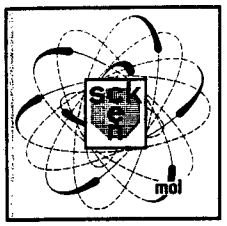

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LONG TERM SAFETY AND PERFORMANCE ASPECTS OF HIGH LEVEL WASTE DISPOSAL IN CLAY

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1. INTRODUCTION

The most recent exhaustive investigations concerning the long term safety and performance of HLW-repositories in geological formations are surely those undertaken in the framework of the CEC's PAGIS-action [1]. It is as a consequence obvious to explore the credentials of the argillaceous formations for their long term performances and safety capabilities on the basis of the results obtained within the PAGIS-action.

Within the framework of the PAGIS-action the performance assessments for the clay option were accomplished by SCK/CEN, who was in charge of the secretariat of the option. SCK/CEN is the Belgian research establishment for nuclear energy. Input data about the sites to be studied were obtained from the British Geological Survey (BGS) through Department of Environment of the United Kingdom (DOE) and from the Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare et delle Energie Alternative (ENEA) of Italy. These bodies also reviewed afterwards the parameter sets and scenarios selected. Data about waste characteristics were made available by the Commissariat à l'Energie Atomique (CEA) of France. The Joint Research Center of Ispra (JRC) was actively involved in model and code improvements. Corapro, a Belgian nuclear controlling body, reviewed the modelling work in the geosphere. The Department of Environment of the United Kingdom, the Belgian nuclear waste managing body NIRAS/ONDRAF, the scientific staff of DG-XII and the PAGIS steering committee and the Joint Research Center of Ispra of the CEC were actively involved in reviewing the progress of this work and the obtained results.

2. THE SITES

In the very early stage of the PAGIS-exercise three argillaceous sites were selected as possible cases for the performance assessments :

1) the Mol site in the northeastern part of Belgium ;
2) the Harwell site in central southern England, and
3) the Val d'Era area in Toscany in Italy.

Each site was considered as representative for a specific environment of clay genesis. However soon in the PAGIS-action, the Val d'Era area, which represented a continental type of genesis, was dropped as case study, because of the lack of sufficient site data.

The Mol site was selected as the reference case because of several reasons. It is, in the Belgian programme, considered as a potential site for the disposal of conditioned high level and long lived radioactive wastes. Due to its interest for the Belgian national programme and due to the intensive investigations that have been undertaken already at that site, a good documentation about the site and about possible disposal concepts is available. All these allow to draw a coherent picture of how a clay repository site and its characteristics look like.

From the scientific point of view the site is representative for one type of genesis namely the subhorizontal open coast sedimentary environment.

In addition to that, the site of Mol itself satisfies the site selection criteria that have been established for the European Catalogue. The target formation, the so called Boom clay, is found in the underground of the site and its thickness is more than 100 metres. The depth of it is such that a repository might be built at more than 200 metres below ground level. The Boom clay displays some very attractive particularities such as a lithologic homogeneity, a very low permeability and an excellent retention capability. The site is located in a tectonic and seismic stable area.

Also, preliminary risk assessment studies about radioactive waste disposal at the Mol site were undertaken in an earlier cooperation between SCK/CEN and JRC-Ispra.

As a variant site the Harwell site was selected because it represents from genetic point of view an intermediate between the sedimentary environment of the open coast (case of Mol) and the intra-continental basins such as those encountered in Italy.

The Harwell site was selected also because the site is well documented and it satisfies almost all the site selection criteria applied in the European Catalogue. The Oxford Clay and its immediately overlying Corallian Beds mudstones were selected as host formations for this case study.

An appropriate way for getting an understanding of how the site of Mol looks like is to examine a west-east geological cross section through the site as shown on Fig. 1. One sees the Boom clay formation, gently dipping to the north east, covered by an about 180 metres thick cover of sands of various nature and composition. A repository can been assumed in the midplane of the Boom clay. Beneath the Boom clay, a sequence of alternating sands and clays is observed. At the Mol site and its immediate surroundings the sand layers below the Boom clay are not used for pumping of groundwater because its relatively high solutes content and of its low yielding rate. The overall general water drainance pattern, which is very important in defining the possible pathways, is shown also on the same cross section. A westward flow towards the outcropping area is seen in the sands (black arrows), whereas a vertical drain is assumed to occur in the low permeability clay formations (white arrows).

