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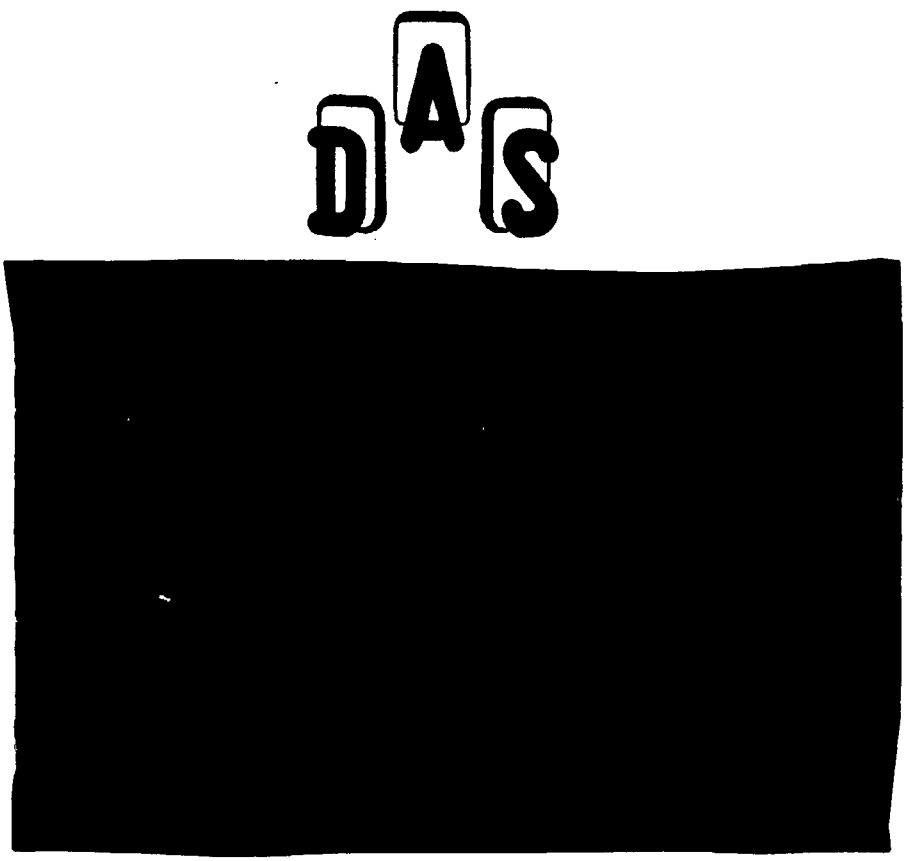

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SAFETY ASSESSMENT METHODOLOGY FOR WASTE REPOSITORIES IN DEEP GEOLOGICAL FORMATIONS

A.M. CHAPUIS*, J. LEWI*, J. PRADEL*,
D. QUENIART*, P. RAIMBAULT*, M. ASSOULINE*

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A.M. CHAPUIS, J. LEWI, J. PRADEL, D. QUENIART,
P. RAIMBAULT, M. ASSOULINE

Commissariat à l'Energie Atomique
Institut de Protection et de Sûreté Nucléaire
B. P. n° 6 - 92265 Fontenay-aux-Roses - France

INTRODUCTION

The long term safety of a nuclear waste repository relies on the evaluation of the doses which could be transferred to man in the future. This implies a detailed knowledge of the medium where the waste will be confined, the identification of the basic phenomena which govern the migration of the radionuclides and the investigation of all possible scenarios that may affect the integrity of the barriers between the waste and the biosphere.
Inside the Institute of protection and nuclear safety of the French Atomic Energy Commission (CEA/IPSN), the Department of the Safety Analysis (DAS) is currently developping a methodology for assessing the safety of future geological waste repositories, and is in charge of the modelling development, while the Department of Technical Protection (DPT) is in charge of the geological experimental studies.
Both aspects of this program will be presented.

I - MODEL DEVELOPMENT

The modelling activity at the IPSN is based on the development of the global risk assessment code MELODIE (1).
MELODIE is a deterministic code which can perform best estimate calculations by using detailed models; a small number of reasonable scenarios are then studied. Sensitivity analysis and uncertainty calculations can also be performed, using simplified models.

