KBS TEKNISK RAPPORT

23

**Water uptake in a bentonite buffer mass.
A model study**

Roland Pusch

Högskolan i Luleå 1977-08-22

WATER UPTAKE IN A BENTONITE BUFFER MASS,

A MODEL STUDY.

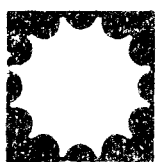Roland Pusch

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TEKNISK RAPPORT KBS 6

Report on

WATER UPTAKE IN A BENTONITE BUFFER MASS

A MODEL STUDY

Luleå 1977-08-22
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MASKINTEKNIK · GEOTEKNOLOGI · ARBETSVETENSKAP

WATER UPTAKE IN A BENTONITE BUFFER MASS

A model study

DEFINITION OF PROBLEM

Safe deposition of radioactive waste products re-
quires a number of conditions, an important one
being the maximum temperature of about 100°C that can
be accepted for the buffer mass[1]. This temperature
level has been chosen to guarantee the crystal sta-
bility of the bentonite component, to restrict the
solubility of all mineral components, and to minimize
the various negative effects of water vapor in the
system. All this means that the heat conductivity λ
of the buffer mass must be sufficiently high. Since
λ varies considerably with the degree of water satu-
ration, which will change from a low value at the
deposition ("air-dry" mass) to a fairly high value
when water has migrated from the surrounding rock,
the water uptake and the associated temperature
changes have been investigated in model tests.

HEAT CONDUCTIVITY BASICS

λ for a dry powder mass can be computed fairly accurately
($\pm20\%$) if the compact density ρ_S and the dry density
ρ_D are known. For such a dry condition the heat con-
ductivity of the individual mineral grains does not
have any great influence while the fraction of air-
filled pores of the total volume is decisive. For
pure sodium bentonite and quartz or feldspar powders
λ is within the interval $0.2-0.5$ W/mK$^{\circ}$ when ρ_D varies
between 1.4 and 2.0 t/m³. In a water saturated con-

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[1] Buffer mass compositions have been discussed in
various KBS reports, see for instance papers by
JACOBSSON & PUSCH.

dition on the other hand the λ-value of the mineral components will be important. We find:

$$\lambda_{total} = \lambda_{water}^{n} \cdot \lambda_{particles}^{1-n} \tag{1}$$

where n = porosity

For a mixture of 10% bentonite (by weight) and 90% quartz powder $\lambda \sim 3$ to 3.5 W/mK^{o}, while for 20% bentonite/ /80% quartz λ will be 2.5 to 3 W/mK^{o} etc. Here it is important to notice that if the quartz is replaced by feldspars the λ-values will be reduced by about 50%.

The situation in the tunnels (or the bore holes from the tunnel floor) is as follows. The canisters with the radioactive substance produce heat and are thus warm already when they are brought into the deposition space. The buffer mass is then applied in an "air dry" condition. When water migrates from the surrounding rock and is taken up by the buffer mass it is plausible to believe that water vapor is produced and transported out of the system and that a fairly dry zone is left close to the warm canister surfaces. In a later phase, when the tunnel system has been closed and the ground water situation is being reestablished, the water pressure will be increased to about 5 to 10 MPa at 500 and 1000 m depth respectively. In this phase the degree of water saturation will then probably be complete or almost complete even close to the canisters.

The consequence concerning λ will be as follows. When the buffer mass is dry it is homogeneous and has a constant heat conductivity in all parts. When water is brought in contact with the mass water uptake (a complex process which can be described mainly as an osmotic and a "crystallization" phenomenon, cf. the LuH report KBS 3 "Influence of cementation on the deformation properties of bentonite/quartz buffer

substance" by the author) takes place and the pore
system will be filled partly with water. By this λ
is increased. Since a temperature gradient exists
it is reasonable to believe that the water content
(w) and the degree of water saturation (S_r) will be
high at the outer periphery and low close to the canister
in the first phase of deposition, that is when there
is an access of water but the water pressure is
moderate. The consequence of this is:

- λ varies in the mass. This means that a safe
  estimation of λ can only be performed if the
  distribution of the degree of water satura-
  tion is known. This is of course essential
  for a safe estimation of the temperature
  distribution in the whole system.

- The water uptake is associated with the
  formation of water vapor in the central,
  warmest parts of the mass. Streaming water
  vapor may form cavities or channels in the
  mass. This would ruin the low permeability
  required for the buffer mass.

These two main points were tested in model tests as
follows.

MODEL TESTS.

Two tests were performed with the intention to simulate
the in situ conditions. The tunnel (or bore hole)
was represented by a permeable container consisting
of a finely perforated steel cylinder, 20 cm high
and with a diameter of 25 cm. It was equipped with
a 1 cm thick filter of araldite-stabilized sand and
with a steel bottom and lid with sealed passages for
electric cables for heating the "canister" and for
measuring the temperatur in three points in the mass.

The "canister" was represented by an electrically
heated copper body with a length of 15 cm and a
diameter of 5 cm. Its surface temperature was kept
at 100°C in both tests. The components are illustrated
by Fig. 1.

Test I

In the first test an idealized axi-symmetric case
with all-round access of water was studied. An air-
dry mass consisting of 10% (by weight) sodium bento-
nite and 90% Pite silt (mainly quartz) was applied by
very moderate compaction with the canister in position.
The water content of the "dry" mass was estimated to
about 5%. The bulk density was found to be 1.41 t/m³
which is a very low value. This means that the λ-value
is lower than it will be in the tunnels or bore holes
where the compaction will be much more efficient,
especially if the water content can be increased to
8-12%. The grain size composition of the components
is illustrated by Fig. 2.

