International
Progress Report

IPR-01-07

Äspö Hard Rock Laboratory

Prototype Repository

Finite element analyses of heat transfer and temperature distribution in buffer and rock

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SWECO Industriteknik AB

November 1999

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Report no.	No.
IPR-01-07	F63K
Author	Date
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Approved	Date
Christer Svemar	01-03-14

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Keywords: Prototype Repository, temperature distribution, numeric modelling

Foreword

This report is an addendum to a main report [1] that describes the Finite Element Model developed for the purpose of thermal analyses in the research project named *Prototype Repository* at Äspö Hard Rock Laboratory. The model will be used to verify design parameters during the construction stage and to predict temperature conditions in buffer and rock as the research goes on. A number of cases will be investigated with regard to geometry, material properties and heat load. Each case will be given an identification number, which, for the time being, will be simply sequential. This report includes the analyses and results of Case No. 2.

The main report [1] is divided into two parts:

Part I	constitutes a general description of the problem, modelling requirements and common model features.
Part II	accounts for the models, analyses and results specific for the Case No. 1 calculations.

This report consists of:

Part II	models, analyses and results specific for the Case No. 2 calculations.

Abstract

The report describes the Finite Element Model developed for the purpose of thermal analyses in the research project named *Prototype Repository* at Äspö Hard Rock Laboratory. The model will be used to verify design parameters during the construction stage and to predict temperature conditions in buffer and rock as the research goes on. A number of cases will be investigated with regard to geometry, material properties and heat load. This report describes results of the second case study where geometry and material properties have been modified from the first case.

Sammanfattning

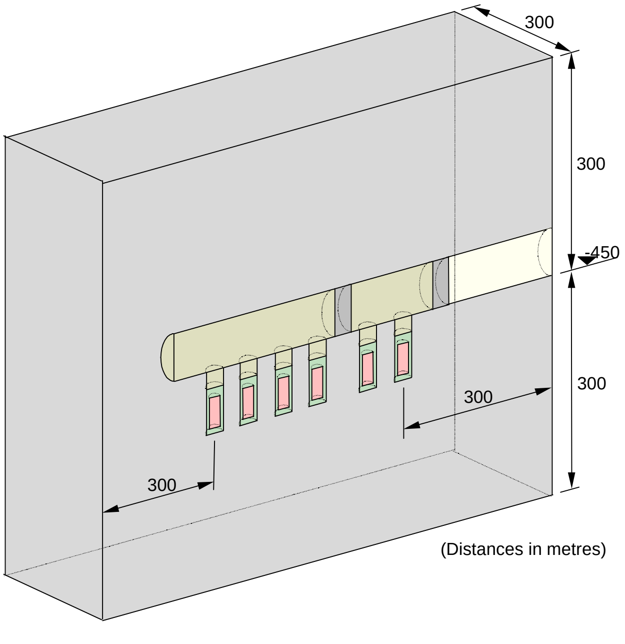
Rapporten beskriver den finit-element-modell (FEM) som utvecklats för termiska analyser i forskningsprojektet *Prototype Repository* vid Äspö Hard Rock Laboratory. Modellen kommer att användas under byggfasen och för att prediktera temperaturförhållanden i buffer och berg under hand som forskningsprojektet framskrider. Ett antal fall kommer att studeras med avseende på geometri, materialdata och värmebelastning. Denna rapport beskriver resultat från den andra studien där geometri och materialparametrar är modifierade jämfört med den första studien.

Executive Summary

The objective of the development of the finite element model (FEM), described in this report, is to provide the Prototype Repository research project at Äspö Hard Rock Laboratory (HRL) with a flexible tool for highly accurate thermal analyses of the local domain with the capability of handling transient and non-linear problems. The domain includes canisters, buffer and rock and encompasses the total volume that will be significantly affected by the canister heat loads within the time frame of the project. The particular heat transfer inside the canisters with respect to their various components such as fuel elements, casings and copper claddings, is not included in the scope of the model. That issue will be addressed in another context.

The programme code chosen for this study is ANSYS, a universal FEM code well established within SKB as the tool for thermal analyses in various contexts. ANSYS has been used for a number of years in analyses concerning for instance canister optimisation and layout studies of the deep repository. ANSYS was chosen in view of its powerful pre- and post-processing capabilities, a feature of importance in studies involving a great deal of variations and sensitivity analyses.

A major uncertainty in the heat flow process is the influence of the gap between the canister and the bentonite buffer. Also the properties of the gap between the buffer and rock is uncertain to some extent but will not have the same impact on the canister temperature as the inner gap. The ability to calculate a wide variety of events in the thin inner gap (10 mm) has strongly affected the modelling.



Above is a schematic figure of the model and the physical model range.

Material properties will be specified for each case. There are no limitations to characteristics of material properties regarding, for instance, time or temperature dependency or anisotropic behaviour. Every single canister and its surrounding buffer are modelled separately in that respect.

The initial effect in the canisters can be defined specifically for each canister and be time-dependent. An exponential function describes the decrease by time of the heat output.

Case No. 1 - typical canister centre to centre distance 6,0 m

The first case is described in a main report [1]. This report is an addendum to the main report and describes only Case No. 2.

Case No. 2 - typical canister centre to centre distance 6,0 m with modified geometry and material parameters.

The prime objective of Case No. 1 was to demonstrate the feasibility of the modelling approach in general and of the model itself with respect to versatility and accuracy, as well as to its requirements regarding computer capacity and software. Since the calculations of the first case the layout geometry has been changed. Material parameters have also been modified. The changes have been adapted to Case No. 2.

General provisions for Case No. 2 include a typical canister centre to centre distance of 6,0 m and highly saturated bentonite as buffer material. The initial heat output is 1 800 W per canister. Two cases were investigated with respect to the water bearing capacity of the rock.

For case No. 2A and 2B, it is assumed that the gap between bentonite and the canister is filled with air. For case No. 2C, it is assumed that the gap between bentonite and the canister is filled with water. For the wet rock condition, it is however assumed that the gap will be filled with bentonite after two years.

Heat transfer for air filled gap has been separately investigated and calculated [2].

The results of the Case 2 calculations are summarised in table below. Canister No. 1 is the innermost canister in the deposition tunnel.

Calculations for dry rock condition give as a result a maximum temperature on the canister surface of 90.3°C.

Maximum temperature on canister surface, Case No. 2

Canister No.	Maximum temperature [°C] on canister surfaces			
	Case 2A Dry rock, air in gap	Case 2B Wet rock, air in gap		Case 2C Wet rock, water in gap
1	84.7	80.9*		
2	89.9	85.7*		
3	**90.3**	**85.8***	**79.5**	**79.5**
4	85.9	81.4*		
5	83.1	79.7*		
6	82.2	79.3*		

* = After two years when there is a material transition in the gap.

Contents

Appendices

PART II
CASE No. 2 - ANALYSES AND RESULTS

1 Case Specific Objectives

Being the first calculation, the prime objective of Case No. 1 was to demonstrate the feasibility of the modelling approach in general and of the model itself with respect to versatility and accuracy, as well as to its requirements regarding computer capacity and software, see [1].

Since the calculations of the first case the layout geometry has been changed. Material parameters have also been modified. The changes have been adapted to Case No. 2.

For case No. 2A and 2B, it is assumed that the gap between bentonite and the canister is filled with air. For case No. 2C, it is assumed that the gap between bentonite and the canister is filled with water. For the wet rock condition, it is however assumed that the gap will be filled with bentonite after two years.

The program version used in Case No. 2 was ANSYS Mechanical, Version 5.5.3 [3].

2 Parameters and Geometry

2.1 Models

Within Case No. 2, three models were set up and calculated. The objective was to study two subcases, 2A and 2B, differentiated with respect to the water bearing capacity of the surrounding rock, dry and wet rock conditions respectively. The difference in the water bearing capacity was reflected in the modelled water saturation process in the bentonite buffer. Subcase 2C is the same as 2B except that the gap is filled with water instead of air.

Case 2A	Complete model with six canisters split by one symmetry plane. Dry rock condition. Gap filled with air.
Case 2B	Complete model with six canisters split by one symmetry plane. Wet rock condition. Gap filled with air during the first two years.
Case 2C	Complete model with six canisters split by one symmetry plane. Wet rock condition. Gap filled with water during the first two years.

2.2 Parameters

Case No. 2 consists of a six canisters configuration, each canister with an initial heat output of 1 800 W. The initial state of the compacted bentonite with respect to water content is ”highly saturated”. Inner gaps in the deposition holes are filled with air from the start. For the wet rock case the air filled gap is however assumed to be filled with bentonite after two years. The deposition tunnel is backfilled and plugged.

Parameters are selected according to Appendix 1.

Heat transfer through the air filled gaps is a key parameter for accuracy of results. The finite element modelling of the gap is done with solid elements, which allows heat transfer only by conduction. Convection and radiation may however also contribute to total heat transfer.

An air filled gap has been calculated with the Computational Fluid Dynamics (CFD) code FLUENT, where convection and radiation also can be included. Results showed that convection contributes strongly besides conduction [2].

Equivalent heat conduction values corresponding to the total heat transfer through the gap was then derived and adapted to the finite element model. It was found that dry air and 100% humid air has close to same equivalent heat conduction.

2.3 Geometry and Keypoints

The centres to centre distances between the six canisters are given in Figure 5-1 below. The change of geometry in Case No. 2 is a new distance of 18 m between the two groupings of canisters, see Figure 2-1.

The canisters were considered as being concentrically located in the shafts and with their centre lines in parallel to those. The radial gap between canister and bentonite buffer was set to 1.0 cm and the radial gap between bentonite buffer and rock was set to 5.0 cm.

