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NATIONAL BOARD FOR SPENT NUCLEAR FUEL

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THE SWEDISH GEOLOGIC REPOSITORY

Contribution at NWTRB's Full Board Meeting on An Evaluation of Thermal Loading of Geologic Repositories for High-level Radioactive Waste

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The title of my presentation has been given by the Board. It is broader in scope than the subject of this meeting. That is helpful since the thermal loading of the conceptual Swedish geologic repository has on the whole not been a controversial issue. What I can say about thermal loading may be commonplace, but I have also been asked to explain the rationale leading to the proposed repository design including the reasons for a 100 C temperature limit for the waste package.

Background to Swedish repository development

The available geology is obviously the most important factor governing the choice of a repository concept. We are restricted in our choice to pre-cambrian, hard, fractured rock, which is almost everywhere saturated up to ground level. The considerations we have made and the options we have preferred are, we hope, appropriate for our circumstances. They may not be appropriate at all in other geologic contexts. You should keep this in mind all through my presentation.

The choice of repository design was made abruptly rather than after careful deliberations, because a situation arose where prompt action was needed. Nuclear power had initially been well thought of in Sweden. When the nuclear opposition spilled over to Sweden from abroad years before Three Mile Island and Chernobyl, the opposition focused on the unresolved issue of how to dispose of the long lived radioactivity in the spent nuclear fiuel. This concern became expressed politically in the Stipulation Act which required that the owner of a nuclear reactor had to describe how the spent fuel would be managed and disposed of before he could obtain permission to fuel the reactor for the first time.

The nuclear utilities, unprepared for this requirement, established a task force, the KBS-group, with assignment to prepare a report, which should describe in broad but extensive detail how HLW could be disposed of with "absolute safety" as the requirement was formulated in the Act. They were pressed for time since several reactors were in the pipe-line. There aim [illegible] method which could be implemented with established

technologies and which had, to the extent possible, convincing safety characteristics. They opted for strong engineered barriers. Credible safety was the main issue, economy, retrievability or repairability were of secondary importance to the extent they were considered at all.

The first report from the KBS group, the KBS-1 report, described a method to dispose of vitrified high level waste from reprocessing. It was conceived, supported by site investigations, and published within one year, an impressive achievement in my opinion. The government approved of the report after a comprehensive review, including an international remit which made the report well-known abroad.

A second report on disposal of spent nuclear fuel as such followed within another year.

A third report KBS-3, also on disposal of spent fuel, was published in 1983, when the utilities had ran out of reprocessing contracts and two more reactors were due for commissioning. This report again was reviewed by Swedish and international review groups and approved by the government for its purpose to allow fuelling of new reactors.

Are we in Sweden bound to the KBS design and conservative data now that this concept has passed two extensive national and international reviews and been approved by two governments? No! The same governments have stated repeatedly that SKB, the nuclear utilities arm for waste management, shall continue to search for the "best" solution to disposal.

SKB has also extended their studies to other concepts and I will use two of these to illustrate our approach to disposal credibility, safety and also cost efficiency

Philosophy and rationale of the Swedish repository design

The KBS-3 design is the design in figure 1 with waste packages in vertical pits drilled in the floors of tunnels at some 500 m depth in our bedrock. The waste package consisted originally of spent fuel assemblies embedded in lead to attenuate the radiation and surrounded by a cylindrical shell of copper (fig 2). This design has recently been changed to one where the copper mantle is supported by steel (fig 3), so that this shell can stand the external pressure without buckling. This allows for a free choice of filler material which can suitably be selected to suppress fuel leaching once the shell has been penetrated by groundwater. It will anyhow take a very long time for groundwater to penetrate the shell if the penetration is caused by corrosion, provided that the environmental conditions are benign. The buffer material around the waste package shall take care of that. This buffer is made of compacted bentonite, a clay which swells when soaked by ground water and then prevents further percolation of ground water past the canister surface. Passage in or out of the bentonite is only possible by diffusion and passing particles must be small since bentonite forms a tight sieve.

The new design places the canisters along the center-line in drilled tunnels at similar depth (fig 1). The waste package, fig 4, is larger. It has twice the external diameter of the first package and contains more fuel, 24 BWR assemblies compared with 8 to 9 in the earlier designs. Fig 5 illustrates consecutive steps in the excavation and loading of the tunnels.

This design is much more economical than the KBS-3 design. The excavated volume in the tunnel alternative is about a third of the KBS-3 excavation volume to mention just one cost saving aspect.

The designs differ but the principle remains. Use long-lived canister materials to protect the fuel, use bentonite, a naturally occuring clay of volcanic origin, to protect the canister.

There is one rationale for this reliance on engineered barriers which has gained ground steadily with time. Originally, the common wisdom was that the natural barrier, the host rock, was the only barrier which could be trusted in the long term. The rock had been there for the last billion years and should remain, perhaps not for billions but at least for millions of years. Man made barriers could not be trusted over a time period which is far longer than the history of technology and industrial production. This argument has some merit, but it has proven difficult to build confidence around the natural barrier. There is seemingly no end to the objections various specialists on colloids or organic acids or microbes in the bedrock and groundwater can raise against quantitative assessments of the capability of the host rock to retain radionuclides, not to mention the chronic difficulties to chart the groundwater paths through the rock.

This is not meant to imply that the bedrock is useless as a barrier against radionuclide migration to the biosphere, only that its usefulness is difficult to quantify and validate, and therefore also difficult to account for, credibly, in a safety analysis of the total system performance.

The engineered barriers are in comparison more tractable to validation. Their properties can be studied in depth. Their long term function can be validated - for the canister by the laws of thermodynamics, for the fuel matrix by laboratory measurements and observations at next to atomic scale resolution, and for bentonite by natural analogues. The overall long term capacity of the bedrock to protect the engineered barriers can also be validated by the geologic record, whereas the present, detailed characteristics of e g the geohydrological regime are difficult even to determine by observations.

Thermal loading of the repository

The temperature in the surrounding rock was maximised to 80 C already in the first KBS-report. The canister was made of steel at that time, the buffer of quartz sand. None of these imposed any temperature limit. Instead the temperature limit was dictated by concerns that excessive thermal expansion of the surrounding rock mass would cause adverse rock mechanical consequences. Remember that this first study was made on a tight time schedule. There was no time for more sophisticated analyses than absolutely necessary. Conservatism saved time.

The rock mechanics problem might have been sorted out given sufficient time and incentive. But SKB had in the meantime changed from quartz sand to bentonite as buffer material, and bentonite sets a solid stop for temperature excesses. Somewhere not far above 100 C, bentonite starts to convert to illite in the presence of potassium ions, and the buffer loses its swelling properties at an unacceptable rate. The bentonite temperature is clearly the most important reason for our conservative thermal loading in the repository.

The development with time of the temperatures around the repository is illustrated in fig 6 to 8 for the original design and in fig 9 for the tunnel design. The trend towards less conservatism is there.

