A GIS BASED METHODOLOGY FOR NUCLEAR REACTOR SPENT FUEL DISPOSAL

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ABSTRACT. This article aims at studying the use of Geographical Information Systems for selecting a site for radioactive waste disposal of spent fuel generated by operation of Angra 1 and 2 nuclear power stations, in order to provide additional means for solving this problem in Brazil. This spent fuel continues to generate decay heat and radiation after its use in power stations. The disposal shoul be done in such a way as to isolate the nuclear spent fuel from people and the environment, protecting them from the heat and radioactivity for a long period of time.
After elaboration of a database containing geological, hydrological, tectonical, weather, transport, conservation unit, amongst other informations, one intends to combine these informations, and make comparisons using preset criteria, in order to indicate the most adequate sites for disposal
Keywords: radioactive waste management, spent fuel, geographic information systems

1. INTRODUCTION

Nuclear energy has brought a renewed interest in the world, mainly due to global warming aspects. This phenomenon, resulting from emission of gases such as CO2, steam and methane, consists of retention of part of the solar energy which earth would send back to space. This causes the earth temperature to rise, producing a series of impacts, such as the increased occurrence of adverse weather conditions, such as draughts, floods and heat waves, which in turn cause deaths, material damages and agricultural losses.

IPCC, in its last report, *Climate Change 2007 – Fourth IPCC Assessment Report*, states that nuclear energy can be beneficial to global warming issue if carefully deployed. Nuclear energy has a large potential for mitigating CO2, emissions, having a good cost-benefit ratio, although problems such as potential accidents, proliferation and waste management cam represent a restrictive factor.

The issue of radioactive waste disposal, specifically, the high level and long lived isotopes generated in spent fuel has always been the “Achilles heel” of nuclear energy electrical generation, although nowadays, in the last two decades, a huge progress in the waste management and final disposal problems has been accomplished. The state of the art indicates as a reliable solution the construction of geological underground disposal 500 m deep, in sites which present certain characteristics making them adequate to long time storage, according to international criteria. This work describes a methodology for initial site selection in order to indicate an appropriate place for geological disposal storage building to accommodate spent nuclear fuel from Angra I and Angra II power stations.

2. Theoretical considerations

A system for geological disposal can be defined as a combination of engineering barriers (man made) and natural barriers, conceived to isolate the hazardous material from people and retain any emissions which could occur in a time span of the order of millions of years.

The engineering barriers are defined during the repository design phase. The natural barriers, formed by the host rock (where the repository is to be built) and by the geological environment around, should present certain characteristics demonstrating their adequateness to isolate and contain the material for the necessary period of time.

Considering long term safety, the most important condition, one should identify first a global favorable scenario. Natural barriers are more reliable in the long term, since they were formed and have been maintained unaltered during a time span of order of millions of years and one cam reasonably assure that they will remain in this condition for an equivalent period of time. Structural changes occur extremely slow, favoring radioactive decay within the disposal system.

In this way, the site selection process is an important step in developing a disposal system which will satisfy all technical, environmental and safety conditions appearing in various international documents (IAEA, 1994).

3. SELECTION PROCESS

The sites Selection process must consist of at least four steps, according to AIEA (AIEA, 1994):

(a) Conception and planning step:

In this step, planning of the selection process and potential rock types and geological formations which can serve as a basis for the area analysis step is done, using available data

(b) Area analysis step:

In this step, areas which can contain adequate sites, through the use of relevant criteria or factors identified in the previous strep are selected. This can be done by a step by step analysis of a region of interest, selecting in this region smaller adequate areas.

(c) Site characterization step:

This step consists of studying and investigating one or more potential *in situ*, so as to demonstrate that they are acceptable, mainly from the safety point of view.

(d) Site confirmation step:

This step consists of detailed study and investigations on the chosen site, before repository construction begins. Details of the site and surroundings are obtained through field studies in the laboratory and underground facilities, in order to allow modeling of involved processes of repository. These results are used to define the site location, establish engineering and construction characteristics of the site and also to assess involved costs.

4. METHODOLOGY

The methodology presented in this work intends to satisfy the initial steps of the selection process, such as: Collecting available data about criteria used in the selection processes and use of these data to identify áreas which may contain adequate sites. The final investigation and confirmation steps require further studies and analysis which are to be done only for the selected site, in order to minimize costs and the time involved in the analysis process.

The developed methodology took as a basis the Comissão Nacional de Energia Nuclear Rule (CNEN, NE-6.06, 1989) concerning siting of low and medium waste. This rule establishes minimum requirements applicable to the selection process and therefore will be used in this methodology.

The selection process starts from larger regions, which are then reduced in the development of the process, by using criteria which confirm (or not) its adequateness to host a repository,

The areas to be analyzed will have the following hierarchy (CNEN, 1989):

- Interest region – Territory initially identified in the selection process on a regional level,
- Preliminary area – Area within the interest region, which has not been excluded from regional analysis and to be investigated for potential area identification,
- Potential area- Area within the preliminary area, identified as potentially satisfactory to host a radwaste disposal building, through use of restrictive technical criteria and specific technical studies,
- Candidate sites – Selected favorable site, within potential areas, through use of technical studies of a more profound nature than before. Among these candidate sites will be the selected site for hosting a radioactive disposal facility, as confirmed by the competent regulatory authority.
- Site – Geographical area containing a disposal facility.