The surface temperature of the "canister" was constantly
kept at 100°C throughout the test while the room
temperature was kept constant at 20°C. In the first
phase no water was added to the system. When tempera-
ture equilibrium had been reached the outer container
was filled with water which was then kept constantly
at 30°C. When the new condition of temperature equili-
brium was reached the test was stopped, the container
opened and undisturbed samples taken for direct
determination of water content, degree of water satu-
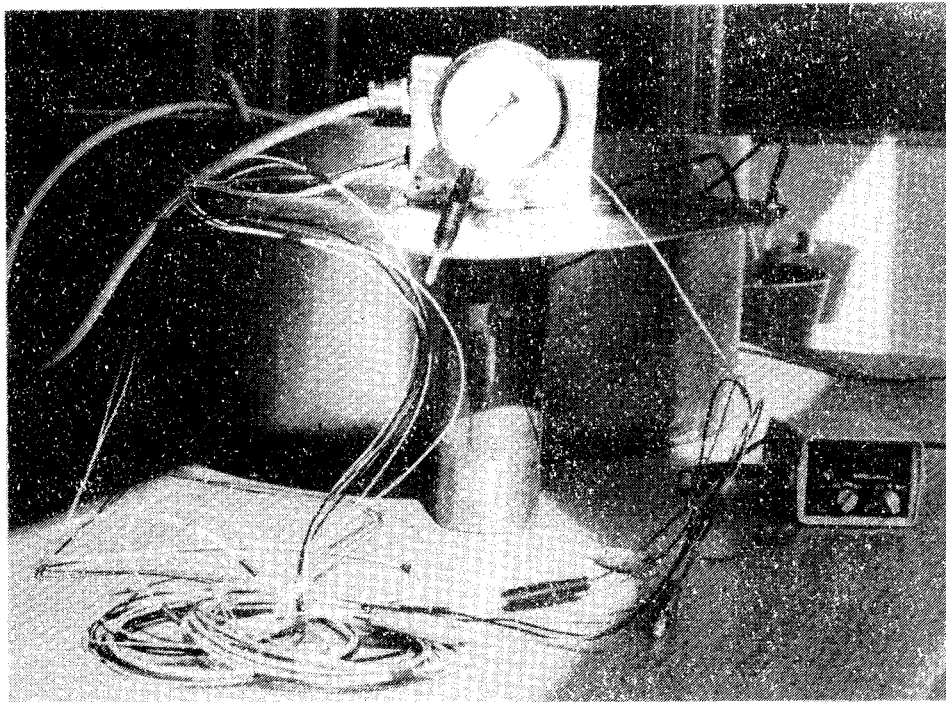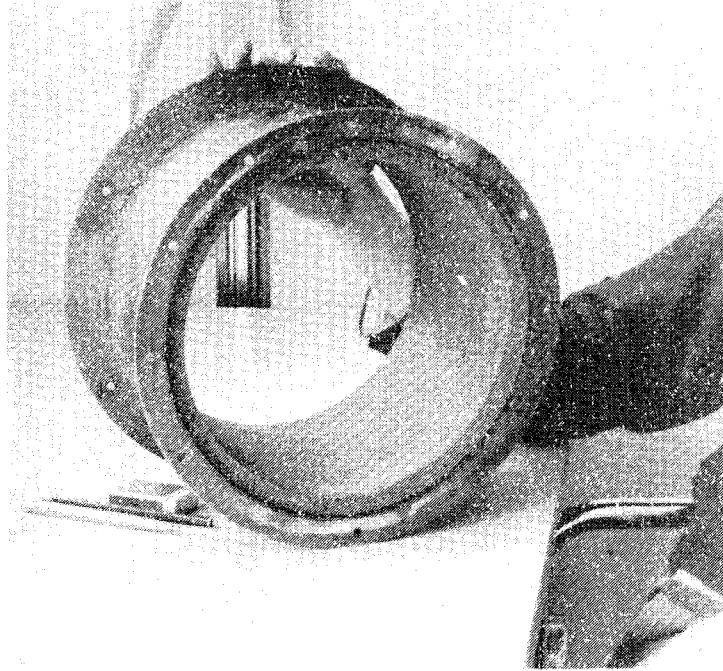ration, and possible effects of water vapor on the
structure.

Fig.1. Upper picture: The steel cylinder with sand filter.
Lower picture: The cylinder lid with the "canister".
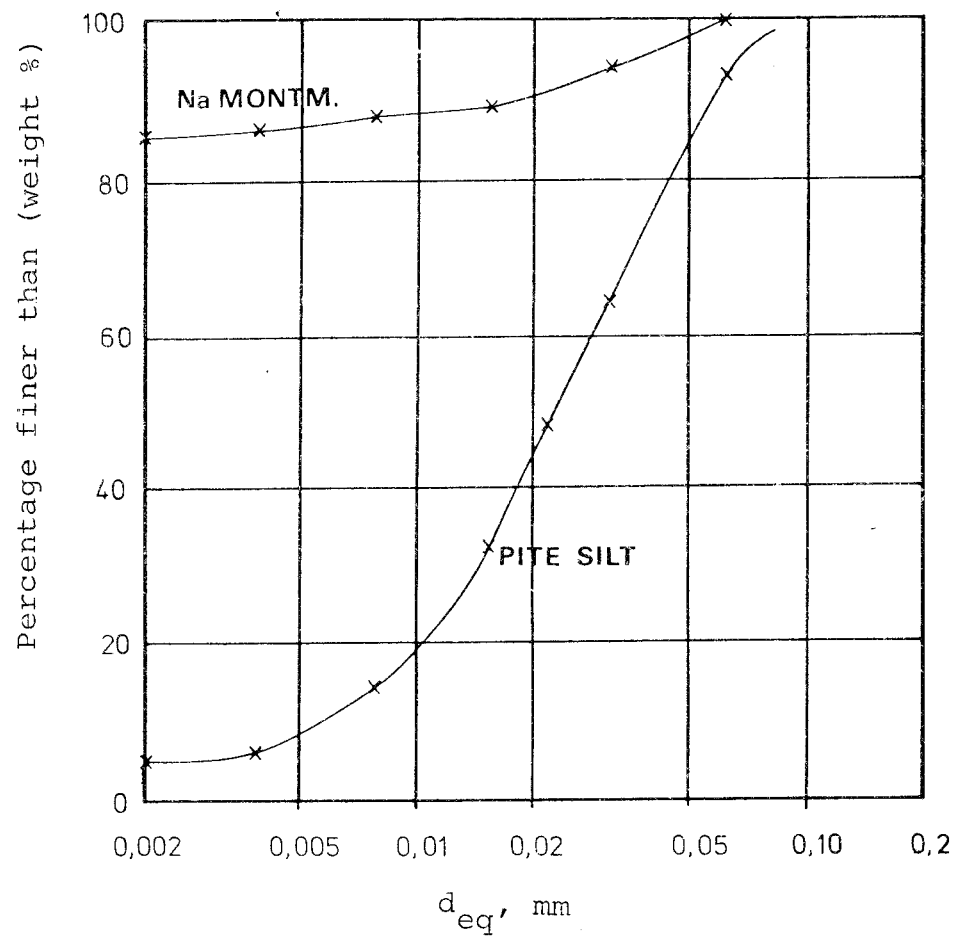The outer container is seen behind.