A - Development of sub-models

The IPSN coordinates for its own needs the modelling activity and the code development in the areas of source term modelling, hydrogeology, radionuclide transport, dose calculation, geochemistry, thermomechanics and geoprospective. We will describe hereafter the activities on source term, groundwater flow, radionuclide transport and biosphere.

1 - Source term

The source term modelling development is performed at the CEA/DRDD (Département de Recherche et Développement sur les Déchets). The first version of the code CONDIMENT, fitted for high-level wastes in a glass matrix, has been made available : it is a 1D code where the near field is represented in axisymetric geometry; it includes the glass matrix, the bentonite and a layer of the host rock formation (granite).
The code solves the advection-dispersion equation in the various media for a Nusselt number smaller than unity. The chemical interactions between radionuclides are represented by linear isotherms.

Future developments will include the coupling of chemical reactions such as precipitation reactions, the elaboration of a model for the source evolution in a salt environment and of a model for intermediate level wastes with α emitters.

2 - Groundwater flow and radionuclide transport

The basic model for groundwater flow and radionuclide migration, in crystalline rock or in surrounding aquifers for salt and clay formations, is the METIS code developed at the Ecole Nationale Supérieure des Mines de Paris. METIS is a 2D finite element code which solves the diffusivity equation and the advection-dispersion equation for equivalent porous medium. Linear adsorption kinetics as well as matrix diffusion and nuclear decay chains are included. Fractures are represented as linear elements and thermoconvection can be taken into account.
A future development will concern the transport of brine to describe more rigourously radionuclide transport close to a salt formation.
METIS participates to INTRACOIN and HYDROCOIN international validation exercises (2,3).

3 - Biosphere

The biosphere model, called ABRICOT, which has been developed at the DPT is based on a water and food consumption description. Individual, regional or collective doses are calculated from the ingestion of radionuclides corresponding to menus which components originate from different agricultural systems in the pathways of radionuclides. Doses from inhalation and direct exposure are taken into account as well.
A specific biosphere model valid for a coastal site is being developed.
This code participates in the BIOMOVS international validation exercice (4).

B - Development of the global model MELODIE

The elaboration of the first version of the code has been in progress for one year and a half. Its objective was to be able to perform a complete dose evaluation with time from a repository in granite on a specific site.
This version was obtained from the coupling of the METIS code, the source term CONDIMENT code and the biosphere ABRICOT code.
The groundwater flow in the geosphere is calculated as a permanent one. The repository is represented as a series of nodes in a 2D cross-section of the geosphere. At each node, a group of source terms is introduced. These sources are individualized since their outward flow will depend on the local water velocity and radionuclide concentration.
The geosphere migration submodel utilizes the water velocity chart, calculated by the groundwater flow model, and the radionuclide activity outflow, calculated by the source model, to compute the concentrations in the geosphere as a function of time.
Since the outward flow from each source is controlled by the local gradient of concentration, the level of interaction between models depends on the ratio of the radionuclide concentration in the source and in the geosphere. Strong coupling occurs when the permeability of the

geosphere has a low value, and this requires to carry an iteration procedure at each time step.
The discharges of the geosphere are identified from the groundwater flow distribution on the surface. The individual or collective doses are then computed from the concentration in the rivers which originate from these discharges and from the different transfer paths to man.
An algorithm for performing sensitivity analysis has been developed. It is based on the Latin Hypercube Sampling technique (5), takes into account correlation between parameters and allows to calculate the sensitivity coefficient of each parameter by regression analysis of the response surface. This algorithm is now under test with a 1D version of the geosphere migration part of MELODIE.
The main line of development of the code is toward its versatility. A modular structure has been defined. A management module calls each sub-modules independently. The calculation is performed following a chronology which depends on the individual time steps and connects the computational modules. Exchange of variables between modules are currently being optimized and will allow easy data storage and retrieval for reprocessing. Conversational pre and post processors are being developed.

C - Currently performed calculations

Various calculations are currently performed in the frame of the PAGIS project (6). This project is a joint study in the European Community which should assess the adequation of the models developed in the individual countries to risk assessment evaluation on specific sites.
France is responsible for the exercises on three granite sites : Auriat, Barfleur (coastal site) and a notional site in England. Two concepts of repository have been defined (case A and case B) which correspond respectively to 30 and 100 years of preliminary storage.
A set of first results obtained with the MELODIE code are joined to illustrate this purpose : Figure 1 shows different steps of the migration of ^{135}Cs activity through the 2-D geosphere representation in case B. The two sets of curves of Figure 2 indicate doses to critical individual due to fission products (^{135}Cs, ^{99}Tc, ^{93}Zr) in case A and in case B.

