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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

RADIOACTIVE WASTE REPOSITORY STUDY
PART III
(SUMMARY)

ETUDE D'UN DEPOT DE DECHETS RADIOACTIF
PARTIE III
(SOMMAIRE)

Acres Consulting Services Limited
in conjunction with:
conjointement avec:
RE/SPEC Inc.
Dilworth, Secord, Meagher and Associates
Hagconsult AB

Whiteshell Nuclear Research Establishment

Etablissement de Recherches Nucléaires de Whiteshell

Pinawa, Manitoba R0E 1L0
November 1978 novembre
(Work done during 1976-1977)
(Etude entreprise en 1976-1977)

This report is a reissue of a previous report on consultant's work done two years ago. The views and conclusions are those of the authors at that time and do not necessarily represent the official position or policy of AECL today. In particular, the timetables of events are no longer valid.

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ETUDE D'UN DEPOT DE DECHETS RADIOACTIFS

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RESUME

Ce rapport représente la troisième partie d'une étude préliminaire faite pour l'Energie Atomique du Canada, Limitée. Il résume les sujets des rapports AECL-6188-1 et AECL-6188-2 en ce qui concerne les conditions requises d'un dépôt souterrain des déchets produits dans le cadre du programme canadien de combustible nucléaire.

L'Energie Atomique du Canada, Limitée
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ABSTRACT

This is the third part of a report of a preliminary study for Atomic Energy of Canada Limited. It summarizes the topics considered in reports AECL-6188-1 and AECL-6188-2 as requirements for an underground repository for disposal of wastes produced by the Canadian Nuclear Fuel Program.

Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba R0E 1L0
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CONTENTS

1. INTRODUCTION

A program has been initiated by Atomic Energy of Canada Limited (AECL) to develop techniques for the ultimate disposal of high-level radioactive wastes into geological formations. Part of this program requires the design, construction and operation of an underground repository which will satisfactorily isolate the waste produced by the Canadian nuclear power program.

A conceptual design study of a radioactive waste repository was carried out by Acres Consulting Services Limited of Niagara Falls, Ontario, with Atomic Energy of Canada Limited. The technical coordinator was Dr. H. Tammemagi of the Whiteshell Nuclear Research Establishment at Pinawa, Manitoba. RE/SPEC Inc. of Rapid City, South Dakota, U.S.A., Dilworth, Secord, Meagher and Associates Limited of Toronto, Ontario, Hagconsult AB of Stockholm, Sweden, and Professor J.A. Cherry of the University of Waterloo, Ontario, acted as subconsultants to Acres. Their report is divided into Part I (AECL-6188-1), Part II (AECL-6188-2) and this summary (Part III, AECL-6188-3), and presents the major objectives, results and conclusions of the study.

The major objectives of the study were to

- develop a preliminary conceptual facility design
- assess the feasibility of a repository situated in plutonic rock
- estimate development and construction costs
- identify areas requiring research or development in order to validate feasibility.

The schedule for the repository development is given in Table 1. A repository size was selected large enough to contain all the wastes from approximately 700 000 Mg of irradiated fuel, based on an upper-limit estimate of the nuclear power generating capacity which could be operating in Canada to the year 2025. This would require emplacement of approximately 1 082 000 canisters of high-volume reprocessing wastes.

A test facility is also required. It was therefore proposed that, initially, a small segment of the proposed underground facility should be constructed, and that various emplacement concepts, handling and monitoring techniques would be tested using heaters and, later, small quantities of radioactive material.

A necessary criterion for acceptance of design concepts was that the construction should use presently available technology. Furthermore, the emplacement systems and operation should be as simple as reasonable, in order to maximize safety and reliability.

At this time, there are no operational high-level radioactive waste disposal repositories in hard rock which would provide precedent data for this design. Consequently, as part of the study, a review was made of U.S. experience and concepts for high-level waste repository designs in salt beds, together with an assessment of relevant aspects of underground construction in hard rock for powerhouses, hydrocarbon storage, compressed air storage and mines.

The results of the study are presented in AECL-6188-1 and AECL-6188-2. The principal points and conclusions are summarized in the following sections of this report. Section 2 reviews the available data on expected site rock conditions and properties. Section 3 introduces the reference or "baseline" design concept which is used for the technical studies in Sections 4 through 8. Section 9 presents alternative emplacement and layout concepts, Section 10 gives cost estimates for the various schemes, and Section 11 summarizes the principal research and design engineering requirements.

2. GEOTECHNICAL INVESTIGATIONS

Attention was mainly focussed on intact rock at the two ends of the mineralogical spectrum for plutonic rocks, namely granite (acidic) and gabbro (basic). In addition, the exploratory techniques which will be required to establish geotechnical data at specific facility sites were reviewed.