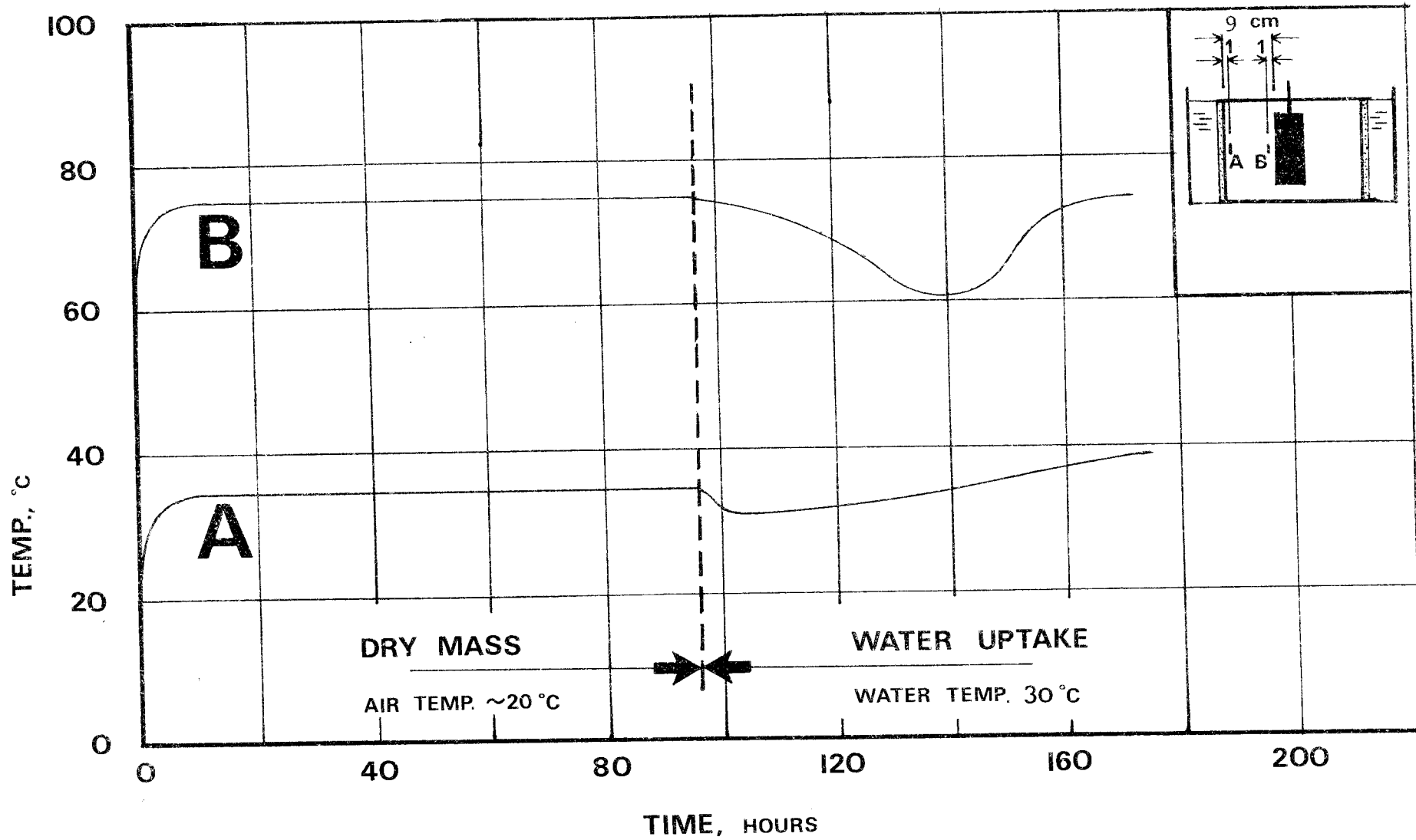Fig. 2. Grain size distribution of Na bentonite
and Pite silt

Fig.3. Temperature development in the powder mass as a function of time (Test I).

Fig. 3 shows the temperature development. It is seen
that temperature equilibrium was reached already
after about 12 hours. When water (30°C) was being
taken up in the mass the temperature was temporarily
reduced by about 15°C close to the "canister" but
was then successively increased approaching the
original temperature of the dry mass at the point
of measurement (75°C). A corresponding but less
obvious process was observed close to the outer peri-
phery. Temperature equilibrium in the course of
water uptake was reached after about 4 days. Fig. 4
shows the variation in water content and degree of
water saturation at the end of Test I while Fig. 5
shows the device in operation and an illustration of
the position of the samples used for the water content
determination. A surprisingly uniform distribution
of the water is observed and it should be noticed
that the degree of water saturation is high also close
to the warm "canister". The calculation of the S_r-values
have been made by using an approximate mathematical
relationship which yields values which are somewhat
on the safe side. Thus, the real S_r-values may be
up to about 10% higher than shown in Fig. 4.

The results call for some comments. In the author's
opinion the surprising uniformity of the water uptake
is mainly due to the strong bonds by which water
molecules are kept in intra-lamellar montmorillonite
position. This means that the adsorbed water is not
readily vaporized or easily moved in the system.

