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THE ARGENTINE RADIOACTIVE WASTE REPOSITORY

Basic criteria, preliminary siting and design conceptual basis

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Abstract

THE ARGENTINE RADIOACTIVE WASTE REPOSITORY: BASIC CRITERIA, PRELIMINARY SITING AND DESIGN CONCEPTUAL BASIS.

The paper describes studies carried out for siting a repository for high level radioactive wastes originating in the nuclear programme of Argentina. A summary is given of the basic criteria governing the study, as well as a description of the activities involved in the selection of the site, its validation and the derivation of the design basis of the repository, together with conceptual definitions regarding its engineering. At the end of the 1970s the Argentine authorities decided to explore alternatives for disposing of the high level radioactive wastes that would eventually be generated by the country's nuclear programme. This programme involves nuclear power reactors that will generate a time integrated electric energy of about 100 GW·a by the end of the century. The programme also includes the reprocessing of the spent fuel. On the basis of the criteria adopted for the disposal of high level wastes, a site in stable, unfractured granite, near Gastre in the Province of Chubut, was selected for detailed studies out of about 200 potential sites. This site has been thoroughly investigated and its suitability will be validated. Work has also progressed on the design of the repository.

1. INTRODUCTION

At the end of the 1970s the Argentine authorities decided to explore alternatives for disposing of the high level radioactive wastes that would eventually be generated by the country's nuclear programme. This programme involves nuclear power reactors that will produce a time integrated electric energy of about 100 GW·a by the end of the century.

The option of direct disposal of spent fuel elements was discarded in Argentina because of the energetic value of the remaining fissionable materials and also for radiation protection reasons. Fuel elements are not designed for the retention of radionuclides for a long time after disposal, and a substantial inventory of actinides in the non-processed fuel would imply a higher radiological impact than that caused by the recycling of fissionable materials [1, 2].

No significant amounts of liquid high activity wastes have been produced yet in Argentina. These wastes, however, will be generated from the operation of a fuel reprocessing plant that is in an advanced stage of construction.

The need for solving the problem created by high activity radioactive wastes is expected to be significant during the second half of the 1990s. However, the Argentine authorities decided to explore potential solutions of the technological problems connected with the elimination of high level radioactive wastes well in advance [3].

A feasibility study is being carried out for the construction of a repository for radioactive wastes in a deep geological formation. This paper describes the basic criteria, the preliminary siting studies and the design conceptual basis of such a repository.

2. RADIOLOGICAL SAFETY CRITERIA FOR THE DISPOSAL OF RADIOACTIVE WASTES

Disposal of radioactive wastes involves isolation of the radioactive material from the human environment over a sufficient period to permit decay in isolation. Any exposure of man that could still occur would be due to mechanisms that may be described as:

(1) Normal scenario: 'normal' release mechanisms, leading to a predictable exposure pattern in space and time;
(2) Random, disruptive events, for each of which a probability of occurrence and an exposure pattern can be postulated.

The difficulties in direct application of the normal basic radiation protection principles are mainly caused by:

(a) The very long periods involved
(b) The randomness of the types of exposure.

In principle, both the normal scenario and the disruptive events would be expected to give exposure patterns of the general type shown in Fig. 1 [4, 5]. The main difference is that the normal release is expected to occur after a retention period which is long enough to permit the activity to decay to clearly acceptable values, while disruptive events may cause releases before there is sufficient decay to make the exposures acceptable.

