers are of a decisive significance for RW quality and quantity and final disposal site selection.

2.3. Formation of the hierarchical structure of research procedure, decision making levels and direct and back feeds

The research procedure structure in the context of barrier approach is presented in Fig.1. In the RW environmental space the input and output barriers are included. The intersection of these two sets is the container barrier (CNB). In more detail the research procedure is shown in Fig.2.

In the RW space variants are generated and estimated under two sets of criteria, according to RW production and conditioning. In the respective space variants of sectors and sites are formed and selected according to the criteria of natural and regime barriers. In the repository and sites space variants of repositories are generated under criteria of engineered barriers and variants of sites and repositories are selected under environmental impact criteria. Site-repository variants are analyzed and chosen, applying economic, socio-psychological and nontechnical criteria.

The direct and back feeds system reflects the iterative character of the procedure. In case of not meeting some of the criteria (for example - dose exposure) the other variants of sites are considered and only if they are not found the repository variant will be changed and so on until changing the nuclear technologies development variant.

The national RW repository construction variant is a set of several groups of variants which include the characteristics of RW; RW disposal concept and repository design; RW disposal sites; economy, socio-psychology and other.

3.METHODS FOR ANALYSIS AND CHOICE OF VARIANTS FOR REPOSITORY DEVELOPMENT - AHP APPLICATION

There are many approaches and methods for solving such kind of decision making problems [2,4]. One of the most suitable and effective from theauthors' point of view is the Analytic Hierarchy Process (AHP) [5]. First of all the AHP provides a framework which formulates a problem as a hierarchy. In our case of a complex interdisciplinary problem it is impossible to think about and to solve it without hierarhization. We are dealing with highly varied kind of uncertainty, object domain, scientific methods, thinking style, experience of experts and not at the last place very dynamic surroundings. Another advantage of the AHP is the flexibility of methods and technics for giving experts judgments and developed environment for adequacy analysis. Finally for practical purposes it is extremely important that there are numerous well interpreted and documented diverse AHP applications. Briefly the AHP and Expert Choice (EC) program are a powerful tool for the incorporation of knowledge, judgment and compromising human intuition and feeling.

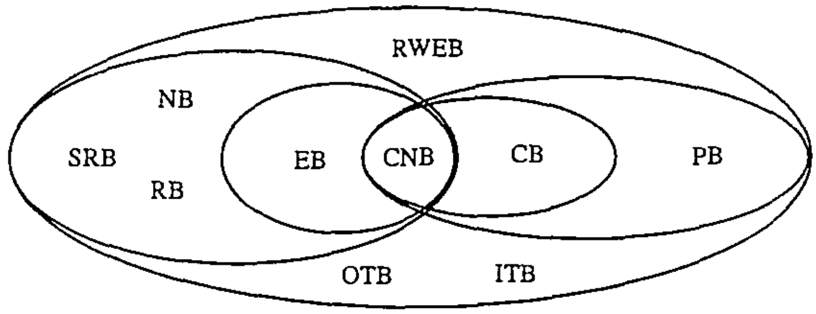

Fig. 1. Research procedure (in the context of barrier approach)