In Case No. 2, no keypoints were explicitly defined. As the target was to investigate the highest temperature on the canister surface for each canister, the built-in functions of ANSYS could be used to distinguish the extreme values.

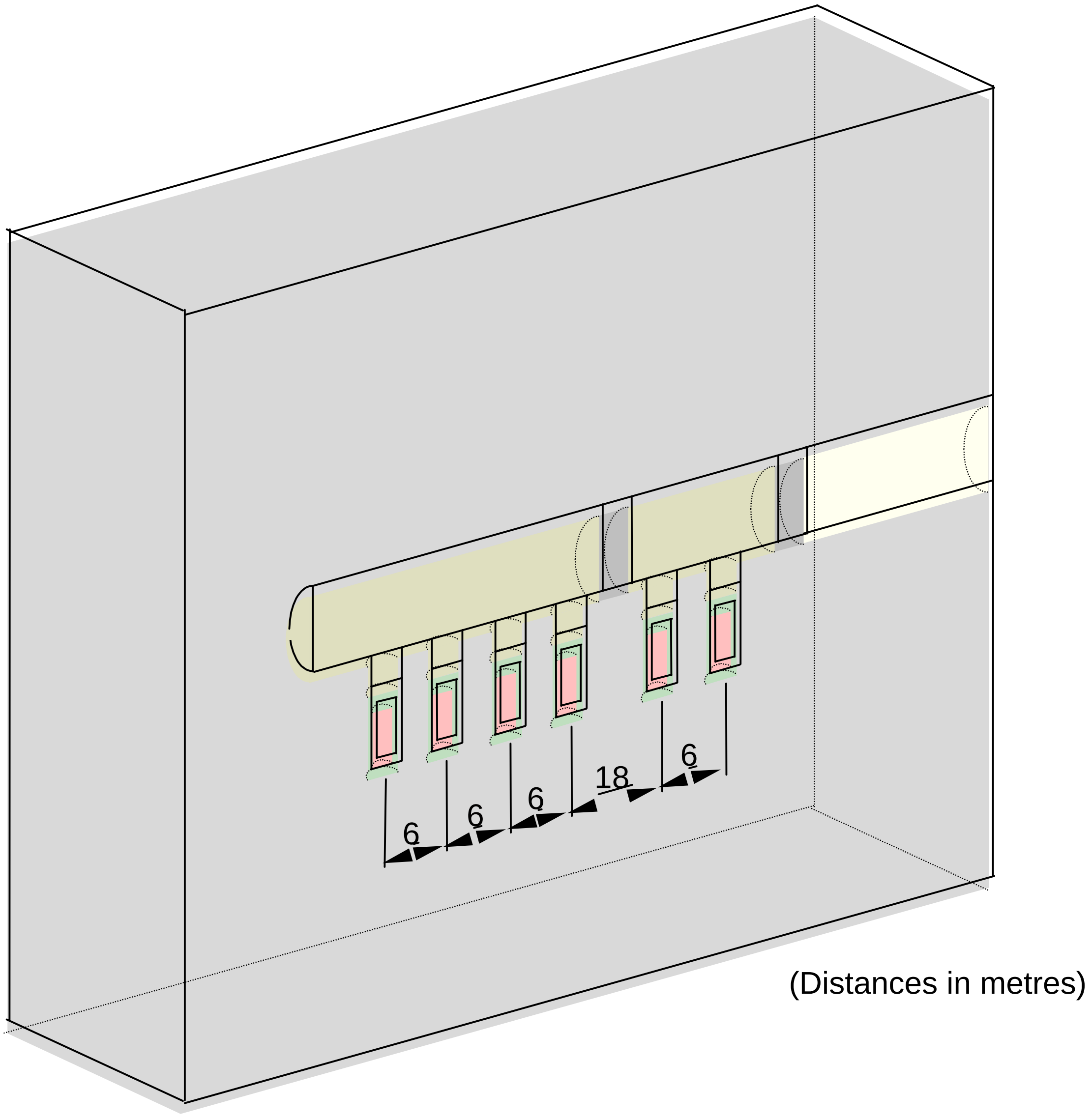


Figure 2-1 Schematic figure of the model. Centre to centre distances between canisters.

2.4 Job-name and List of Files

This section contains file control information for the purpose of backtracking of all model data and result output.

Table 2-1 Job-name and list of files

Job name	Model	Files	
5540075 Case 2	Case 2A	Input: Database: Solution:	dry_O2.mac dry_O2.db dry_O2.rth
	Case 2B	Input: Database: Solution:	wet_O2.mac wet_O2.db wet_O2.rth
	Case 2C	Input: Database: Solution:	wet_H2O.mac wet_H2O.db wet_H2O.rth

3 Results

The result plots of the various subcases are presented in Appendices 3 to 5.

3.1 Case 2A

See Appendix 3.

The calculation was stopped at a simulation time of 6.0 years. The highest temperature on the canister surfaces was 90.3 °C at 4.5 years and occurred, as expected, on canister No. 3.

3.2 Case 2B

See Appendix 4.

The calculation was stopped at a simulation time of 6.5 years. The highest temperature on the canister surfaces was 85.8 °C at 2 years and occurred, as expected, on canister No. 3.

At 2.0 years, however, there is a temperature drop because of a material transition in the gap (air to bentonite).

After 5 years, there is a new maximum of 79.5 °C

3.3 Case 2C

See Appendix 5.

The calculation was stopped at a simulation time of 6.5 years. The highest temperature on the canister surfaces was 79.5 °C at 5 years and occurred, as expected, on canister No. 3.

At 2.0 years, however, there is a small temperature drop because of a material transition in the gap (water to bentonite).

3.4 Conclusions

The results of the Case 2 calculations are summarised in Table 3-1 below.

Table 3-1 Maximum temperature on canister surface, Case No. 2

Canister No.	Maximum temperature [°C] on canister surfaces			
	Case 2A Dry rock, air in gap	Case 2B Wet rock, air in gap		Case 2C Wet rock, water in gap
1	84.7	80.9*		
2	89.9	85.7*		
3	**90.3**	**85.8***	**79.5**	**79.5**
4	85.9	81.4*		
5	83.1	79.7*		
6	82.2	79.3*		

* = After two years when there is a material transition in the gap.

References

1 Ageskog L, Jansson P, Finite Element Analyses of Heat Transfer and Temperature Distribution in Buffer and Rock, General Part & Case No. 1. SKB Progress Report HRL-98-20, 1998

2 Jansson P, Kuokkanen M, Prototype Repository, 1999, Heat Transfer For Air Filled Gap, Technical report, SWECO Industriteknik AB, 1999

3 ANSYS, Swanson Analysis Systems Inc., P.O. Box 65, Johnson Road, Houston, PA 15342-0065, U.S.A. User's Manual for Release 5.

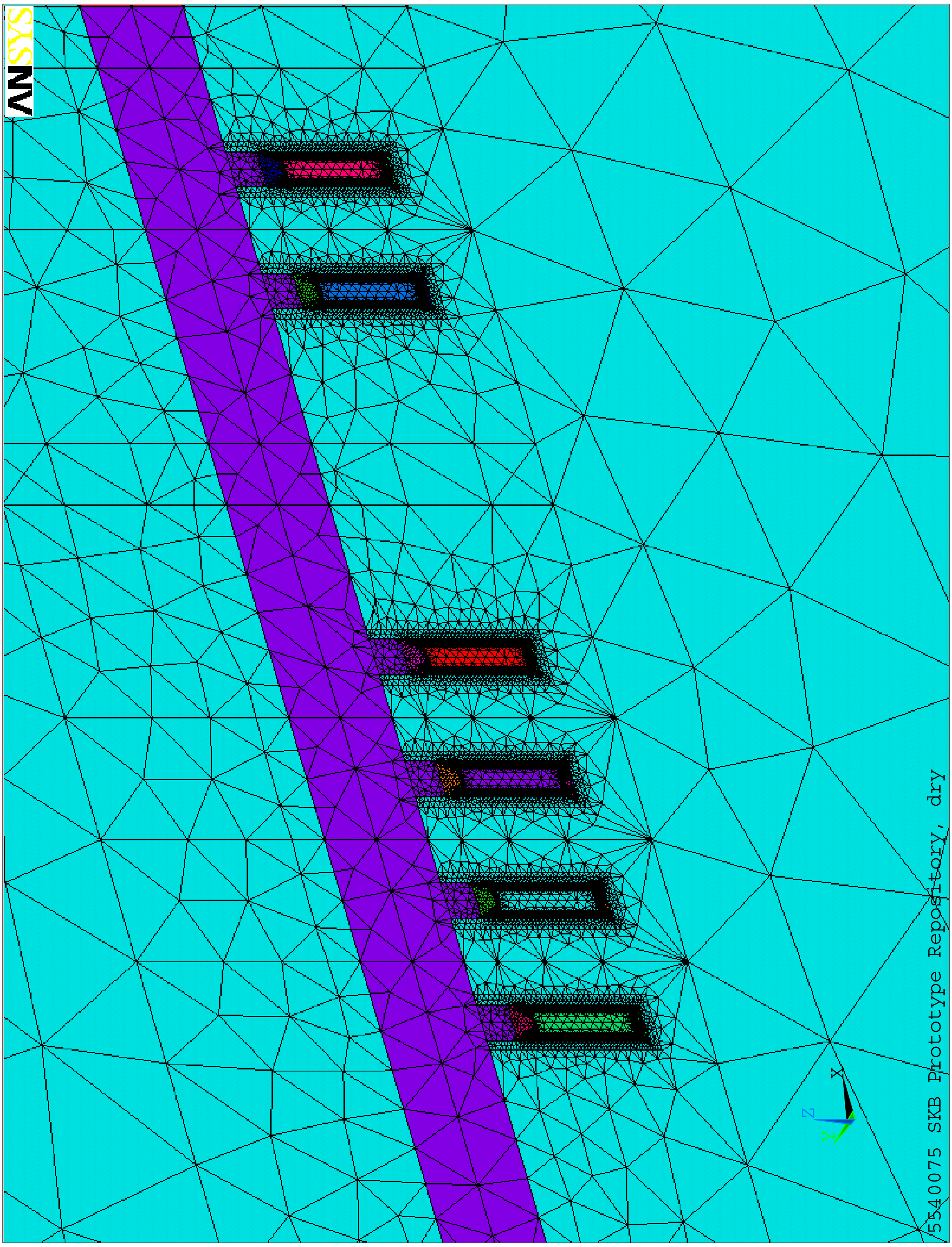
SKB Prototype Repository - parameters for thermal calculations