Finally, in Test I an attempt was made to investigate
whether vapor transport had produced cavities or
channels in the mass. For this purpose an X-ray
technique has been applied which is currently used
at the Div. of soil mechanics, University of Luleå,
for investigating structural variations in natural
soils. Characteristic X-ray photos of "undisturbed"
cylindrical samples from the buffer mass are shown
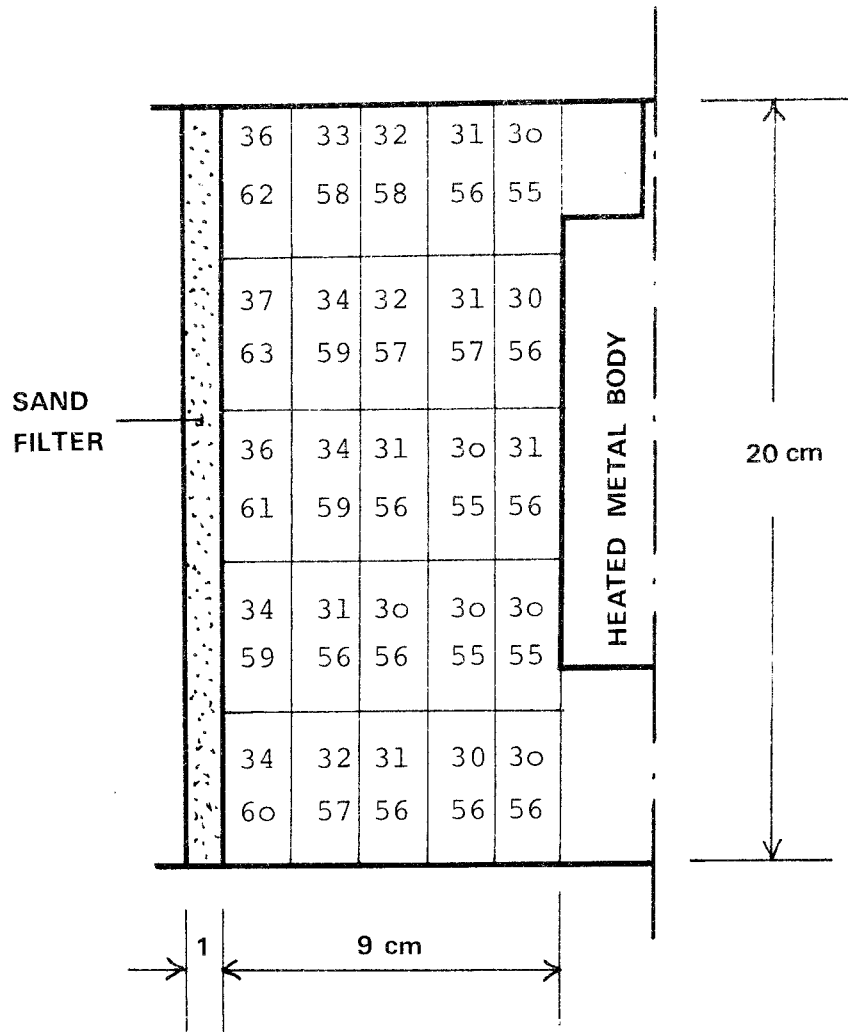in Fig. 6. It was found that the mass was very homo-

Fig.4. Distribution of the water content (upper value for the respective element) and the degree of water saturation in % (lower value) at the end of the test (Test I).
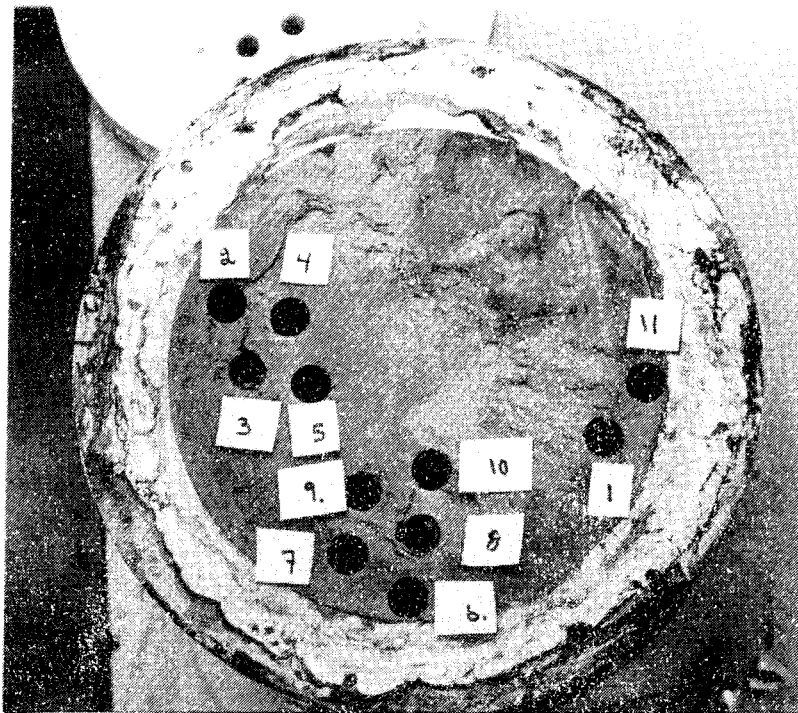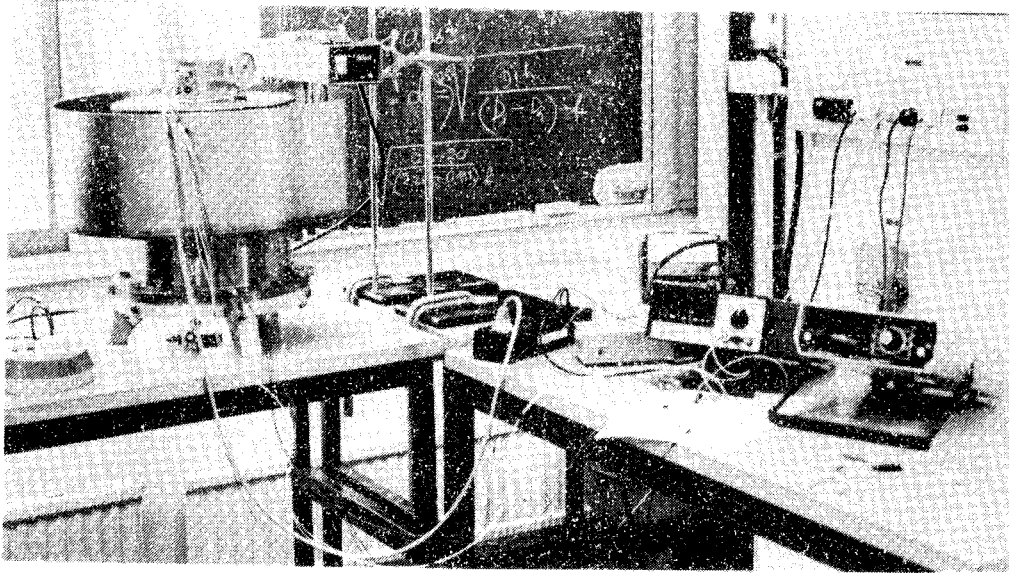
Fig.5. Upper picture: The device in operation. Temperature
                     measurement is being made.