I said as an introductory remark that the thermal loading of our repository had not been a controversial issue in our repository development. There has been an exception to this. We studied some years ago an ingenious repository design, the WP-Cave. It had a different approach. A large amount of fuel, 1 000 to 1 500 tons, was emplaced in a configuration designed to promote natural convection of the decay heat away from the fuel canisters. The whole fuel loading was surrounded at a distance by a common ground water barrier of a sand-bentonite mixture in combination with a hydraulic cage. This repository is intended as a dual purpose facility. Initially it should serve as an airfilled interim storage, while the most intense decay heat is dissipated to the atmosphere via heat exchangers. After this initial cooling time, the repository is backfilled with coarse sand and water and sealed. The economy of the design called for high temperatures up to 150 C in the centre of the cavity after sealing.

One of the factors sinking this concept, or putting it on the shelf for the moment, was a remark by one of our authorities on chemistry that it would take at least 1 000 man-years to develop a satisfactory thermodynamic data base for the chemical reactions in the rock-groundwater-canister-system at these temperatures.

I would rate this type of concern about the data-base as the second most important reason for us to stay away from high repository temperatures.

We are also studying since some years, the interactions between rock mass tempertature, rock stress fields, their impact on fracture openings and the coupling to thermal buoyancy effects on groundwater circulation. It is a complex issue. Firm conclusions are yet to be reached. Higher temperatures would of course make this problem even harder to tackle and more important to solve. I rate this as the third most important reason to stay cool.

You might object that if we trust our engineered barriers to carry the burden of proof of safety, then we need not worry about thermally induced impacts on the surrounding rock-groundwater system, but remember that we trust our engineered barriers provided we give them a benign environment. We do not want to violate favourable environmental conditions by adventures into high temperatures.

As I said in the beginning, the temperatures in our repository have not been much in focus in our development work since they have been low, and I have been somewhat categorical on this point in my presentation. We may not have looked into this issue at the depth it deserves. I look forward to the presentations and discussions during these days. I may gain insights we have missed so far but can use with advantage in our future work.

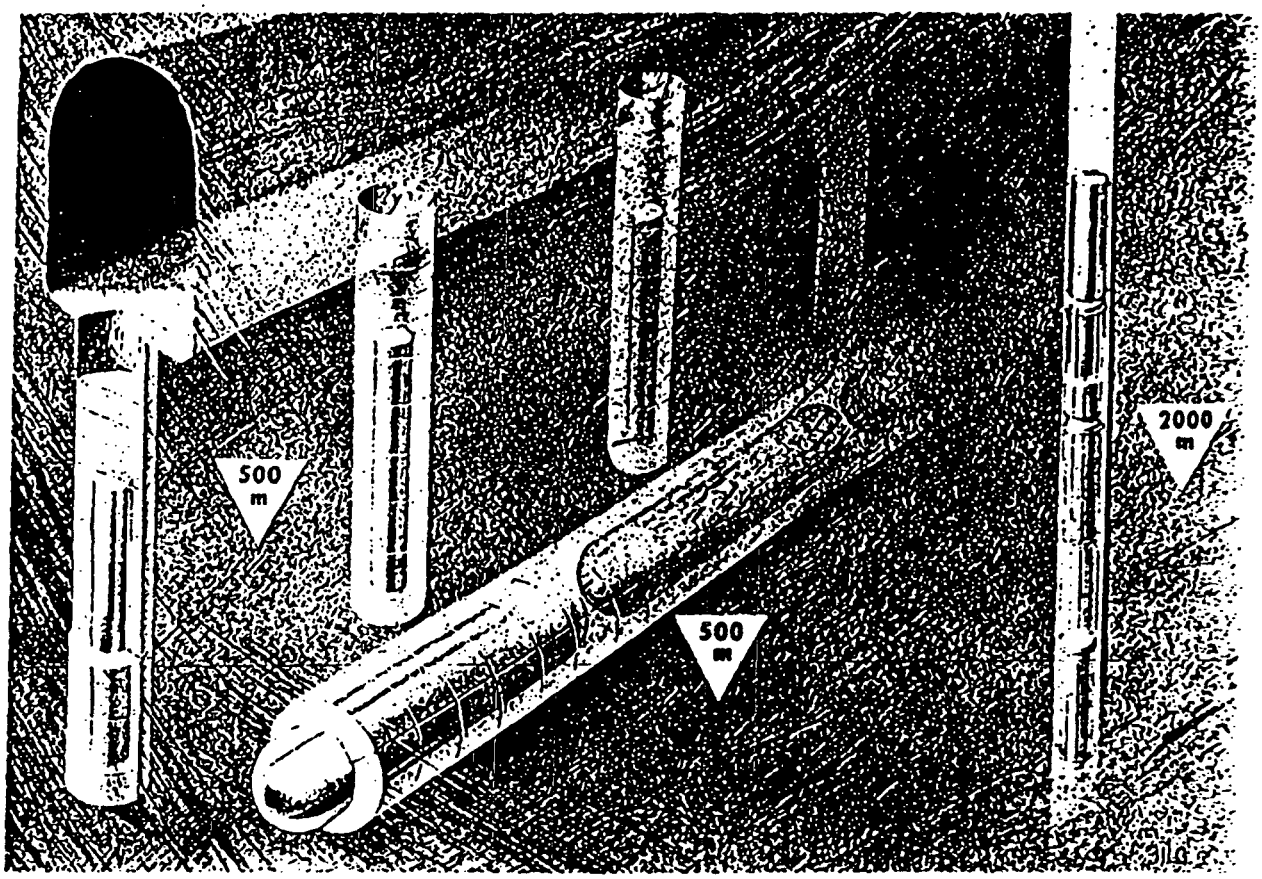


Figure 1. Left; KBS-3 - The Swedish reference concept for final spent fuel disposal with deposition holes containing one canister each.
Middle; VLH - An alternative concept with bigger canisters in a long deposition drift made by full face boring machine (TBM).
Right; VDH - An alternative concept with smaller canisters deployed in vertical deep boreholes.
In all concepts the canisters are surrounded by a buffer of bentonite clay.