The results of the study indicated that an adequate data base exists for most mechanical, thermal and mineralogical rock properties for the purpose of conceptual design studies, and tables listing these values were presented. However, detailed design activities will require the use of site-specific data. Ranges of key parameters were: unconfined compressive strength at ambient temperature 138 to 275 MPa; Young's modulus 20 to 80 GPa; thermal conductivity 1.6 to 3.3 kJ/m·s·°C; coefficient of linear thermal expansion 6 to 8×10^{-6}/°C. The host rocks are expected to have equivalent permeabilities in the range 0.01 to 10 nm/s due the systematic joints, although singular features with higher local permeabilities may exist.

In general, the state-of-the-art investigation techniques for obtaining site-specific geotechnical data are adequate. However, it should be noted that the measurement of the frequency, orientation and mechanical properties of discontinuities by current "down-the-hole" techniques is difficult at depths of 1000 metres.

A need for the implementation of a major laboratory testing and research effort for evaluation of the behaviour of the rock at elevated temperatures was emphasized. These data are scarce for rock of the plutonic type in general. The extrapolation of available data to site-specific rock may be difficult to justify adequately. Some research is also required for evaluation of the long-term stability of minerals subjected to the combination of heat, moisture and irradiation.

3. THE REFERENCE CONCEPT

A reference repository concept was developed as a basis for study and comparison. This design could accommodate 1 082 000 canisters 0.3 m in diameter and 3.0 m long. Decay heat production was specified as 250 W per canister at time of emplacement. The canisters will be set singly into vertical drill holes in the floors of the rooms. The facility has been designed on a modular basis with identical rooms grouped together into panels (Figure 1) which in turn are grouped about the central shaft facilities to form the repository facility at an assumed depth of 1000 m (Figure 2). The dimensions of an individual room are adequate for the emplacement of 500 canisters. With each panel containing 50 rooms, 44 panels are required. To permit concurrent mining and radioactive waste operations, separate shafts, haulageways and ventilation systems have been provided. For the test facility, the periphery of one panel with approximately six rooms would be excavated.

The completed underground facility requires a total rock excavation of approximately 15 000 000 m^3, plus an additional 500 000 m^3 for the drill holes for emplacement of the waste canisters. The initial development of the facility for the test facility requires a rock excavation of approximately 90 000 m^3.

The average round-trip haulage distance for transportation of excavated rock is of the order of 4000 m, and will probably require use of rail haulage in the main haulageways.

The construction aspects of this facility do not appear to present any serious difficulties. The repository compares in excavation size to existing large Canadian mines.

4. THERMAL LOADING

The emplacement of heat-generating radioactive waste in an underground repository gives rise to thermal and thermomechanical phenomena which need special consideration in the design stage. Closed-form heat conduction solutions were utilized to study the effect of canister spacing, number of canister rows in a room, and canister heat-generating capacities on the canister-rock interface temperatures. The reference concept is based on a gross thermal loading of 32 W/m^2 which is expected to be a feasible level. Rock temperatures around the canisters, in the unventilated reference concept, may reach 180°C locally. Major reductions in temperature may occur with ventilation. These are preliminary results and more detailed analyses are required to confirm the thermal response and to establish maximum permissible temperature criteria.

5. ROCK MECHANICS

Stress analyses using the finite-element method indicated that for a room at a depth of 1000 m, the post-mining stress levels will be substantially less everywhere than the strength of the intact rock. At the most critically stressed points on the periphery of the disposal room, a factor of safety of at least two should exist. The maximum temperature gradients occur during the first year of waste emplacement, but the increases in rock stress due to thermal expansion will have only a modest effect on the stresses on the periphery of the room. The stresses after 30 years of emplacement, at which time the maximum temperatures occur in the room area, were also found to be acceptable. From this study, it was concluded that, on a preliminary basis, the room-and-pillar geometry of the reference concept is feasible.

In future detailed design studies, it is recommended that an analysis of a discontinuous rock mass be undertaken to relate the induced stresses to the postulated joint shear resistance. Also, detailed thermo-mechanical analysis of the rock immediately adjacent to the emplaced waste containers should be made to evaluate retrievability, utilizing non-linear material behavior when necessary. Temperature effects on the joint water pressure should be studied, and analyses for long-term thermal conditions should be undertaken, including creep and creep rupture phenomena.

6. HYDROGEOLOGY AND WASTE CONTAINMENT

The hydrogeology of potential facility sites is a crucial aspect in the evaluation of technical feasibility. Investigative methods and monitoring programs for hydrogeological site investigations were reviewed, and preferred hydrogeological site conditions for a repository facility in plutonic rock identified.

The review of expected host rock permeabilities and porosities indicated that groundwater inflow during construction and operational phases of the repository should be minimal and easily acceptable.

