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

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(*) Not shown in INIS Thesaurus 1985.

THE ARGENTINE RADIOACTIVE WASTE REPOSITORY:

BASIC CRITERIA, PRELIMINARY SITING AND DESIGN CONCEPTUAL BASIC

D.J. Beninson; A.J. González; E. Palacios; N.R. Ciallella

ABSTRACT

The paper presents the studies carried out for a future repository for high-level radioactive wastes originating in the nuclear programme of Argentine. These studies started in November 1981. A summary of the basic criteria governing the study as well as a description of the activities involved in the selection of the sites, its validation and the derivation of the design bases of the future repository is presented, together with conceptual definitions of its engineering.

At the end of the seventies, the Argentine Authorities decided to explore alternatives for disposing 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 an integrated electrical energy of a fraction of terawatt year by the end of the century (1). The country's programme also foresees the reprocessing of the spent fuel.

The paper describes the basic criteria adopted by the Argentine authorities for the disposal of high-level wastes. On the basis of these criteria, a site in stable, unfracturated granite was selected for detailed studies, near Gastre, Province of Chubut, out of about 200 potencial sites.

This site has been thorounghly investigated and its suitability has been validated. On the other hand, work has progressed on the design of the fu ure repository.

1. INTRODUCTION

At the end of the seventies, the Argentine Authorities decided to explore alternatives for disposing 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 an integrated electrical energy of a fraction of terawatt-year by the end of the century.

The option of the direct disposal of spent fuel elements was discarded in Argenitne, because of the energetic value of the remaining fissionable materials and also due to radiation protection reasons. Fuel elements are not designed fot the retention of radionuclides for a long time after disposal and the presence of a substantial inventory of actinides in the non-processed fuel would imply a higher radiological impact than that caused by the recycling of fissionabke 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 now 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 1990 decade. However, the authorities decided to explore potential solutions of the technological problems connected with the elimination of high-level radioactive wastes well in advance(3).

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

2 RADIOLOGICAL SAFETY CRITERIA FOR THE DISPOSAL OF RADIOACTIVE WASTES

Disposal of radioactive waste involves isolation of the radioactive material from the human environment over a sufficient period of time 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;

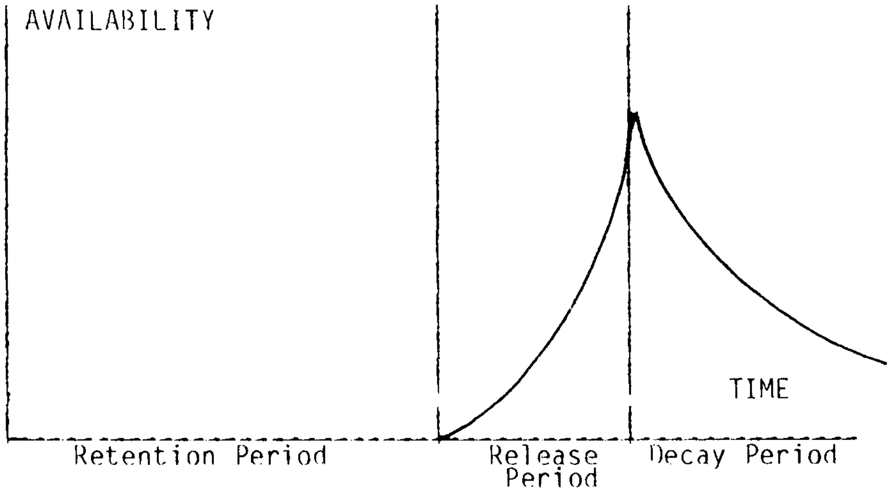
(2) Disruptive events: random disruptive events, for each of which a probability of occurrence and an exposure pattern can be postulated.

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

(a) The very long time periods involved;

(b) The randomness of type exposures.

In principle, both the normal scenario and the disruptive events would be expected to give exposure patterns of the general type shown in the following graph (6)(7):



The main difference is that the normal release is expected to occur first 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 of disposal of radioactive waste are compatible with the recomendations of the International Commission on Radiological Protection (ICRP)(4)(5). 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 are intended for the total dose from all sources (excluding natural background and medical exposures of patients). For the contribution from any one 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 (4)(8).