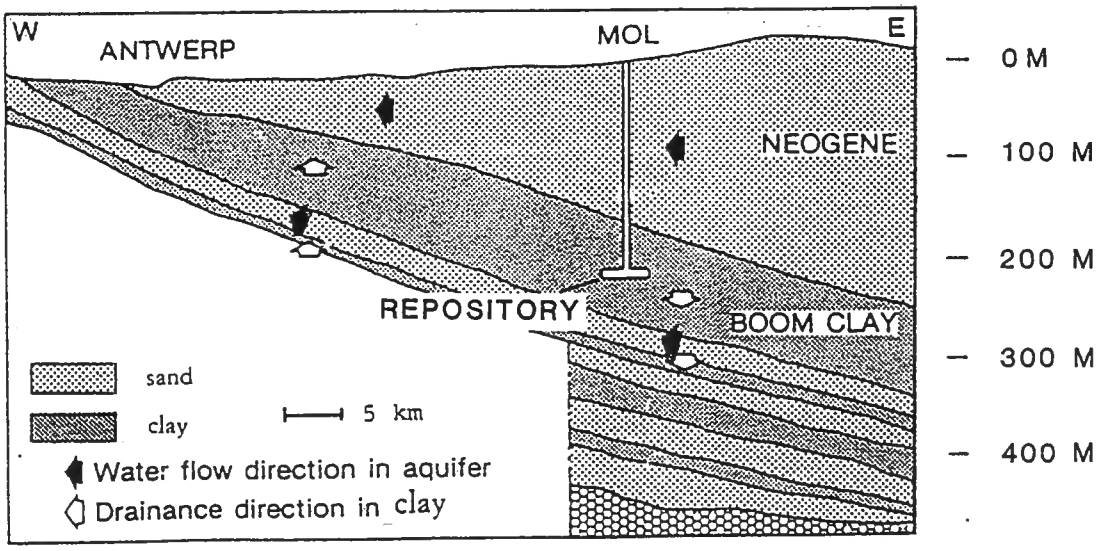

Fig. 1. Schematic geological cross section Mol site

Surprisingly we find a very comparable picture for the situation at the Harwell site (see Fig. 2). The geological cross section, from the south-southeast to the north-northwest displays a dip of the formations to south-southeast. With regard to the Mol site, the sequence of the geological strata is however of a slightly different lithology. The argillaceous formations are rather marls or mudstones and they alternate mostly with calcareous aquifers. The disposal formations, the Oxford Clay and the Corallian Beds together, reach more than 100 metres thickness and extend between 223 and 328 metres below ground level. The Corallian Limestone on top of this package effectively drains the whole sequence beneath the Harwell site and forms a locally important aquifer.

