SCK/CEN'S INTEGRATED R&D AND DT&E PROGRAM ON FINAL NUCLEAR WASTE DISPOSAL IN ARGILLACEOUS FORMATIONS

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ABSTRACT

Taking into account the national context and the priorities set within it, SCK/CEN focuses essentially on: 1) The final disposal of the various radioactive waste types arising from the reprocessing of nuclear fuel from the electronuclear power stations and from various nuclear facilities in support of the nuclear energy and applications and; 2) On the final disposal in a specific argillaceous formation identified as a potential host for radioactive wastes (the Boom clay formation at the Mol site).

SCK/CEN's R&D and DT&E program integrates existing knowledge and tools with innovative technology and approaches to solve the specific problems related to the final disposal of various waste types in clay. R&D (desk, laboratory and in-situ) has been undertaken on the most important issues and problems identified (e.g. in the field of waste characterization and waste compatibility, concept feasibility, siting, backfilling and disposal technology). DT&E activities embrace development of new tools and technologies (e.g. tunnelling techniques, optical sensing systems), validation (e.g. on radionuclide migration, geomechanical modelling), reduced or full scale simulations, performance and technology assessment.

NATIONAL WASTE MANAGEMENT PROGRAM

According to the law of August 1980, NIRAS/ONDRAF is in charge of collecting the waste (conditioned or non-conditioned, but satisfying the specifications enacted by it), to treat and condition the non-conditioned waste, to store the waste and to dispose it finally.

A forecast of the quantities of the different waste types expected to be generated in Belgium, with a 5.540 MW(e) electronuclear power production capacity installed (equals about 65% of the electricity production) is given in Table I. The amounts given in this table are forecasts of waste volumes to arise until the year 2050 and thus they include also dismantling waste which contributes for 55 to 60% of the volume in the category A waste and for 20 to 25% of the volume in the categories B and C waste. Category A comes from a variety of producers, whereas category B and C mainly come from the reprocessing of Belgian spent fuel at the COGEMA facilities in France. The nuclear power stations at the sites of Doel and Tihange are presently the only producers conditioning part of their own wastes (essentially resins, concentrates and filters in concrete or bitumen).

Because 1) Belgium is a small country and thus the distances between the production centers and the storage site are rather small, 2) the total volume of the waste to be treated is rather limited and 3) fixed costs of radioactive waste treatment and conditioning are an important fraction of total costs, the strategy of NIRAS/ONDRAF is to centralize treatment, conditioning and interim storage at the Mol-Dessel site (1).

Since in 1983 sea dumping of low level wastes was abandoned one considers still two other options: 1) disposal near the surface in an engineered structure, or 2) disposal in geological clay formations.

NIRAS/ONDRAF plans to start the investigation on the site for near surface disposal in 1995, after approval of the authorities and to submit the required reports in the period 1996-1998. The implementation of the disposal operations should start off from 1999 at earliest.

If the surface option should not be maintained, it is considered that the deep geological disposal in a clay layer should be a valuable alternative and thus the disposal calendar of the low level wastes should then be partly rescheduled according to the progress of the program on high-level and long-lived waste.

The investigation program on the final disposal of long-lived and high level waste has been launched by SCK/CEN in 1974. Soon after its initiation the CEC participated financially on specific issues of its program. A typical exercise that was made within the context of the CEC Radioactive Waste Management and Disposal Program was the drafting of an inventory of geological formations favorable for the final disposal of these wastes.

Several sedimentary formations, all of the pelitic or argillaceous type were identified as potentially favorable. One of these, the Boom clay formation, which occurs in the north-eastern part of the country and in the underground of the Mol-Dessel site has been chosen to organize the investigation program around. The main objective of this program is the demonstration of 1) the safety of the disposal of high level and long-lived wastes in an argillaceous formation, and of 2 the technical feasibility of a disposal concept.

