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Cool Down Analysis of the GEM Conductor Cold Leak Test taking into Consideration the Axial Conduction

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Summary

The purpose of the GEM conductor test is to leak check the conductor. The conductor will be assembled in full module finished lengths of 1200 m, wound in a single layer on a bobbin consisting of 3m outside diameter and 3.5m long (see fig. 11). Before the leak check test is performed the conductor must be cooled down from ambient conditions to liquid nitrogen temperature. A 25.4 mm diameter and 50 m long heat exchanger tube is wound on the inside of the bobbin and is used to cool the bobbin with the conductor from 300 K to approximately 80 K. A Sinda/Fluint model was developed to analyze the cool down taking into consideration the axial conduction along the length of the bobbin as well as the variation of the thermal properties with temperature. In this analysis, we assumed that the conductor mass, which is 4 tons, is made of aluminum only. We also took into consideration the mass of the bobbin which is 2 tons. We ignored the contact resistance between the conductor and the bobbin, and between the bobbin and the heat exchanger tube. The conductor is cooled using nitrogen which is supplied to the heat exchanger tube at a pressure of 2.5 atm and a temperature of 77.3 K (subcooled). The nitrogen flow is made to exhaust to atmospheric pressure. An estimation of the cool down time is made by solving the energy equation in which we assume the total mass of the assembly (bobbin+cable and conduit) as predominantly aluminum. The results are compared against those obtained from the computer analysis.

Results

The conductor cool down was modeled and analyzed using the Sinda/fluint software (fig. 12 and fig.13). The cable -in -conduit bobbin assembly was discretized in 20 segments of 0.175 each. Each segment is cooled by a 2.5 m segment of the heat exchanger tube. Subcooled nitrogen at a pressure of 2.5 atm and a temperature of 77.3 K is made to flow through the heat exchanger tube. Initially rapid boiling occurs at the heat exchanger inlet while the outlet of the heat exchanger tube contains warm vapor. Pressure surges occurring inside the

tube cause the flow rate to vary initially as the cold front travels down the length of the tube. A stationary pressure profile is quickly established with an initial flow rate of about 0.032 kg/sec.

Because of the computer memory requirements and the long time it takes to run this problem, we only present results of the cool down analysis up to 11 hours. Using this result we extrapolated for the whole cool down process in order to estimate the cool down time. Fig.1 through Fig. 8 show the temperature profiles with respect to time for each segment of the conductor after 4 hours, 7 hours, and 11 hours respectively. Fig. 9 and Fig.10 show the conductor and nitrogen temperature profiles after 11 hours of cool down for the first and the last segments respectively. The conductor temperature profile shown in fig. 8 was used in our extrapolation for the whole cool down process. Using a curve fitting technique, this profile is in the form of t = -alog(T) + b, where t and T represent the time and temperature respectively. The values of a and b are 75.54 and 194.1 respectively. The units are degK for the temperature and seconds for the time. Table 1 shows the results of the cool down time obtained from the computer analysis and those obtained from the energy equation $MC_{al}\frac{dT}{dt} = C_{n2}\dot{m}(T_{out} - T_{in})$. The difference is quite substantial. Using the extrapolation results for the whole cool down process, it is estimated that it will take 50 hours to cool the conductor from 300 K down to 80 K.
The same computer model was run by changing the heat exchanger tube diameter to 12.7 mm and keeping all other conditions the same. The flowrate through the exchanger tube is reduced to approximately .006 kg/sec, due to the high pressure drop, and the cool down time has increased drastically.

Table 1

Cooldown Time From 300 K to	Results From the Computer Analysis	Results From the Energy Equation
280	9.1	3.99
260	12.11	8.25
240	14.3	12.9
200	20.28	17.63
160	27.6	22.63
120	37	27.7
100	43.02	30

Conclusion

The cool down of GEM conductor cold leak test was analyzed using a Sinda/Fluint model taking into consideration the axial conduction term. The

results of this model were compared against results obtained from solving the energy equation. The results show that the axial conduction term is quite important and should be taken into consideration in analyzing the cool down time. The results also show that for a reasonable cool down time a heat exchanger tube attached along the conductor is necessary.