2.1. Criteria for normal scenario

The radiological safety criteria adopted by the Argentine authorities for normal scenarios connected with disposal of radioactive wastes are compatible with the recommendations of the International Commission on Radiological

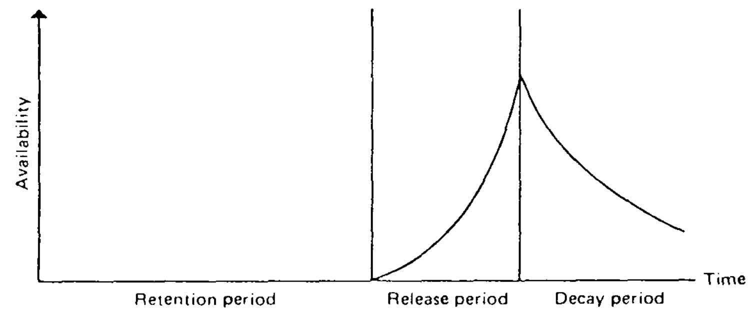


FIG. 1. Typical exposure patterns.

Protection (ICRP) [6, 7]. The main objectives are to keep individual doses below appropriate limits and to reduce the total radiological impact from the disposed wastes as far as it is reasonably achievable.

2.1.1. Upper bounds

The ICRP recommended individual dose limits apply to the total dose from all sources (excluding natural background and medical exposures of patients). For the contribution from any particular source, competent authorities are expected to set an 'upper bound' which should only be some fraction of the ICRP dose limit if exposure from other sources is possible [6, 8].

It should be possible to postulate a generic upper bound for the annual dose contribution arising from the practice of radioactive waste isolation, which would limit the dose to any critical group resulting from all repositories. Such a generic upper bound, however, would be of little use in practice. What is required is an upper bound for the annual dose due to a specific waste repository. In this case, however, it is necessary to take account of the 'per caput' global contribution of all the repositories which would add to the local dose contribution of the repository under consideration [7, 9].

The 'normal' release situation and its resulting exposure pattern, by definition, have an occurrence probability which may be considered equal to one. The design requirement would therefore be that, at all times [5],

$$H_{L,k}\left(1 + r_k \frac{W_t}{W_k}\right) \leqslant fH_{lim}$$

where $H_{L,k}$ is the annual dose contributed locally to its critical group by repository k, r_k is the ratio of the per caput dose to the local critical group dose (both due to repository k), W_t is the total amount of uranium predicted to be used for nuclear power generation and W_k is the amount of uranium originating the waste in repository k, f is the fraction of the ICRP dose limit considered appropriate for waste isolation in general, and H_{lim} is the dose limit.

The upper bound will differ significantly from the simple value fH_{lim} only in the cases where $r_k (W_t/W_k)$ is not small. For planning purposes, and similar to the case of upper bounds used at present for some nuclear installations, the value of fH_{lim} was set by the Argentine authorities at 0.1 mSv in a year as a maximum in the stylized critical group.

2.1.2. *Optimization*

Optimization of protection is the basic requirement recommended by the ICRP for dealing with control of radiation detriment. This requirement implies that the detriment from a radiation source should be reduced by protective measures to a value such that further reductions become less important than the additional efforts required to achieve such reductions.

In the case of waste repositories and owing to the low doses that are expected to be involved, the detriment can be taken to be proportional to the collective dose commitment from the disposal. But, because of the presence of very long lived nuclides, an assessment of the complete collective dose commitment will be highly speculative. In optimization, however, one deals with differences in collective doses between different protection options. The period of interest is therefore that in which the alternative protection levels (engineering solutions) have an influence on the exposure pattern, because the longer exposure tails would cancel when subtracting collective doses of different options. For the Argentine repository, the period of integration for the assessment of the relevant incomplete collective dose commitments was 500 years [10], following procedures similar to those used by the United Nations Scientific Committee on the Effects of Atomic Radiation [11].

2.1.3. *Total collective dose*

The Argentine authorities also established as a design aim of the repository that the total collective dose commitment from high level radioactive waste disposal should be of the same order as that resulting from the other steps in the fuel cycle [10].