The status of the recent and current program is described hereafter but NIRAS/ONDRAF proposed the following schedule for the implementation of a high-level and long-lived waste disposal program:

- until 2000: Continuation of investigations, with preliminary safety report around 1997
- 2000-2015: Underground full scale demonstration
- 2015-2025: Final concept and realization studies
- 2035-2050: Operation of underground facility and closure

The start of the operations in 2035 is based on the assumption that disposal of high-level waste from the reprocessing of spent fuel will require a 50 years cooling time after withdrawal from the reactor.

TABLE I

Types and Approximate Quantities of Radioactive Waste Expected to be Generated in Belgium until the Year 2050

Waste Type	Cat.	Volume (m^3)	Main Producers / Origin
Low-level beta, gamma and non-alpha waste	A	150.000	Operation of power stations and reprocessing, research facilities and dismantling all facilities
Low-or medium-level waste with significant amount of alpha	B	25.000	Reprocessing (Fuel power stations and former Eurochemic plant). Dismantling Research Facilities.
High-level waste	C	5.000	Reprocessing (Fuel power stations and Former Eurochemic plant).

SCK/CEN'S MANDATE AND TERMS OF REFERENCE

End 1991 several decisions have been taken by the Belgian Authorities in the matter of responsibilities, terms of reference and management of the various organizations involved in de nuclear fuel cycle and controlled by it. Among the organizations concerned were NIRAS/ONDRAF, SCK/CEN, IRE (National Institute for Radioelements) and PTE .

By Royal Decree of October 16th of 1991, SCK/CEN's revised tasks were formulated as follows (authors' translation): 1) with priority perform research in the field of nuclear sciences related to: (a) d to the safety of nuclear reactors and reactor fuels, (b) radioprotection, (c) the safe conditioning and disposal of radioactive wastes, (d) physical and auditable control techniques, as well as chemical analysis techniques of fissile and other sensitive substances, and to, (e) the resistance of the nuclear structures with regard to various aggressions; 2) Undertake research on the application of the nuclear energy, and to promote and apply scientific and technological studies of such applications essentially as service for the nuclear industry; 3) On request of the Ministers, responsible for Economic Affairs and Energy, take charge of any investigation or coordination of it in the nuclear domain when the resources of the Centre (= SCK/CEN) can be engaged in a useful manner.

By this new mandate SCK/CEN had to abandon its diversification option and programs, launched and undertaken more than one decade ago. It actually concentrates its efforts on the nuclear business. A new research establishment VITO (Vlaamse Instelling voor Technologisch Onderzoek, 'Flemish Institute for Technological Research') was created by the regional Flemish authorities and it takes over most of SCK/CEN's non-nuclear programs, together with the personnel related those programs and part of the premises dedicated to these.

According to directives of the national authorities SCK/CEN organized its research in three principal research units, each having an own particular mission: 1) Nuclear reactor experiments (safety experiments, scientific research and specific industrial production), 2) Waste and dismantling (waste characterization, conditioning, dismantling, and disposal), and 3) Radioprotection.

SCK/CEN's research programs and projects are systematically reviewed by a Scientific Advisory Committee (SAC) and several Departmental Advisory Committees (DAC). External scientists and technologists, as well from the national as the international community, are member of the SAC and DACs.

The external interdependency of SCK/CEN and its functional interactions in the matter of waste disposal research are best illustrated by a synoptic diagram as shown in Fig. 1. The Ministry of Economic Affairs is overviewing, in general, SCK/CEN's activities and is thus in a position to determine the main research avenues and the resources to be allocated to these. NIRAS/ONDRAF, defines its own research and demonstration program to some extent in co-operation with SCK/CEN . Until now most of the research and demonstrations on behalf of NIRAS/ONDRAF was performed or coordinated by SCK/CEN itself. Since NIRAS/ONDRAF is the main sponsor for SCK/CEN research activities NIRAS/ONDRAF's research program forms the backbone for SCK/CEN's activities i. e. milestones, scientific targets, timing and resources. Since SCK/CEN's research mandate and mission is larger than the one that can be drawn from NIRAS/ONDRAF's program, SCK/CEN acts on a broader and larger radius and performs research under contract with the CEC and foreign organizations such as ANDRA and CEA of France, Enresa of Spain and PNC of Japan, which all demonstrate interest in our competencies in many fields such as those of 1) waste package characterization and compatibility studies, 2) characterization and technology of argillaceous materials 3) in-situ experimentation in clay formations, and of 4) performance assessment areas (deterministic, stochastic, ...).