Technical analysis is performed in a selective and sequential way, consisting of various data and information detailing levels, obeying the previously mentioned hierarchy.

- The interest region and preliminary areas will be identified on a regional basis (defined to be the scale chart, smaller then 1:100.000, used for studies and data gathering).
- Potential areas will be identified in semi detailed scale, within 1:10.000 and 1:100.000, used for studies and data gathering).
- Candidate sites will be identified in detailed scale (greater than 1:10.000, used for studies and data gathering).
- For technical reasons, The Rio de Janeiro State was considered as a interest region, in which candidate sites are to be searched.

4.1. DEFINITIONS

In this work, some definitions are used, listed in the table below:

Table 4.1 Important definitions

Name	Definition
Function	Purpose of repository.
Requirement	Condition defined as necessary and which must be satisfied. Refers to actual conditions irrespective of selection steps. All requirements must be fulfilled.

Preference	Condition which would have to be be satisfied. irrespective of selection steps. Not all requirements must be fulfilled.
Criteria	Refers to a condition in which a decision or sentence may be based. They may be used to determine whether a site meets requirements and/or stipulated preferences. May be qualitative or quantitative and should result from established principles and rules. Since they are related to the information level, may vary according to selection process step.
Parameter/Factor	Quantity, property, condition, state, variable or characteristics, physical or chemical.

Adapted from Andersson, J and Ström, A, et al , 2000 and from IAEA, 2003 (b)

4.1.1. Functions

Safety functions are the functions that a repository must fulfill during its functioning period. Basically, a repository performs three important functions, as discussed next.

4.1.1.1. Isolation

One of the disposal system functions is the human and biosphere long-term waste isolation, that is, to prevent direct access to waste. Disposal of this waste in deep geological layers will make this function possible, as long as the waste is removed from surface, where they are much more vulnerable to human activities and environmental conditions, which may result in radiation exposure. The disposal system and its environment jointly contribute to perform this function.

4.1.1.2 Containment

Another function defined for the safety of the disposal system is the radionuclide contention, that is, even in the event of an engineering barrier failure, one should assure that radionuclides remain confined within the engineering barrier system and its neighboring rock, so that the radioactive decay occurs within the disposal system.

4.1.1.3 Delaying

Although a complete confinement cannot be supplied during all the relevant time for all radionuclides, radionuclide release rates from radioactive waste are small. In the case of a partial or total confinement function failure, a function that delays and limits radionuclide flow in all system is necessary. The aim of this function is to attenuate the radionuclide flow that pass through the disposal system up to its boundary, and many processes attenuate the releases during its transport towards surface and limit radionuclide concentrations in the environment. Theses processes include the radioactive decay during the slow transport through the barriers supplied by the host rock.

4.1.2. Requirements

The requirements are defined so as to fulfill the safety functions. These are minimal requirements that a site must have in order to be considered adequate by CNEN (CNEN, 1989) and apply to surface repositories. For underground repositories, these requirements were adapted and are presented next.

a) To allow the long-term waste confinement;
b) To present features that assure in the long run:
   - Human, property, and environment protection against radioactive releases;
   - Protection against inadvertent intrusion of individuals and animals; and
   - Stability after the repository sealing;
c) To allow to be characterized, mathematically modeled and monitored;
d) Do not have known natural resources subject to exploration;
e) To prevent that underground water access the repository, even partially;
f) To prevent adequate capacity of retaining radionuclides that are planned to be disposed;
g) To be situated outside those areas where tectonic processes that may cause ruptures occur.

These requirements refer mainly to the rock isolation zone that assures the radioactive waste isolation.

4.1.3. Preferences

Preferences refer to the conditions that are searched in a site so as to enhance the safety margins, lower costs, facilitate investigations or the repository construction. In the analysis of the parameters related to the preferences in a site, 'poor' values for certain parameters may be compensated by 'better' values for other ones.

4.1.4. Selection Criteria

Starting from the requirements and preferences, the criteria to be used during the selection process are defined. These criteria may be divided in two groups, discussed next.

4.1.4.1. Exclusion Criteria

These criteria are related to the minimum requirement a site must fulfill in order to be considered adequate for repository construction. They are used to exclude from the selection process the sites presenting obviously unfavorable characteristics to repository location.

Criteria refer to natural processes, such as seismic and volcanic activities, which may damage the barrier system of the repository within the stipulated isolation period, presence of natural resources in the region, which may represent a possible future intrusion into the repository, presence of conservation units, which pose undesirable conflict of interests, etc.

4.1.4.2. Weighting Criteria

These criteria refer to preferences related to presence or absence of a certain parameters or factors important to site adequateness. They have as objectives classify areas in such a way that allows one to select those that seem to be more adequate to host the repository. Among these criteria, one can cite presence of underground water on the repository level, which may facilitate radionuclide transport up to the surface. The chemical composition of this water, of the rocks and soil, which may facilitate retention of radionuclides from disposal system, the proximity to waste producing places, in order to minimize risks involved in the transport of these materials, etc.