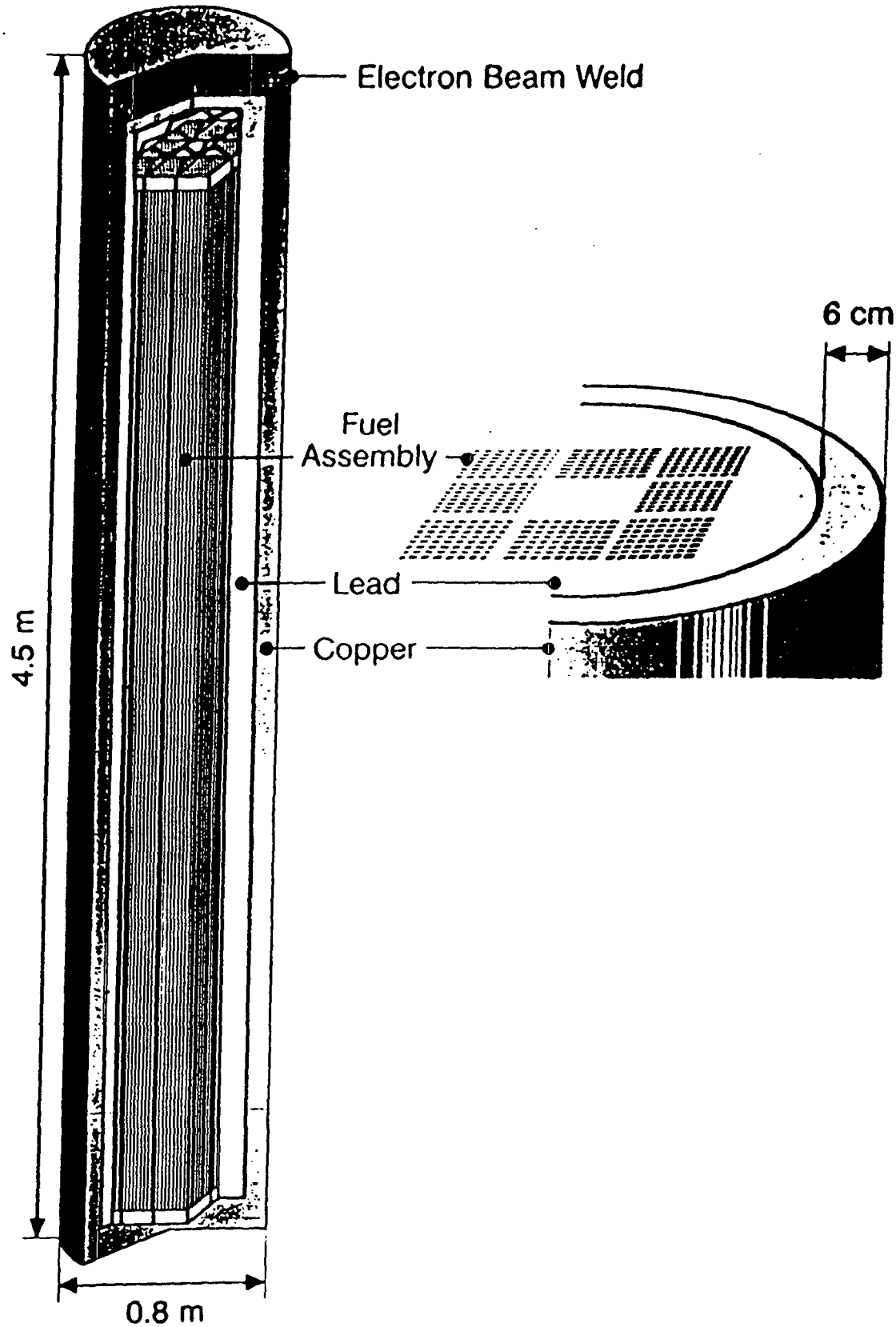
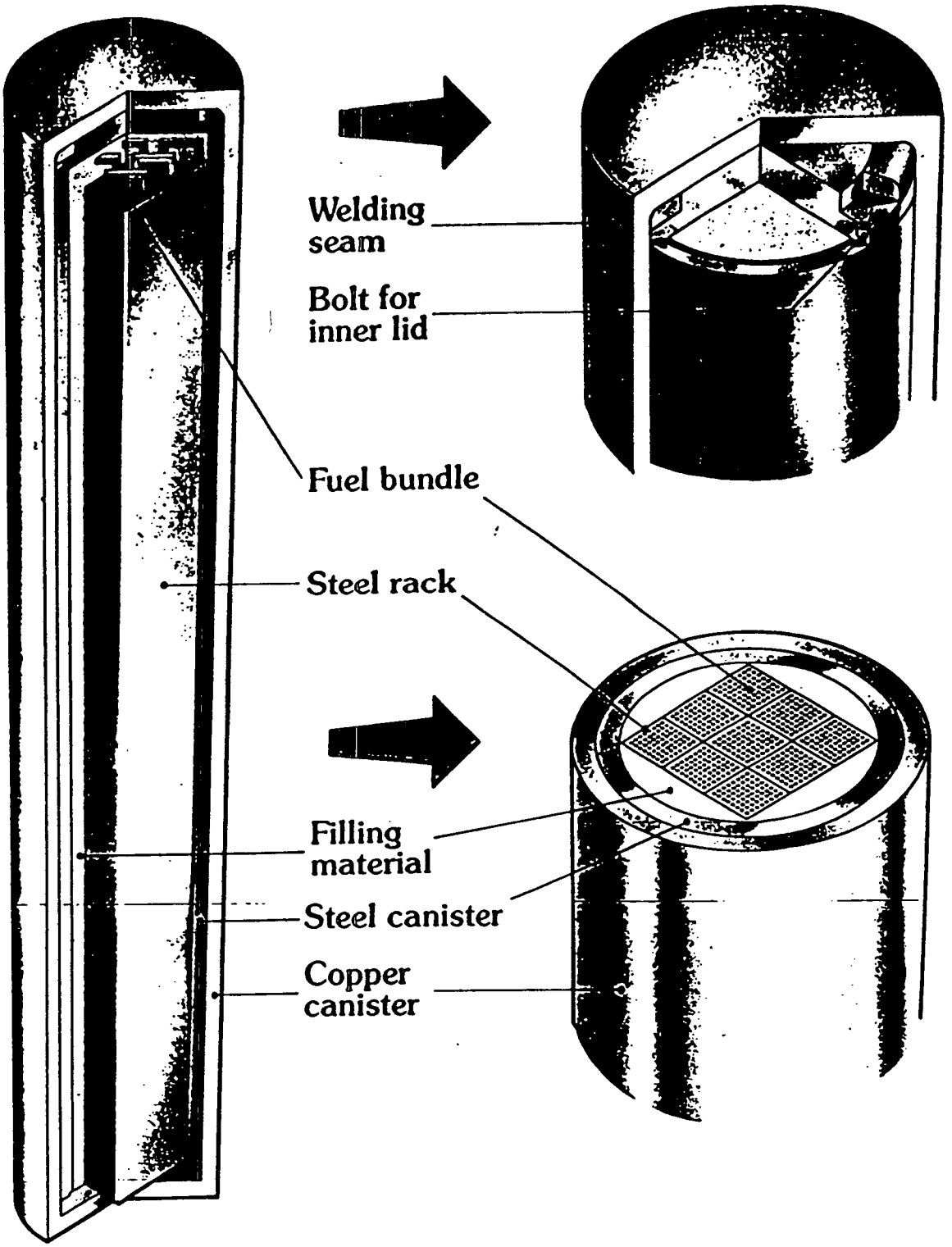


Figure 2. Copper - lead fuel canister.