temp1

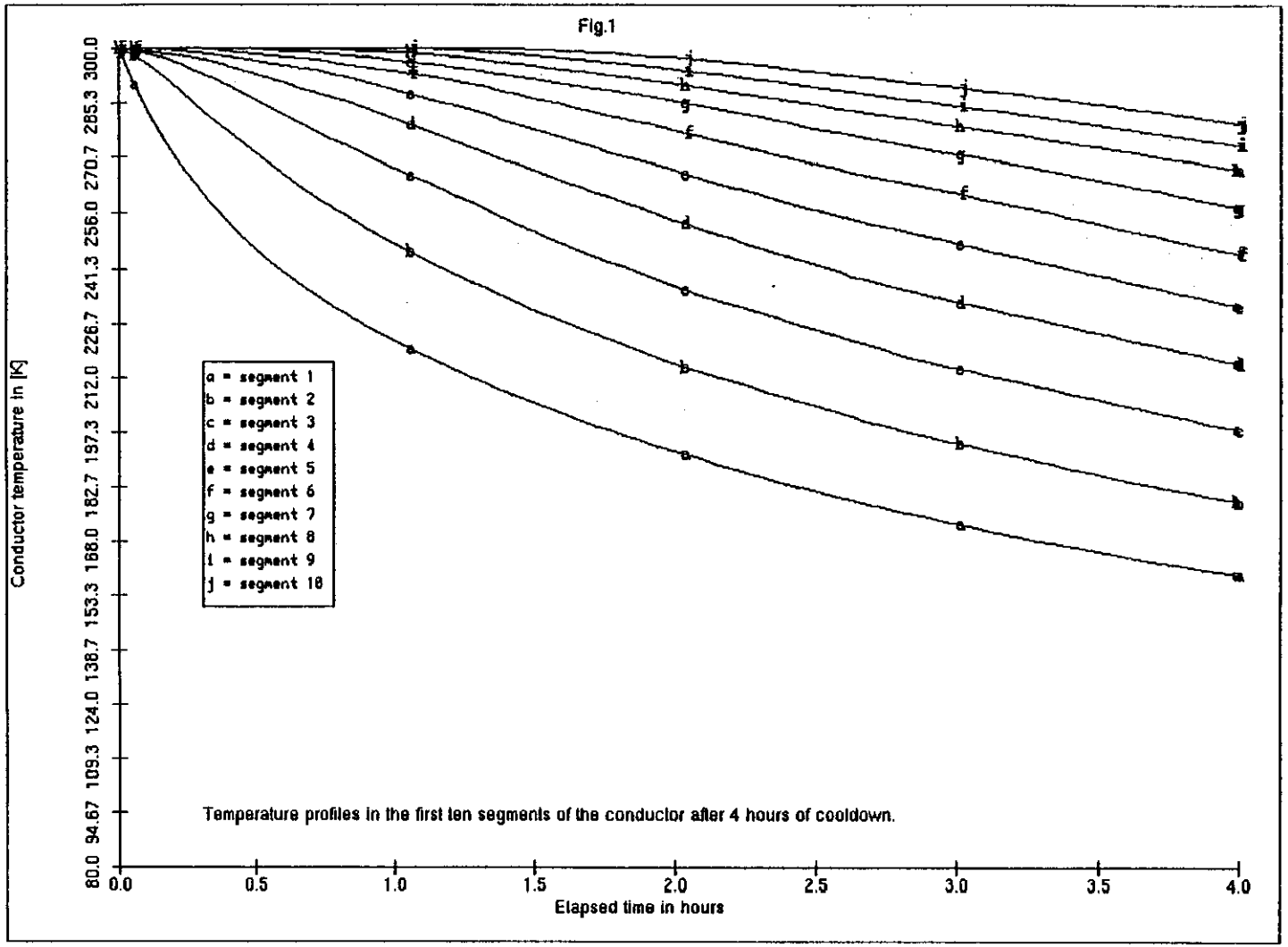


Fig.1
Conductor temperature in [K]
80.0
94.67
109.3
124.0
138.7
153.3
168.0
182.7
197.3
212.0
226.7
241.3
256.0
270.7
285.3
300.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Elapsed time in hours
a = segment 1
b = segment 2
c = segment 3
d = segment 4
e = segment 5
f = segment 6
g = segment 7
h = segment 8
i = segment 9
j = segment 10
Temperature profiles in the first ten segments of the conductor after 4 hours of cooldown.