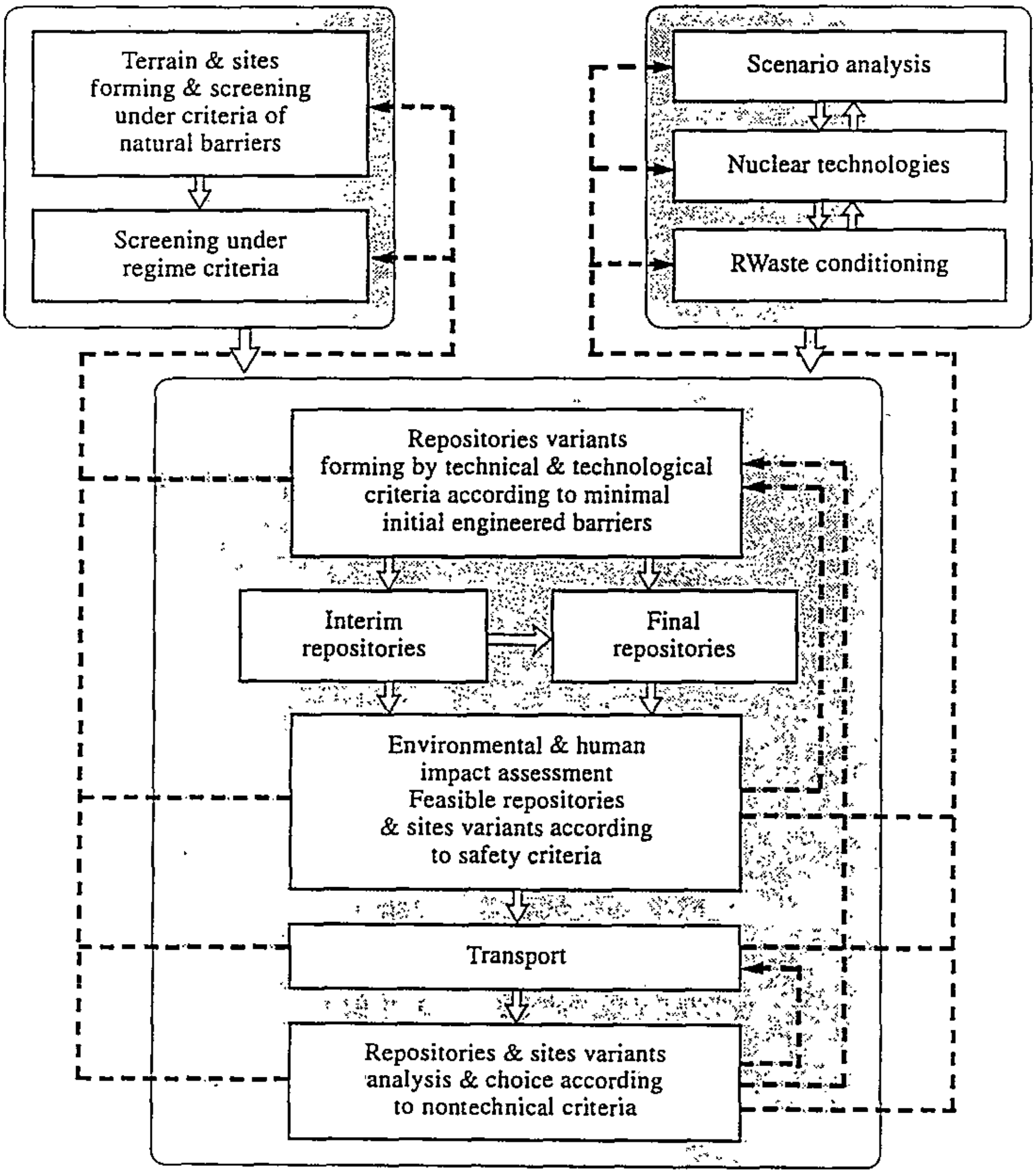

Fig.2. Block-scheme of research procedure

3.1. A system of criteria and constraints for analysis, screening and choice of variants

As it was shown in [1] the safety principles and criteria are prevailing. But the safety technical criteria are a necessary rather than sufficient condition for the choice of the most safe site - it is necessary to involve nontechnical criteria. On every stage of analysis, screening and decision making a specific criteria and constraints system is applied. This system has a specific structure, which depends on both the group of investigation (conditioning technologies, disposal system or sites for disposal) and the level of definiteness as well as on the specificity of the decision making process [3].

The **group 1** of criteria is for analysis and choice of RW conditioning technologies.

The analysis, screening and choice of variants of sectors and sites is made by using two groups of criteria (see Fig.2): **group 2** - the criteria characterizing the inherent safety of natural barriers, and **group 3** - regime criteria. The group is comparatively well organized - there are different kinds of territory regimes (sanitary protection zone, catchment area, natural, architectural-historical and archaeological reserve, communication zone). The former group of criteria is of utmost importance from safety point of view [6].

Group 4 of technical and technological constraints and criteria is the base of the RW disposal concept, the repository as a whole and of the engineered barriers design variants forming.

Group 5 of safety criteria and requirements [1,7] defines assessment, screening and choice of feasible variants of repositories and sites according to their human and environmental impact (under consideration and concretization in Bulgarian legislation).

The transport scheme and technology are optimized by using of **group 6** of specific safety criteria and economic assessments.