       Lower picture: Steel cylinder opened and sampling finished.
                     The surface irregularities were caused by
                     adherence of buffer mass substance to the
                     removed lid.

Fig.6. X-ray photos of samples from the buffer mass in
Test I after water uptake. The slight variations
in density are caused by the sampling disturban-
ces. The two small black bodies are caused by
scratch marks on the plates.

geneous. No softened parts, cavities or channels
could be found and the conclusion is therefore that
no process involved in the water uptake has any
negative effect on the structure of the buffer mass.

Test II

Test II was originally intended to illustrate the
mode of water uptake in the special case where water
could migrate into the buffer mass only through a
fairly narrow slit. This condition would represent the
practical case where water is available only from a
joint in an otherwise low-permeable rock mass. The
idea was that the time to obtain temperature and
water saturation equilibrium may be so long that
the temperature situation in the rock and buffer mass
will be entirely governed by the "air dry" λ for de-
cades or even centuries.

For this purpose the inside of the sand filter (cf.
Fig. 1) was sealed by a plastic sheet so that water
could only enter through a 5 cm wide opening with a
vertical height of 20 cm. In Test II a mixture of 10%
(by weight) sodium bentonite and 90% feldspar (Oskars-
hamn rock species delivered by the KBS) was used.
The idea was that the first "dry" phase of the investi-
gation would illustrate the difference in temperature
development and water uptake between quartz and
feldspar. It was also considered to be suitable to
give the feldspar material a moraine-like grain size
distribution which the author has recommended for
practical use. Therefore, the stones were ground to
various size fractions which were then mixed to give
the curve in Fig. 7. The varying grain size resulted
in a bulk density of 1.85 t/m³ when the same compac-
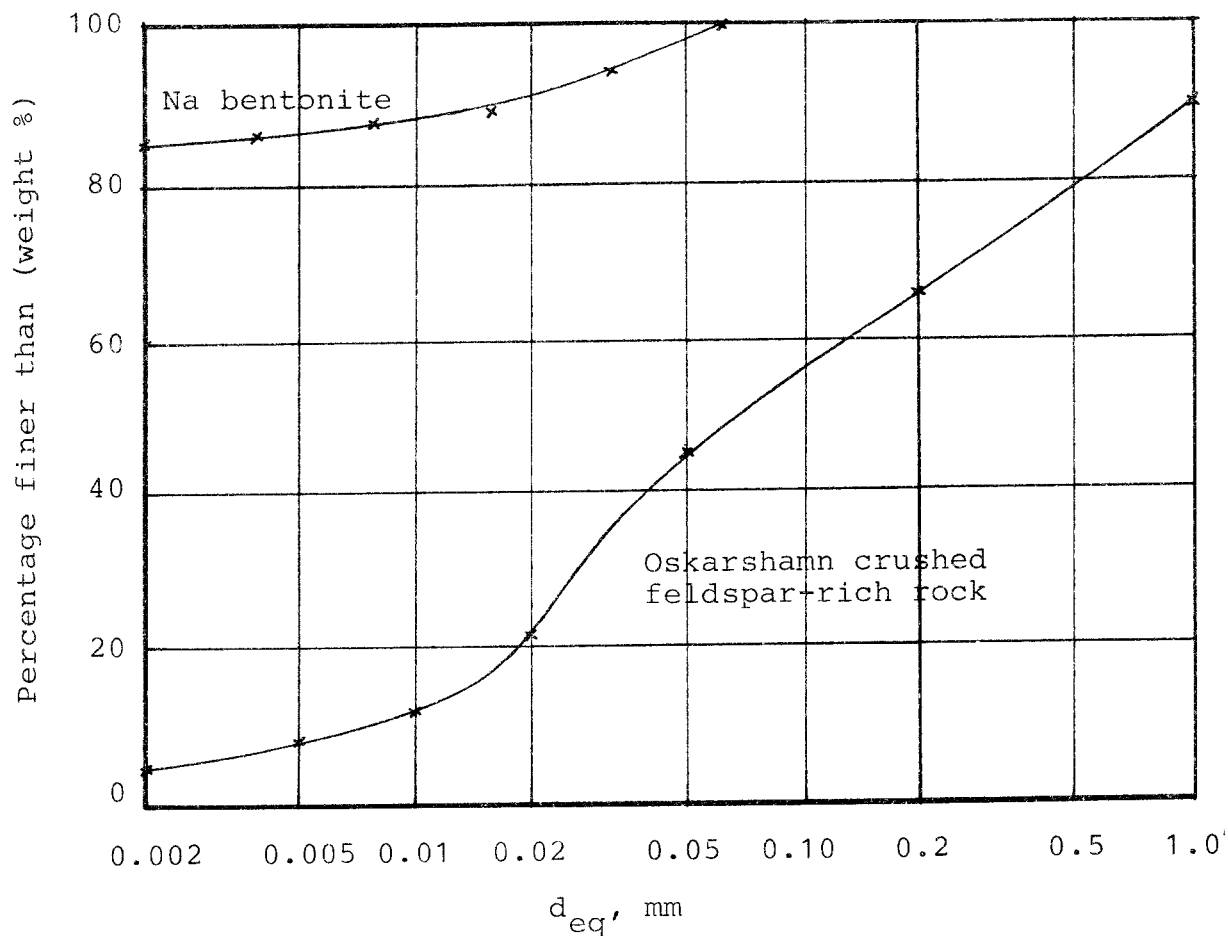tion technique was applied as in Test I.