2.2. Criteria for disruptive events

It should be recognized that even in 'normal' release conditions the occurrence of detrimental biological effects is of a probabilistic nature. For radiation protection purposes the probability of stochastic effects, namely fatal cancer and serious genetic effects, is taken to be approximately 2×10^{-2} per sievert of effective dose equivalent [6]. The probability of non-stochastic effects above the threshold increases from zero to one over a usually small range of doses. For example, for mortality due to the acute radiation syndrome resulting from whole body irradiation, the probability at doses lower than 2 Gy is practically zero while it is nearly one above 6 Gy.

In the case of random disruptive events one deals with the probability of the event and with the resulting doses in the group of individuals receiving the highest doses. Regarding radiation effects one deals, therefore, with effects of a second order of stochasticity. For example, the probability of dying (or risk) for a member of the public due to a given potential disruptive event can be expressed as $R = P_1 P_2$, where R is the 'risk', P_1 is the probability of occurrence of the event which would result in a dose H to the member of the public under consideration, and P_2 is the conditional probability of death, given a dose H [5].

If several potential situations i are taken to be possible, the risk R defined above becomes

$$R \approx \sum_i P_{1_i} P_{2_i}$$

where the summation should be extended over all possible relevant scenarios of exposure.

It should be realized that P_{2_i} is proportional to dose at the lower doses (where only stochastic effects are possible), but increases steeply with whole body dose at values above 2 Gy owing to acute non-stochastic effects.

Probability values must be assigned to the few disruptive events that are expected to cause significant exposures if they occur. Event tree assessments will yield probability values P_{1_i} for a number of exposure situations i due to various sequences of events. In each exposure situation a maximum annual dose, H_i, in time and space may be identified. The simplest approach would be to assess these maximum doses as if they occurred simultaneously in one and the same critical group. This will overestimate the probability of harm to any given person but will grossly simplify the assessment [6].

On the assumption that the maximum probability of harm committed in a year, given an exposure situation i, is a function of the maximum annual dose that would occur in that situation (H_i), the maximum value of the total probability of harm, R_{max}, that is committed for one year cannot exceed the direct summation of the maximum values for each exposure situation:

$$R_{max} \leqslant \sum_i p(H_i) p(\text{harm}|H_i)$$

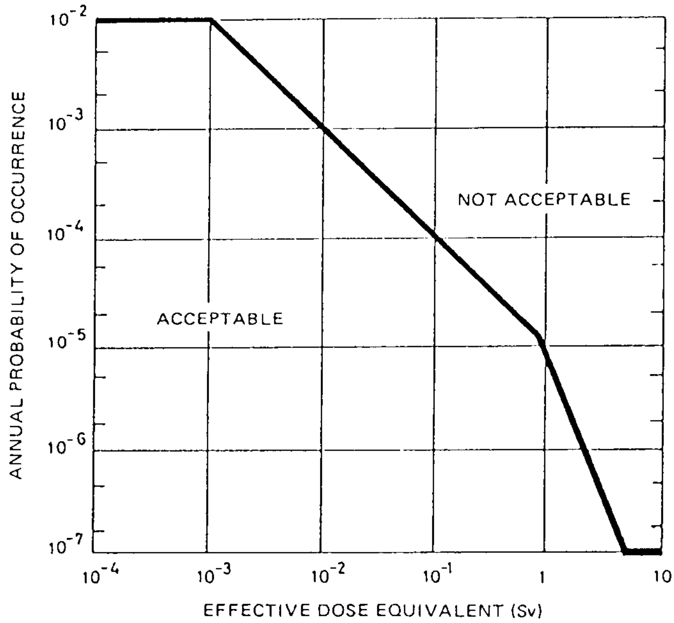


FIG. 2. Criterion curve.

In the criteria of the Argentine authorities, the basic objective is to ensure that the maximum individual risk to a member of the public due to potential disruptive events in a repository does not exceed the risk due to 'normal' radioactive releases. The order of magnitude of the upper bound established by the authorities (0.1 mSv in a year) corresponds to a risk of lethality of the order of 10^{-6} in a year. Therefore, the proposed objective for the Argentine repository was stated as

$$R_{max} \leqslant 10^{-6}$$

where R_{max} is the maximum value of the probability of lethality committed for one year.