A definite statement on the reliability of the waste containment capability of the repository will require considerable additional research and site investigation. However, certain general characteristics which may affect the repository design were noted as follows:

(a) It is expected that groundwater inflow will continue for a lengthy period after the sealing of the repository and therefore contaminant transport away from the repository is unlikely during that period.

(b) The lifetime of the stainless steel cladding of 6-mm thickness may be in the range 1000 to 10 000 years, depending on groundwater chemistry. The cost of providing this cladding could be $500 million. If the rock permeabilities are low and the inflow period is long, the cladding may be redundant.

(c) Geochemical retardation may be a powerful and permanent factor for containment in both systematically jointed rocks and singular features. The design of a suitable retarding backfill should be investigated and may prove to be superior to stainless steel cladding in terms of cost and long-term performance.

Research and investigations are required into in situ groundwater velocity fields, joint systems and singular features, diffusion and convection of contaminants, leaching rates, corrosion rates, and natural and induced geochemical retardation. The objectives of the long-term containment monitoring program are difficult to define realistically because of the very slow response of the hydrogeologic system.

7. RADIOACTIVE WASTE HANDLING

For the surface facility requirements, consideration was given to such topics as shielding requirements, in-transit cooling, handling facilities, accounting, monitoring and decontamination, man-power and man-rem requirements.

A temporary surface storage facility will be required eith(as an independent facility or as part of a reprocessing facility. This will be required for normal operation with additional storage capacity for repository shutdowns. Some in-transit cooling may be required. Presently available hoists appear suitable for simple adaption for waste handling, although certain backup emergency systems will be required.

Because of the size of the repository, a monorail waste transport system appears most suitable. Remote handling should be used since this would minimize shielding requirements on the transporter. No insurmountable technical barriers were identified in this study.

8. RETRIEVABILITY, DECOMMISSIONING, SEALING AND MONITORING

Retrievability of the radioactive waste packages is intimately related to the emplacement concept and the associated thermomechanical and thermochemical behavior of the waste package and site rock. Extensive analyses are recommended to assess waste retrievability properly. These studies should begin prior to specific site selection.

The safe decommissioning of the waste repository can be per formed if adequate sealing of the facility and monitoring of the domain can be assured. For these reasons, the determination of safe decommissioning is dependent on a variety of supporting study efforts.

State-of-the-art methodology for underground excavation and exploration borehole sealing is sufficient (although expensive) for short-term sealing; however, long-term sealing has yet to be demonstrated. Therefore, experiments and analysis methodology for long-term sealing methods must be developed to verify the acceptability of any proposed sealing techniques.

Monitoring instrumentation adequate for the operational period of the repository is presently available. Much of this instrumentation may be adequate for long-term monitoring. However, experiments and analysis methodology for demonstration of the ability of instrumentation to operate over a long period of time must be developed.

9. ALTERNATIVE CONCEPTS

Five underground emplacement concepts were considered:

- floor drill-hole (reference concept, 250 W and 2500 W)
- in-room (floor) emplacement (250 W)
- floor-trench concept (250 W)
- long drill-hole concept (250 W)
- hot shaft concept (250 W).

A description of each concept with summary comments on their containment and operational features is given in Figure 3. These concepts were developed on the basis of a gross thermal loading of 32 W/m^2. A higher gross thermal loading of 125 W/m^2 was also considered in the first two concepts, although this loading appears too high unless a substantial cooling system is provided. The feasibility of these thermal loadings remains to be checked in future studies. The size and cost of the repository is directly related to the thermal loading.

The trade-offs between operation and construction costs remain to be optimized in future conceptual studies. The only concept which appears clearly unsatisfactory at this stage is the in-room concept owing to the requirement for radiation shielding and continuous ventilation to provide heat removal.

In addition to the schemes in Figure 3, the effect of an order-of-magnitude increase in canister thermal power to 2500 W in the reference concept was assessed. In this case, the room layout and ventilation systems were kept the same as the 250 W reference concept with a gross thermal loading of 32 W/m^2. This system allows a reduction by a factor of 10 in the number of drill holes for canister emplacement. Since hole-drilling is a major part of the construction cost, this may offer a significant cost saving. However, the local temperatures are high and may require a lower gross thermal loading.

Preliminary consideration was also given to the layout and operation of a multiple-level facility. The multiple-level repository concept offers advantages in terms of the efficiency of the emplacement operation and in the general reduction of haulage distances. In addition, its compact layout in plan may increase the reliability of the site investigation results and the waste containment system. Although the average round-trip haulage distances will be less, the total excavation required for the multiple-level repository is estimated to be as much as 10 percent greater than that for the single level repository facility.

10. COST ESTIMATES

Preliminary cost estimates for the construction of the various conceptual repositories are summarized in Table 2.