It should be possible to postulate a generic upper bound for the annual dose contribution from the practice of radioactive waste isolation, which would limit the dose to any critical group resulting from all repositories. Such 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(5)(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(7),

$$H_{L,k} \left[1 + r_k \frac{W_t}{W_k} \right] \leq f \, H_{lim}$$

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 which is 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.

It must be indicated that the upper bound will differ significantly from the simple value f H_{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 Authority in 0.1 mSv in a year when maximum in 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 due to the low doses that will expectedly be involved, the detriment can be taken to be proportional to the collective dose commitment from the disposal. Bul, bucause of the presence of very-long life nucleides, an assessment of the complete collective dose commitment will be highly speculative. In optimization, however, one deals with differences of collective doses between different protection options. The time period of interest is therefore the period in which the alternative protection levels (engineering solutions) have an influence on the exposure pattern, because the longer exposure tails would cancel when substracting collective doses of different options. For the Argentine repository, the period of integration for the assessment of the relevant incomplete collective dose commitments was carried over 500 years (10) following procedures similar to those used by UNSCEAR (11).

2.1.3. Total colective dose

The Argentine Authority also established as a design aim of the repository that the total collective dose commitment from the hihg-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 shoud 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 accute radiation syndrome resulting from whole-body irradiation, the probability at doses lower than 2 gray is practically zero, while it is nearly one above 6 gray.

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) of a menber 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 te 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 dose H(5).

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

$$R \simeq \sum_i P_1i \ P_2i$$

Where $\sum$ should be extended over all possible relevant scenarios of exposure.

It should be realized that P_2i 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 due 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_{1i} 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(4).

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 can never exceed the direct summation of the maximum values for each exposure situation:

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

In the criteria of the Argentine Authorities, the basic objective is to ensure that the maximum individual risk of 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 Argentine Authority (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

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

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

The procedure described above for applying individual dose limitation to probabilistic disruptive events has been expressed by the Argentine authority in a "criterion curve" shown in Figure 1, which is similar to that used by the authority 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 above described radiological basic criteria but will obviously satisfy the needs of the Argentine nuclear programme. The nuclear power plants foreseen until the end of this century will generate during their operating period a fraction of terawatt year of electric energy(13). The wastes resulting from the reprocessing of spent fuel elements for the generation of that energy will require approximately 3,000 containers of about 0.6 m in diameter and 1.6 m high. Also, further 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. Taking into account the radiological basic safety criteria and the time elapsed between the waste disposal and its arrival into the biosphere, the disposal problem may be divided into two steps. A first step encompasses the period during which the activity of the fission products is predominant and lasts for the first 1,000 years. After this period, the individual risk is small and the scale of the problem is modified. However, there is still a remaining problem: that of the long half-life radionuclides that will last for millions of years.

3.1. Normal scenario

The requirements related with normal scenario set by the Argentine Authority are: a) a dose upper bound of 0.1 mSv in a year, when 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.

In order to comply with the dose upper bound, the wastes will be kept isolated within the containers during the first 1,000 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 on a hypothetical critical group in the order of some µSv due mainly to the N_p-237. Moreover, they would potentially be incurred some 10^5(!) years later than 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 reduction will be reached by means of engineering and geological barriers. Optimization techniques are to be applied to each step in the design process. Nevertheless, a rough cost-benefit optimization analysis assigning 10,000 US$/man Sv to a unit collective dose shows that an initial isolation period with engineering barriers of the order of ten thousand years should be necessary.

Such retard will be attained by incorporating the wastes in a vitreous matrix of the borosilicate type (with a leaching rate below $4\ 10^{-4}$ g/cm^2 d), with a content of fission-product and actinide oxides in the glass mass of 10% in weight. An additional engineering barrier will be the final sealing of the repository holes with a buffer material opposing great resistance to the arrival of water and to the migration of radionuclides. This will be attained with a mixture of sand and bentonite, with high retention capacity.