4.1.5. Selection Parameters or Factors

In an initial phase of the process, availability of data relating to areas of interest to analysis is very limited. Many factors, important to long term safety and other aspects related to repository construction will only be clarified after *in situ* investigations. Until this happens, one will depend basically on general knowledge as a mean to select sites to be studied later on. Since general data on environmental factors and terrain, as well as social aspects are easy to obtain in an initial phase, these selection factors were used and clarified from the beginning.

In this initial phase of the process, that is, without data from field investigations, the evaluation of the geo-scientific material was focused in adequate/inadequate conditions, based on already available information.

These conditions were selected from a review of geological factors associated with underground radioactive waste disposal. International recommendations from International Atomic Energy Agency - IAEA (1977, 1994 e 2003(a)), Nuclear Energy Agency - NEA (1995), relating to adequate geological scenario were analyzed. Furthermore, several countries have made enough progress in site selection process and have published periodical reports about the status of their waste management programs, among them we can mention Sweden (SKB, 1992, 1994) and Finland (Mc Ewen, and Äikäs, 2000).

From the documents analyzed and also considering the minimum requirements of CNEN, a list of conditions was elaborated, of which we can mention:

- Active fault zones – presence/absence, and distance from the area of the repository;
- Seismic activity – presence, absence, intensity, scope and distance from the repository;
- Undergroun water – presence, absence, location of aquifers and aqüicludes, areas of recharge and discharge of aquifers and their distance from the repository, chemical composition
- Mineral resources – presence, absence, type of use, distance from the repository area, potential for exploitation;
- Rock types – characteristics, lithology, structure, size;
- Soil types – chemical composition, thickness, permeability, class of soil;
- Climate – annual rainfall;
- Elevation/topography – slope, altitude.
- Transportation – highways, railroads and ports of areas;

It then made a survey of data for the analysis and where they get them in order to draw up a database to manipulate, analyse and present this data in a geographic information system - GIS.

To allow any work to be done this type of information must first become available. This can be a problem because this information often are kept in various archives, have varying sizes, are rarely available for the entire region to be examined and vary in resolution, age and quality.

Data on various subjects discussed were obtained from the Geological Service of Brazil (CPRM) and also with the Department of Mineral Resources of Rio de Janeiro (DRM).

These data include information geological, geomorphological, hydrogeological, mineral resources, conservation units, among others concerning the characterization of the State of Rio de Janeiro.

Information obtained were organized in a geographic database, using the software ArcView (ESRI) is a computational tool to deal with geographic information. This software was developed to perform analyses in an environment of GIS information enabling connect to a geographical position. The ArcView makes it easy integration of data allowing access logs of databases and view them on maps.

The data were organized into topics as "layers" of data. A "layer" is a set of logically related geographically and their attributes (information associated with geographic features, presented in the form of tables). The "layers" were organized on the basis of geographic themes such as geology, geomorphology, lithology, pedology, altimetry, mineral resources, among other units of conservation as shown in Figure 1.

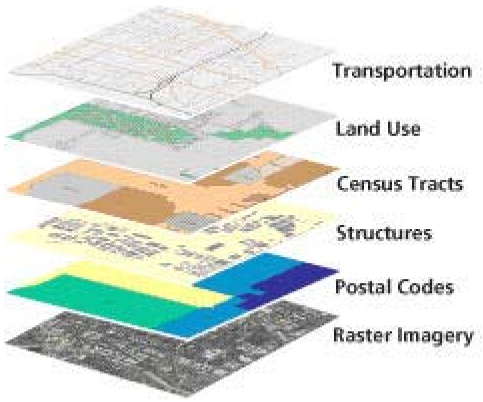

Figura 1 - Types of Spatial Data

The organization of these overlapping layers and led to projects to be submitted for analysis using the first time in a criteria for exclusion. After these tests will be generated maps showing the areas that should be excluded from the procedure. The next stage will include the application of the criteria for balancing the maps resulting from the above analysis. Its goal is to limit the areas remaining after the first partial step to areas with lower geological conditions particularly favourable to the provision. From this analysis will be generated maps which may be identified as homogeneous areas more suited to host the geological repository.

5. CONCLUSIONS

As mentioned earlier, the methodology presented is being applied for the adequate site selection for the geological disposal in the state of Rio de Janeiro.

The aim of this work is the development of a selection method that can be applied to any kind of radioactive waste and also to any region in the country. In a small-scale analysis, starting from the pre-definition of the region of interest aiming at verifying the viability of the method, one may conclude that the methodology developed is viable, in a next step, to other regions in the country, and later for application in the entire country.

The method has proven to be able for analyzing and manipulating a wide range of information concerning the different features involved and to present the results from the analyses in maps that facilitate the identification of the criteria used in the selection process and the understanding of the process as a whole. This fulfills a basic principle of this kind of process, widely recognized, that is the transparency all along all process steps.

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