It should be stressed that these are preliminary estimates. Such items as emplacement equipment, sealing, monitoring, maintenance and ventilation cooling have not been included, although the costs of monorail tracks for emplacement are included. Additional costs which are common to all concepts include $10 million for underground handling and $6 million for surface facilities.

Various alternative room and canister cooling systems warrant research effort, since they could significantly reduce mining costs. It can be seen that the cost of drilling canister emplacement holes is a major factor in the reference case. Research into drilling techniques for large-diameter holes is recommended.

It was concluded that repository depth has little bearing on the overall cost within the depth range 500 to 1500 m. The multiple-level concept is expected to have approximately the same capital cost, but should have several operational advantages over the single-level concept.

In summary, the capital cost of constructing a repository to contain the reprocessed wastes in 1 082 000 canisters after extraction of 99.5 percent of the plutonium and uranium from 700 000 Mg of spent fuel probably lies within the range of $400 to $800 per canister, which corresponds to less than 0.02% of the value of the electricity sold. The capital cost of the test facility was estimated to be of the order of $50 million, including research and development to that stage. (The cost estimates are in 1976 dollars).

11. RESEARCH AND DESIGN ENGINEERING NEEDS

One of the purposes of this overall study effort was to assess the research and design engineering required for the development and operation of an underground waste disposal facility. As illustrated in Figure 4, six programs have been identified and their component study elements defined[1].

These programs are

- environmental studies and safety analyses
- geotechnical investigations
- hydrogeological and geochemical research and investigation
- rock mechanics research
- radioactive waste packaging research and design
- repository design.

In addition to delineating the goals of each program, cost estimates and manpower requirements for program implementation were provided. Excluding the environmental studies and safety analysis, a cost of approximately $110 million (1976) will be required over the next 75 years.

12. CONCLUSIONS AND RECOMMENDATIONS

A preliminary reference concept has been developed of an underground repository which could be constructed at a cost in the range of $400 million to $800 million. The corresponding unit costs range from $0.60 to $1.20 per kg of fuel or approximately 0.01 to 0.02 mills per kWh of electricity generated.

No insurmountable construction problems were identified based on preliminary analyses using estimated hard rock data. No reliable conclusions can be drawn regarding long-term waste containment until actual site data on hydrogeological properties are available. However, it appears likely that hard rock with good containment properties can be found in the Canadian Shield.

It therefore appears appropriate that the hard rock development program should proceed into the detailed site study stage and repository conceptual studies should be continued.

13. REFERENCES

1. Acres Consulting Services Limited, "Radioactive Waste Repository Study", Atomic Energy of Canada Limited Report, AECL-6188-1 (1978).

2. Acres Consulting Services Limited, "Radioactive Waste Repository Study", Atomic Energy of Canada Limited Report, AECL-6188-2 (1978).

TABLE 1

TIMETABLE OF EVENTS FOR THE DEVELOPMENT AND OPERATION OF AN UNDERGROUND RADIOACTIVE WASTE ISOLATION FACILITY

Time	Event
1975 - 1976	Preconceptual facility design, feasibility studies, planning
1976 - 1980	Geological concept verification
1977 - 1979	Conceptual facility design
1980 - 1983	Selection of facility site
1980 - 1982	Detailed facility design
1981 - 1982	Construction bids and negotiations
1983 - 1987	Test facility construction and mining: includes construction of requisite surface facilities, shaft-sinking, and excavation of mine level shaft station facilities and several radioactive waste disposal rooms for experimental purposes in the immediate vicinity of the shaft station
1986 - 2000	Test facility operation
1996 - 2000	Reassessment and refinement of detailed facility design Construction bids and negotiations Initiation of augmented surface facility construction, additional shaft sinking, and underground excavation for the first panel of waste disposal rooms Optional operation of test facility for emplacement of radioactive waste containers on a preproduction basis
2001 - 2025	Production repository excavation and radioactive waste emplacement
2023 - 2025	Reassessment and refinement of the detailed design for sealing, decommissioning, and monitoring of the facility
2026 - 2100(+)	Sealing, decommissioning, and monitoring of the facility.

TABLE 2

SUMMARY OF UNDERGROUND CONSTRUCTION COSTS

Concept	Canister Power (W)	Gross Thermal Loading (W/m^2)	Costs (Millions of 1976 dollars)			
			Shafts	Headings	Emplacement	Total
1 Floor drill-hole emplacement	250	32	30	300	360	690
(reference concept)	2500	32	30	300	70	400
2 In-room placement	250	32	30	300	80*	410
3 Floor-trench emplacement	250	32	30	300	455	785
4 Long hole emplacement	250	24	30	45	305	380
5 Hot shaft emplacement	250	32	30	35	475*	540

* No allowance for ventilation cooling.