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

Finally, in order to verify the 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 reprocessing waste disposal 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 a and 10^6 a, respectively. The collective dose commitment from 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 requirement related with disruptive events established by the Argentine Authority has been expressed with the criterion curve shown in

Figure 1. For validating the final design, a full risk analysis will be performed. The authorities are aware of the fact that compliance with the criterion curve is a necessary but not necessarily sufficient condition to ensure the repository compliance with the criteria for disruptive events. Optimization should play a role in this case too. The authorities, however, have not yet taken a position on this matter.

At the current stage of the project, the criteria adopted was to ensure that the selection of the site were performed taking into account the probability of occurrence of both disruptive natural events and human intrusions were sufficiently low, so as to ensure that the criterion curve can be respected and that any further reduction of risks can be performed practically. For site selection purposes, consideration was given to avoiding sites within seismic areas or in areas with present or potential mining interest.

4 SELECTION OF THE SITE

The safety criteria and basic criteria of design described above related with the siting selection for the repository 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.

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

The selection of the site was scheduled in five steps:

i) preliminary survey of the granitic outcrops;

ii) pre-selection of granitic formations;

iii) selection of the most appropriate sites for detailed studies;

iv) detailed studies in a selected site; and,

v) 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 one 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 and its potential mining interest. Thus, 200 granitic outcrops were identified, spread all over the country (14)(15)(16) (Figure 2).

As a second step, a previous selection of the identified formations was performed, on the basis of the following discarded criteria: a) formations located within seismic areas; b) formations located in areas with present or potential mining interest; c) petrographic features of the rock denoting important alterations, such as advanced erosion or decomposition stages; and, d) formations located in areas with know unfavourable hydrogeological characteristics. As an additional selection criterion, certain unfavourable characteristics connected with the eventual construction and operation of the repository were taken into account. These were locations within highly-populated or touristic areas or in areas that are costly to be reached. As a result of this second step, seven formations were identified, in the south of Argentina, as those most adequate following 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, allowed for identifying four formations as those more appropriate for continuing with detailed studies: La Esperanza and Chasicõ, in the Province of Rio Negro, and Calcatapul and Sierra del Medio, in the Province of Chubut (18)(19) (Figure 3).

In the fourth step, detailed studies were performed at Sierra del Medio, according to the following scheme: a) photointerpretation; b) alignment statistical analysis; c) geological and geophysical recognition 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)(21)(22). On the basis of the analysis of alignments and of the geological and geophysical surveys of the formation, ten sites were located for the drilling of wells aimed at petrographic and structural research work. These wells, with depths ranging between 200 and 280 m, were performed for analyzing -in depth- the borders of the selected area, as well as fractures, dikes and other abnormalities found in the surface. The results obtained were analyzed by means of geostatistical techniques, so as to identify the site with minimal alterations in the formation (Figure 4). Later on, four drillings were made down to 800 m. These were aimed at studying the petrographic features of the rock and the potential behaviour of deep underground water(23).

5 OUTLOOK

At present, the fifth step is underway. A programme for in-situ hydraulic conductivity measurements is being carried out, so as 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 from the projected repository is being performed and the degree of confidence of the results will be assessed.

The deepness at which the repository will be installed shall be determined following the results of an optimization study taking 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 the tensions to be induced during the construction and of the costs involved.

The criterion curve used by the Argentine authority 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 authority is studying this matter and some supplementary safety criteria might be introduced in the future.