		Calculation Case 2A										
		Canister No. (No. 1 innermost position)										
	Unit	1		2		3		4		5		6
layout geometry												
Location depth	m	450										
Distance between canisters	m		6.0		6.0		6.0		18.0		6.0	
Canister data												
length	mm	4 830		Ditto		Ditto		Ditto		Ditto		Ditto
diameter	mm	1 050										
initial heat output	W	1 800										
thermal conductivity	W/m,K	390										
specific heat	MJ/m^3,K	2.40										
Inner gap [1)]												
width of gap	mm	10										
copper surface		normal										
conductivity from start to 2 years	W/m,K	*										
conductivity from 2 to 5 years	W/m,K	*										
conductivity after 5 years	W/m,K	*										
*) $4.544 \cdot 10^{-4} \cdot T + 5.046 \cdot 10^{-2}$												
(100% Humid Air)												
Bentonite - layer 1												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	0.50										
conductivity after 2 years	W/m,K	0.90										
specific heat	MJ/m^3,K	2.20										
Bentonite - layer 2												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	1.15										
conductivity after 2 years	W/m,K	1.20										
specific heat	MJ/m^3,K	2.20										
Bentonite - layer 3												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	1.25										
conductivity after 2 years	W/m,K	1.25										
specific heat	MJ/m^3,K	2.20										
Bentonite - outer gap												
initial conductivity	W/m,K	0.80										
conductivity after 0.5 year	W/m,K	1.25										
conductivity after 2 years	W/m,K	1.25										
specific heat	MJ/m^3,K	2.20										
Bentonite - top/bottom												
initial conductivity	W/m,K	1.20										
conductivity after 10 years	W/m,K	1.25										
specific heat	MJ/m^3,K	2.20										
Rock												
initial conductivity (at 14°C)	W/m,K	2.60										
conductivity at 100°C	W/m,K	2.45										
specific heat	MJ/m^3,K	2.22	2.45	at 100 ° C								
initial temp. at deposition depth	°C	14.0										
temperature gradient	°C/km	15.0										
Backfill in tunnel												
thermal conductivity	W/m,K	1.00										
specific heat	MJ/m^3,K	1.75										

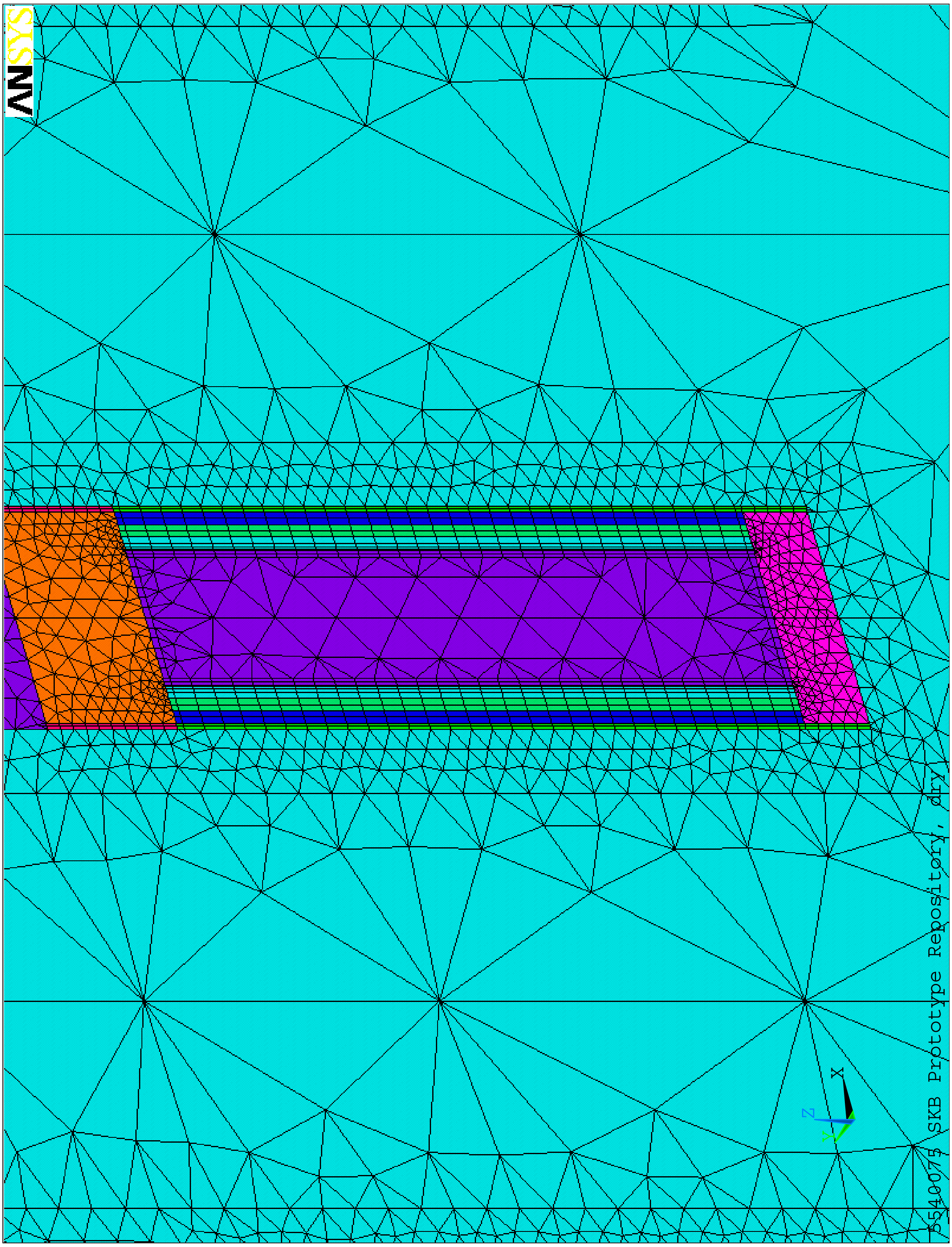
SKB Prototype Repository - parameters for thermal calculations

		Calculation Case 2B										
		Canister No. (No. 1 innermost position)										
	Unit	1		2		3		4		5		6
layout geometry												
Location depth	m	450										
Distance between canisters	m		6.0		6.0		6.0		18.0		6.0	
Canister data												
length	mm	4 830		Ditto		Ditto		Ditto		Ditto		Ditto
diameter	mm	1 050										
initial heat output	W	1 800										
thermal conductivity	W/m,K	390										
specific heat	$MJ/m^3,K$	2.40										
Inner gap 1)												
width of gap	mm	10										
copper surface		normal										
conductivity from start to 2 years	W/m,K	*										
conductivity from 2 to 5 years	W/m,K	1.30										
conductivity after 5 years	W/m,K	1.30										
*) $4.544\cdot10^{-4}\cdot T+5.046\cdot10^{-2}$												
(100% Humid Air)												
Bentonite - layer 1												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	0.90										
conductivity after 2 years	W/m,K	1.30										
specific heat	$MJ/m^3,K$	2.20										
Bentonite - layer 2												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	1.15										
conductivity after 2 years	W/m,K	1.30										
specific heat	$MJ/m^3,K$	2.20										
Bentonite - layer 3												
initial conductivity	W/m,K	1.20										
conductivity after 0.5 year	W/m,K	1.30										
conductivity after 2 years	W/m,K	1.30										
specific heat	$MJ/m^3,K$	2.20										
Bentonite - outer gap												
initial conductivity	W/m,K	0.80										
conductivity after 0.5 year	W/m,K	1.30										
conductivity after 2 years	W/m,K	1.30										
specific heat	$MJ/m^3,K$	2.20										
Bentonite - top/bottom												
initial conductivity	W/m,K	1.20										
conductivity after 10 years	W/m,K	1.30										
specific heat	$MJ/m^3,K$	2.20										
Rock												
initial conductivity (at 14°C)	W/m,K	2.60										
conductivity at 100°C	W/m,K	2.45										
specific heat	$MJ/m^3,K$	2.22	2.45	at 100 ° C								
initial temp. at deposition depth	°C	14.0										
temperature gradient	°C/km	15.0										
Backfill in tunnel												
thermal conductivity	W/m,K	1.00										
specific heat	$MJ/m^3,K$	1.75										