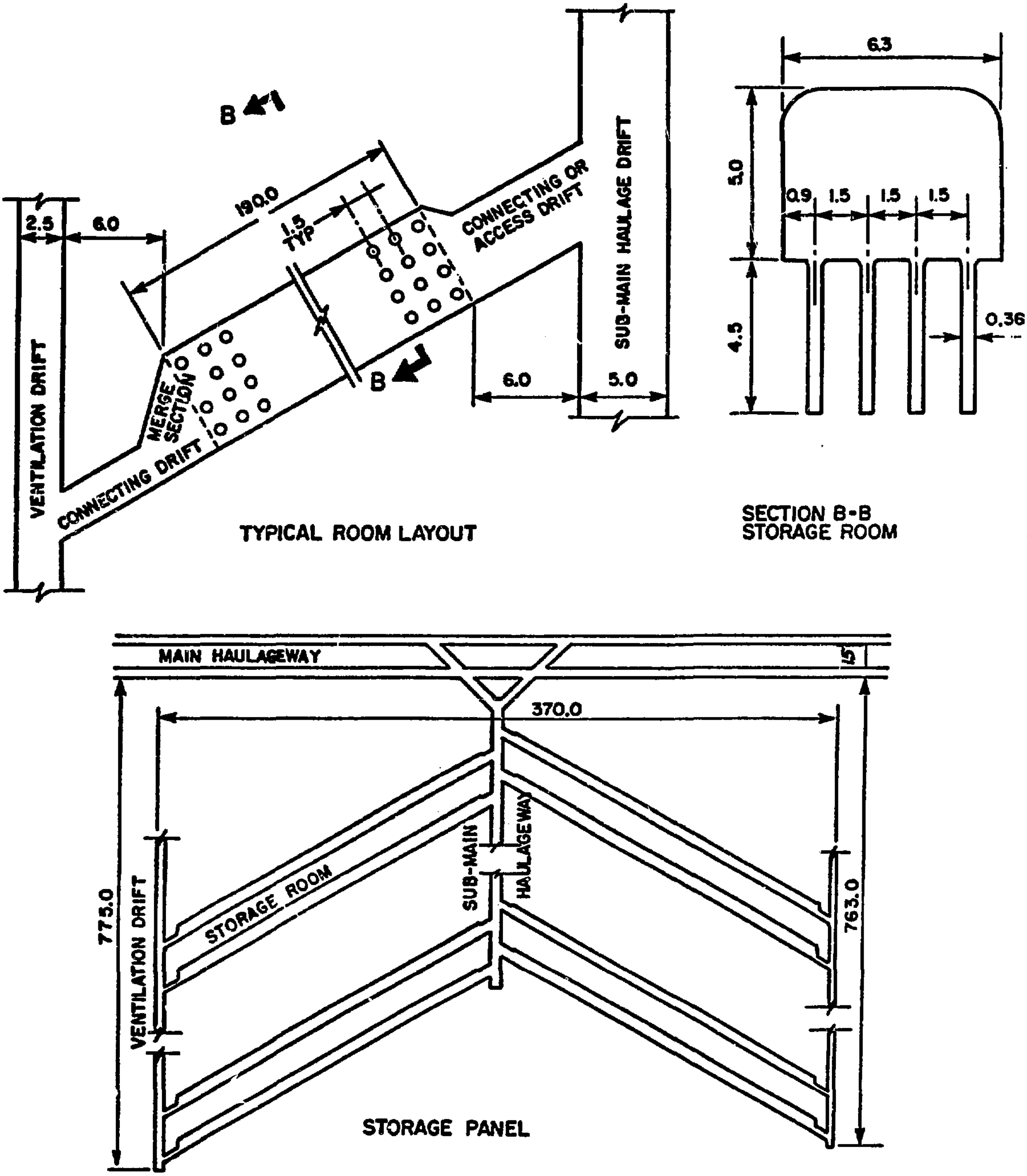


FIGURE 1: TYPICAL ROOM LAYOUT AND STORAGE PANELS (ALL DIMENSIONS IN METRES)