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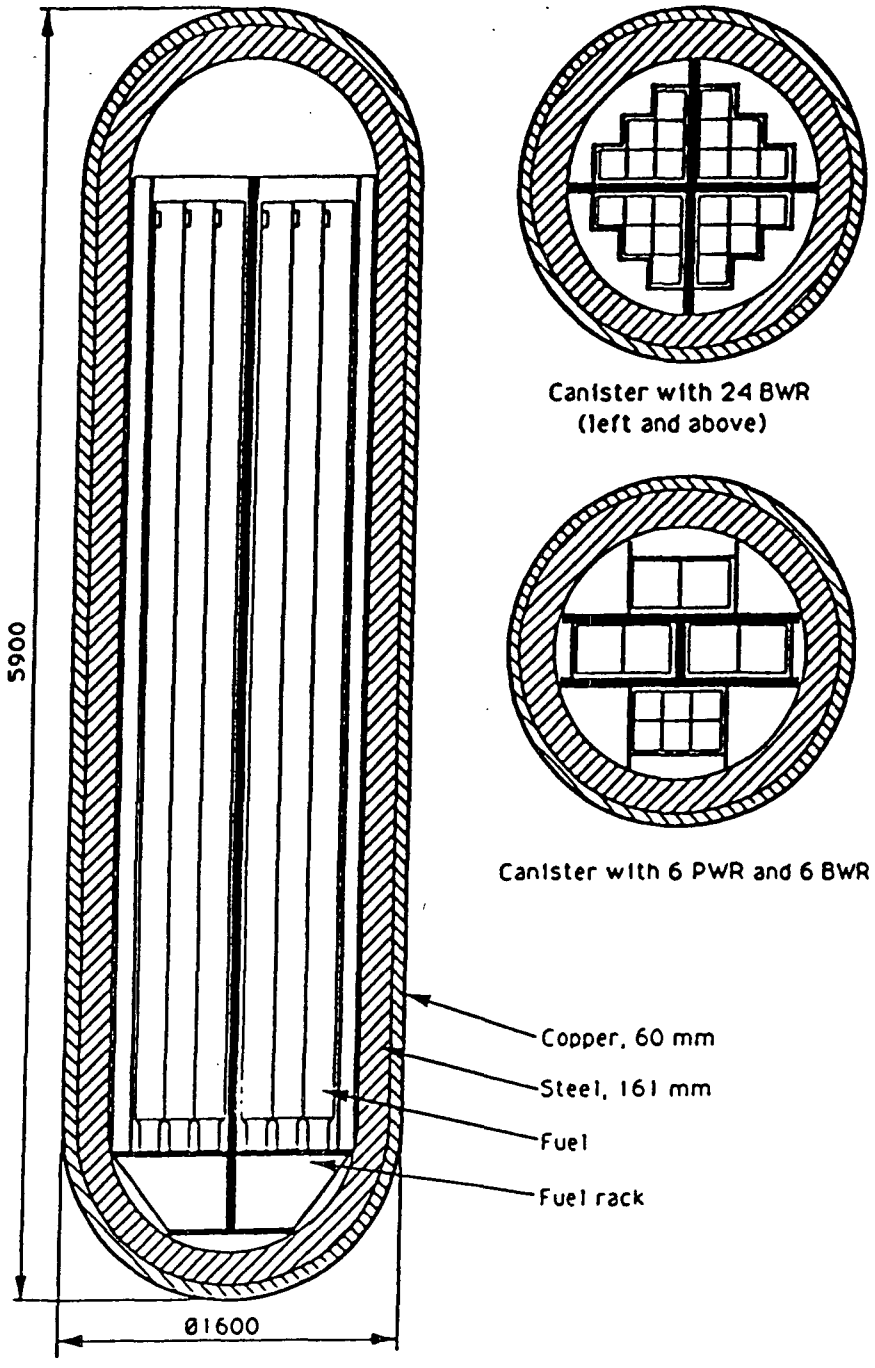


Figure 4. Fuel canister for long horizontal tunnels.