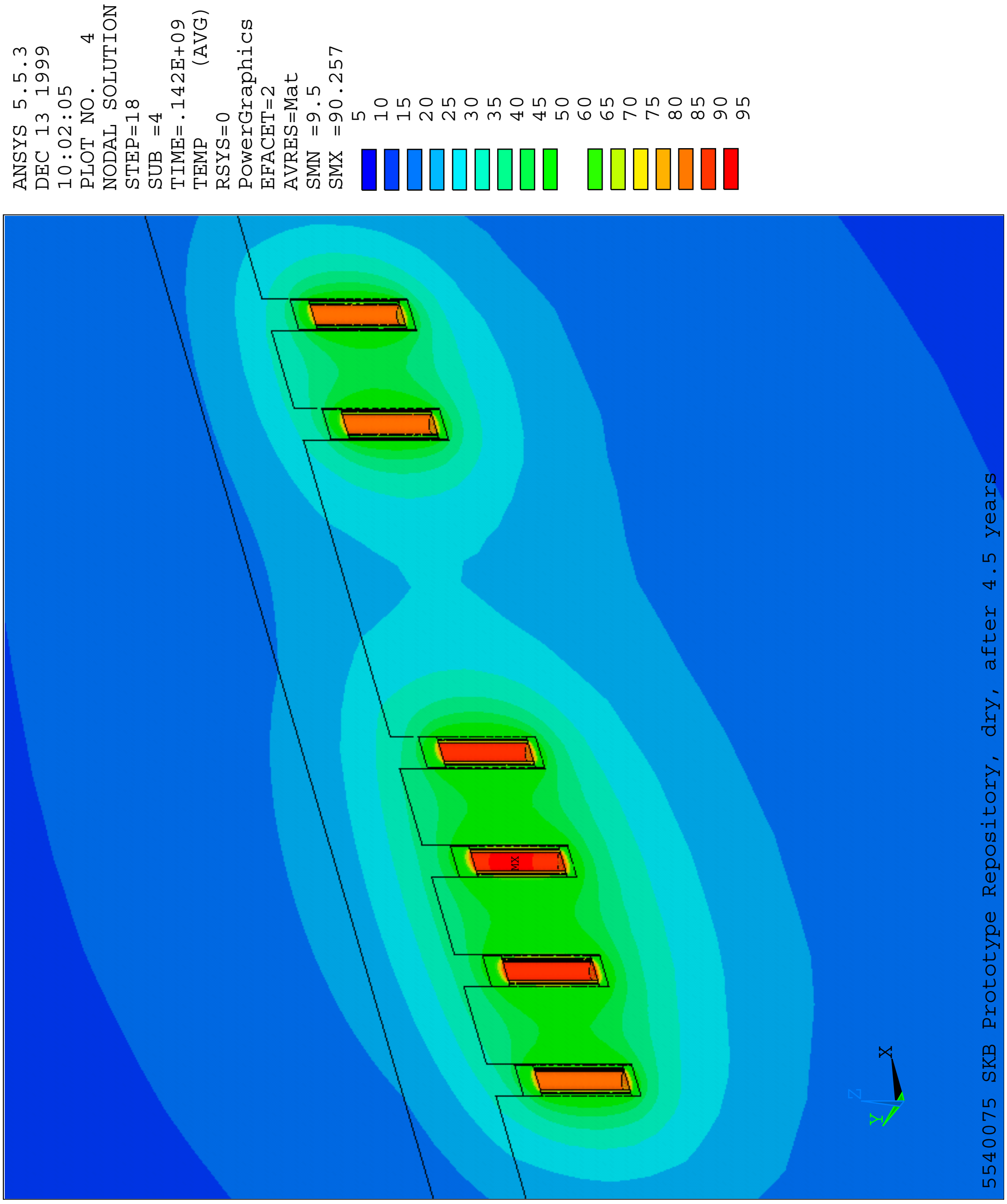
Case 2A
Mesh



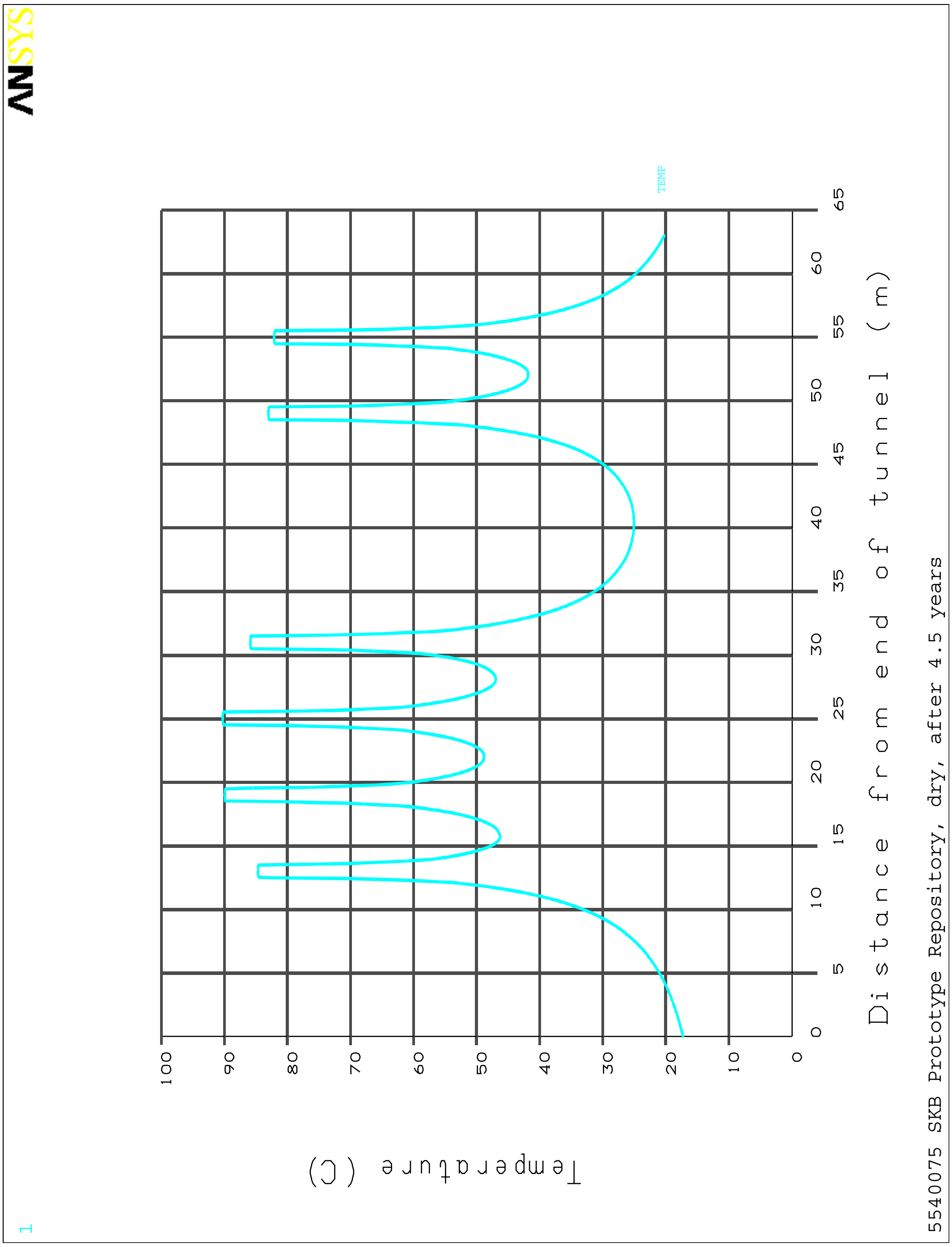
Case 2A
Mesh



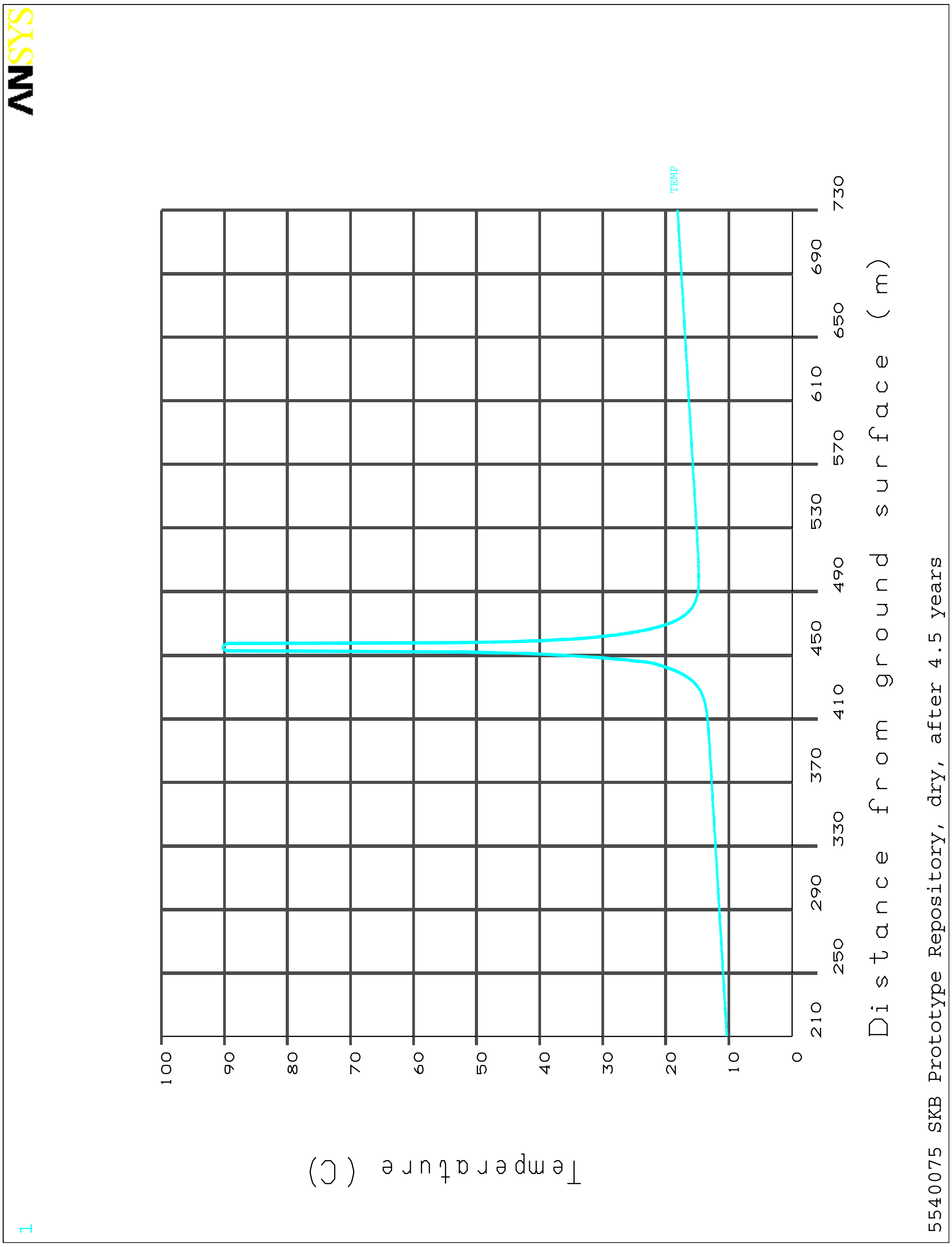
Case 2A
Simulation time = 4.5 years.