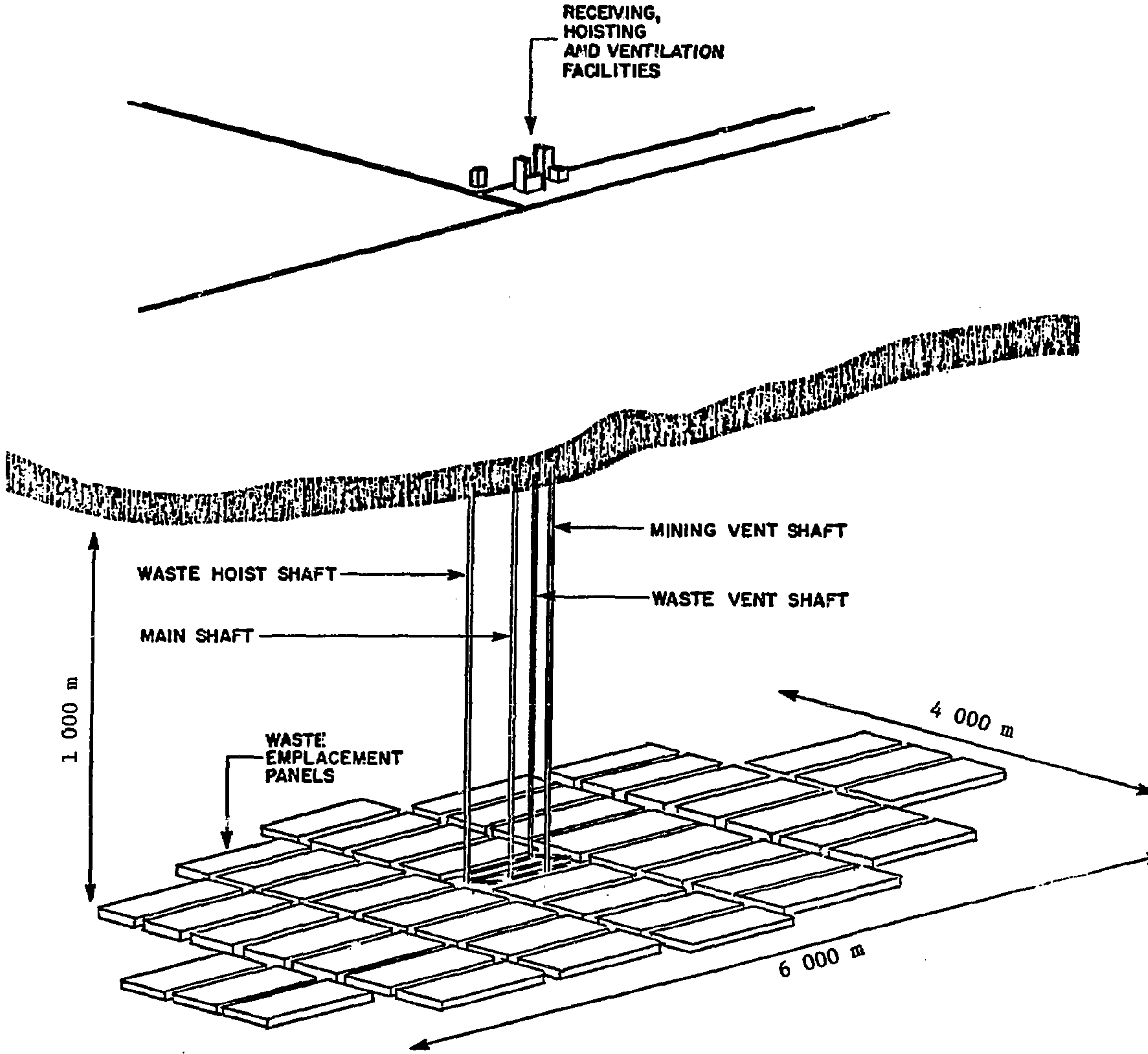
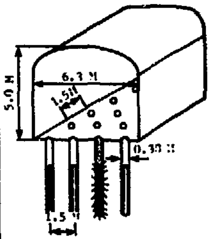
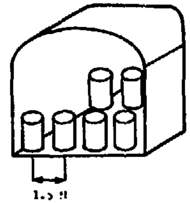
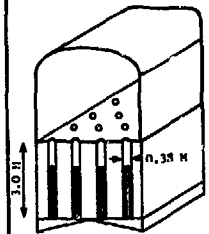
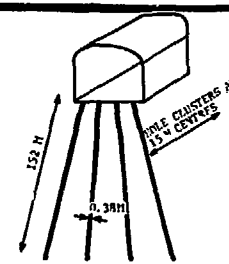