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LISTA DE FIGURAS

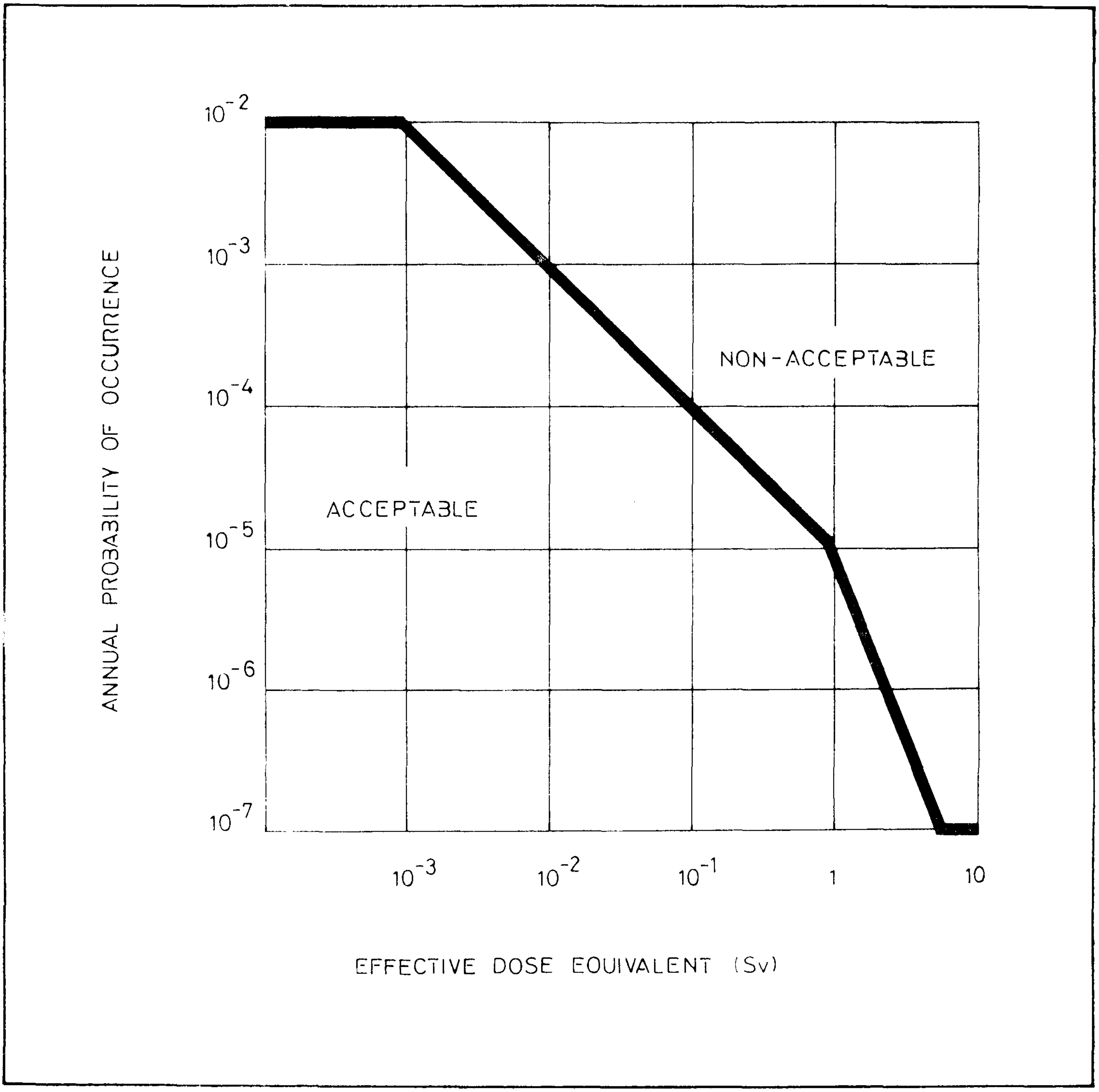