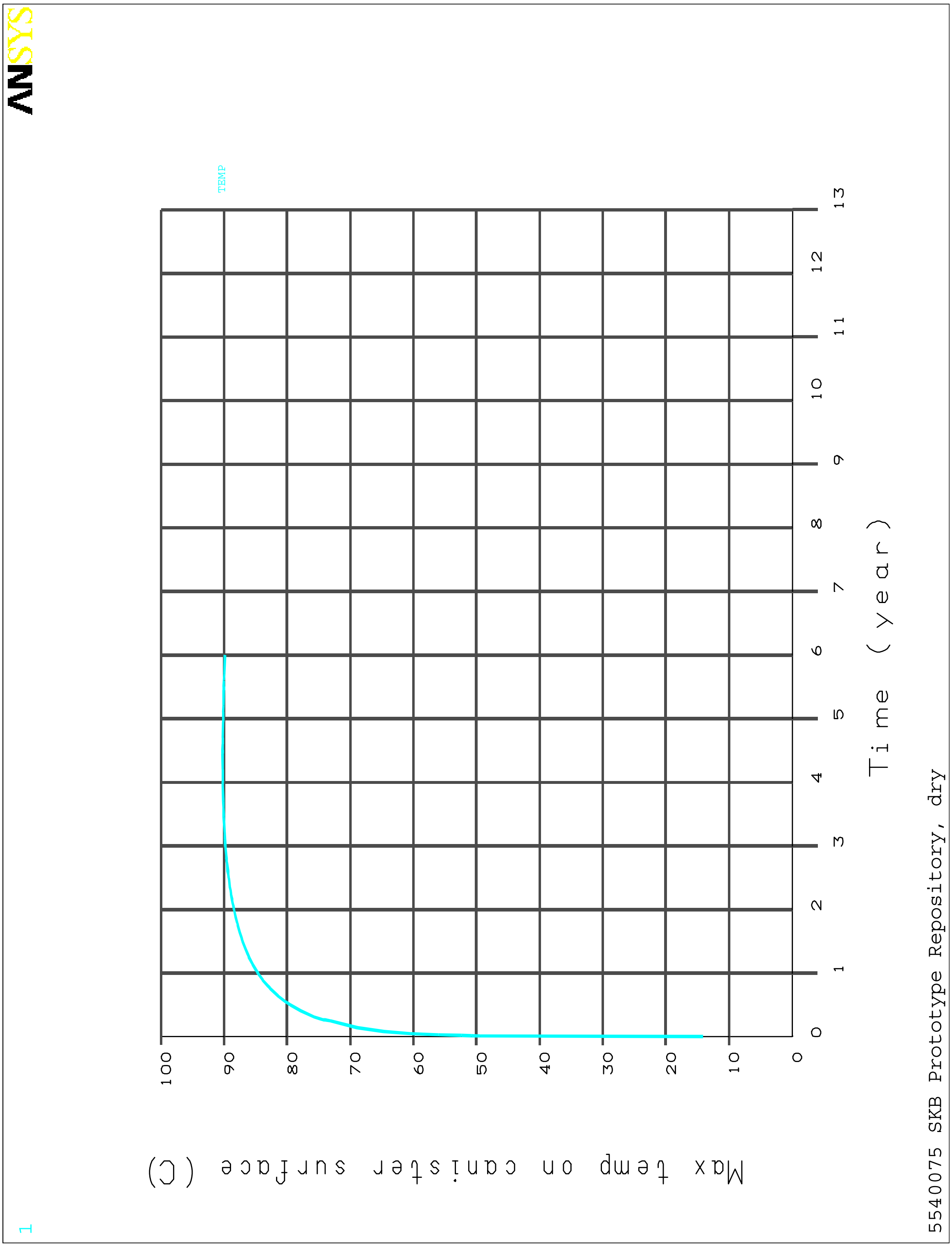


Case 2A
Simulation time = 4.5 years.



Case 2A
Simulation time = 4.5 years.




ANSYS
TEMP
Max temp on canister surface (C)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Time (year)
5540075 SKB Prototype Repository, dry
1

Case 2A
Max temp on canister surface. Canister No. 3

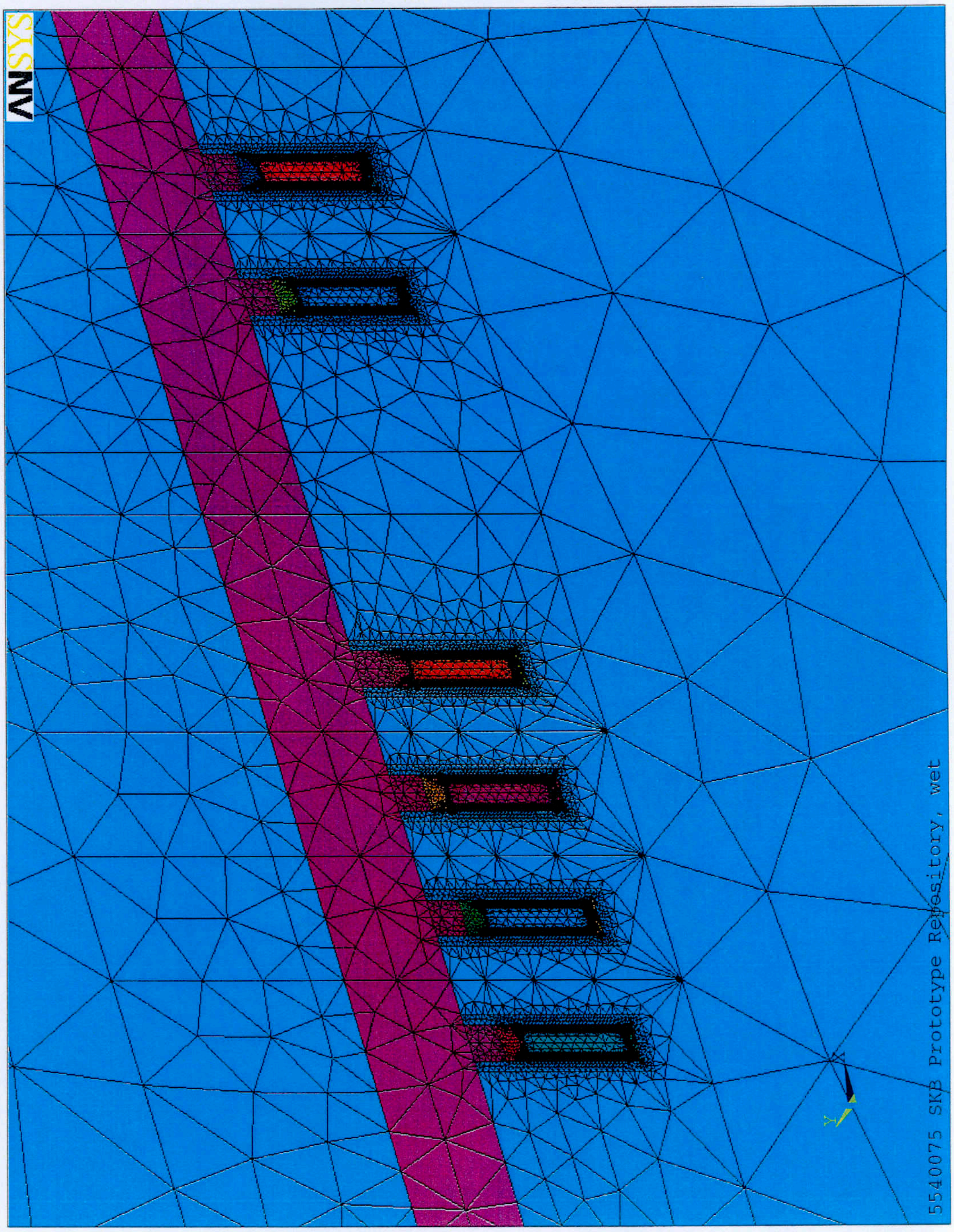
```
*** ANSYS POST26 VARIABLE LISTING ***

TIME          2 QUOT         NSOL TEMP
              Year           TEMP
0.10000E-09   0.316888E-17   14.1827
0.31557E+06   0.100000E-01   49.4375
0.42076E+06   0.133333E-01   50.8505
0.52595E+06   0.166667E-01   52.4254
0.84152E+06   0.266667E-01   56.0711
0.14857E+07   0.470803E-01   60.5483
0.25762E+07   0.816377E-01   64.7690
0.45440E+07   0.143993       68.9870
0.78892E+07   0.250000       73.1957
0.82048E+07   0.260000       74.0335
0.83175E+07   0.263572       74.2253
0.84302E+07   0.267143       74.3847
0.87684E+07   0.277859       74.7849
0.97828E+07   0.310004       75.7727
0.12826E+08   0.406441       77.8845
0.15778E+08   0.500000       79.5358
0.16094E+08   0.510000       79.6926
0.16410E+08   0.520000       79.8524
0.17356E+08   0.550000       80.3243
0.20196E+08   0.640000       81.5184
0.23668E+08   0.750000       82.6942
0.23983E+08   0.760000       82.7493
0.24299E+08   0.770000       82.8360
0.25246E+08   0.800000       83.1262
0.28086E+08   0.890000       83.9025
0.31557E+08   1.00000        84.6966
0.31872E+08   1.01000        84.7282
0.32188E+08   1.02000        84.7847
0.33135E+08   1.05000        84.9819
0.35975E+08   1.14000        85.5253
0.39446E+08   1.25000        86.0943
0.39762E+08   1.26000        86.1119
0.40077E+08   1.27000        86.1504
0.41024E+08   1.30000        86.2915
0.43864E+08   1.39000        86.6895
0.47335E+08   1.50000        87.1129
0.47651E+08   1.51000        87.1215
0.47967E+08   1.52000        87.1481
0.48913E+08   1.55000        87.2524
0.51753E+08   1.64000        87.5527
0.55225E+08   1.75000        87.8758
0.56014E+08   1.77500        87.9128
0.56802E+08   1.80000        87.9752
0.59169E+08   1.87500        88.1697
0.63114E+08   2.00000        88.4564
0.63272E+08   2.00500        88.4616
0.63429E+08   2.01000        88.4706
```