temp2

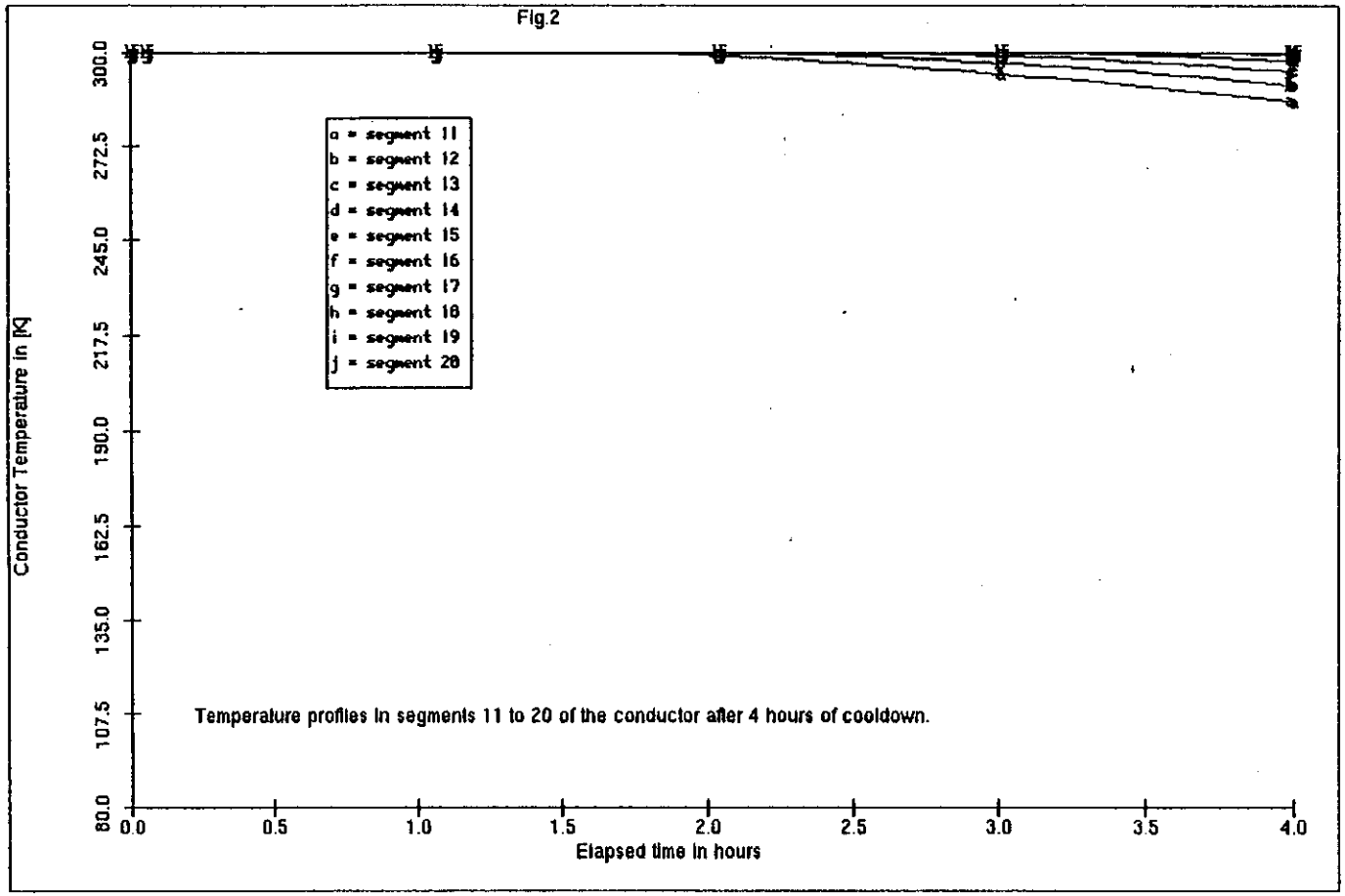


Fig.2
a = segment 11
b = segment 12
c = segment 13
d = segment 14
e = segment 15
f = segment 16
g = segment 17
h = segment 18
i = segment 19
j = segment 20
Temperature profiles in segments 11 to 20 of the conductor after 4 hours of cooldown.
Conductor Temperature in [K]
300.0
272.5
245.0
217.5
190.0
162.5
135.0
107.5
80.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Elapsed time in hours