FIGURE N°1 CRITERION CURVE

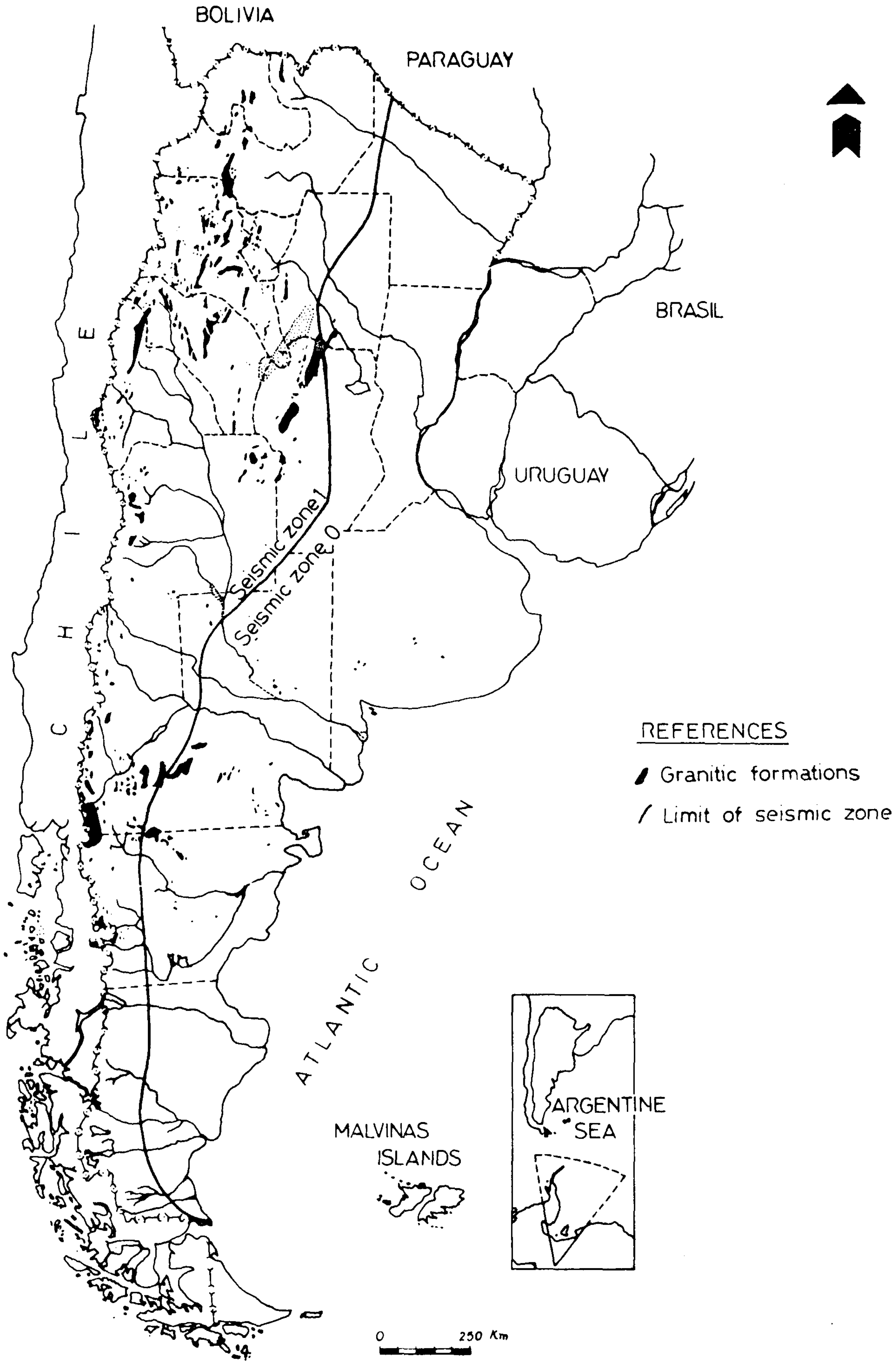

FIGURE N° 2 : Granitic outcrops in Argentine.