Fig. 7. Grain-size distribution curves for the buffer
substance used in Test II.

Fig. 8 shows how the temperature changed during
Test II. A and B stand for thermometers situated as
in Test I but on the opposite side of the water
entrance. The initial temperatures at A and B are
higher than in Test I which is partly due to the insulating
power of the plastic sheet. It is seen that temperature
equilibrium in the "dry condition" was reached after
about 10 hours, which means that the process was
even faster than in Test I. Since feldspar has a
much lower λ-value than quartz this means that the
increased bulk density and correspondingly reduced
porosity had a decisive influence as was also stated
previously in the text. When water was added an instant
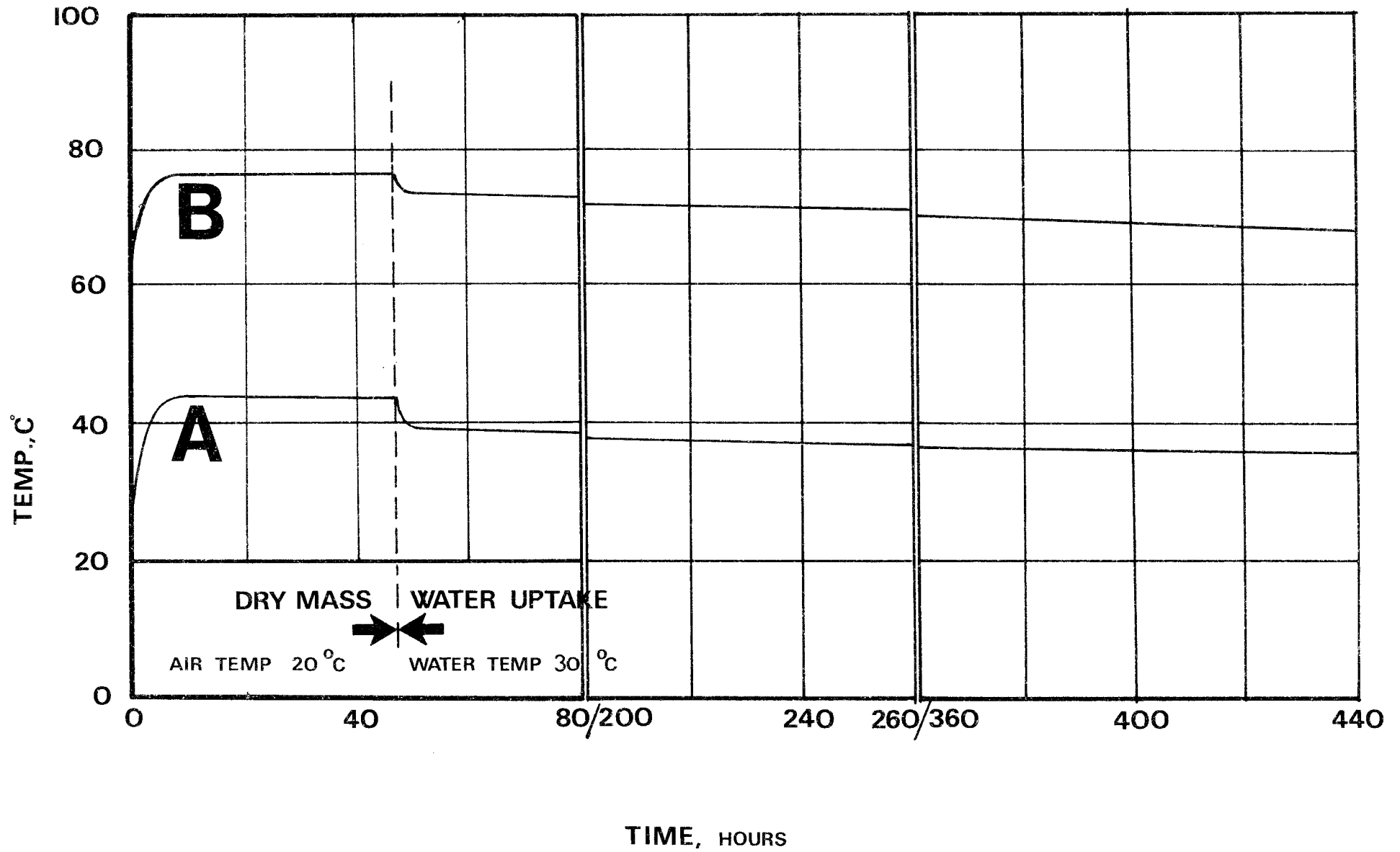rapid reaction in the form of a temperature decrease

Fig.8. Temperature development in the powder mass as a function of time (Test II).

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of 3-4°C was recorded. This cannot be correlated with
the entrance of water into the mass, it is merely
due to a change of the temperature situation close
to the outer wall. We can see, however, that a slow
temperature reduction is then produced in the mass.
It is much slower than in Test I due to the much
longer diffusion distance of the water molecules.
Probably the temperature will also, as in Test I,
increase again but there is <u>definitely a temperature</u>
<u>reduction</u> during the long period of water uptake.

When the test had been run for about 3 weeks it had
to be stopped and, as in Test I, sampling was made.
Fig. 9 illustrates the position of the samples while
Fig. 10 shows the distribution of the water content
and the degree of water saturation. The sections show
that the water uptake is non-uniform which is of
course for obvious reasons. Samples 2, 3, 4 and 5
which are fairly close to the water inlet show the
same general pattern as was observed in Test I. Thus,
in this group of samples the water content is within
the fairly narrow interval of 16 and 22% while S_r is
70% as an average. For some of the elements the
degree of water saturation is as high as 76-78%. Ob-
viously, water is built into the mass also close to
the heated "canister". It should be noticed that the
lower water content in Test II is due to the low
porosity. The degree of water saturation, on the
other hand, is somewhat higher than in Test I for
certain elements.