AN INTEGRATED PROGRAM

One can consider SCK/CEN's program as an integrated program for several reasons.

The implementation of the final disposal requires the development of an adequate technology. The technology development can be performed by integrating the knowledge from the basic research and applied research and transferring it, together with other innovative technologies into specific

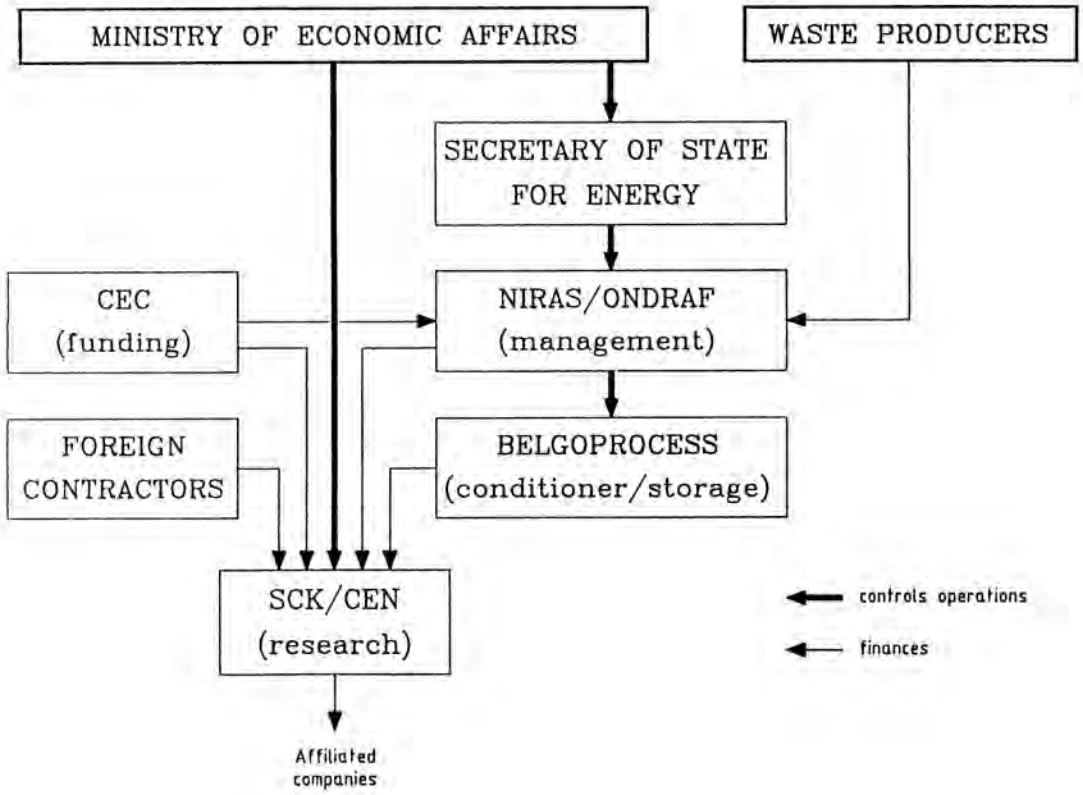

Fig. 1. Functional relation of SCK/CEN in the matter of research on waste management and disposal.

test implementations (demonstrations). SCK/CEN builds its testing and demonstration activities exactly that way.

The two objectives of the program, namely to demonstrate the feasibility and to demonstrate the safety of the final disposal of radioactive wastes in the Boom clay force SCK/CEN to investigate all relevant issues needed to achieve both objectives. The osmotic action between safety performance assessment and technology demonstration for one and the same issue can only be achieved successfully if both avenues are dealt with in an integrated way.