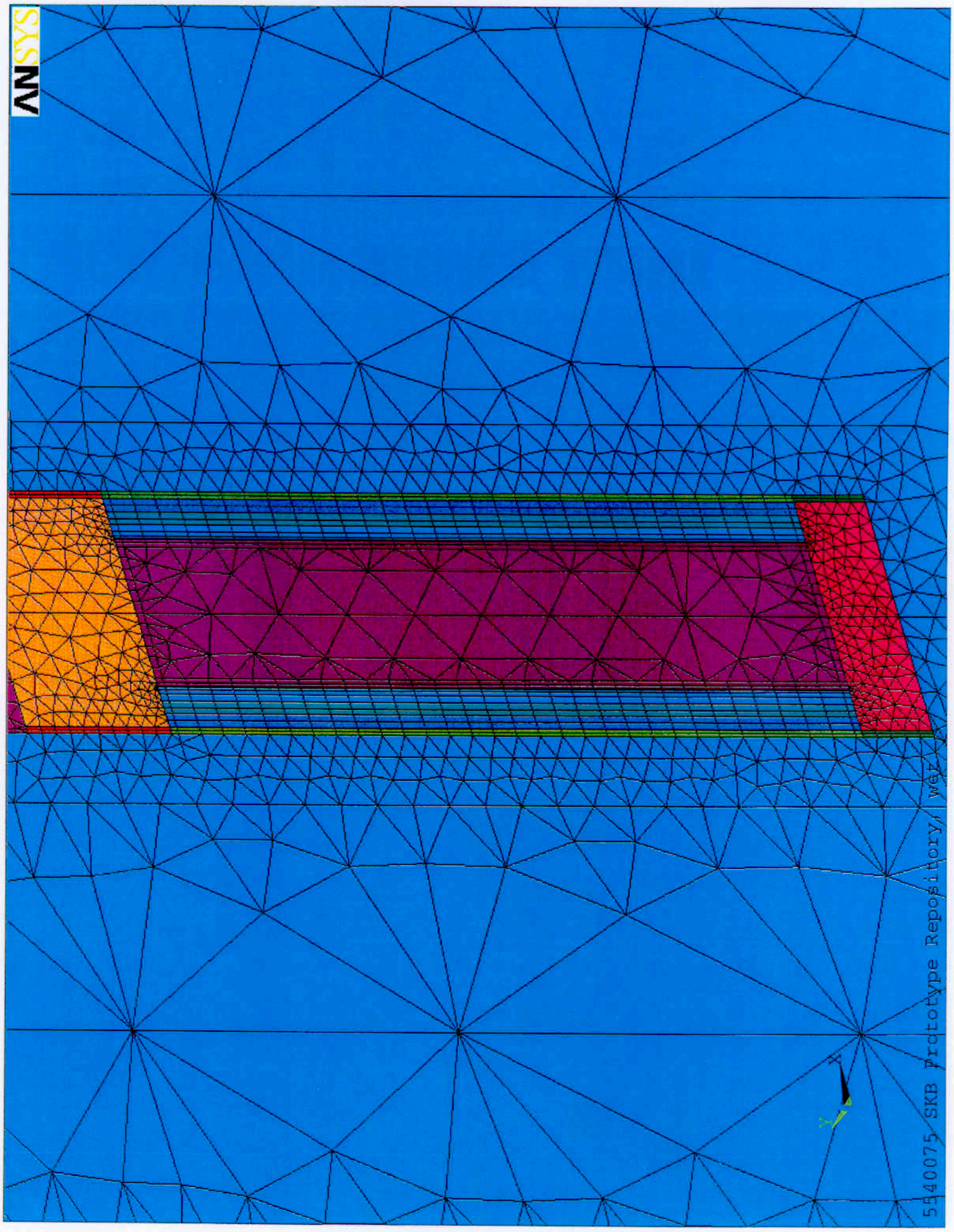
```
*** ANSYS POST26 VARIABLE LISTING ***

TIME          2 QUOT         NSOL TEMP
              Year           TEMP
0.63903E+08   2.02500        88.5031
0.64692E+08   2.05000        88.5577
0.64849E+08   2.05500        88.5672
0.65007E+08   2.06000        88.5773
0.65481E+08   2.07500        88.6092
0.66270E+08   2.10000        88.6613
0.67216E+08   2.13000        88.7187
0.68163E+08   2.16000        88.7762
0.70530E+08   2.23500        88.9132
0.71003E+08   2.25000        88.9368
0.72581E+08   2.30000        89.0170
0.74159E+08   2.35000        89.0965
0.78103E+08   2.47500        89.2770
0.78892E+08   2.50000        89.3076
0.80470E+08   2.55000        89.3690
0.82048E+08   2.60000        89.4313
0.85993E+08   2.72500        89.5725
0.86781E+08   2.75000        89.5965
0.88359E+08   2.80000        89.6434
0.89937E+08   2.85000        89.6917
0.93882E+08   2.97500        89.8011
0.94671E+08   3.00000        89.8196
0.97826E+08   3.10000        89.8849
0.10098E+09   3.20000        89.9515
0.10887E+09   3.45000        90.0787
0.11045E+09   3.50000        90.0995
0.11360E+09   3.60000        90.1302
0.11676E+09   3.70000        90.1653
0.12465E+09   3.95000        90.2234
0.12623E+09   4.00000        90.2326
0.12938E+09   4.10000        90.2383
0.13254E+09   4.20000        90.2499
0.14043E+09   4.45000        90.2561
0.14201E+09   4.50000        90.2566
0.14516E+09   4.60000        90.2432
0.14832E+09   4.70000        90.2370
0.15621E+09   4.95000        90.2032
0.15778E+09   5.00000        90.1970
0.16094E+09   5.10000        90.1689
0.16410E+09   5.20000        90.1487
0.17199E+09   5.45000        90.0835
0.17356E+09   5.50000        90.0719
0.17672E+09   5.60000        90.0321
0.17987E+09   5.70000        90.0009
0.18776E+09   5.95000        89.9105
0.18934E+09   6.00000        89.8946
```

