

Thermo-Mechanical Analysis of High Level Nuclear Wastes in Granite

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ABSTRACT

In order to appraise the safety of a storage of high level nuclear wastes in rock masses, it is necessary to assess, among other features, the thermo-mechanical behaviour of the host rock for long periods (thousands of years).

In France, four different media are considered as potential host rocks: granite, shale, salt, clay.

The present paper is devoted to some analysis of a generic storage configuration in granite. The case of a rock mass without any major fault has been considered. The granite is modelled by means of an elastic fracturing model (no tension type).

The results obtained show that some fissures, induced by the heat generation, develop mainly above the repository. The opening of the fissures, within the frame of the adopted hypothesis, have not a strong influence on the rock mass, as a geological barrier for the radionuclides.

1 INTRODUCTION

In France, granite is considered as a potential host rock for the deep storage of high level nuclear wastes. For this purpose, two major problems must be solved:

- a design problem, which concerns the feasibility and the construction of the repository,
- a safety problem, which concerns the long-term operation of the repository and the possible migration of radionuclides.

In this paper, a limited portion of the safety problem is addressed: the thermo-mechanical behaviour of the whole repository, during time. Of course, real phenomena are more numerous and more complex: couplings can occur between thermal, hydraulic, mechanical, migration and chemical problems. Some of these couplings have been considered in ref. [1].

Since no site has been chosen in France, the analysis are performed on a generic storage configuration in granite. The purpose of the present paper is to present and discuss the assumptions and the results of some calculations and to draw some conclusions about the thermo-mechanical behaviour of the granite as a host rock.

SMiRT 11 Transactions Vol. L (August 1991) Tokyo, Japan, © 1991

2 MODELLING ASSUMPTIONS

Granite is a rock where various discontinuities may exist in a natural state, such as well identified major faults or minor faults, like diaclasis, which can be considered as uniformly distributed in the rock. Such discontinuities can be modelled on one hand by means of joint finite elements, and on the other hand by means of the so called ubiquitous model (see ref. [2] and [3]). Here, attention will be focused on the case of a sane rock mass, without any major fault nor any distributed diaclasis.

The second assumption consists in supposing that the mechanical behaviour of the granite has no influence on its thermal behaviour. Therefore the thermal analysis can be decoupled from the mechanical one and performed first.

CONFIGURATION TO STUDY

A plane in the mid-section of a storage site has been chosen as configuration. A realistic surface profile has been introduced, for subsequent hydraulic calculations. The dimensions of the domain are shown on fig. 1. In the study, the repository itself is treated as an homogeneous zone with the same material properties as the surrounding granite.

The thermal and mechanical properties of various types of granite have been reported in ref. [4]. Unfortunately, they were derived from short-term experiments.

With other respects, since we study a generic storage configuration without any precise material data, we have assumed constant material properties versus temperature, as a first order approximation. The calculations are performed for a 10 000 years period.

THERMAL CALCULATION HYPOTHESIS

The thermal material properties are chosen as follows:

conductivity: 3.5 W/m/°C,
heat capacity: 1000 J/kg/°C,
density: 2650 kg/m³.

The heat source, distributed in the repository, has a power given on fig. 2.

The initial temperature is given by a $2.25 \cdot 10^{-2}$ °C/m geothermal gradient.

The boundary conditions are:

- zero prescribed heat flux on the lateral boundaries,
- 13°C prescribed temperature at the free surface,
- at the bottom, the temperature remains equal to its initial value, i.e. 46.75°C.

MECHANICAL CALCULATION HYPOTHESIS

For such a calculation, granite is often modelled using a no-tension material law (see ref. [6]). Here, to be consistent with the previous hypothesis on sane granite, the traction resistance of the granite has been accounted for. The model is an elasto-plastic one, based on a maximum principle stress

criterion and with a post peak strain softening branch. This is a way to account for the degradation of the material, which corresponds in reality to the development of cracks.

The mechanical properties are chosen as follows:

Young's modulus	74000 MPa
Poisson's ratio	0.26
Traction resistance	10 MPa
Rupture traction strain	$2.25 \cdot 10^{-4}$
Thermal expansion coefficient	$3 \cdot 10^{-5}/^{\circ}\text{C}$

The initial state of stresses is a lithostatic one, due to gravity loads.

The loading consists of the Duhamel's forces computed from the temperature field previously calculated.

The boundary conditions are:

- zero prescribed horizontal displacement on the lateral boundaries,
- zero prescribed vertical displacement at the bottom.

3 RESULTS OF CALCULATIONS

THERMAL CALCULATION RESULTS

Fig. 3 shows the evolution of the maximum temperature, located at the middle of the repository, versus time.

It can be noticed that the maximum temperature ($\sim 90^{\circ}\text{C}$) is reached around 55 years.

Then, the temperature decreases slowly while the heat front is propagating in the rock mass: fig. 4 shows the isothermatures at $t = 500$ years.

MECHANICAL CALCULATION RESULTS

The maximum uplift movement of the free surface is equal to 0.62 m around 850 years. It then slowly decreases and there is still a residual vertical displacement of 0.15 m at $t = 10000$ years.