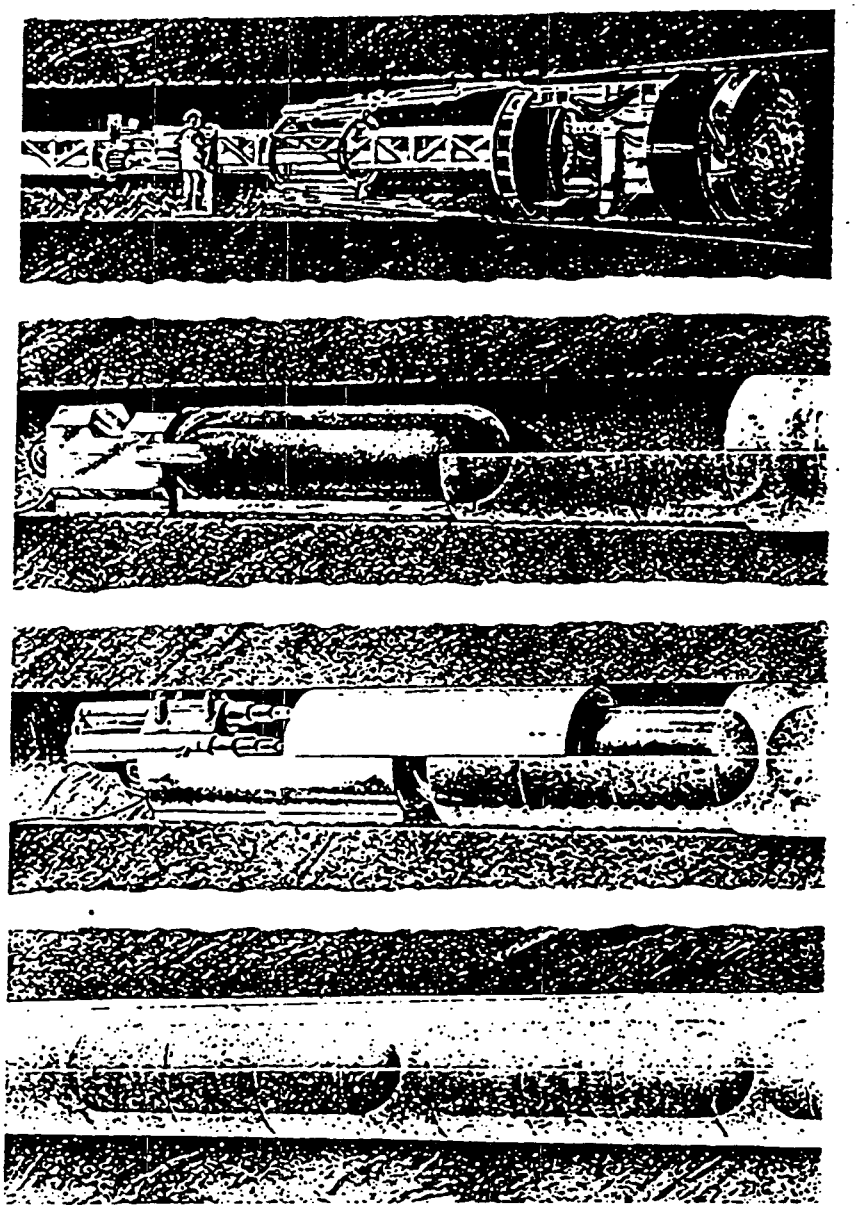
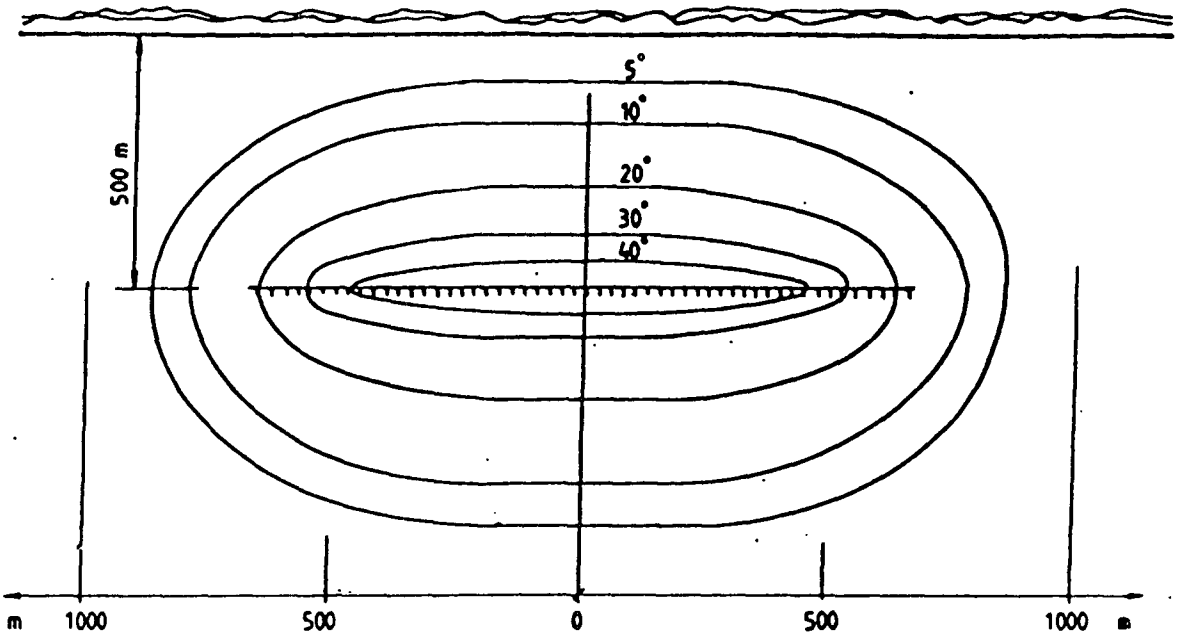
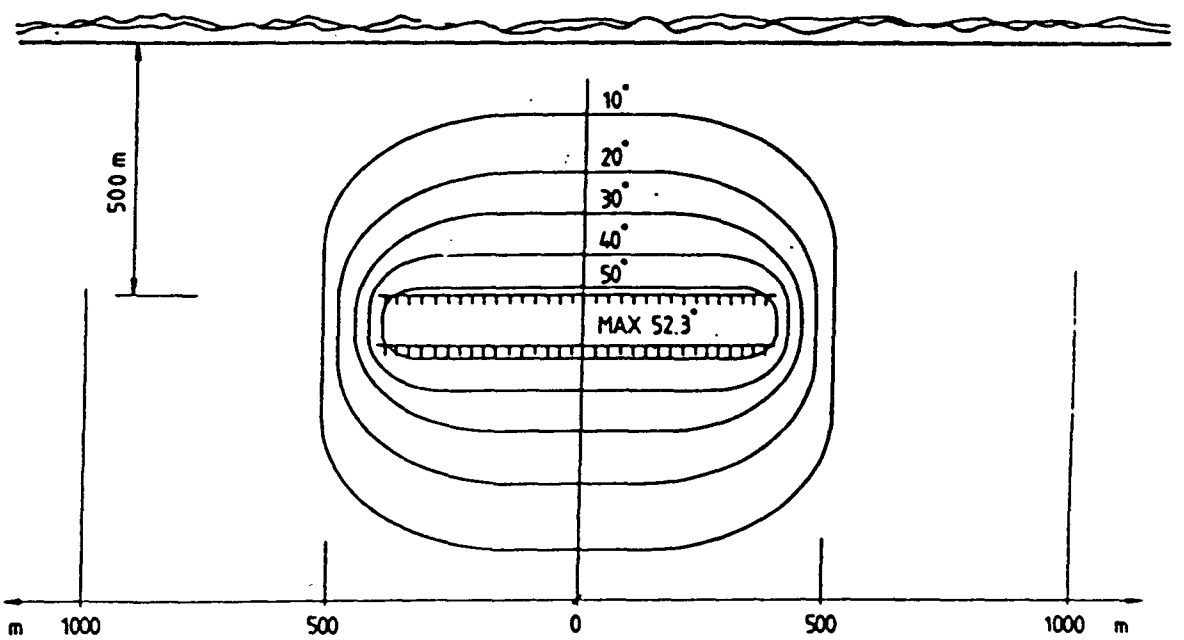


Figure 5. Full face boring of long tunnels, deposition of canisters and emplacement of bentonite buffer.



TEMPERATURE INCREASE IN BED-ROCK AROUND THE FINAL STORAGE
960 YEARS AFTER DEPOSITION ALT. 1A



TEMPERATURE INCREASE IN BED-ROCK AROUND THE FINAL STORAGE
960 YEARS AFTER DEPOSITION ALT. 14 A

Figure 6. Temperatures around the KBS-3 repository, single-layered viz two-layered design.