At the final stage of the research procedure a specific set of criteria is used. It has the most crucial importance for the successful choice of RW repository construction variant (and in broad terms for RWM). **Group 7** is the set of economic, social, socio-psychological, political, geopolitical, national security criteria, etc. [3]. The socio-psychological and sociological criteria are very important for successful site selection and construction of RW repository. They are immediate and topical for Bulgaria. Four years ago, in consequence of an increased social pressure, the construction of the second Bulgarian NPP-Belene was stopped [8].

3.2. Scenario analysis. Scenarios and variants tree

The analysis and choice of variants for construction of a RW repository are made under vast and unstudied subjective and objective uncertainty. The overall uncertainty results from various specific sources[3]. One of the tools for reflection of this uncertainty is the multi variant approach and the scenario analysis based on it [2,4].

The above mentioned considerations define one of the main specific for RWM problems - the impossibility of taking the final solutions at the different stages of the decision making procedure - many of the solutions during the decision making process are intermediate, because the procedure is interactive and has a system of feed-backs. For example the national energy (respectively nuclear energy) development can not determine RWM absolutely because of the strong backward economic influence - 1.5-2 billion USD are the preliminary estimations of RWM total costs [10]. Hence the final decision can be considered only in the RWM system study context as a result of the analysis of the overall scenarios and variants tree. It determines the significance of the scenario approach and analysis and our interest in application of AHP

There are two basic differentiated groups (levels) of investigation in the scenario analysis. The first is RW volume estimation and the second one is high level RWM conception choice. The volume of RW (especially of low level RW) primarily depends on the nuclear energy development strategy [3] and on the processing level of nuclear technologies. According to the preliminary estimation the expected low level RW volume is relatively high [10]. The RW volume is of great importance for disposal concept and repository design, site selection, economic and socio-psychological estimations. The other key study is connected with the choice of the high level RWM concept and consists mainly of two possibilities - making a decision and deferring a decision for the spent fuel disposal [10]. Both groups of study are the object of continuing and future detailed research, using AHP and EC.

The hierarchical structure of the repository construction scenarios and variants tree includes the following levels:

Level I: Nuclear technologies processing and development. It characterizes the quality and quantity dynamics of nuclear technologies. It involves a rational processing level, according to the international standards and practice. The development is considered in a long term prospect - until 2020 year. Because of lack of a long term energy development concept, only 3 conditional scenarios are considered , in which the new type of reactors is not included but only the total processing time of WWER-440 reactors is varied.

Level II: Site of disposal (in the country or abroad). The possibility to export the spent fuel back to Russia again for final disposal is considered.

Level III: Types of stored high level RW and their conditioning. The possibilities of storage and disposal of both conditioned and unconditioned RW are considered as well as the different conditioning technologies, producing RW with different quality and quantity.

Level IV. Interim RW storage. There exist different combinations of technologies for temporary storage of RW on the national or another territory.

Level V: Sites for siting of RW repository and disposal concept. Possible variants of sites and specific (for the national conditions) disposal concepts are developed.

Level VI: RW transport. Different transport technologies and routes are considered.

Level VII: Socio-psychological characteristics and approaches to the public during site selection process and repository development.

Level VIII: Economic and financial characteristics

What are the main results of the scenarios and variants tree analysis? The structurig, hierarchization of uncertainty and quality and quantity estimation of external conditions (their probability, possibility, priority etc) are performed before the decision making at every level Another very important result is the generation of the overall scenario and variants as a formal and informal combination of different levels - this is a specific kind of hypothesis.

After completing of the decision making process at the different levels the scenarios - variants tree is transformed into its new version. For every variant an integral estimation is generated. This estimation can be considered as a special kind of the folding of the estimation under the technical and safety criteria. This folding depends on the estimations at the different technological levels and on the scenario-variant combination evaluation as a complete object.

3.3. LLW and ILW conditioning - technological choice [1]

Two basic methods for solidification are considered - cementation and bitumenization. A 3 level EC model is constructed: at **level 1** - 4 groups of criteria, at **level 2** - 4 groups of 16 subcriteria (respectively 6,7,1,2) listed below and at **level 3** - 2 alternatives - bitumen and cement. The criteria set is the following: physical - definition, homogeneity, mechanical resistance, thermal conductivity, volume reduction, dimensional stability; physico-chemical - compatibility, thermal resistance, radiological resistance, porosity, permeability, solubility, leaching rate; biological criteria - micro-biological resistance; economic and technological criteria - total costs, operational criteria.