The rock mass remains elastic up to 12 years. Then, some cracks develop at the ends of the repository, there where shear stresses are important. The fig. 5 shows the cracked zones at $t = 25$ years, plotted on the deformed rock mass (displacements being amplified by a factor 500).

Then a brittle rupture of the whole layer of granite above the repository occurs, giving way to vertical cracks as shown on fig. 6. This can be understood by comparing the behaviour of this layer to the one of a beam subjected to an imposed displacement in its central part, corresponding to the thermal expansion induced by the heat flow. The brittle character of this rupture is due to the material model chosen for the granite.

After, the cracked zones spread slowly and are the largest at $t = 100$ years (see fig. 7).

From then, some cracks located in the vicinity of the repository begin to close, while new cracks are created, following the heat front propagation. A close examination of the cracked zones reveals that complex stress redistributions occur when new cracks are created, some others tending to close. Finally, all the cracks tend to close when the temperature comes back

to the initial state.

4 DISCUSSION AND CONCLUSION

The hypothesis of a sane granite without major discontinuities, and a rather large traction resistance might seem unrealistic.

In fact, some other calculation performed either with a no tension material have shown a larger zone of cracked granite (cf. ref. [6]). Moreover, the introduction of major discontinuities may or not change the results, depending on the position of these discontinuities.

One important conclusion from the present calculation is that the phenomenon is much strain-controlled, and therefore the brittle rupture of the granite layer above the repository is much likely to occur, provided that the heat flux produced is sufficient.

The boundary condition assuming a zero horizontal displacement on the lateral edges of the model tends to limit the cracks in the granite. A dual boundary condition with prescribed stresses would lead to more cracks. However, reality is in-between.

One main question which remains to be solved is the objectivity and unicity of the results. Indeed, since the material model obeys a strain softening law, the results obtained may depend of the finite element mesh and they may be not unique: some bifurcations may occur during the load-history.

These points have not been looked at in this work.

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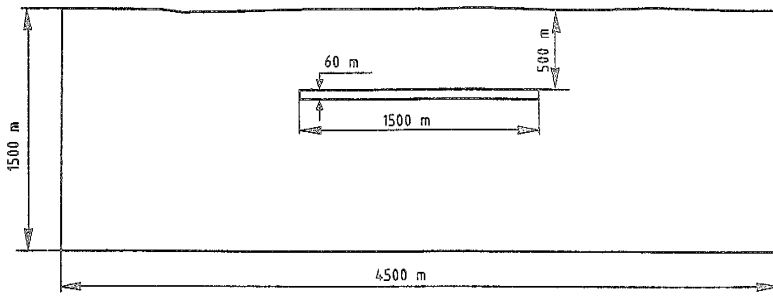


Fig. 1 - Repository configuration

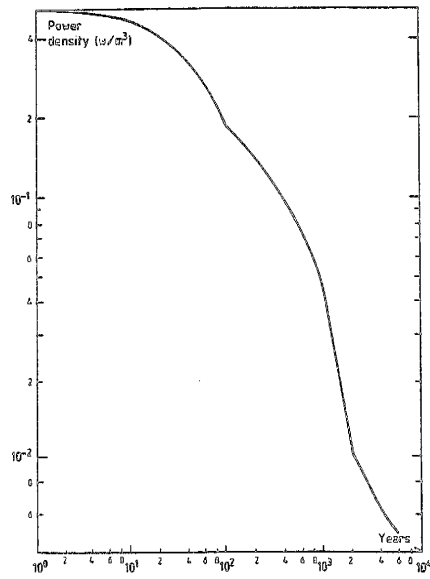


Fig. 2 - Heat source power

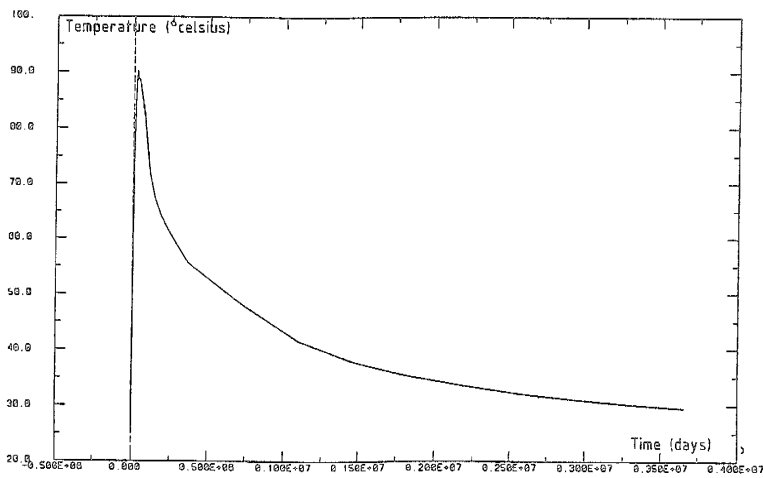


Fig. 3 - Maximum temperature versus time