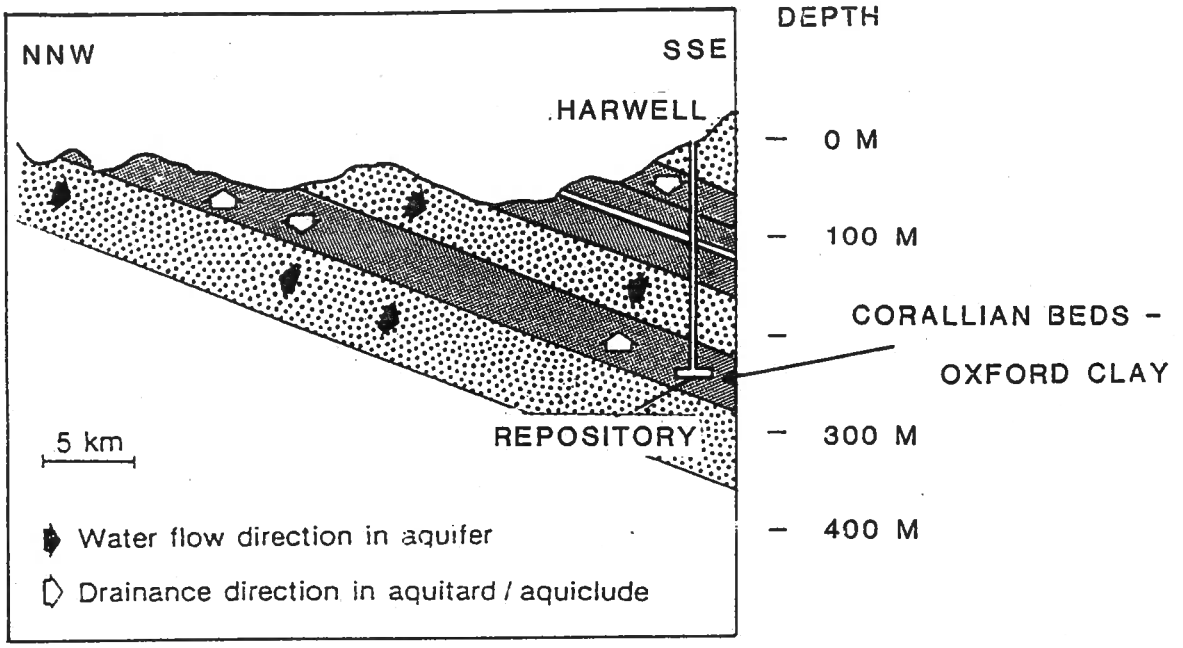

Fig. 2. Schematic geological cross section Harwell site

At the two sites the nature of the sedimentary sequence and the properties of the host rock impose to conceive a repository as a mined repository, consisting of a network of galleries.

3. THE SCENARIOS

The basic scenario for the performance assessments is the normal evolution scenario, as shown schematically on Fig. 3. It is assumed in this scenario that, after sealing of the repository, various components will be contacted eventually by the interstitial clay moisture. Natural degradation of the repository will thus occur and corrosion of canisters and glass blocks will allow a gentle release of radionuclides, forming the source term for a migration path through the clay formation. The behaviour of the host rock will be influenced by the presence of the waste package. Indeed, we have to expect heat dissipation, irradiation and release of corrosion products in the near field of the repository. However, it is taken as a hypothesis that these phenomena will not alter the properties of the bulk of the host rock. The only way for the radionuclides to reach the aquifers is by migration and diffusion through

the interstices of the intact clay formation. Once the aquifers are attained, a fraction of the still decaying radionuclides will be conveyed by the groundwater flow system and potentially arrive at the biosphere.