For many of the issues to be investigated one can follow various ways to reach the final demonstration. Each of them does not bring itself the final ultimate demonstration, but in combination they do provide sufficient confidence to the demonstration. For instance theoretical approaches, laboratory simulation, modelling, analog analysis and in-situ testing all combined contribute to the demonstration issue.

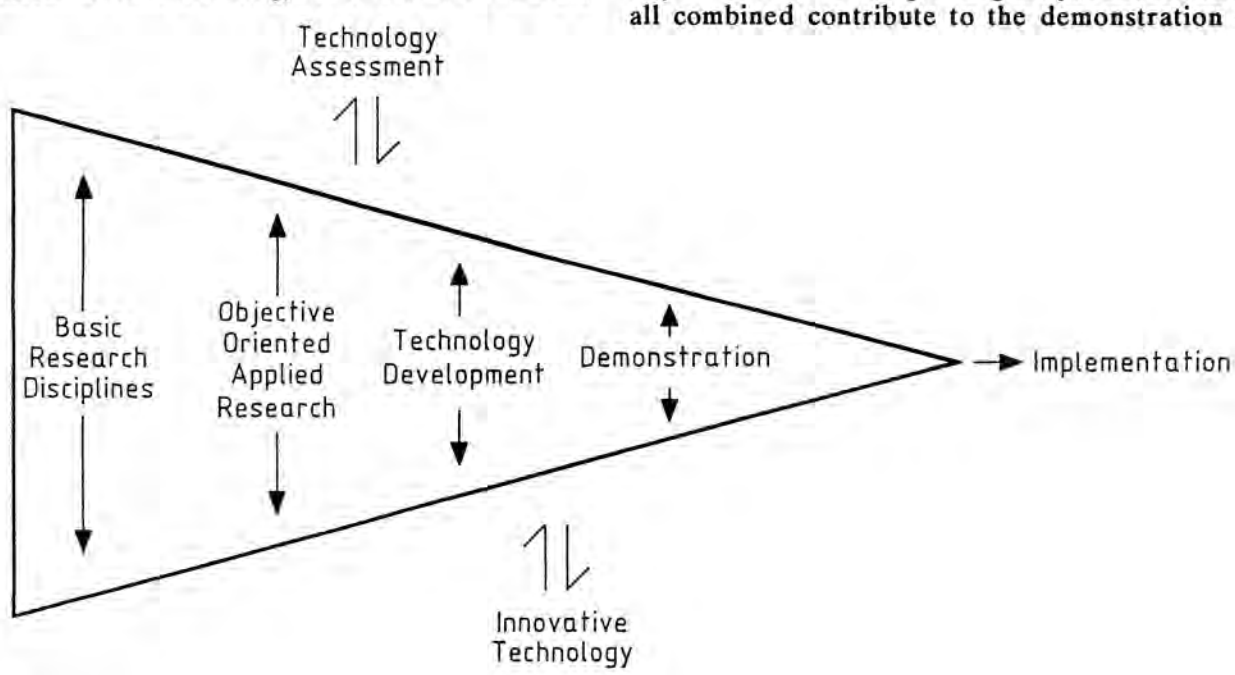

Fig. 2. Scheme of the integrated approach in SCK/CEN's program.

SCK/CEN integrates all these various approaches in its program.

Figure 2 illustrates synoptically the integration process of SCK/CEN's program.

SHORT DESCRIPTION OF SCK/CEN'S PROGRAM ITEMS

The favorable potentials of clay formations for hosting radioactive wastes were shown by Baetslé and Bonne at the occasion of the Waste Management '90 meeting (2). Many of the grounds and convincing elements for the position of these authors are based on the outcome and results of the research and investigations performed by SCK/CEN on the Boom clay present in the underground of at its own site.

SCK/CEN's program is organized along two main avenues: 1) the R&D avenue which essentially deals with identifying, understanding and describing processes, determination of parameters and parameter values, selection among options, materials and techniques and design studies, and developing tools for these actions, and 2) the DT&E avenue which essentially deals with testing, validation, demonstration and evaluation of the system behavior as it is expected to occur in the final repository conditions or near to these conditions.