In the two other groups we find fairly low water
content and S_r-values (3-17% and 17-67% respectively).
This means that even after almost 3 weeks the water
uptake is far from completed at a distance of 15 cm
or more from the water inlet. This means that a very
long time, several months or even years, will be
required to yield a condition of complete water
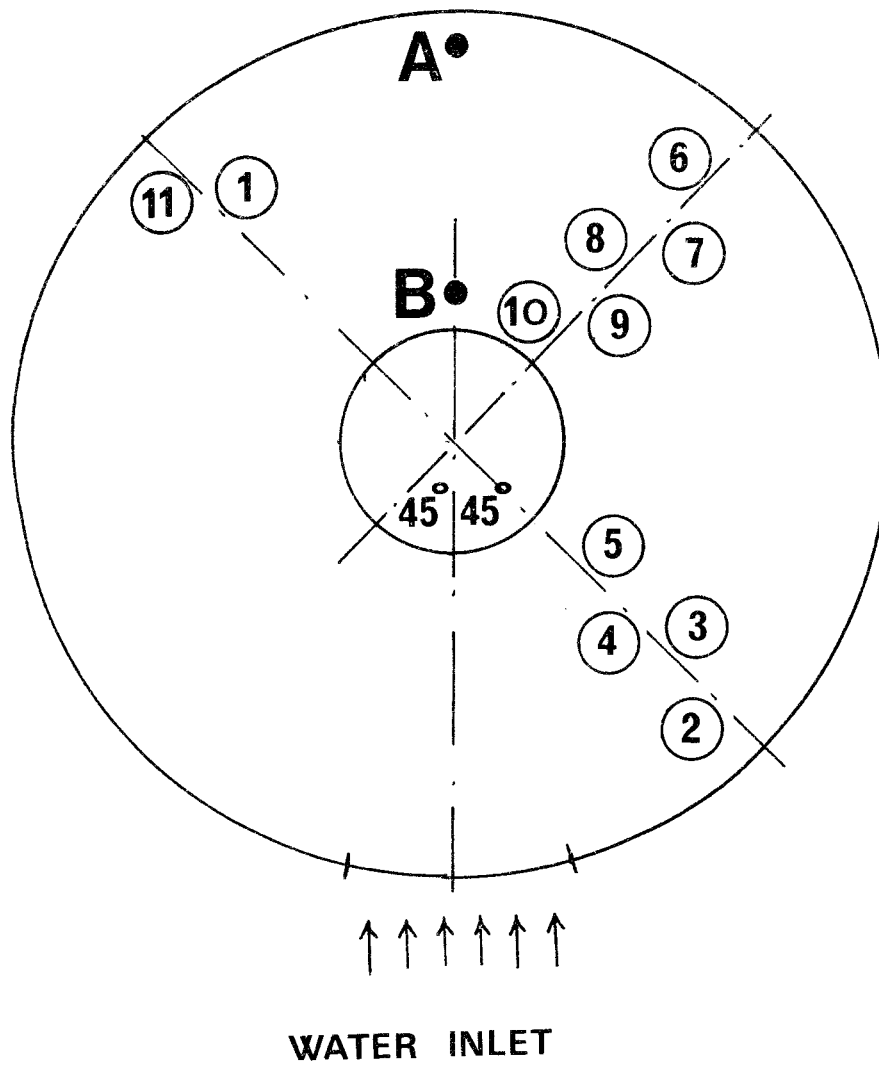adsorption in dense, homogeneous rock. If a high

Fig. 9. Position of samples. A and B shows position of thermometers placed at a depth of about 10 cm.

11 1   **5 4 3 2**

11	8
49	39
13	9
56	42
15	8
61	39
12	9
53	42
13	12
56	53

HEATED METAL BODY

5	4	3	2
18	20	18	21
69	74	69	76
16	20	17	22
64	74	67	78
16	18	17	21
64	69	67	76
16	18	17	
64	69	67	
17			21
67			76