temp3

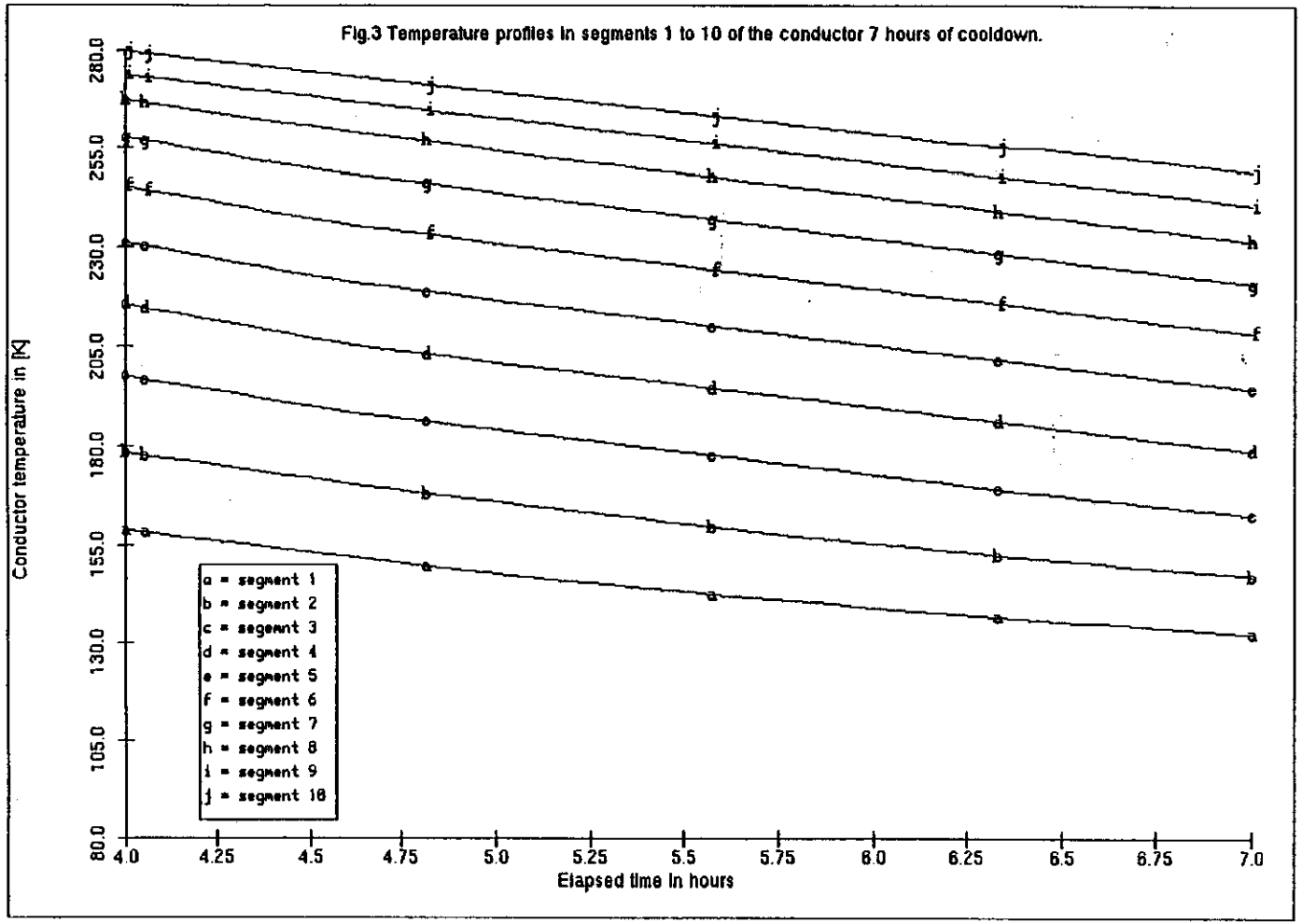


Fig.3 Temperature profiles in segments 1 to 10 of the conductor 7 hours of cooldown.
Conductor temperature in [K]
280.0
255.0
230.0
205.0
180.0
155.0
130.0
105.0
80.0
4.0
4.25
4.5
4.75
5.0
5.25
5.5
5.75
6.0
6.25
6.5
6.75
7.0
Elapsed time in hours
a = segment 1
b = segment 2
c = segment 3
d = segment 4
e = segment 5
f = segment 6
g = segment 7
h = segment 8
i = segment 9
j = segment 10