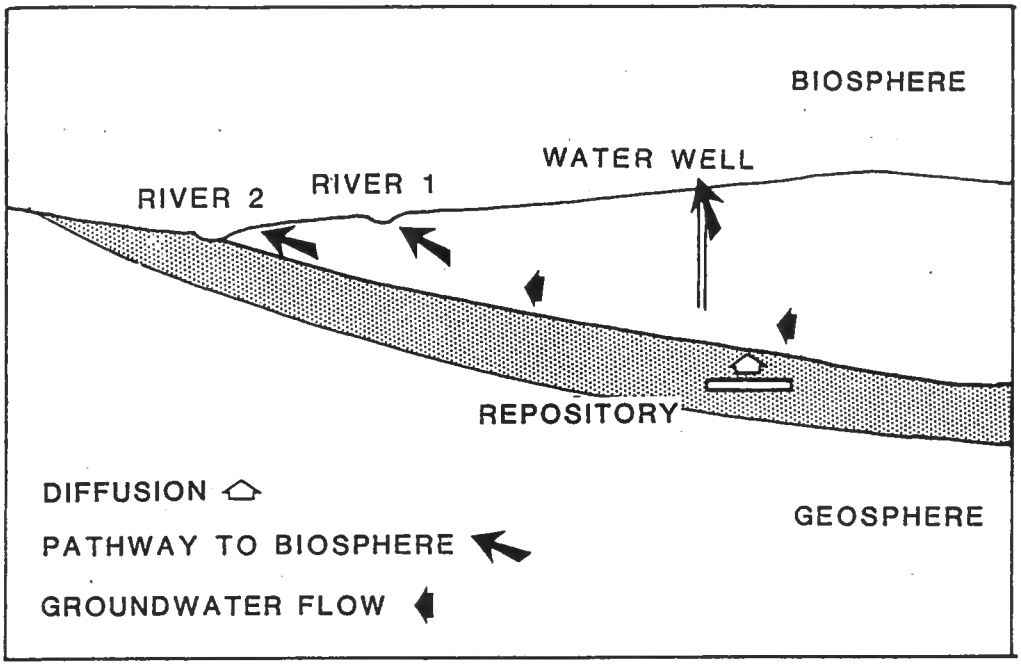

Fig. 3. General scheme of the radionuclide paths considered in the clay option

For the Mol site, strictly speaking, the normal evolution scenario is for the radionuclides to migrate along overlying aquifers and eventually contaminate the River Nete by groundwater seepage. However, because of the relative importance of the probability of a well being sunk into the path of the migration plume of the radionuclides, a second important pathway to the biosphere is considered being the presence of a water supply well. This case of water supply well is treated as an additional pathway, occurring simultaneously with the river release pathway, all part of the normal scenario for the Mol site. As the exposed population groups are different for the two cases, doses from the two pathways are not additive.

In the well pathway a small well for private use is considered for individual dose rate calculations. A low extraction rate, which does not disturb the water flow in the aquifer is assumed ; this is a conservative assumption as it implies no dilution of the contaminated water.

Collective dose rates are also computed for these two pathways ; however in the well pathway, a well is assumed with a large abstraction rate for regional water supply which diverts and extracts the whole of the radioactive plume emerging from the clay host rock.

In addition to these two cases of normal evolution, also three altered evolution scenarios were examined in PAGIS. Climatic changes may cause medium term perturbations in the hydrological system. The particular expression of climatic change envisaged here is a reduction in the annual effective rainfall. The main consequences of that climatic change are altered aquifer and river flow rates.

Several scenarios, such as climatic changes, glaciation effects, river erosion and sea level changes, have the potential to drastically modify the regional hydrology over time scales of some millions of years. The probability that they will affect the clay layer at a depth of about 200 metres is however extremely low. All these scenarios are combined with the water well scenario into one scenario, a combined scenario, for which very large uncertainties in the hydrological parameters are taken into account.

Tectonic displacements (faults) have been shown to be important in statistic and stochastic analyses. However tectonic displacements which cause a direct release of radionuclides are expected to be very improbable, because of the plastic behaviour and self-sealing capabilities of the clay. Nevertheless such faults may be responsible for local disturbance in the properties of the geological barrier, thus altering the normal evolution of the system.

The variant site of Harwell has been considered in a manner very similar to that adopted for Mol, with a normal evolution addressing radionuclide transport via the Corallian aquifer into the Rivers Ock and Thames, and a water supply well sunk into the migration path. However the occurrence of the well pathway is considered to be less probable than that at the reference site, because several other water resource aquifers are known in the area.

4. RESULTS AND CONCLUSIONS

A general abstract calculation scheme of the normal evolution scenario is represented in Fig. 4. The scheme shows the modular calculation approach that has been followed, where the transport of the radionuclides through different parts of the migration route has been addressed using appropriate models and codes for each module. The adopted stochastic approach incorporates sub-models and codes for each module of the migration route and allows input data to be sampled from specific parameter distributions.