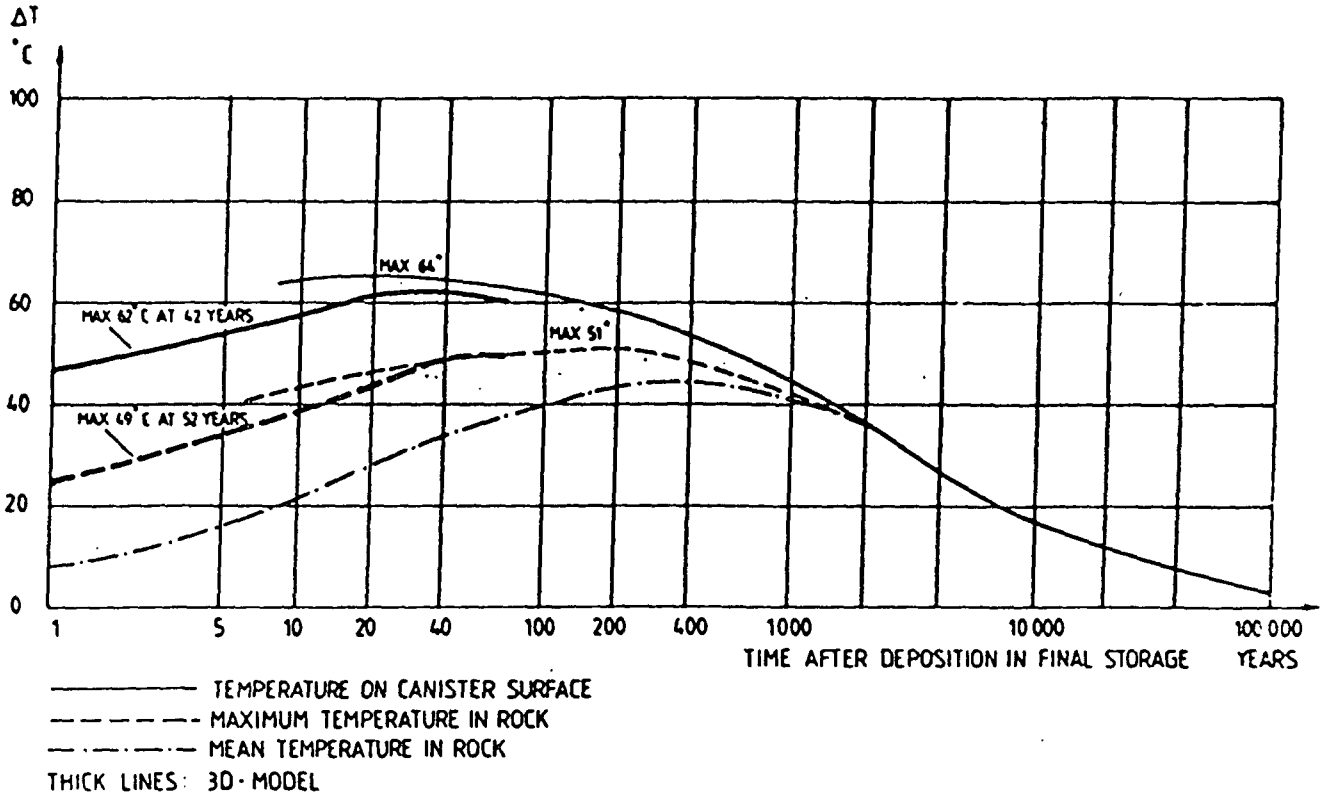


Figure 7. Centrum temperature as a function of time for a single-layered KBS-3 repository.