Since the Argentine criterion is to require that several disruptive event sequences be considered (of the order of ten), then on the average their individual risk contribution should not exceed a value $R_i = 10^{-7}$ in a year.

Therefore, the 'acceptable' probability of occurrence of a sequence giving dose H_i is taken to be $\leqslant 10^{-7}/10^{-2}\ Sv^{-1}\ H_i$ in the region of doses H_i where only stochastic effects can occur. At higher dose values the 'acceptable' probability of occurrence is $\leqslant 10^{-7}/f(H_i)$, where $f(H_i)$ is a non-linear function of dose which becomes one at high doses. The annual probability of disruptive sequences yielding non-stochastic lethal doses should therefore not exceed the order of 10^{-7}.

The procedure described above for applying individual dose limitation to probabilistic disruptive events has been expressed by the Argentine authorities in a 'criterion curve', shown in Fig. 2, which is similar to that used by the authorities as a probabilistic criterion for nuclear safety [12].

3. BASIC CRITERIA FOR DESIGNING THE REPOSITORY

The design of the Argentine repository shall not only comply with the basic radiological criteria described above but will obviously satisfy the needs of the Argentine nuclear programme. It is expected that by the end of this century the nuclear power plants will have generated about 100 GW·a of electric energy during their operating period [13]. The wastes resulting from the reprocessing of spent fuel elements used for the generation of that energy will require approximately 3000 containers of about 0.6 m diameter and 1.6 m height. Also, future expansions of the repository must be foreseen as the needs of the nuclear programme are expected to be increased [3].

The high activity wastes resulting from the reprocessing of irradiated fuel elements contain more than 99.9% of the whole activity produced in the fuel cycle. With the basic safety criteria and the time elapsed between the disposal of the waste and its arrival in the biosphere taken into account, the disposal problem may be divided into two steps. The first step encompasses the period during which the activity of the fission products is predominant, and lasts for the first 1000 years. After this, the individual risk is small and the scale of the problem is modified. However, there is still the problem of the long half-life radionuclides that will last for millions of years.

3.1. Normal scenario

The requirements related with the normal scenario set by the Argentine authorities are: (a) a dose upper bound of 0.1 mSv in a year as a maximum in a stylized critical group, (b) optimization of radiation protection, and (c) a total collective dose commitment of the same order as that resulting from the other steps in the fuel cycle.

To comply with the dose upper bound, the wastes will be kept isolated within the containers during the first 1000 years. They will be vitrified and placed within a stainless steel container covered with a lead layer approximately 10 cm thick. Preliminary assessments have shown that the Argentine repository would imply doses to a hypothetical critical group of the order of some microsieverts, due mainly to ^{237}Np. Moreover, they would potentially be incurred some 10^5 years after the waste disposal [10].

The requirement to reduce the detriment to a value such that further reductions become less important than the additional efforts required to achieve such reductions will be met by means of engineered and geological barriers. Optimization techniques are to be applied to each step in the design process. Nevertheless, a rough cost–benefit optimization analysis which assigns US \$10 000/man·Sv to a unit collective dose shows that an initial isolation period with engineered barriers of the order of 10 000 years should be necessary.

Such retardation will be attained by incorporating the wastes in a vitreous matrix of the borosilicate type (leach rate below 4×10^{-4} g·cm^{-2}·a^{-1}) with a content of fission products and actinide oxides in the glass mass of 10 wt%. An additional engineered barrier will be formed with the final sealing of the repository holes using a buffer material providing great resistance to the arrival of water and to the migration of radionuclides. This will be attained with a mixture of sand and bentonite of high retention capacity.