The common result is that both methods have approximately equal priority. But in fact there is another kind of problem - the technological choice decision has been already made (obviously without taking into account the above described system of criteria). Two companies have developed in different way containers and technology for cementation of LLW and ILW - as a result many difficult technological, financial and organizational problems have been raised. Hence, the real problem is the reconsideration and correction of the old decisions. In this case we see the possibility of NewTech application.

3.4. Site selection problem

3.4.1 Problem formulation and characterization

One of the substantial elements of the above discussed site selection procedure is the problem for analysis, estimation and choice of sites. It's a typical discrete multi criterial multi experts decision making problem.

The main characteristic of this problem is that the decision making process is under uncertainty. Two types of uncertainty are considered [2]: objective and subjective one.

The proposed approach and tools for solving this complex problem - reflection and decreasing of uncertainty , are the following:

- hierarchical structuring - special kind of structure among sets of criteria and variants (sites);
- adequacy analysis, including "What - If" analysis, sensitivity analysis and others;
- multi model approach - using different types of models for choice of variants and comparative analyzing of their results;
- adequate system for measurement and evaluation of available statistical, empirical data and expert judgments.

3.4.2. Site selection for LLW and ILW disposal

This site selection problem is more easy but more topical and immediate for Bulgaria than the site selection for HLW. A two level relative EC model is formed [12] (see fig.3) - level 1 includes 6 decision making criteria and level 2 includes a set of 7 sites {S1,S2,S3,S4,S5,S6,S7} separated in 4 groups: marles, loess, clays and mining.

The results are shown at fig.3. Three subsets are distinctly differentiated: G1={S2,S1} with priority from 0.256 to 0.237, G2={S6,S7} with priority from 0.175 to 0.160 and G3={S3,S5,S4} with priority from 0.075 to 0.044. Sensitivity and "What - If" analysis are directed preferably to the most uncertain estimations connected with the socio-economic criteria - they conform to the above mentioned results. If the natural barriers have priority the marles sites Sumer and Vabitsa are preferable and on the contrary - if the engineered barriers

[1] The investigation is developed jointly with E.Guteva and I.Stefanova

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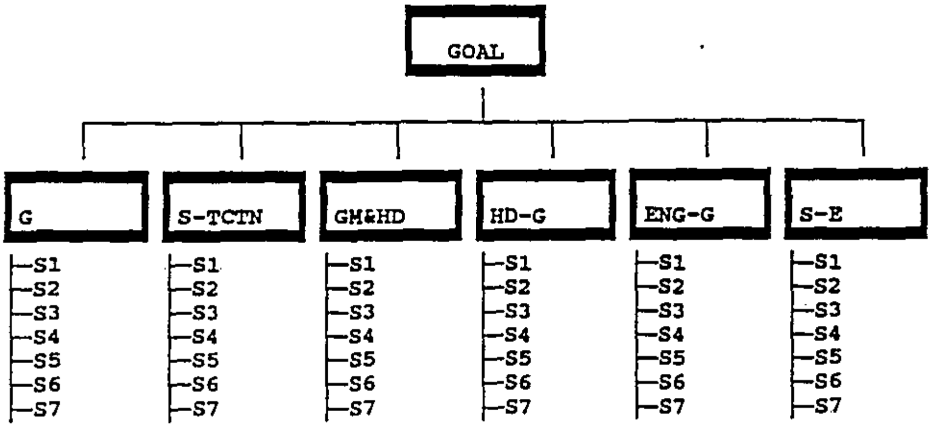
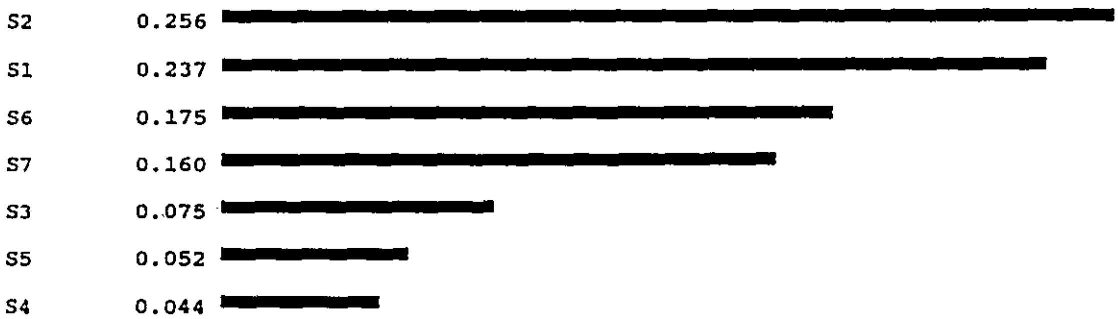
Site Selection for Low & Middle Level Radioact. Waste Repository