II - EXPERIMENTAL PROGRAMS

The experiments necessary to understand and to model the basic phenomena involved in the transfer of the radionuclides through the geosphere have been conducted in granite. They are underway in the Laboratory for Methodological Instrumental Studies situated in the Fanay uranium mine in a granitic formation (7). It is not a potential repository site but, on the one hand, the hydraulic conductivity of the fractured medium, which is rather high, makes possible the measurement of significant inflows of water; on the other hand, the extensive studies of the fracturation pattern in a large number of drifts in the mine and of outcrops at the surface are available and makes it a good facility for studying the geometry of the fracturation network. Two main programs are underway in this laboratory.

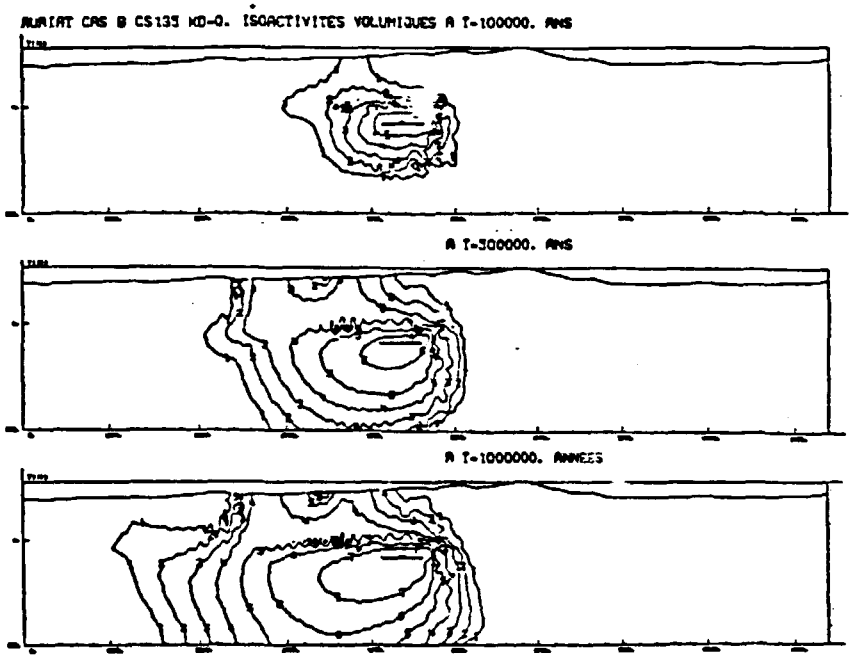


Figure 1

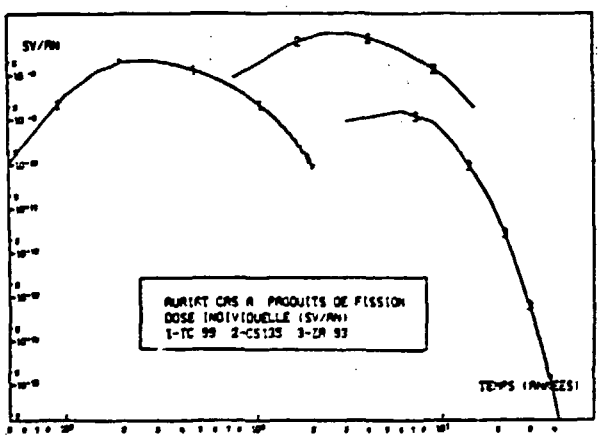
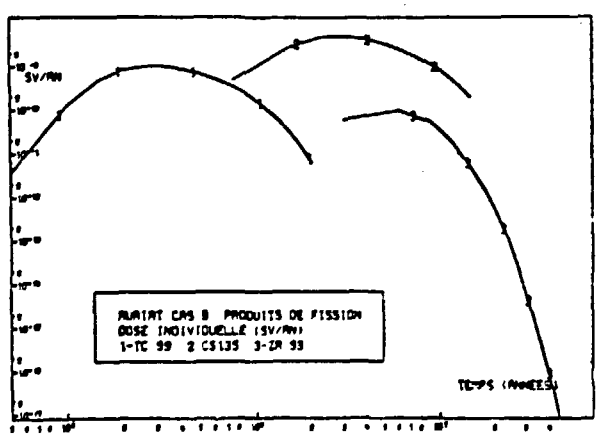