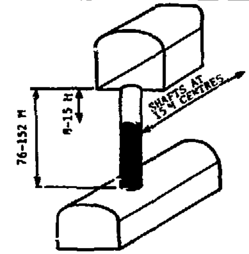
FIGURE 2: REFERENCE CONCEPT LAYOUT











CONCEPT		1. FLOOR-HOLE STORAGE ('BASELINE CONCEPT')	2. IN-ROOM STORAGE	3. FLOOR-TRENCH STORAGE	4. LONG-HOLE STORAGE	5. HOT SHAFT STORAGE
DESCRIPTION	MINE	LANE AND PILLAR. EXTRACTION RATIO 0.3	AS BASELINE CONCEPT	AS BASELINE CONCEPT	LANE AND PILLAR. EXTRACTION RATIO 0.03	LANE AND PILLAR AT TWO LEVELS. EXTRACTION RATIO 0.03
	EMPLACEMENT	INDIVIDUAL DRILLED HOLES IN ROOM FLOOR	IN-ROOM	INDIVIDUAL HOLES FORMED IN BACKFILLED TRENCH IN ROOM FLOOR	LONG HOLES IN CLUSTERS RADIATING FROM ROOM FLOOR	SHAFTS CONNECTING UPPER AND LOWER ROOM NETWORKS
CONTAINMENT	THERMAL	BASELINE GTL 32 W/m², HTL 106 W/m² ALTERNATIVE GTL 128 W/m². HTL 424 W/m² 250M and 2500M CANISTERS CONSIDERED	AS BASELINE-CONCEPT. ONLY 250M CANISTERS CONSIDERED	AS BASELINE CONCEPT. 250M CANISTERS	GTL 24 W/m². 250M CANISTERS	GTL 32 W/m². 250M CANISTERS
	GROUNDWATER	DIFFICULT TO CONTROL INFLOW TO DRILLED HOLES IN ROOM FLOOR. CANISTER CORROSION COULD COMMENCE IMMEDIATELY.	INFLOW TO ROOMS CAN BE CONTROLLED DURING EMPLACEMENT & SURVEILLANCE PHASES. INTIMATE CONTACT WITH EXTERNAL HYDROGEOLOGICAL REGIME IN LONG TERM.	GOOD OPPORTUNITIES TO CONTROL INFLOW DURING EMPLACEMENT & SURVEILLANCE PHASES. INTIMATE CONTACT WITH EXTERNAL HYDROGEOLOGICAL REGIME WITHOUT GEOCHEMICAL SEALING.	NO CONTROL POSSIBLE	INFLOW TO SHAFTS CAN BE CONTROLLED DURING EMPLACEMENT SURVEILLANCE PHASES. INTIMATE CONTACT WITH EXTERNAL HYDROGEOLOGICAL REGIME WITHOUT GEOCHEMICAL SEALING.
	ROCK STABILITY	SPALLING MAY BE A PROBLEM IN ROOMS AT THE HIGHER THERMAL LOADINGS, AND IN HOLES WITH THE HOTTER CANISTERS.	SPALLING MUST BE PREVENTED, PROBABLY BY VENTILATION INITIALLY.	AS BASELINE CONCEPT BUT FURTHER STUDY REQUIRED, PARTICULARLY IN NEAR FIELD.	LOCALIZED PROBLEMS MAY OCCUR IN HOLES AND ROOM FLOOR.	SPALLING MAY BE A PROBLEM IN SHAFTS AND "HOT SPOTS".
	RADIATION	GOOD SHIELDING WHEN HOLES ARE PLUGGED.	NO SHIELDING WITHIN ROOMS.	PROBABLY SIMILAR TO BASELINE CONCEPT, BUT FURTHER STUDY REQUIRED.	AS BASELINE CONCEPT.	POTENTIALLY GOOD IN ROOMS, BUT NOT IN SHAFTS. REQUIRES FURTHER STUDY.
	SEALING	GOOD SEALING POSSIBILITIES AT EVERY STAGE (HOLES, ROOMS, SHAFTS)	MORE DIFFICULT IF ROOM SEALING REQUIRED.	AS BASELINE CONCEPT WITH GOOD POSSIBILITY OF USING GEOCHEMICAL SEALING IN TRENCHES.	AS BASELINE CONCEPT.	GOOD POSSIBILITY TO USE GEOCHEMICAL SEALING IN SHAFTS.
OPERATION	RETRIEV-ABILITY	GOOD	GOOD WITH REMOTE EQUIPMENT	GOOD	VERY POOR. RISKS OF HOLE CLOSURE AND CANISTER DAMAGE.	UNSTACKING REQUIRED, BUT POTENTIALLY SATISFACTORY.
	MONITORING	GOOD POSSIBILITIES	DIFFICULT BECAUSE OF LACK OF MAINTENANCE OPPORTUNITIES.	GOOD POSSIBILITIES	VERY POOR. COMPLEX REMOTE EQUIPMENT REQUIRED.	POOR. COMPLEX REMOTE EQUIPMENT REQUIRED.
	ACCESS (SAFETY)	GOOD	RELATIVELY DIFFICULT	GOOD	GOOD TO ROOMS ONLY	GOOD TO ROOMS ONLY
	MAINTENANCE	STRAIGHTFORWARD (BECAUSE OF GOOD SHIELDING)	RELATIVELY DIFFICULT (BECAUSE OF LACK OF SHIELDING IN ROOMS)	MORE DIFFICULT THAN BASELINE CONCEPT	GOOD FOR ROOMS. DIFFICULT FOR CANISTERS.	GOOD FOR ROOMS. DIFFICULT FOR CANISTERS.
	VENTI-LATION	REQUIRED DURING CONSTRUCTION. MAY BE DESIRABLE FOR HEAT REMOVAL	CONTINUOUS VENTILATION PROBABLY REQUIRED FOR HEAT REMOVAL UNTIL END OF SURVEILLANCE PHASE.	AS BASELINE CONCEPT	REQUIRED DURING CONSTRUCTION, BUT NOT FEASIBLE FOR HEAT REMOVAL.	CONTINUOUS VENTILATION PROBABLY REQUIRED FOR HEAT REMOVAL UNTIL END OF SURVEILLANCE PHASE ASSISTANCE POSSIBLE FROM "CHIMNEY EFFECT" IN SHAFTS.
UNDERGROUND CONSTRUCTION COST ESTIMATES ($ MILLIONS)		145-490	125-410	275-795	380	540