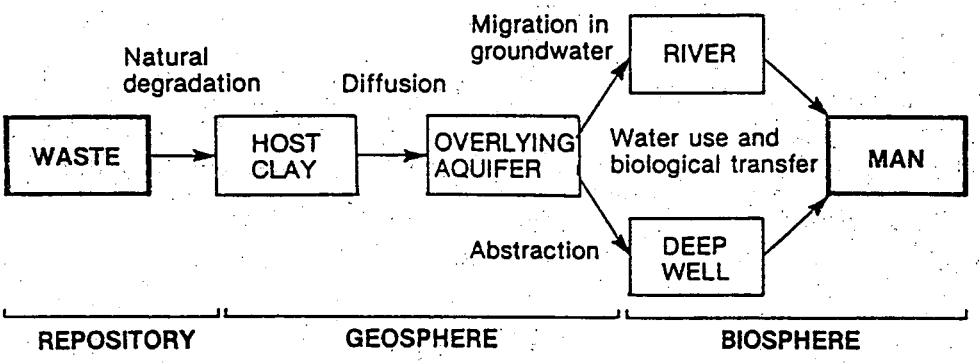

Fig. 4. Scheme of the system components considered in the dose calculations

The most striking conclusion that we can draw from all the cases studied is that all calculations show that for the clay option there will be no radiation exposure in the biosphere within a time span of ten to hundred thousand years (see Fig. 5 and 6).

If we really want to explore the very long time spans, the only numerically meaningful levels of radiation are calculated to occur around one million years (due to Technicium) and around ten million years (due to Neptunium and its daughter products). However the calculated radiation levels for the scenarios considered and for all time spans are orders of magnitude below the natural background radiation level. Although numerically meaningful figures are obtained, the intrinsic value of the doses calculated may be regarded as totally insignificant from the point of view of radiological impact.

The sensitivity studies have shown for the clay option that :

- the retention capability of the clay host formation dominates the overall system ;
- the thickness of the clay barrier is a second important factor which determines the time of occurrence and level of radionuclide flux released by the host rock ;
- the aquifer characteristics are of importance in defining the trajectories and the dilution rates ;
- the dose rate to man is virtually independent of the release rate from the near-field ;
- within the altered fault scenario the hypotheses taken for (1) the time of occurrence of the fault and (2) the fault characteristics are of prime importance.

Taking into account that for several parameters a variability of their value has to be considered and that for some parameters their exact value is uncertain, appropriate assessments have been applied in order to cope with this particularity of the system by the so called uncertainty analysis. Not less than 12 cases have been analysed and 4,500 calculation runs were made. The main conclusion to be drawn from the uncertainty analysis in the clay option studies is that, including uncertainties of the model parameters, 95 % of all the calculated doses do not exceed 100 times the doses from best estimate calculations. As a consequence they all fall fully within the acceptable area (see Fig. 7).

Still other conclusions may be drawn, for instance with respect to the needs for additionnal research and development :

- the conclusions about the limited importance of the near-field effects are only valid in case it can be demonstrated that these effects do not alter to a large extent the clay barrier thickness. Indeed the thickness of the clay barrier has proven to be a sensitive parameter. Intensive investigations are thus required to define and assess an acceptable near-field disturbance ;
- the results are very sensitive to the retention capabilities of the clay barrier. It is thus evident that a thourough understanding of the migration and physico-chemistry of the radionuclides in the clay environment is needed ;
- the results of the altered fault scenario indicated that this is the only relevant altered scenario which could be responsible for a noticeable deviation from the normal evolution scenario. Within this context the hydraulic disturbance in the faulted zone appeared to be the most sensitive altered parameter.