An Underground Research Facility, called the HADES-facility, was built in the Boom clay at about 230 meters below ground level at the premises of SCK/CEN between 1980 and 1984. In 1984 the HADES-facility was already extended. This facility was built with financial support of the CEC. It is at present a unique tool for DT&E activities.

The very general overview of the program activities given hereafter is a cross-section of the present program and does mention only marginally achievements of the past. These past activities can be learned from previous publications (3,4,5,6,7).

R&D-ACTIVITIES

The main R&D-items in the program deal with the most important system components of a geological repository: 1) The waste package, 2) The near-field, 3) The host geological medium, 4) The surrounding geologies , and 5) Design and technical support studies.

WASTE PACKAGE

The research on the waste package components is focused on two problem areas : the determination or verification of the materials properties, and the investigation of the interaction (compatibility) between the package components and the disposal surroundings. The program includes work on different waste forms (glass, bitumen, cement) and canister/container materials (stainless steel, C-steel, Hastelloy-C, Ti/0.2%Pd).

SCK/CEN is developing and implementing verification actions in addition to the QA/QC programs carried out by the various waste conditioners (Belgoprocess, Cogema, Nuclear Power Plants). The verification action has to provide independent information to the Authorities in order to allow these to decide about the acceptability of the waste products. A broad basis of exploratory research has enabled to master the discipline. As a new orientation, SCK/CEN is evaluating and optimizing techniques for non-destructive analysis of waste packages.

The studies related to the compatibility of waste package are designed to obtain basic understanding of the interaction phenomena between either the waste form or the container and the Boom clay disposal surrounding. The experiments on the waste forms consider in particular the following parameters: 1) interaction medium: Boom clay / claywater mixture, with additions of container corrosion products and backfill, 2) waste form composition, 3) temperature, 4) the presence of a gamma-irradiation field, 5) performance of fully active samples versus inactive simulates, 6) test geometry, e.g. the surface exposed per leachant volume, which can be used to accelerate the interaction phenomena.

The source term studies on glass matrices include 1) characterization of the physico-chemical form of the actinide containing phases in the solutions, 2) separation of mobile and immobile activity inventory in the leachates, 3) modelling of the corrosion behavior of waste glass (using geochemical and kinetic computer codes), and 4) comparative assessment of the existing waste glass with alternative matrices (e.g. SYNROC).

In-situ testing on the interaction of the waste package components with the Boom clay repository is another important issue in the program, which is expected to validate the results from the laboratory work and corrosion models. Eight in-situ assemblies have been installed since 1986, considering the direct exposure to Boom clay or to the water saturated atmosphere extracted from the clay. Comparison of the performance of waste glass in various repository media has been attempted through participation in a joint CEC effort, and through other participation in International in situ programs (STRIPA, WIPP) (8).

Collaboration exists with a large number of Belgian universities and foreign institutes such as the CEA (F), KFK and KFA (D), ANSTO (Aus), SRL (USA) and SKB (S).

NEAR-FIELD

Related to the investigations about the near field one directs the efforts to 1) the effects related to the excavation/construction and to 2) the immediate effects resulting from the emplacement of waste. With regard to the first issue as well elasto-visco-plastic models (rock mechanics approach) and a pore pressure dissipation models (soil mechanics approach) have being investigated. Both approaches are followed, not only from the theoretical point of view but also from the experimental point of view: as well in the laboratory as in the in-situ experiments (9). The effects of oxygenation of the clay, (which are reducing under de normal conditions) have been investigated (10).

Effects of release of corrosion products and of radiation in the near-field have been investigated as well from the point of view of their formation (radiolysis of moisture content and of organic substances, or iron released from structural materials), as from the position of alteration of the clay properties.

The permeation of gases (e.g. hydrogen from corrosion of waste matrices and packaging materials or from radiolysis) is presently under investigation as well from the theoretical point of view as through laboratory and in-situ experiments.