SEAL

10 9 8 7 6

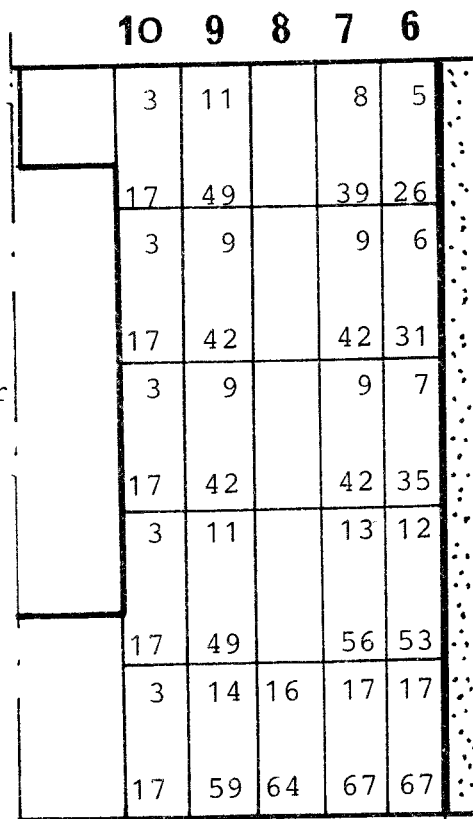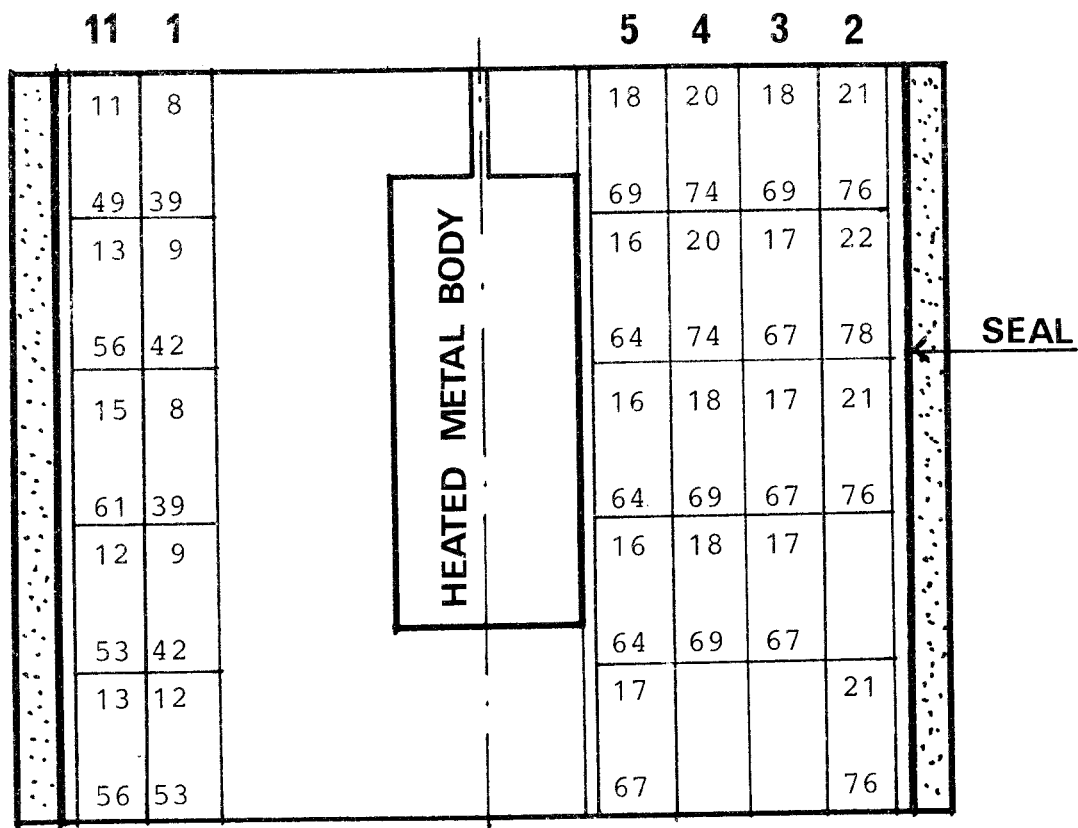| 10	9	8	7	6
3	11		8	5
17	49		39	26
3	9		9	6
17	42		42	31
3	9		9	7
17	42		42	35
3	11		13	12
17	49		56	53
3	14	16	17	17
17	59	64	67	67

Fig. 10.
Distribution of the water content (upper value for the respective element) and the degree of water saturation in % (lower value at the end of Test II.

degree of water saturation is required to get a
suitable λ-value already at an early stage it should
be possible to speed up the process by applying
perforated water pipes in the mass. The pipes, from
which water is expelled, must be removed and replaced
by buffer mass when the respective tunnel section
or bore hole is closed.

Structural X-ray investigation of the buffer mass could
not be made in Test II. This is because the shear
strength of the mass was so high (due to the low
porosity and due to the water uptake) that ordinary
larger sampling tubes could not be used.

It should be stressed, finally, that the tests indi-
cate that the water which is taken up in a bentonite-
containing buffer mass will be so strongly adsorbed
that drying out is prevented. Thus, if there is an
access of water there will be a one-way process
leading to a continuous, but slow, increase of the
water content.

Luleå 1977-08-22

Roland Pusch

Förteckning över tekniska rapporter

01.   Källstyrkor i utbränt bränsle och högaktivt
        avfall från en PWR beräknade med ORIGEN
        Nils Kjellbert
        AB Atomenergi 77-04-05

02.   PM angående värmeledningstal hos jordmaterial
        Sven Knutsson och Roland Pusch
        Högskolan i Luleå 77-04-15

03.   Deponering av högaktivt avfall i borrhål med
        buffertsubstans
        A Jocobsson och R Pusch
        Högskolan i Luleå 77-05-27

04.   Deponering av högaktivt avfall i tunnlar med
        buffertsubstans
        A Jacobsson, R Pusch
        Högskolan i Luleå 77-06-01

05.   Orienterande temperaturberäkningar för slut-
        förvaring i berg av radioaktivt avfall
        Roland Blomqvist
        AB Atomenergi 77-03-17

06.   Groundwater movements around a repository,
        Phase 1, State of the art and detailed study plan
        Ulf Lindblom
        Hagconsult AB 77-02-28

07.   Resteffekt för KBS del 1
        Litteraturgenomgång Del 2 Beräkningar
        K Ekberg, N Kjellbert, G Olsson
        AB Atomenergi 77-04-19

15.   Orienterande temperaturberäkningar för
        slutförvaring i berg av radioaktivt avfall
        Rapport 2
        Roland Blomquist
        AB Atomenergi 77-05-17

16.   Översikt av utländska riskanalyser samt
        planer och projekt rörande slutförvaring
        Åke Hultgren
        AB Atomenergi Augusti 1977

17.   The gravity field in Fennoscandia and
        postglacial crustal movements
        Arne Bjerhammar
        Stockholm 1977

18.   Rörelser och instabilitet i den svenska
        berggrunden
        Nils-Axel Mörner
        Stockholms Universitet 1977

19.   Studier av neotektonisk aktivitet i mellersta
        och norra Sverige, flygbildsgenomgång och
        geofysisk tolkning av recenta förkastningar
        Robert Lagerbäck
        Herbert Henkel

20.   Tektonisk analys av södra Sverige
        Vättern - Norra Skåne
        Kennert Röshoff
        Erik Lagerlund

21.   Earthquakes of Sweden 1891-1957
        1913-1972
        Ota Kulhånek
        Rutger Wahlström

22. The influence of rock movement on the stress/strain situation in tunnels or bore holes with radioactive conisters embedded in a bentonite/quartz buffer mass.
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23. Water uptake in a bentonite buffer mass.
A model study.

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Högskolan i Luleå 1977-08-22

24. Beräkning av utlakning av vissa fissionsprodukter och aktinider från en cylinder av franskt glas.

Göran Blomqvist
AB Atomenergi 1977-07-27