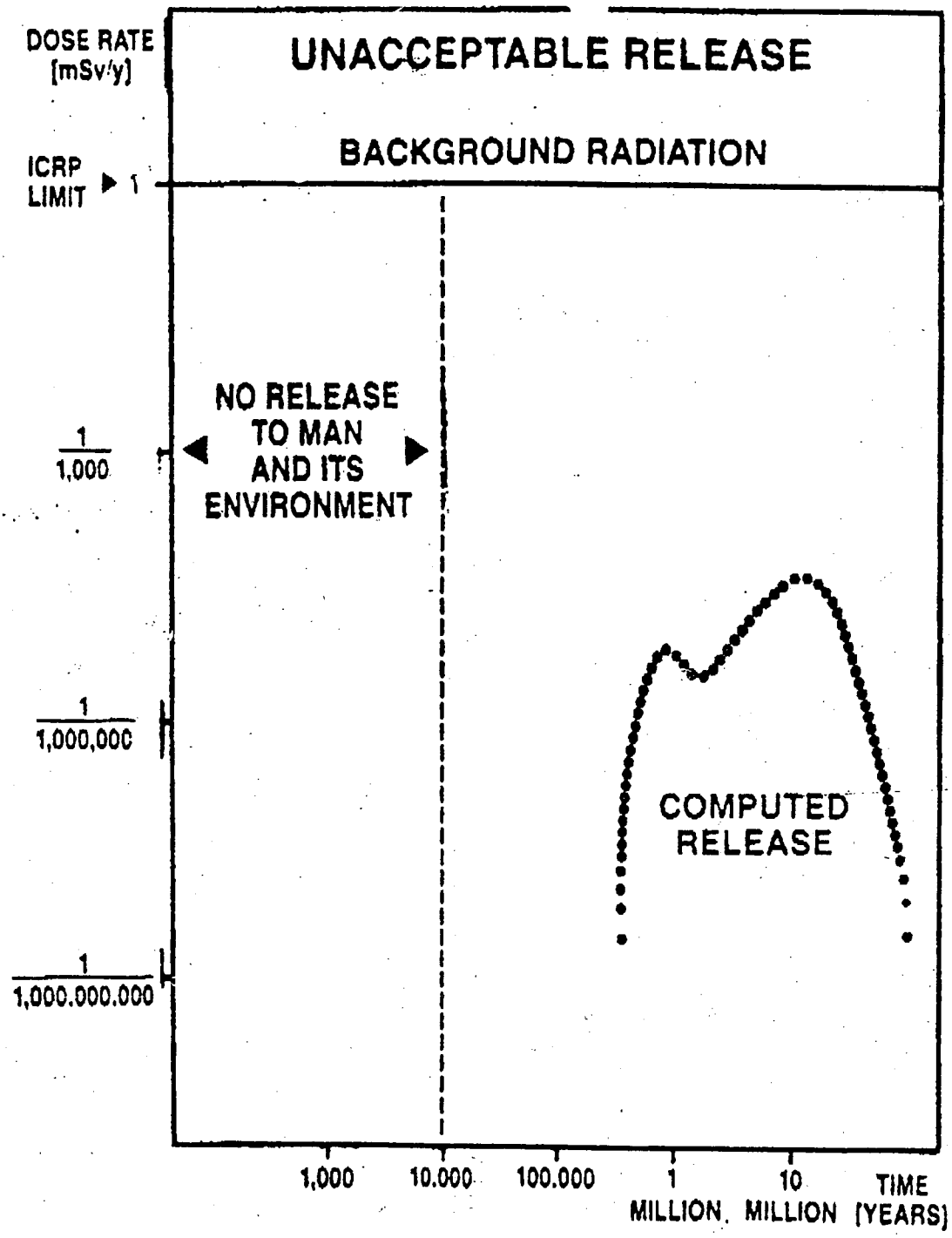

Fig. 5. Evaluated dose rate to man as a function of time after closure of a waste repository in clay (reference site, normal evolution, well scenario)