Figure 2



A - Scale effect experiment

The first study, the scale effect experiment, is carried out in a 100 m long test section situated in a drift of the mine, 170 m below ground. Two separate objectives are assigned to this experiment. The first one it to develop a methodology for evaluating the hydraulic properties of a fractured crystalline rock from an underground facility. The second is to understand how these hydraulic properties at large scale, representative of a real repository, can be inferred from relatively small scale measurements. Six 10 to 20 m long boreholes were first drillsd from the drift to test the suitability of the site for the experiment; then ten 50 m long radial boreholes were fully cored, and equiped with 68 packers isolating 68 measurement chambers, where the hydraulic pressure is recorded. In the same time, the flow of water arriving in the test section of the drift is measured. In addition to the pressure measurement, 250 injections tests were carried out in the boreholes, and the fracture network geometry and properties were recorded both on the drift walls and on the cores. Stress measurements have also been made, and, in a later phase, injection of tracers in the radial chambers of the boreholes, with a monitoring of the concentration of the tracer in the water arriving in the drift and in the other boreholes. Low retention tracers have been injected in ten chambers in two boreholes situated in the same plane. Tne results are not yet interpreted but it seems that, at this scale, this formation cant be modelled as a porous equivalent medium.

B - Hydro-thermo-mechanical experiment

The second study, the hydro-thermo-mechanical experiment, is carried out in another drift of the same mine. Only preliminary investigations are now in progress. The purpose is to perform a simulation on a reduced scale in time and space of the different physical phenomena linked to the thermal loading of radioactive waste. A chamber with a 10 m x 10 m floor has been excavated in the granite. The rock mass will be heated by means of electrical resistors placed in boreholes two meters below the floor. Temperatures, fluid pressure and mechanical deformations will be measured in the rock mass and on the surface of the chamber floor. Particular attention will be paid to the behaviour of fractures and to the modifications in rock mass permeability induced by the thermal effect. The different thermal, mechanical and hydraulic data obtained during a six months experiment including a heating phase of about one month will be interpreted using several models that will be compared to each other.

C - Migration studies

The retention of radionuclides in granite formations are not studied in the underground laboratory. Two experiments are underway, one in a laboratory within the EEC Mirage project (8), the other uses a small apparatus : the FORALAB which can be inserted into a borehole and enables in situ measurements of radionuclide transfer. The apparatus is now ready to work and in situ experiments will soon begin.
The outflow of deep water into the biosphere may be located by the study of the water characteristics : geochemistry, isotope concentration,

temperature, or by the interpretation of infra-red photography.
Experimental facilities similar to the Fanay facilities but in salt and clay formations are being planned. The corresponding sites are under investigation.

D - Geoprospective studies

Experiments are also made in order to collect the parameters needed for the geoprospective approach. An inventory of significant natural factors has been made. They concern climatic evolution, erosion and weathering, vertical movements, tectonic activity, volcanism, seismic activity. As the favorable H.L.W. disposal sites have not yet been chosen in France, the methodology is being applied to the Auriat site which is one of the granitic formation studied in the PAGIS project.
The underground movements are measured in one drift near Fanay using extensometers and inclinometers. Some data on the evolution of the Auriat area will be collected through relevelling comparisons and morphostructural studies.
General climate varations over long periods of time may be modelled from the variations of the Earth orbital parameters. The results from these models will be adapted to specific sites. These modifications of the climate, for example the occurence of glaciations, lead mainly to variations of the levels which modify the erosion phenomena.

III - CONCLUSION

The methodology for risk assessment developed in France stresses the needs for coordination between data acquisition and model development which should result in the obtention of an efficient tool for safety evaluation. Progress needs to be made in source and geosphere modelling. Much more sophisticated models could be used than the ones which have been described here; however sensitivity analysis will determine the level of sophistication which is necessary to implement. Participation to international validation programs are also very important for gaining confidence in the approaches which have been chosen.

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