FIGURE 3: SUMMARY OF MAJOR FEATURES OF ALTERNATIVE REPOSITORY CONCEPTS

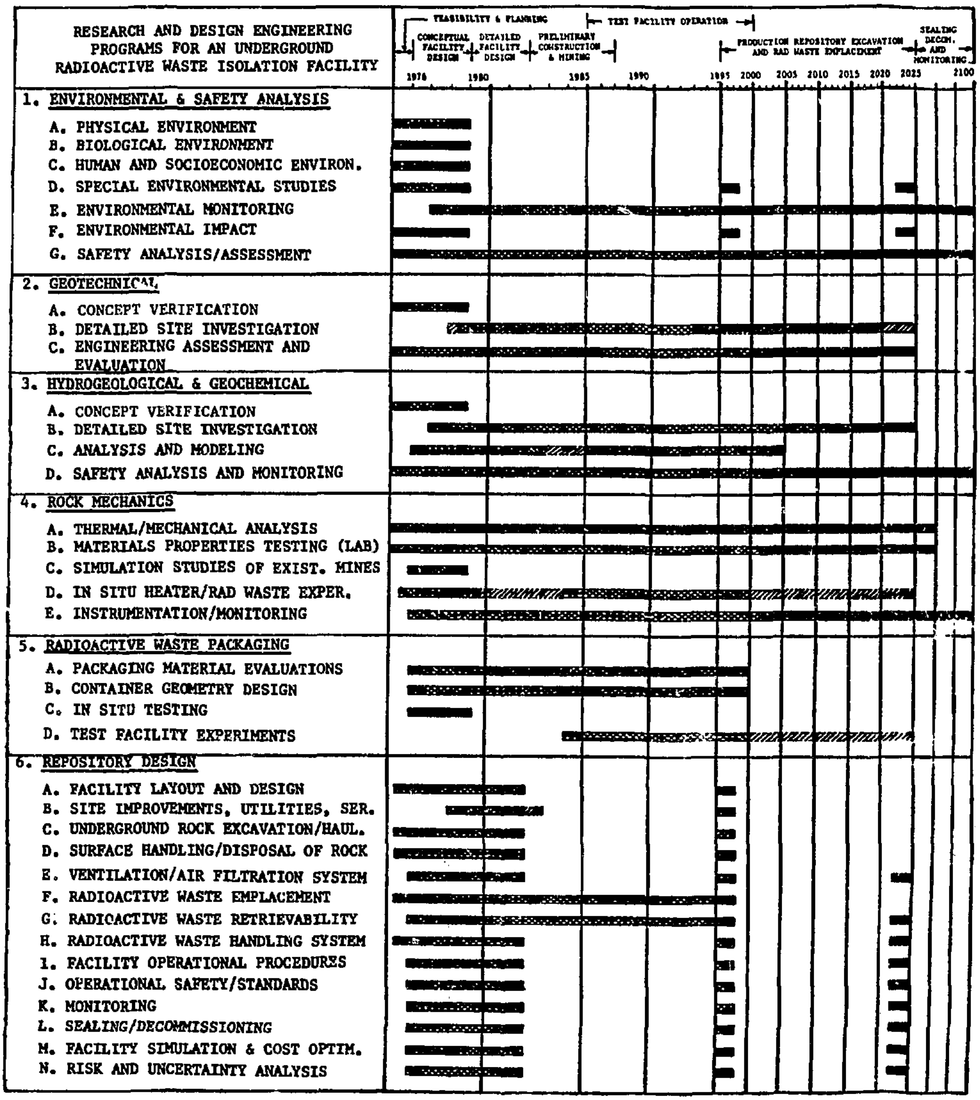


FIGURE 4: RESEARCH AND DESIGN ENGINEERING PROGRAMS

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