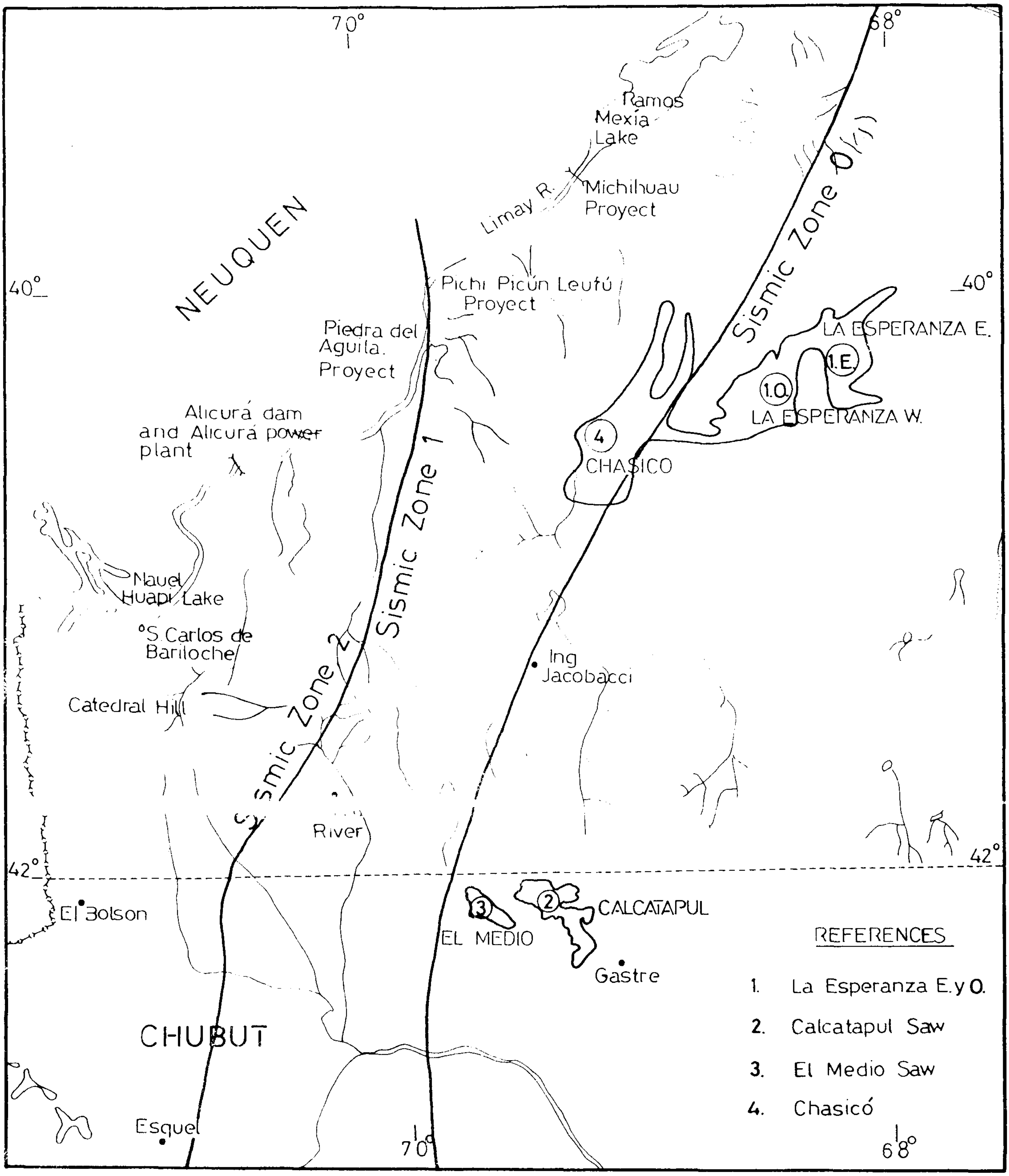

FIGURE N°3 : PRESELECTED SITE

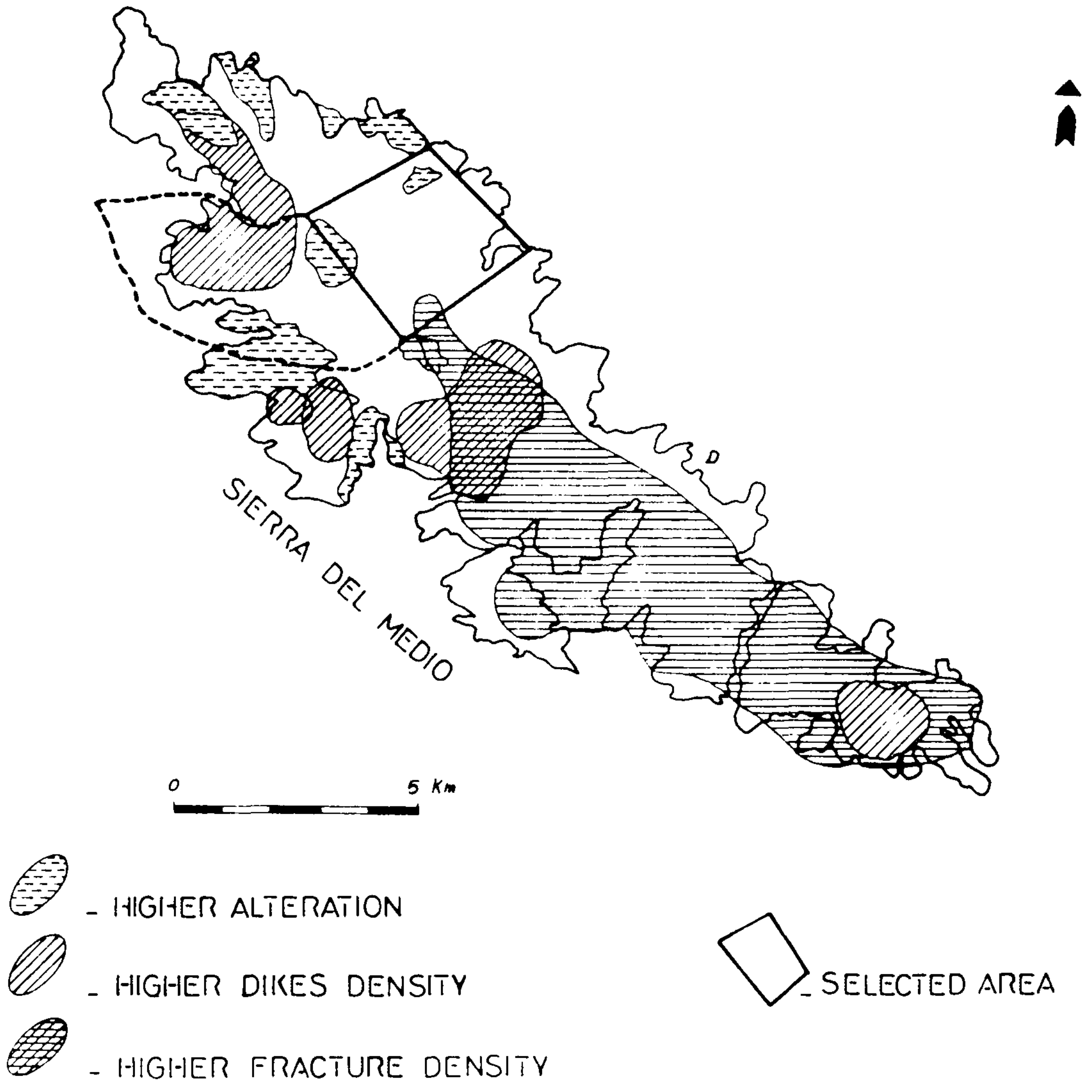

FIGURE N°4 Area with less density of discontinuities.

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"Radiological impact of radioactive waste management"

REPO-02 Lucero Michaut, H.
"Aplicación de la geoestadística a la resolución de problemas estructurales en macizos rocosos homogéneos"

REPO-03 Ventura, M.; Ferreri, J.C.
"Evolución temporal de un macizo granítico bajo cargas térmicas generadas por productos de fisión"

REPO-04 Ventura, M.; Ferreri, J.C.
"Evolución temporal de un macizo granítico bajo cargas térmicas generadas por productos de fisión (estudio paramétrico)"

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"Radioactive emissions and radiation exposures resulting from nuclear power production"

REPO-06 Beninson,D.; Lindell, B.
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REPO-07 Migliori de Beninson, A.; Cancio, D.
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