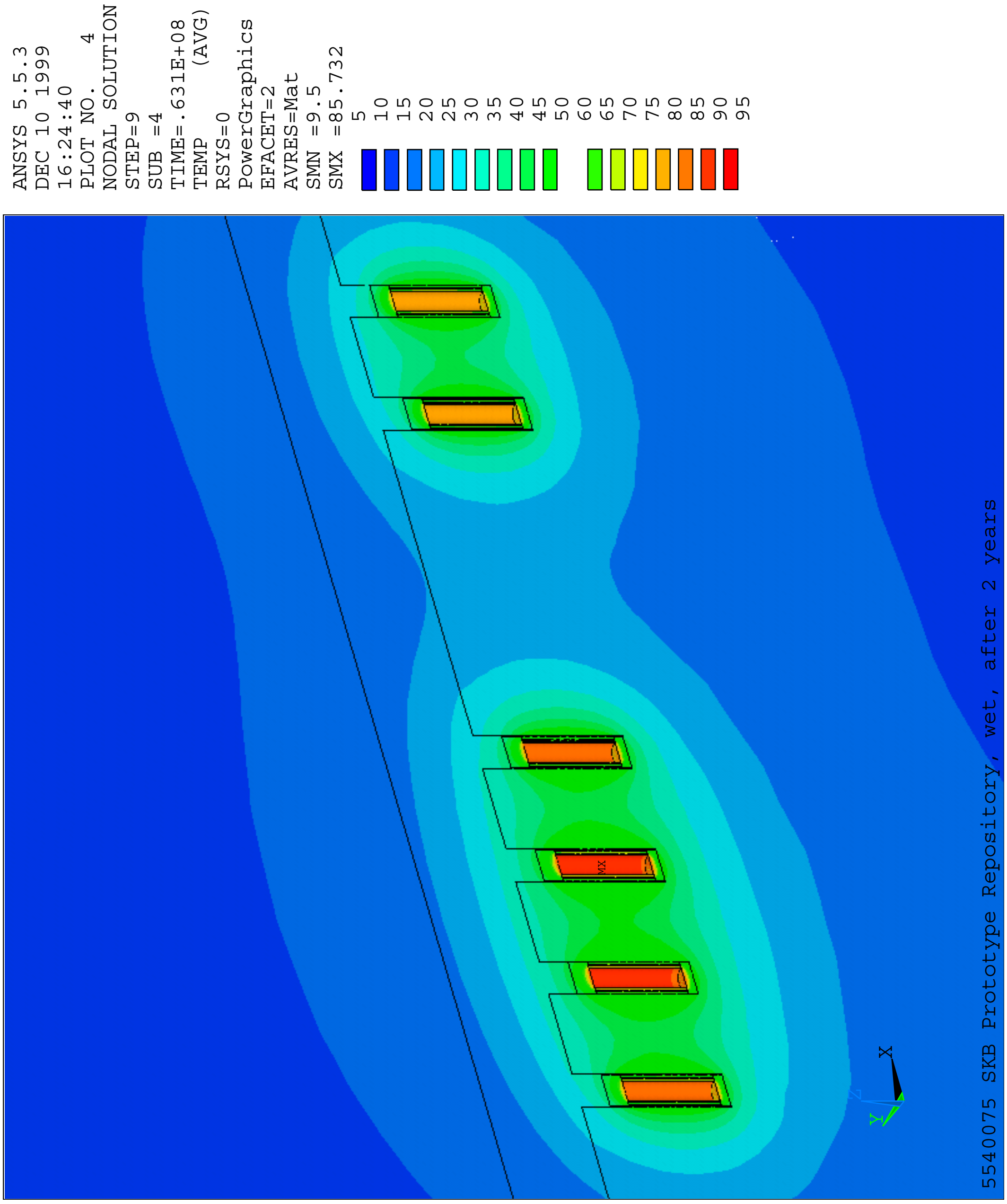
Case 2B
Mesh



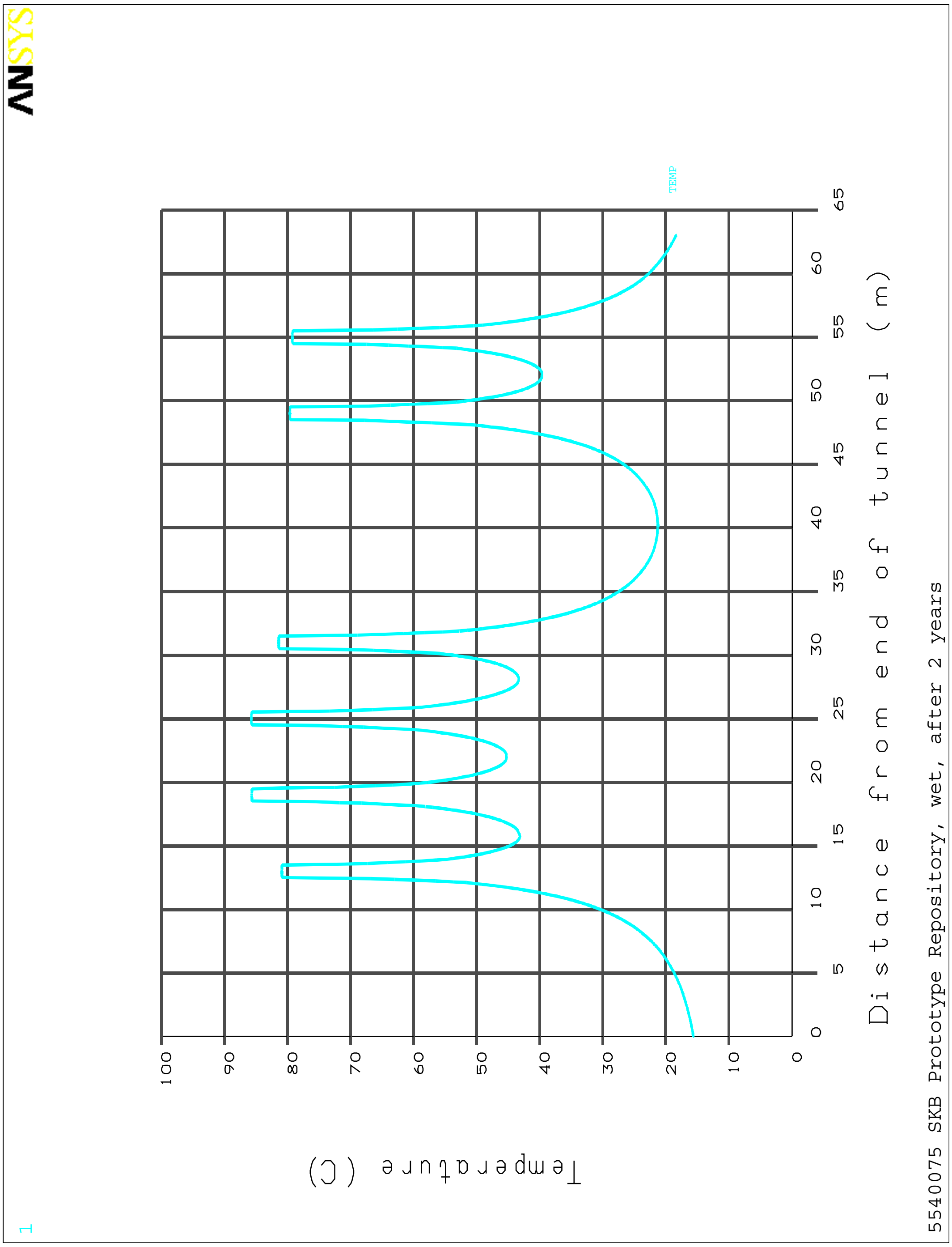
Case 2B
Mesh



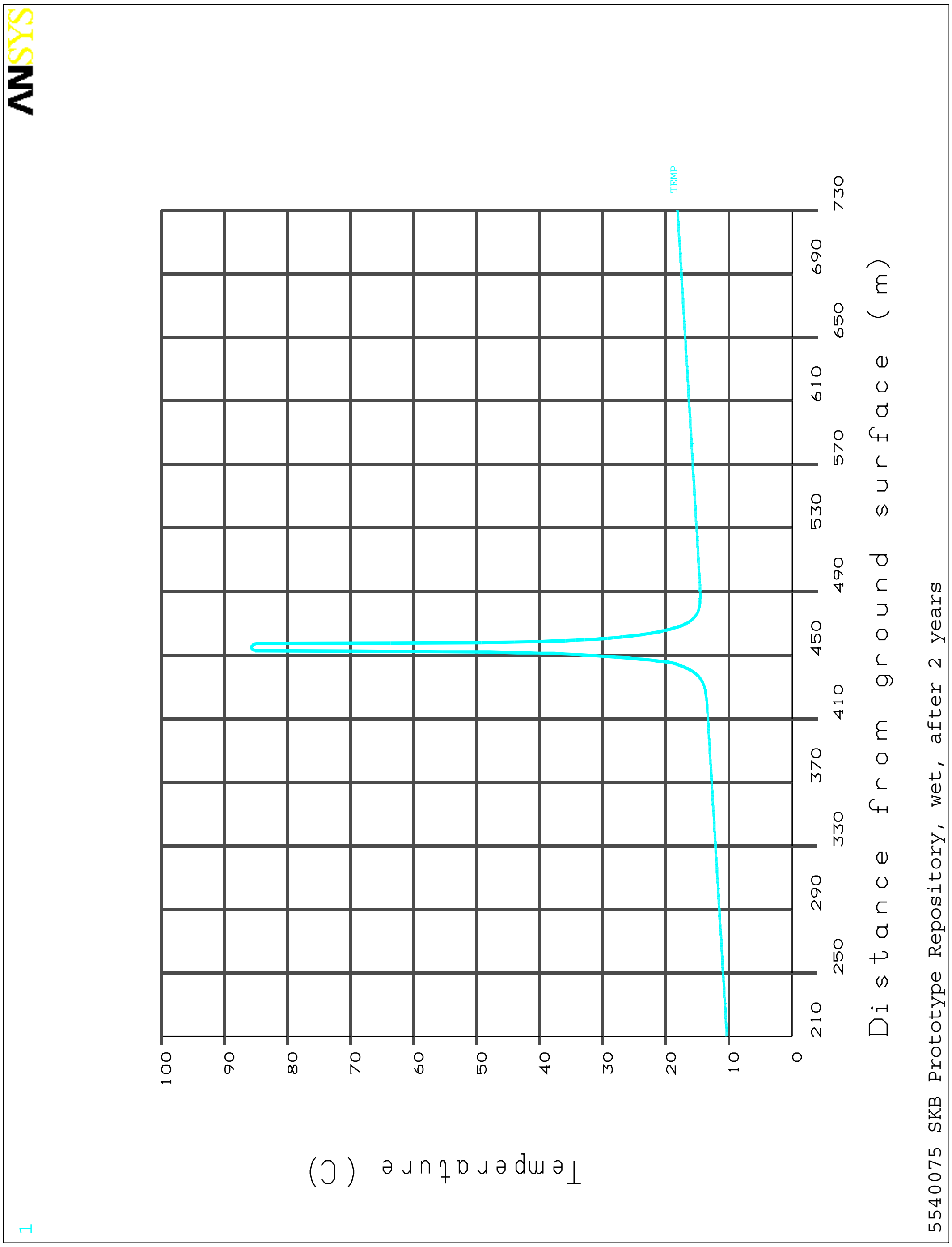
Case 2B
Simulation time = 4.5 years.