temp4

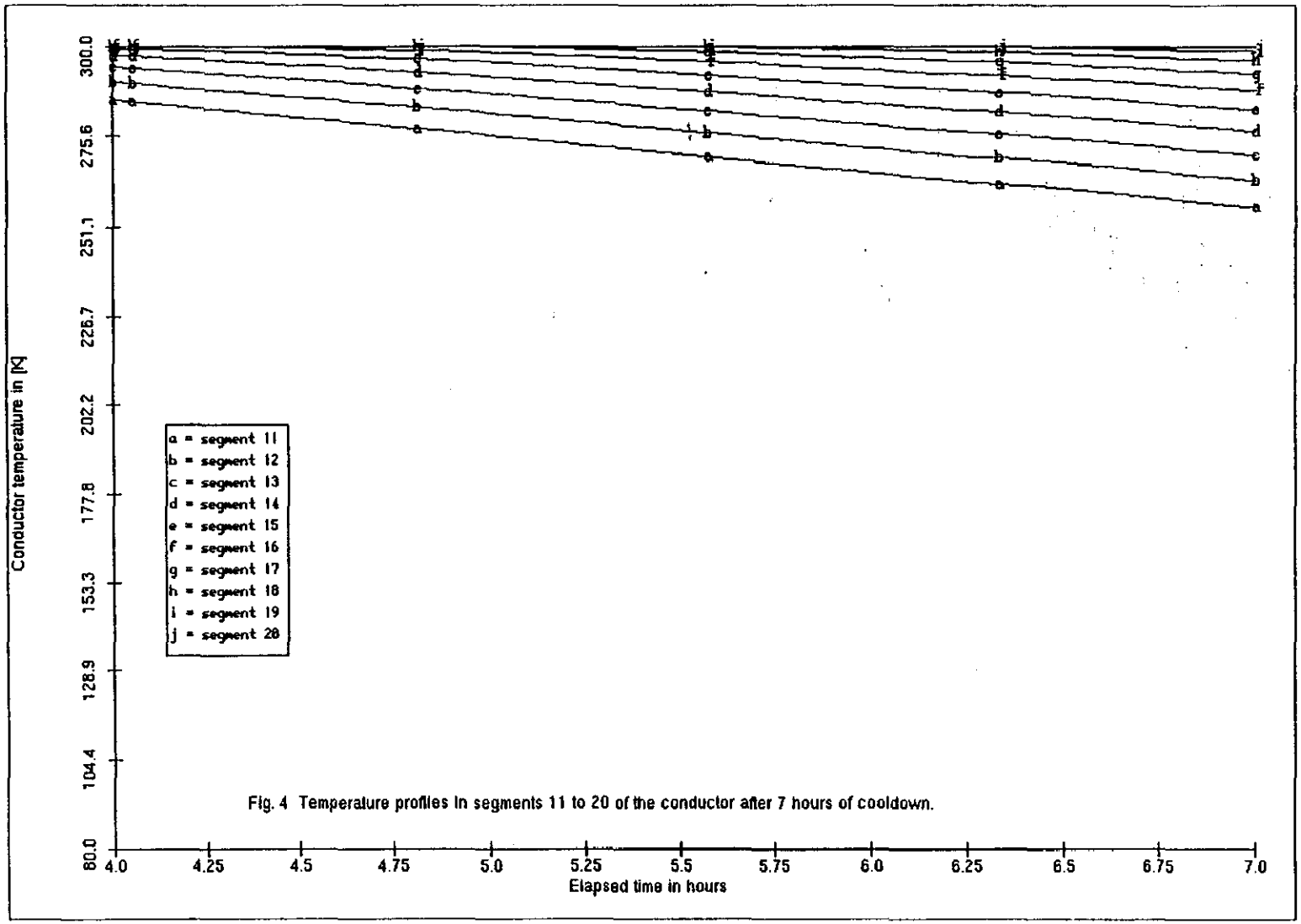


Fig. 4 Temperature profiles in segments 11 to 20 of the conductor after 7 hours of cooldown.