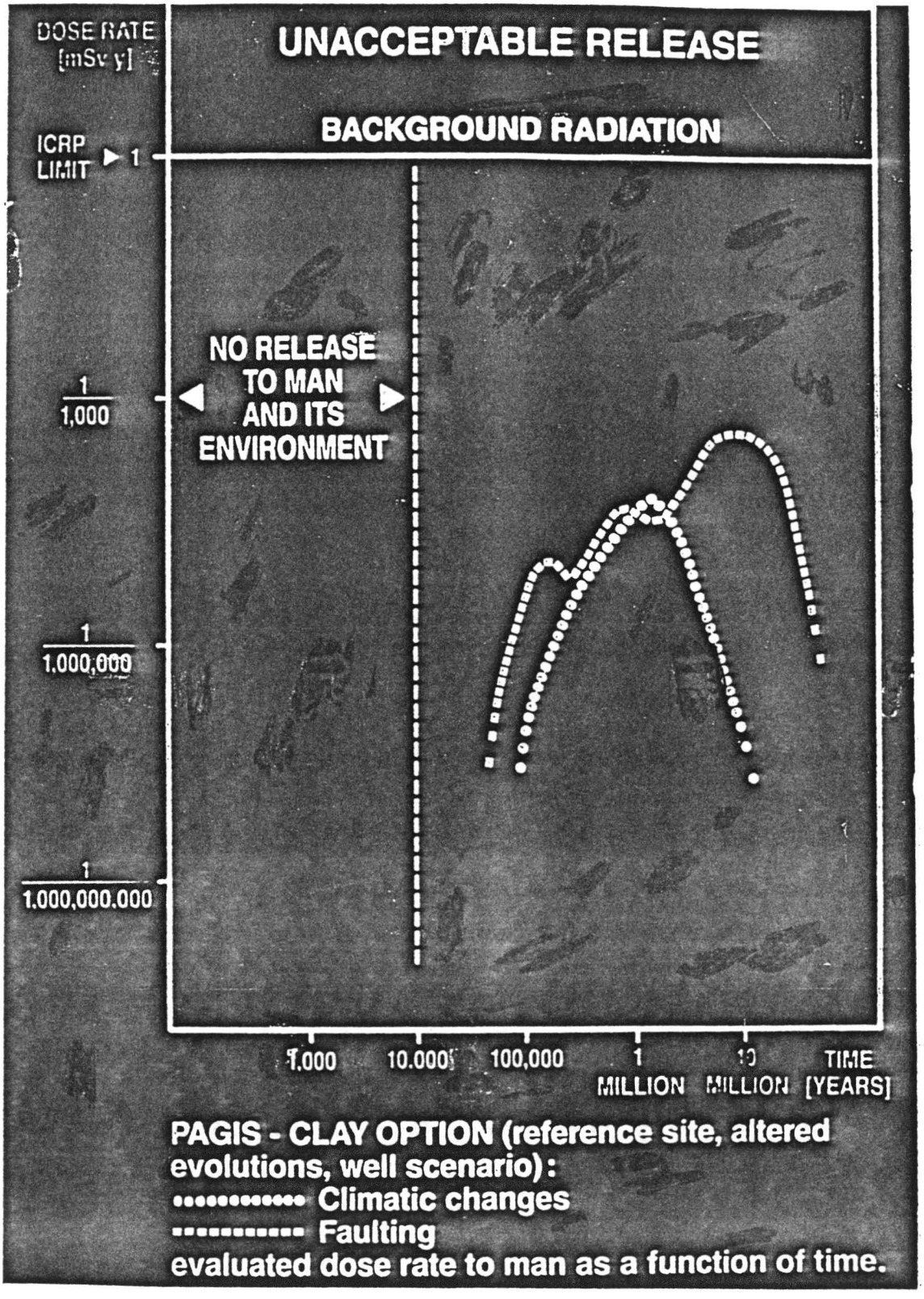

Fig. 6. Evaluated dose rate to man as a function of time after closure of a waste repository in clay (reference site, scenarios of climatic change and faulting)