Also, to reduce the global detriment, in addition to the engineered barriers the geological barriers of the site should retard the arrival of the radionuclides in the biosphere for a period of the order of 100 000 years. To achieve such isolation, the containers will be placed within a stable geological formation with low hydraulic conductivity ($<10^{-9}$ m/s) several hundred metres below ground level. To guarantee the properties of the geological formation and of the buffer material, the maximum temperature in the rock was fixed at 60°C and, consequently, the thermal power of a single container and the thermal density at the repository level were limited to 500 W and to 5 W/m^2, respectively. The aim of having the maximum rock temperature, 60°C, significantly lower than that established in other, similar projects, is to reduce the possibility of a significant increase of the hydraulic conductivity resulting from microfractures produced by thermal stresses and by rock decomposition.

Finally, to verify compliance with the requirement that the total collective dose commitment from the high level radioactive waste disposal should be of the same order as that resulting from the other steps in the fuel cycle, an assessment of the radiological impact of the repository was made [1, 10]. The collective dose commitment from the disposal of reprocessing waste of the Argentine programme was assessed to be 3.8×10^4 man·Sv and 2.6×10^4 man·Sv for delays in reaching the biosphere of 10^5 and 10^6 a, respectively. The collective dose commitment due to the operation of the nuclear plant that generates these wastes was assessed to be 4.8×10^4 man·Sv.

3.2. Disruptive events

The requirements related with disruptive events established by the Argentine authorities have been expressed with the criterion curve shown in Fig. 2. For validating the final design a full risk analysis will be performed. The authorities are aware that compliance with the criterion curve is a necessary but not necessarily sufficient condition to ensure the compliance of the repository with the criteria for disruptive events. Optimization should play a role in this case too. The authorities, however, have not yet fixed their position on this matter.

For the current stage of the project, the criterion adopted was to ensure that the selection of the site took into account that the probabilities of occurrence of both disruptive natural events and human intrusions would be sufficiently low as to ensure that the criterion curve could be respected and that any further reduction of risks could be performed practically. For site selection purposes, attention was given to excluding sites within seismic areas or in areas with present or potential mining interest.

4. SELECTION OF THE SITE

The safety criteria and basic design criteria related with the selection of the repository site could be summarized as follows:

(a) Normal scenario: deep, stable geological formation with low hydraulic conductivity;
(b) Disruptive events: areas with a sufficiently low probability of occurrence of disruptive natural events and human intrusion.

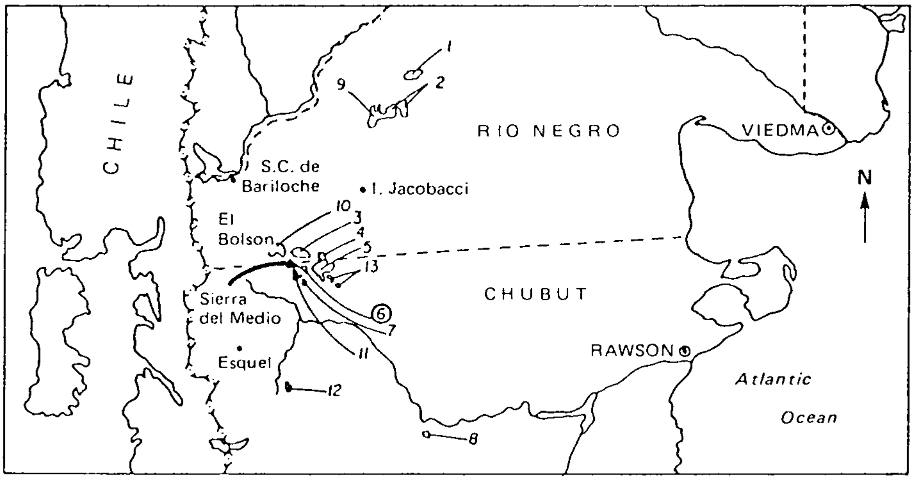
In view of the geological features of the Argentine territory, where no appropriate salt domes have been found, the normal scenario requirement will be attained by disposing of the wastes in a stable granitic formation with low hydraulic conductivity. The disruptive events requirement will be met by avoiding areas within the seismic zone or with present or potential mining interest, and by placing the repository several hundred metres deep.