temp5

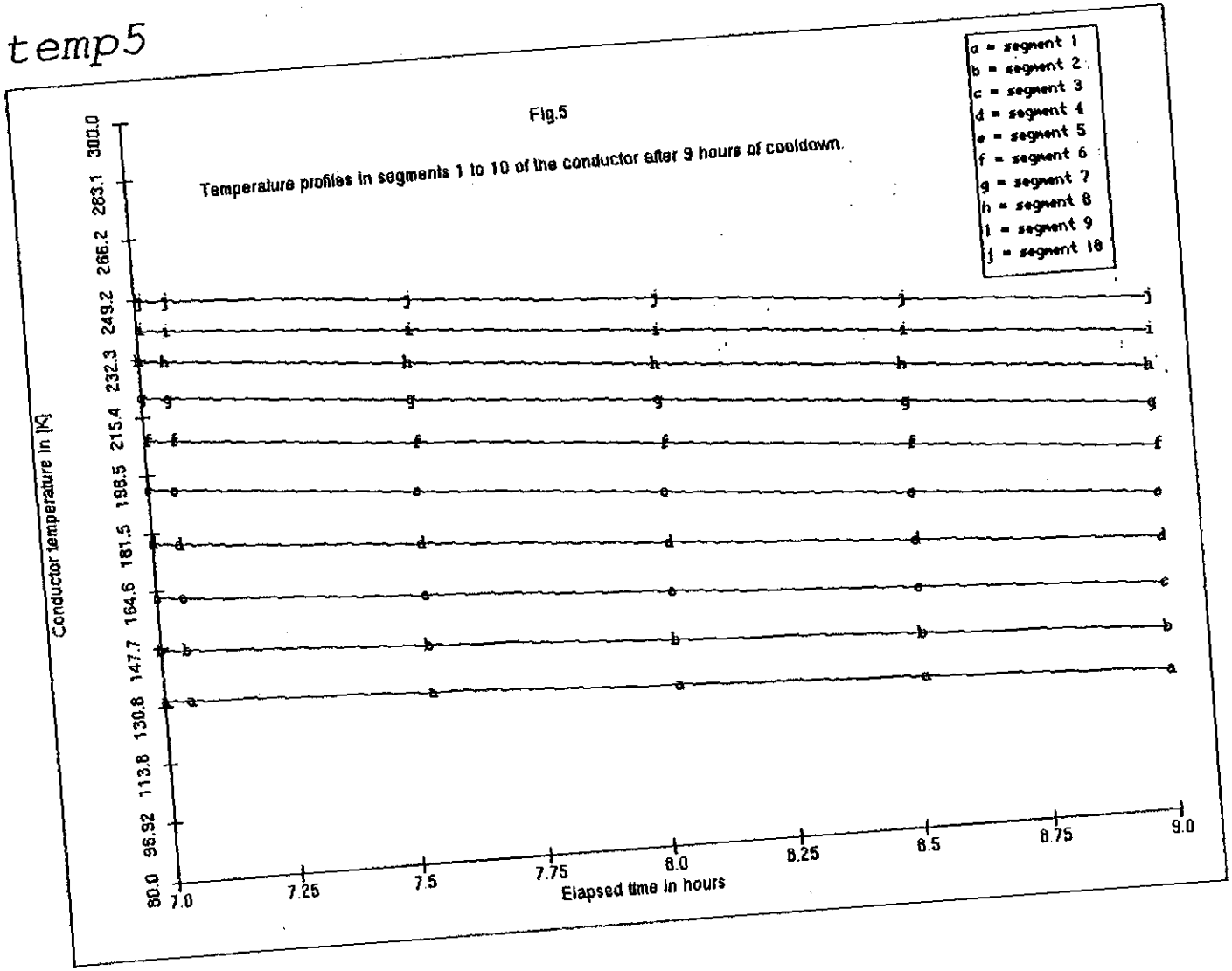


Fig.5
Temperature profiles in segments 1 to 10 of the conductor after 9 hours of cooldown.
a = segment 1
b = segment 2
c = segment 3
d = segment 4
e = segment 5
f = segment 6
g = segment 7
h = segment 8
i = segment 9
j = segment 18
Conductor temperature in [K]
80.0
96.92
113.8
130.8
147.7
164.6
181.5
198.5
215.4
232.3
249.2
266.2
283.1
300.0
7.0
7.25
7.5
7.75
8.0
8.25
8.5
8.75
9.0
Elapsed time in hours