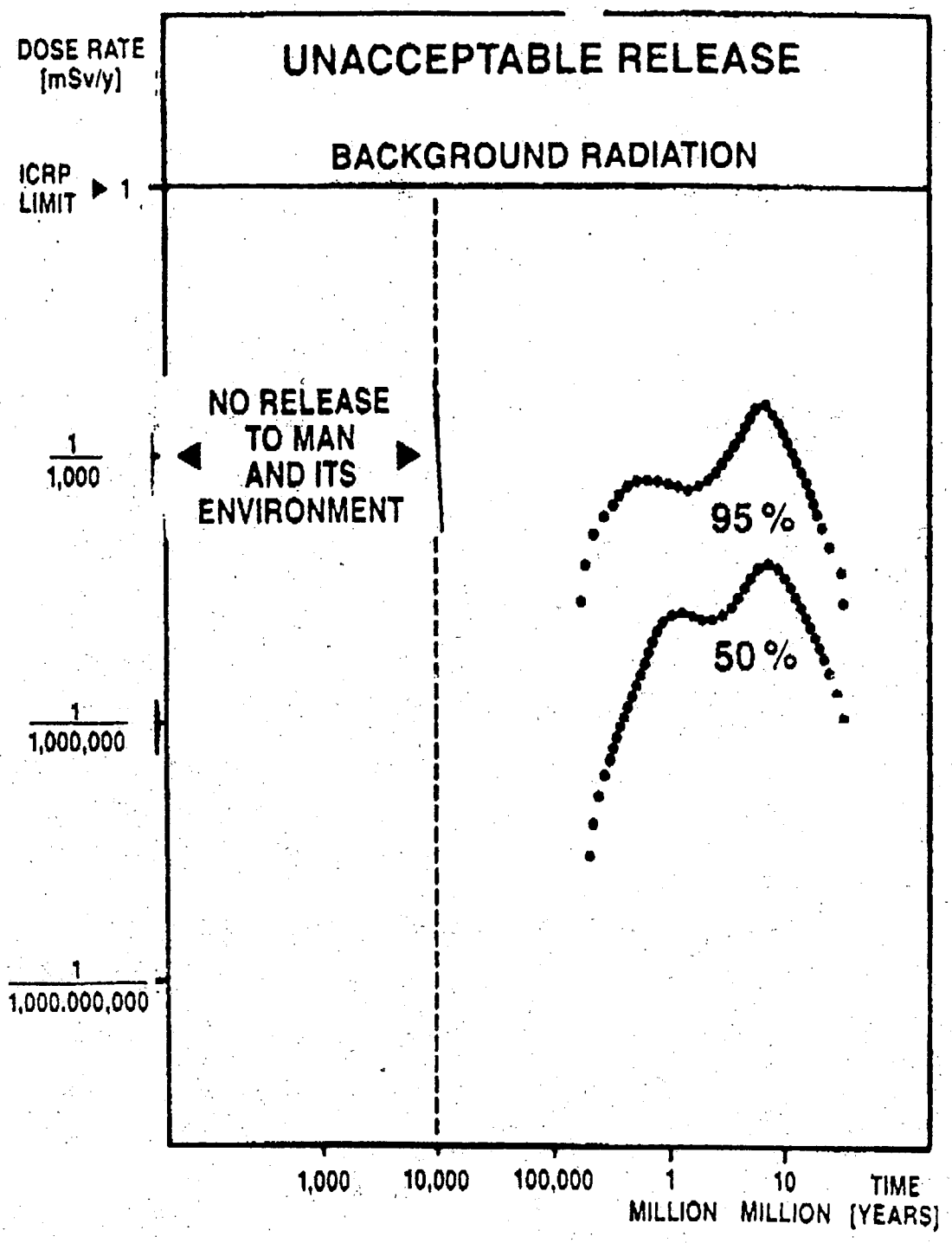

Fig. 7. Variation of evaluated dose rate to man, resulting from uncertainty analysis (50% and 90% confidence limits for reference site, normal evolution, well scenario)

Some interesting conclusions can also be drawn concerning site selection and characterisation :

- the very promising results obtained for the Mol site indicate, that the site selection criteria set for the European Catalogue are realistic and appropriate ;
- the performance assessments impose (1) to put emphasis onto the characterisation of the clay layer, so that reliable predictions can be made about the retention capabilities of the clay barrier and, (2) to examine carefully the hydrological system enveloping the clay barrier in view of defining the real pathways toward the biosphere.

In relation to concept developments it is to be concluded from PAGIS that the design has to be such that the near-field effects are kept within acceptable boundaries.

BUT THE PARAMOUNT CONCLUSION REMAINS THAT A CLAY FORMATION, PROVIDED IT SATISFIES DEFINED CRITERIA, CAN ENSURE A SAFE DISPOSAL OF HIGH-LEVEL WASTE.

Reference

[1] J. Marivoet and A. Bonne : "PAGIS, Performance Assessment of Geological Isolation Systems for Radioactive Waste : Disposal in Clay Formations", EUR 11776, ISBN-92-825-9254-5, in Nuclear Science and Technology, ECC, Luxemburg 1988