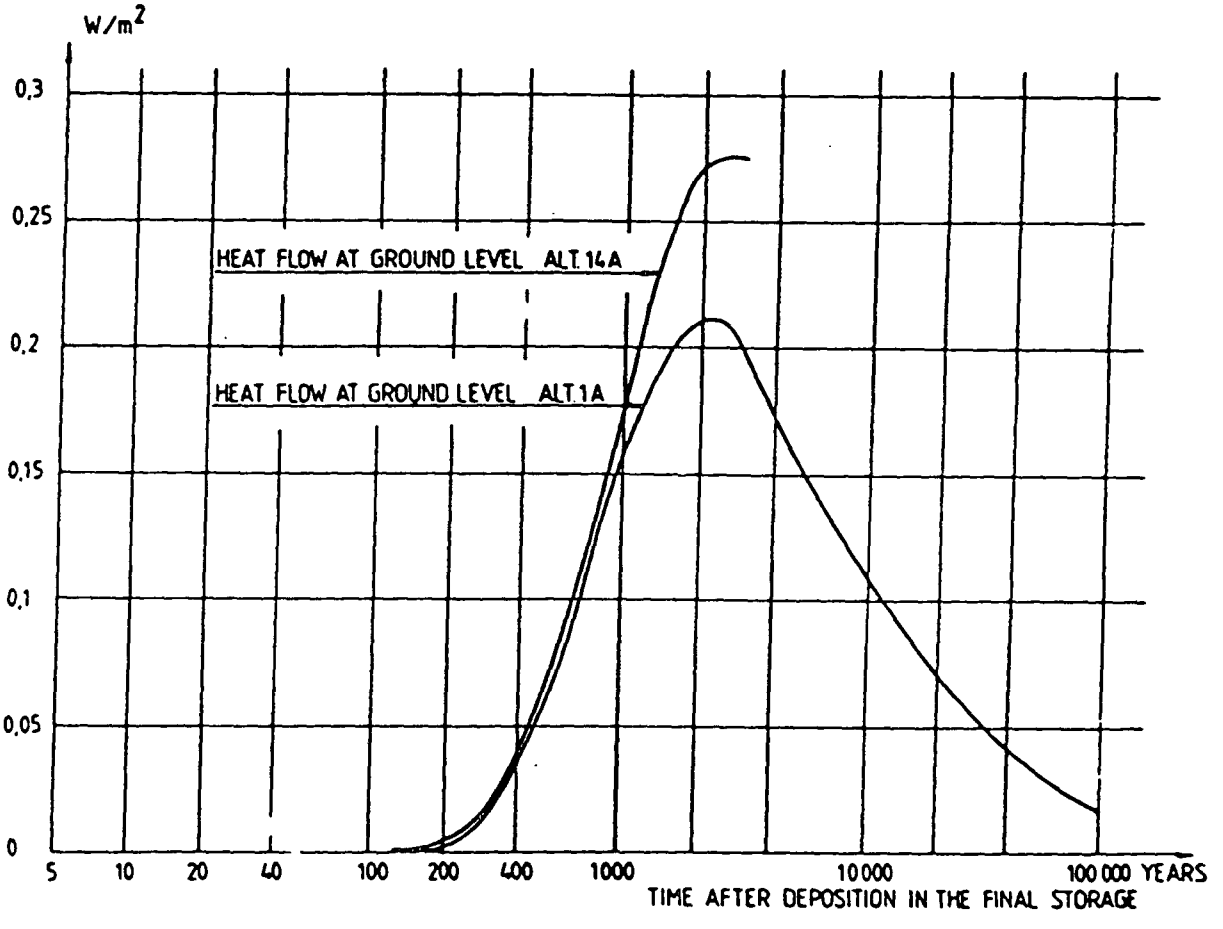


Figure 8. Heat flow at ground level as a function of time for a single

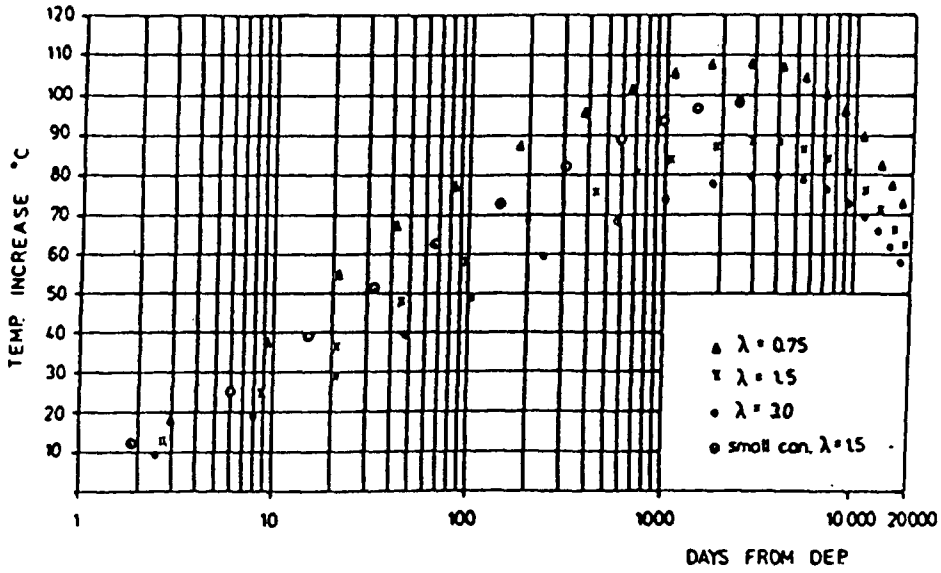
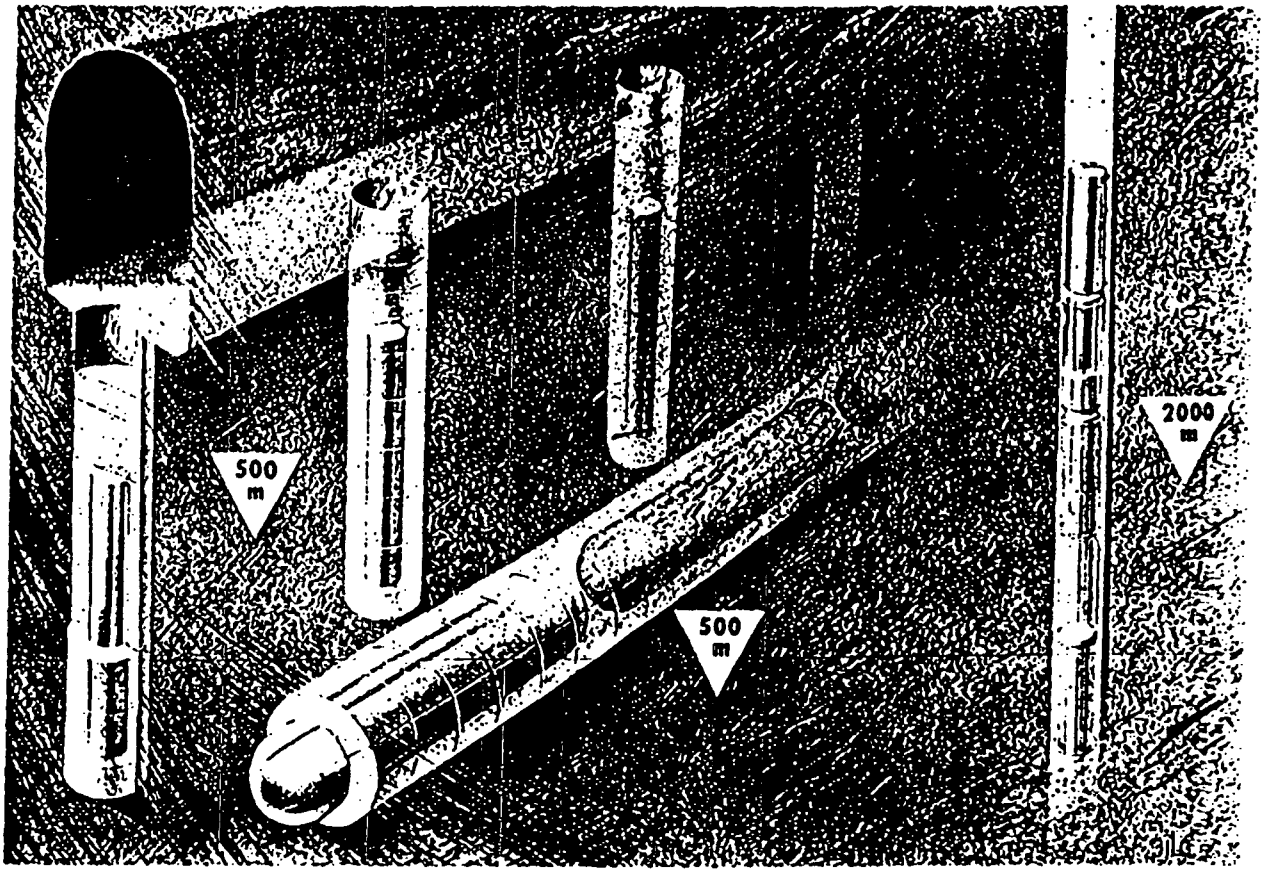


Figure 9. Maximum temperature in the bentonite as a function of time for the bored tunnel alternative. The parameter lambda denotes heat conductance in the bentonite which depends on the water saturation.



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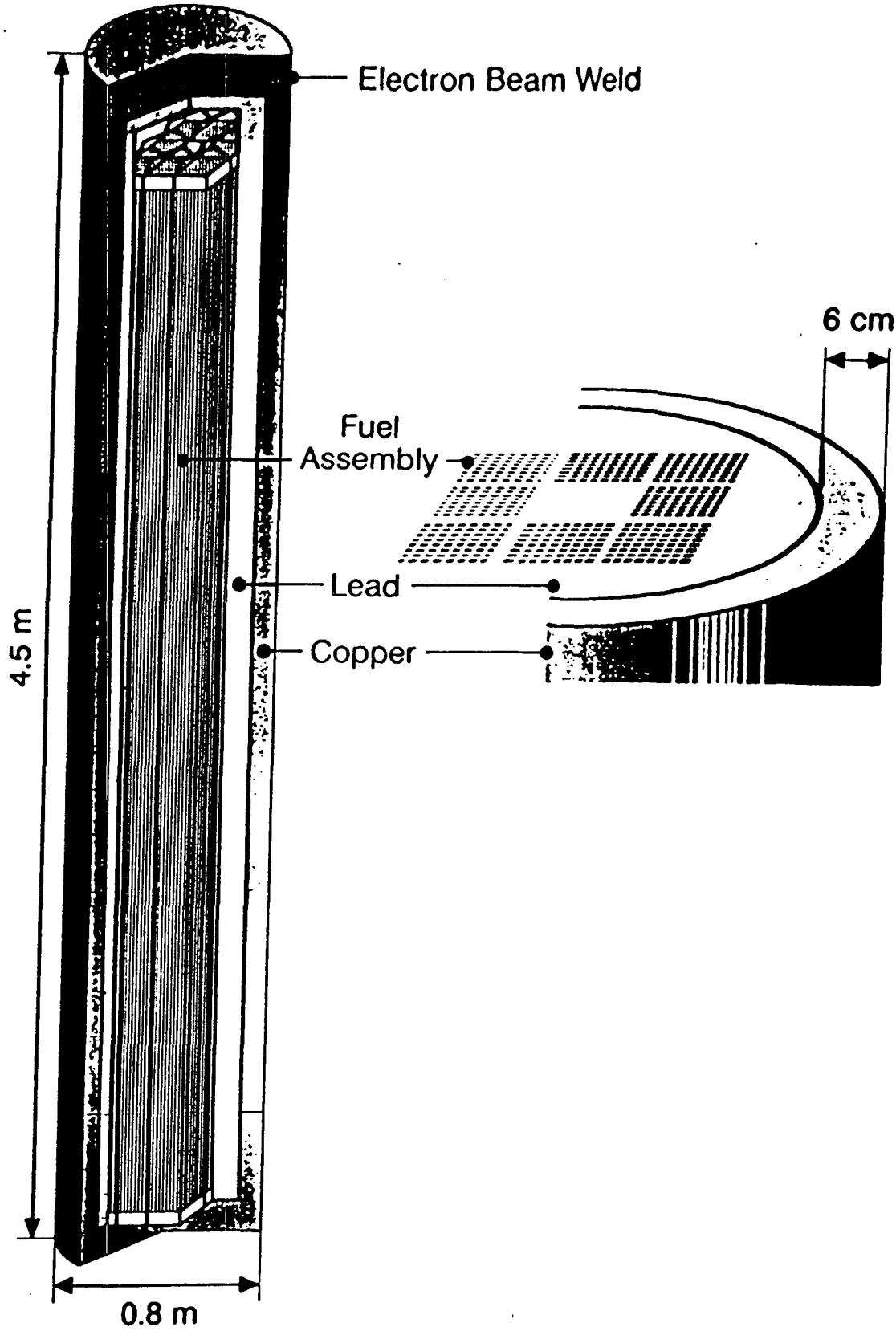