The selection of the site was scheduled in five steps:

(1) Preliminary survey of granitic outcrops
(2) Preselection of granitic formations
(3) Selection of the most appropriate sites for detailed studies
(4) Detailed studies in a selected site
(5) Validation of the selected site.

The first step of the siting study was an analysis of all the granitic rock outcrops known in the country. Both petrographic and structural features in each of the outcrops were surveyed, together with the dimensions of the rock bodies, as well as characteristics liable to cause disruption, such as seismic and hydrogeological features of the area; potential mining interest was also considered. Thus, 200 granitic outcrops were identified all over the country [3, 14–16].

As a second step, a preselection of the identified formations was performed on the basis of the following criteria for rejection: (a) formations within seismic areas; (b) formations in areas with present or potential mining interest; (c) petrographic features of the rock denoting important alterations, such as advanced



Group 1	
La Esperanza E y W	2
Sa. Calcatapul	5
Sa. del Medio	6
Chasicó	9
Río Chico	10

Group 2	
Tricacó - El Cuy	1
Sa. Lipetrén	3
Sa. de Moligüe	4
Sa. de la Bandera	7
Paso de Indios	8
Sa. de Huanacache	11
Lg. Aleusco	12
Gastre	13

FIG. 3. Preselected formations in Argentina.

erosion or decomposition stages; (d) formations in areas with known unfavourable hydrogeological characteristics. As an additional criterion, certain unfavourable characteristics connected with the eventual construction and operation of the repository were taken into account. Such locations were those in highly populated or tourist areas or in areas that are costly to reach. As a result of this second step, seven formations were identified, in the south of Argentina, as those most adequate according to the established selection criteria [17]. They are located in the Provinces of Chubut and Rio Negro.

A third step, based on an in situ geological survey of the preselected granitic formations, led to the identification of four formations as those most appropriate for further, detailed studies: La Esperanza and Chasicó in Rio Negro, and Calcatapul and Sierra del Medio in Chubut [18, 19] (Fig. 3).

In the fourth step, detailed studies were performed at Sierra del Medio according to the following scheme: (a) photographic interpretation, (b) statistical analysis of alignments, (c) geological and geophysical surveys of the rock formation, (d) drilling down to 200 m, (e) geomorphological and hydrogeological analysis of the area, and (f) deep drilling down to 800 m [20–22]. On the basis of the analysis of alignments and of the geological and geophysical surveys, ten sites were located for the drilling of wells for petrographic and structural research work. These wells, with depths ranging between 200 and 280 m, were sunk to analyse, at depth, the borders of the selected area, as well as fractures, dykes and other abnormalities found in the surface. The results obtained were analysed by means of geostatistical techniques so as to identify the site with the least alterations in the formation [3]. Later, four holes were drilled down to 800 m to study the petrographic features of the rock and the potential behaviour of deep underground water [23].

5. OUTLOOK

The fifth step, validation of the selected site, is under way. A programme for in situ hydraulic conductivity measurements is being carried out to complete the information necessary to validate the site under the aforementioned safety criteria. Additionally, a validation of the models used for assessing the radiological impact of the projected repository is being performed and the degree of confidence of the results will be assessed.

The depth at which the repository will be installed will be determined on the basis of the results of an optimization study that takes into account several repository design alternatives.

The decision to apply blasting or drilling techniques in the construction of the repository and its access facilities will be made on the basis of estimates of the tensions expected to be induced during the construction, and of the costs involved.

The criterion curve used by the Argentine authorities to judge the acceptability of the safety analysis results is based on the limitation of individual risk. This criterion, however, fails to take into account the overall radiological impact expected from the repository. The national authorities are studying this matter and some supplementary safety criteria might be introduced in the future.

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