ENG-G --- Eng-Geological criteria
G --- Geological criteria
GM&HD --- Geomorphological and Hydrological criteria
HD-G --- Hydro-Geological criteria
S-E --- Socio-Economical criteria
S-TCTN --- Seismicity and Tectonical criteria

Synthesis of Leaf Nodes with respect to GOAL
DISTRIBUTIVE MODE

OVERALL INCONSISTENCY INDEX = 0.05



S1 --- Marles - Varbitsa
S2 --- Marles - Sumer
S3 --- Tertiary clays
S4 --- Gypsum - Koshava
S5 --- Uranium mining - Smolyanovci
S6 --- Loess - Kozlodui
S7 --- Loess - Ostrov

Fig.3. Site selection for LLW and ILW repository

are prevailing - the loess sites Kozlodui and Ostrov are preferable.

3.4.3. Site selection for HLW disposal

In line with the accepted practice in European Community countries [12,7], the site selection criteria have been divided up in four groups: rock-linked criteria; basically formation-linked criteria; formation-environment linked criteria; and supplementary selection factors.

The rock-linked criteria comprise the rock's sorption capacity, thermal conductivity and solubility. The formation is evaluated by a greater number of criteria: thickness, minimum depth, surface area, homogeneity and uniformity, permeability and geotechnical properties. It has been assessed that under Bulgarian conditions, the latter two criteria should more correctly be applied to evaluation of the formation rather than of the rock.

The environment within which the formation exists is evaluated by three key criteria: hydraulic gradient, seismicity and tectonics.

The additional criteria feature the availability in the region of a rock formation and its potential use for economic purposes, the sensitivity of the zones to climatic and hydrological changes and sociogeographic and settlement conditions.

Some of the most important criteria are estimated as criteria of tentative reliability: sorption of the rock, permeability of the formation and hydraulic gradient. There is insufficient quantity of data at the conceptual stage of fulfillment of the task of selection of a site for national repository for RW.

A 4 level EC rating model is formed (see Fig.4) [7,13]. **Level 0** contains the Goal node - Site Estimation for High Level RW Disposal. **Level 1** contains the criteria subsets - 4 items. **Level 2** contains the criteria - 15 items (respectively. 3,6,3,3). **Level 3** contains the subsets of ranges for every criterion' absolute scale. **Level 4** contains sites - 20 items.

The results of the present stage of investigations taking into account several conventions are as follows: the more perspective for future evaluations are 5 marl sites (S5,S4,S6,S7,S1), 2 serpentine sites (S15,S16), a gneiss (S14), granite (S13) and volcanic rocks site (S10) [12].

These results are preliminary because of several reasons (for example the uncertainty and unreliability of some criteria). Another problem is the adequacy of formed scales for each criterion and the priority of the ratings intensities for scales. There are some well defined and well felt by experts criteria for which well determined scales are existing - like seismicity, thickness etc. But for some criteria like the above mentioned critera of tentative reliability, it is difficult to form an adequate scale and to make absolute estimations. For this reason another 4 level EC relative model is formed with the main idea to compare the results of both rating and relative models. This model is the following: **Levels 0-2** are the same, **Level 3** contains the sites' subgroups - 5 items and **Level 4** contains sites - 20 items (respectively. 7,4,4,1,4).