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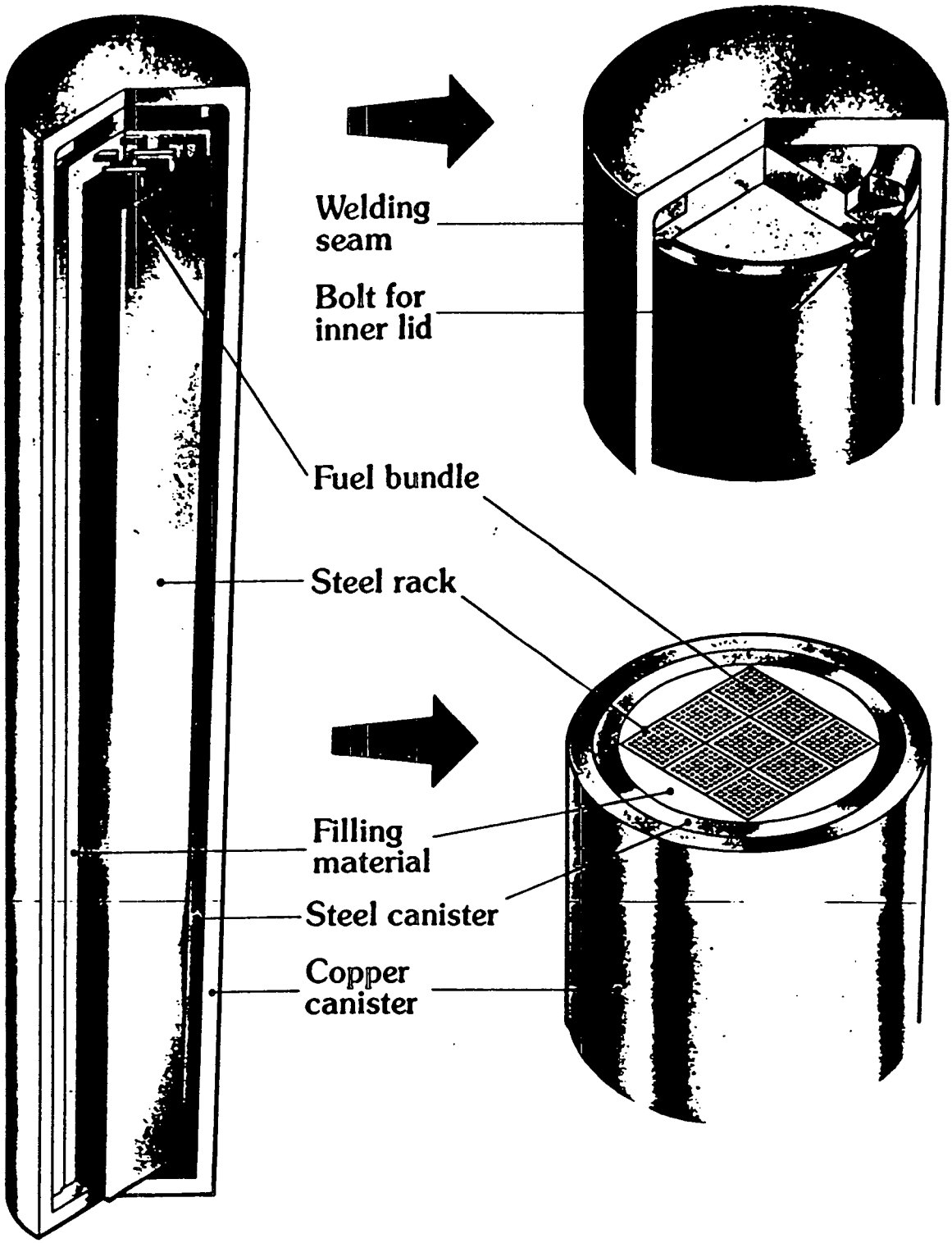

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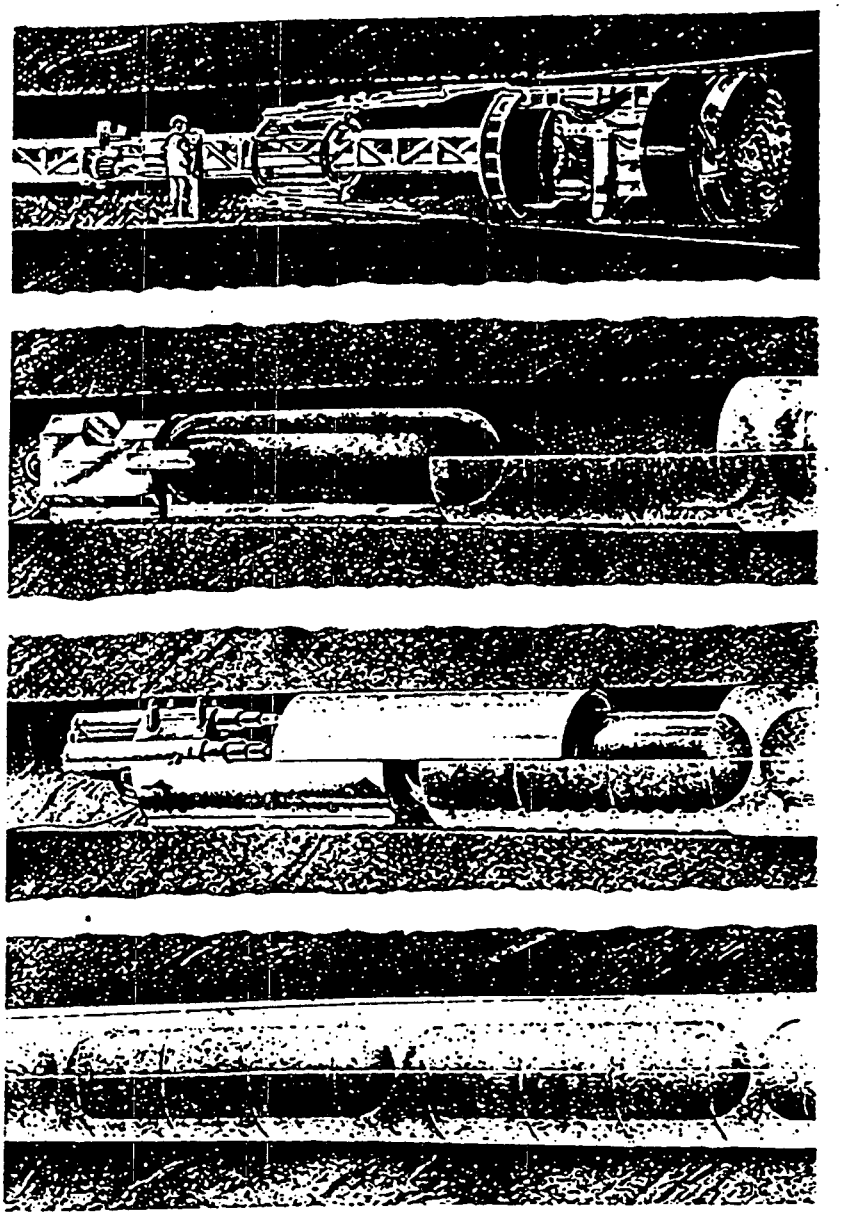

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