Studies on the backfilling and sealing features of a repository in clay has been dealing with the use of cement based materials, clay based materials and mixtures of theses. The reuse of Boom clay as backfill and the effect of heat on these has been calling special interest. Mixtures of Boom clay with

other industrial minerals, treated according specific procedures allows to make precompacted dimension blocks with physical properties close to those of intact Boom clay. Modelling and testing (also in-situ) of clay based backfill and seal features have been undertaken in collaboration CEA, ANDRA, LGC of France, ENRESA, CIEMAT, Univ. de Cataluna of Spain, Intera, GCG and universities of the United Kingdom, in the framework of CEC research contracts.

HOST FORMATION

The investigations related to the host rock have been addressing essentially the following aspects directly related to the migration of radionuclides within it: 1) physical and chemical characterization of the Boom clay (chemical composition and speciation of the main various components, granulometry, homogeneity/ heterogeneity, etc.), 2) sampling and determination techniques (cryogenic methods, lyophilisation, etc.), 3) speciation of the various corrosion products and released products within the clay material and modelling of speciation, 4) migration modelling and model validation (e.g. within the framework of the INTRAVAL-II exercise) and 5) determination of the clay specific and species specific parameters intervening in the modelling (diffusion parameters, hydraulic parameters) on theoretical basis, by laboratory experiments, by in-situ experiments and when possible on the basis of natural analogons (e.g. the case of uranium).

Many references may be found in literature about this research, the most recent ones being (11,12,13,14).

Co-operation with other organizations in this field is for instance with PNC (Japan), CEA and ANDRA of France, and the University of Louvain (KUL) in Belgium.

SURROUNDING GEOLOGIES

The regional investigations essentially have been focusing on the hydrological conditions of the site and its behavior in the larger geological context and aim at providing a reliable tool and data to be inserted and used in the long term safety and performance assessments.

Since 1980 a regional hydrological observation network (covering more than 2,000 sq. km with more than 132 observation wells) has been monitored. Along with modelling, field efforts have been devoted to complete the hydrogeological picture of the site surroundings on the basis of the drillings, samplings, loggings and geophysical campaigns, water level monitoring, hydrological tests for determining the hydrological parameters of the main hydrogeological units and of pilot studies on the use of natural analogons in the aquiferous system surrounding the Boom clay in the region around the Mol site. A regional hydrological flow model has been developed but the confirmation exercises indicated that further and more detailed hydrological investigations are required. Local and small scale information (e.g. permeabilities and carbon-14 dating) does not fit with the outcome of the regional hydrological model. A critical review is now under progress and a new regional investigation program will be drafted on the basis of this review.

Collaboration in this field has been performed with the Belgian Geological Survey, the Ecole des Mines of Paris, AEA of the U.K. and with the Free University of Brussels.

DESIGN AND TECHNICAL SUPPORT STUDIES

In the past SCK/CEN was involved in developing overall design and conceptual studies for a repository structure in the Boom clay at the Mol site. In recent years this activity of overall design has been taken over progressively by NIRAS/ONDRAF and at present SCK/CEN is devoting its design efforts more to system components or implementations related to construction, backfilling, sealing and monitoring systems.

As an example one should mention here the efforts SCK/CEN is paying in the development of: 1) new technologies for backfilling and sealing of open spaces with clay-based materials (collaboration here has been essentially with the CEA of France), 2) new monitoring systems (networks with various new types or adapted types of sensor devices, such as optical sensors) which are expected to satisfy more stringent requirements on redundancy, long term performance/longevity, and safety (close collaboration with manufacturers of high technology monitoring and sensor devices and universities are set up).

DT&E-ACTIVITIES

A the basic principle in the DT&E of SCK/CEN's program is to rely on present day technology or technology which is readily on hand in a short time span. One takes the position to demonstrate and evaluate performances, impact and feasibility of the final situation or option, by applying present skills, considering and knowing that finally the applied techniques and assessments will surely be better than those today because of general quality improvement and optimization in the mean time. The technological DT&E-items are addressed by tests in the HADES-URF and are part of the CEC's demonstration programs.