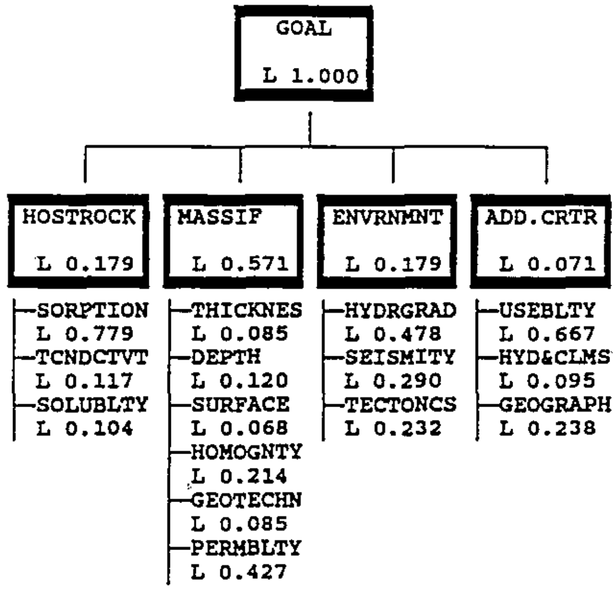
Both rating and relative models are included in the following common site selection procedure:

Step 1. Generating a rating (absolute measurement) model.

- measuring the importance among criteria's subsets and in each subset of criteria by pairwise comparison;
- forming an absolute scale with rating intensities for each criterion and assigning priorities to ranges (in a pairwise manner);
- in a ratings' table the sites are estimated under each criterion by using scales;
- analysis of results.

Step 2. Generating a relative (pairwise) model: estimating preferences between sites

EVALUATION AND CHOICE OF SITES FOR HIGH LEVEL RADWASTE DISPOSAL



ADD.CRTR --- ADDITIONAL CRITERIA
DEPTH --- Massif depth
ENVRNMNT --- ENVIRONMENTAL CRITERIA
GEOGRAPH --- Population and settlement dencity criteria
GEOTECHN --- Geotechnical qualities
HOMOGNTY --- Homogenity and uniformity
HOSTROCK --- HOST ROCK ESTIMATION CRITERIA
HYD&CLMS --- Hydrological and climatic sensitivity of the region
HYDRGRAD --- Hydraulic gradient
MASSIF --- ROCK MASSIF CRITERIA
PERMBLTY --- Permeability
SEISMITY --- Seismisity
SOLUBLTY --- Solubility
SORPTION --- Sorbtion
SURFACE --- Massif surface area
TCNDCTVT --- Thermal conductivity
TECTONCS --- Tectonics
THICKNES --- Massif thickness
USEBLTY --- Compatitive usebility of rock massif

L --- LOCAL PRIORITY: PRIORITY RELATIVE TO PARENT

Fig.4. Site selection for HLW repository

under each criterion and each subgroup of sites; "What-If" analysis; sensitivity analysis; analyses of results.

Step 3. Building a relative model with 7 sites from the rating model - finer,more detailed analysis, including "What-If" and sensitivity analysis.

Step 4. Comparative analysis of the results from all models.

Step 5. Adequacy analysis.

In a broad sense adequacy includes [2]: adequacy of problem formulation; adequacy of approach and method; adequacy of decision making procedure; adequacy of decisions (sensitivity and interpretation) analyses; adequacy of uncertainty reflection.

The adequacy analysis compensates the uncertainty and unreliability of some of the decision criteria and demonstrates the possibility at this stage of site selection procedure to make a good decision and produce adequate evaluations.

3.5. Choice of a variant for RW repository construction

The main specificity inf this case of the decision making is that the economical and other non-technical criteria are not used for choice at the different technological levels, i.e. the technical criteria have priority at the local level. As a result a set of the feasible variants for RW repository construction is formed which is based on the technical and safety criteria. The economic and other non-technical criteria have to take effect on the feasible variants as a whole, only in general, but not at the single technological levels.

Several important questions are raised in connection with the process of the final decision making. The first conserns the priorities of variants from the technically feasible set. The second one conserns the proportion between technical and non-technical criteria priorities and the third one is the joint consideration of the measurable and unmeasurable (or measured by the different kinds of measures) criteria.

The answers of these questions can be given effectively by use of the AHP Benefit-Cost scheme [13]. Formulating this scheme we suppose that the only benefit of the variants chosen in accordance with the technical and safety criteria is represented by "safety" integral estimation and all the rest benefits and costs are the result of the non-technical criteria application.

4. CONCLUSION

The proposed hierarcical procedure reflects the complexity of radioactive wastes management. Investigations at the separate decision making levels are of different degree of completeness and correspond to the development of radioactive wastes management practice and to the radioactiwe wastes environment conditions.

The first preliminary results of the AHP approach, ideas and Expert Choice application display their effectiveness and suitability especially for site selection, scenario-variants tree analysis and decision making under non-technical criteria.

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