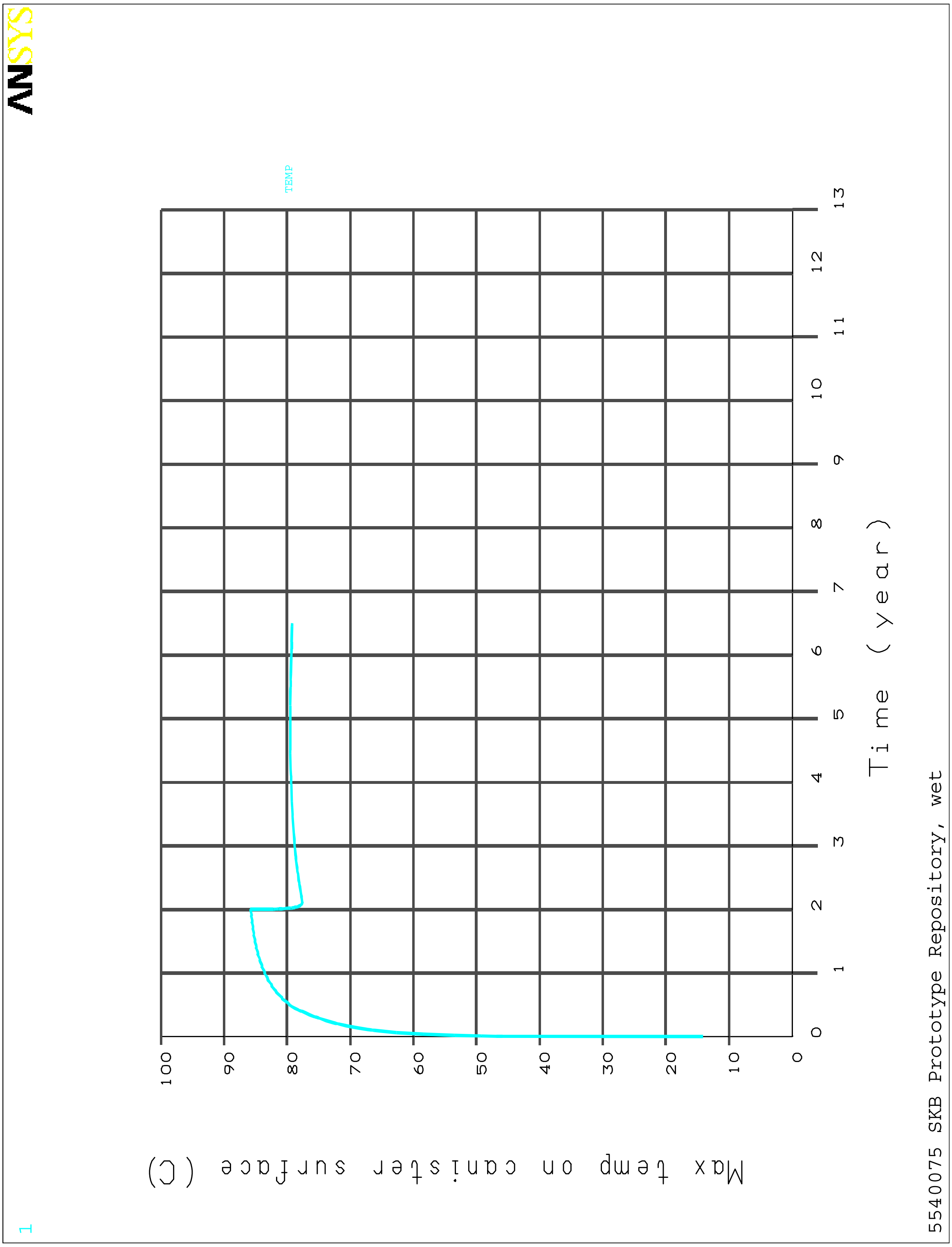
Case 2B
Simulation time = 4.5 years.



Case 2B
Simulation time = 4.5 years.



Case 2B
Max temp on canister surface. Canister No. 3



Case 2B
Max temp on canister surface. Canister No.3

```
 *** ANSYS POST26 VARIABLE LISTING ***

 TIME          2 QUOT        NSOL TEMP
               Year          TEMP
 0.10000E-09   0.316888E-17  14.1827
 0.31557E+06   0.100000E-01  49.4006
 0.42076E+06   0.133333E-01  50.8008
 0.52595E+06   0.166667E-01  52.3643
 0.84152E+06   0.266667E-01  55.9879
 0.14873E+07   0.471297E-01  60.4505
 0.25816E+07   0.818064E-01  64.6635
 0.45564E+07   0.144387      68.8784
 0.78892E+07   0.250000      73.0654
 0.82048E+07   0.260000      73.8629
 0.83100E+07   0.263333      74.0331
 0.84152E+07   0.266667      74.1758
 0.87307E+07   0.276667      74.5412
 0.96775E+07   0.306667      75.4646
 0.12518E+08   0.396667      77.4781
 0.14148E+08   0.448333      78.5336
 0.15778E+08   0.500000      79.4252
 0.16094E+08   0.510000      79.2204
 0.16410E+08   0.520000      79.2588
 0.17356E+08   0.550000      79.6466
 0.20196E+08   0.640000      80.7991
 0.23668E+08   0.750000      81.9583
 0.23983E+08   0.760000      81.7158
 0.24259E+08   0.768748      81.6969
 0.24535E+08   0.777496      81.7366
 0.25364E+08   0.803739      81.9539
 0.27848E+08   0.882469      82.6182
 0.31557E+08   1.00000       83.4616
 0.31872E+08   1.01000       83.2253
 0.32104E+08   1.01734       83.1885
 0.32336E+08   1.02467       83.1968
 0.33030E+08   1.04668       83.3082
 0.35114E+08   1.11271       83.7012
 0.37280E+08   1.18135       84.0793
 0.39446E+08   1.25000       84.4278
 0.39762E+08   1.26000       84.2108
 0.39965E+08   1.26645       84.1712
 0.40169E+08   1.27291       84.1665
 0.40780E+08   1.29227       84.2261
 0.42613E+08   1.35035       84.4746
 0.46557E+08   1.47535       84.9675
 0.47335E+08   1.50000       85.0485
 0.47651E+08   1.51000       84.8471
 0.47838E+08   1.51594       84.8079
 0.48026E+08   1.52188       84.7976
 0.48588E+08   1.53969       84.8305
 0.50274E+08   1.59313       84.9995
 0.54219E+08   1.71813       85.3784
 0.55225E+08   1.75000       85.4618
 0.56014E+08   1.77500       85.2499
 0.56802E+08   1.80000       85.2692
 0.59169E+08   1.87500       85.4474
 0.63114E+08   2.00000       85.7319
 0.63272E+08   2.00500       80.9282
 0.63324E+08   2.00667       80.2279
 0.63357E+08   2.00770       79.9191
 0.63389E+08   2.00873       79.6793
 0.63468E+08   2.01121       79.2946
 0.63578E+08   2.01472       78.9486
 0.63737E+08   2.01974       78.6518
 0.63997E+08   2.02798       78.3987
 0.64584E+08   2.04660       78.1974
 0.64692E+08   2.05000       78.1696
 0.64849E+08   2.05500       77.7880
```

```
 *** ANSYS POST26 VARIABLE LISTING ***

 TIME          2 QUOT        NSOL TEMP
               Year          TEMP
 0.64902E+08   2.05667       77.7289
 0.64955E+08   2.05833       77.6895
 0.65112E+08   2.06333       77.6270
 0.65586E+08   2.07833       77.5677
 0.66270E+08   2.10000       77.5587
 0.67216E+08   2.13000       77.5865
 0.68163E+08   2.16000       77.6321
 0.70530E+08   2.23500       77.7634
 0.71003E+08   2.25000       77.7906
 0.72581E+08   2.30000       77.8733
 0.74159E+08   2.35000       77.9587
 0.78103E+08   2.47500       78.1554
 0.78892E+08   2.50000       78.1952
 0.80470E+08   2.55000       78.2647
 0.82048E+08   2.60000       78.3359
 0.85993E+08   2.72500       78.4975
 0.86781E+08   2.75000       78.5302
 0.88359E+08   2.80000       78.5859
 0.89937E+08   2.85000       78.6438
 0.93882E+08   2.97500       78.7749
 0.94671E+08   3.00000       78.8014
 0.97826E+08   3.10000       78.8830
 0.10098E+09   3.20000       78.9685
 0.10887E+09   3.45000       79.1404
 0.11045E+09   3.50000       79.1751
 0.11360E+09   3.60000       79.2228
 0.11676E+09   3.70000       79.2761
 0.12465E+09   3.95000       79.3785
 0.12623E+09   4.00000       79.3992
 0.12938E+09   4.10000       79.4213
 0.13254E+09   4.20000       79.4503
 0.14043E+09   4.45000       79.4999
 0.14201E+09   4.50000       79.5100
 0.14516E+09   4.60000       79.5126
 0.14832E+09   4.70000       79.5230
 0.15621E+09   4.95000       79.5318
 0.15778E+09   5.00000       79.5337
 0.16094E+09   5.10000       79.5211
 0.16410E+09   5.20000       79.5169
 0.17199E+09   5.45000       79.4935
 0.17356E+09   5.50000       79.4888
 0.17672E+09   5.60000       79.4642
 0.17987E+09   5.70000       79.4484
 0.18776E+09   5.95000       79.3990
 0.18934E+09   6.00000       79.3891
 0.19250E+09   6.10000       79.3548
 0.19565E+09   6.20000       79.3296
 0.20354E+09   6.45000       79.2592
 0.20512E+09   6.50000       79.2450
```