LONG TERM PERFORMANCE AND SAFETY ASSESSMENT

In parallel but in close osmosis with the R&D-activities, SCK/CEN is involved in the performing the long term overall system performance and safety studies. Various reprocessing waste types and their long term impact have been assessed stepwise. Most of this assessment work is being made in the framework of the CEC's safety and performance studies: PAGIS (16), PACOMA (17) and EVEREST.

The standard methodology applied consists of a structured scenario selection and analysis (made now in co-operation with ECN of the Netherlands), best estimate calculations followed by sensitivity and uncertainty analysis (made in co-operation with various organizations e.g. the Joint Research Centre of the CEC at Ispra and IPSN of France). The assessments are systematically upgraded by improving gradually the methodology or components of it by inserting new tools and approaches, e.g. on the selection of the input parameters, parameter sampling techniques and procedures, software engineering and so on, and by actualizing the input data.

All results obtained up to now and the evaluations of performance assessment methodology applied itself are providing reassuring bases for an attitude of confidence in the option and the approach. Results for the spent fuel disposal option are not yet available, but are expected to be within two years.

CONSTRUCTABILITY DEMONSTRATION

Since experience of tunnel construction in clay formations at greater depth was very limited, SCK/CEN and its partners decided to demonstrate directly the tunnelling capabilities under representative conditions. As well tunnelling techniques according to a stiff lining principle for long lasting gallery structures and to a converging lining principle for deeper and short living gallery structures have been demonstrated in the HADES-URF. The test on the second technique was performed on request and co-financed by ANDRA of France. These tests were accompanied by Mine-by tests which allowed to monitor the behavior of the structures and the surrounding clay along the construction and afterwards and to draw the conclusions and evaluations from it (18).

COMBINED EFFECTS

A series of in-situ test have been performed and more are still planned for the future in order to demonstrate combined effects expected to occur in a final repository. Also these tests are performed in the context of the CEC's program on demonstration and pilot facilities.

In 1989 a combined heating and radiation test, called the CERBERUS-test (19), has been placed in the Boom clay , with the aim to create by simulation a very local near field as the one expected from a high-level radioactive waste canister (COGEMA-type after 50 years cooling time). The simulating sources are a Co-60 source (of about 444 TBq at the time of emplacement) combined with two heaters of each a thermal output of 362 W. The test is described elsewhere and is planned to last until 1996. In the near-field of that test monitoring is made for the radiation level, for the moisture content and composition and corrosion and migration test devices can be emplaced in this field as well. Evidences of the performances of Boom clay-based backfill material placed in the near-field of that test will be available in the mid 90's.

HYDRO-THERMAL-MECHANICAL TESTS

In the HADES-URF a series of simulation tests have been undertaken for ANDRA of France (under contract with the CEC) in order to investigate and demonstrate the hydro-thermo-mechanical response of a clay host rock with regard to the emplacement of heat generating high-level waste emplaced in the repository according to different schemes. These tests are representative for the concept of disposing of the HLW canisters in stacks from the floor of the disposal galleries. Two test configurations have been installed and they are planned to last until 1993/94 (20).

THE PRACLAY-TEST

A larger scale demonstration test of tunnelling, emplacement of high-level waste and backfilling by simulation has been initiated by NIRAS/ONDRAF in 1990. The emplacement configuration envisaged for these test is the one with disposal of HLW canisters in the full section of the galleries. For the time being efforts are devoted to a number of feasibility studies related to specific test issues, to general design activities of the test, to the assessment of technologies available for performing the test and monitoring it and to the preparation of the construction of a new emergency shaft since the Mining Authorities require such a structure before licensing for emplacing the new test can be obtained (21).

CONCLUSIONS

An integrated program on the final disposal of various waste types in an argillaceous formation has been developed by SCK/CEN. The integration is obtained by 1) covering the full spectrum from research up to technological developments, 2) applying, when possible, knowledge and/or technologies already developed elsewhere, 3) a multi-approach (multi-disciplinary, -tasking, and -objective).

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