temp20

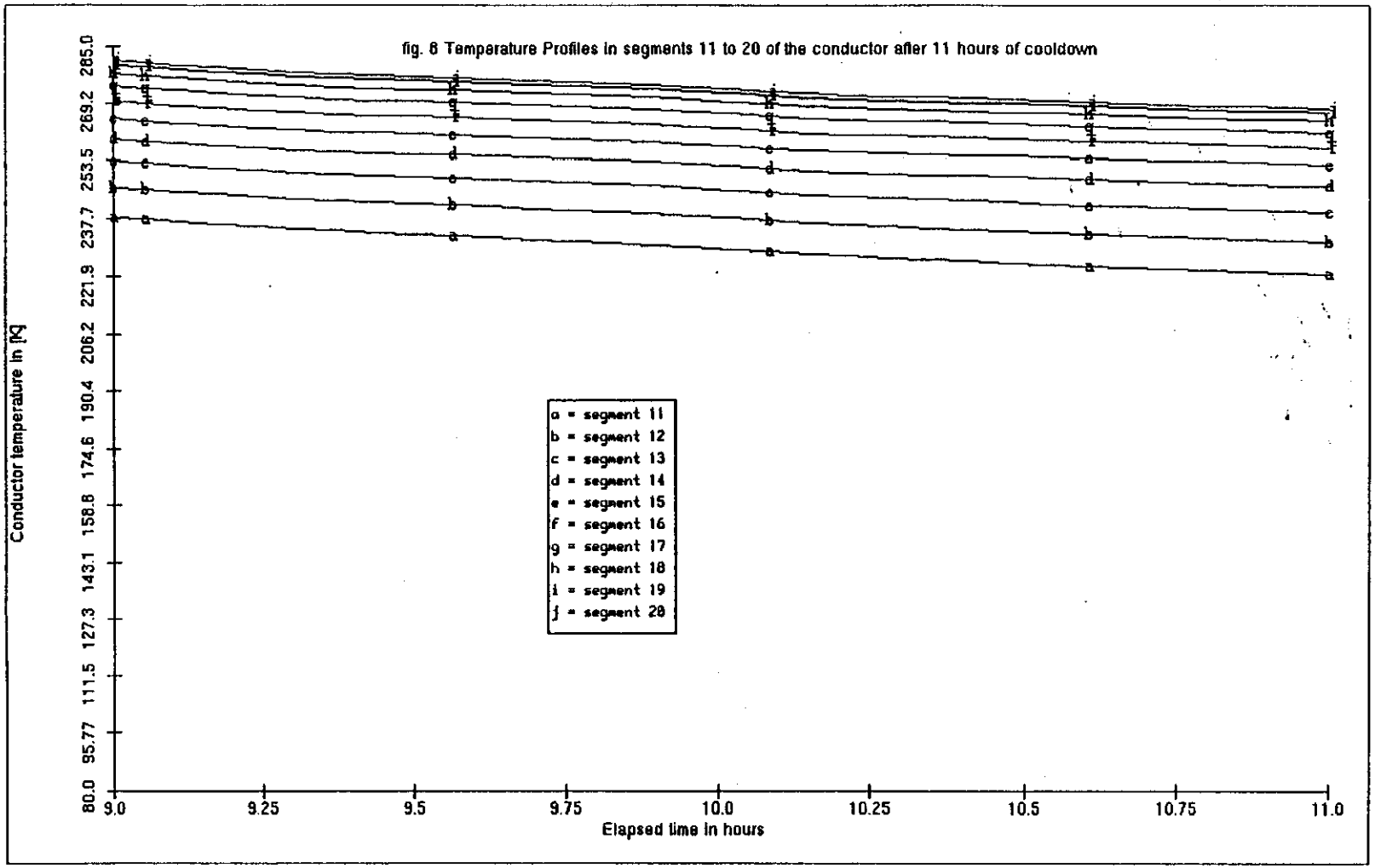


fig. 6 Temperature Profiles in segments 11 to 20 of the conductor after 11 hours of cooldown
Conductor temperature in [K]
80.0
95.77
111.5
127.3
143.1
158.8
174.6
190.4
206.2
221.9
237.7
253.5
269.2
285.0
9.0
9.25
9.5
9.75
10.0
10.25
10.5
10.75
11.0
Elapsed time in hours
a = segment 11
b = segment 12
c = segment 13
d = segment 14
e = segment 15
f = segment 16
g = segment 17
h = segment 18
i = segment 19
j = segment 20

temp11

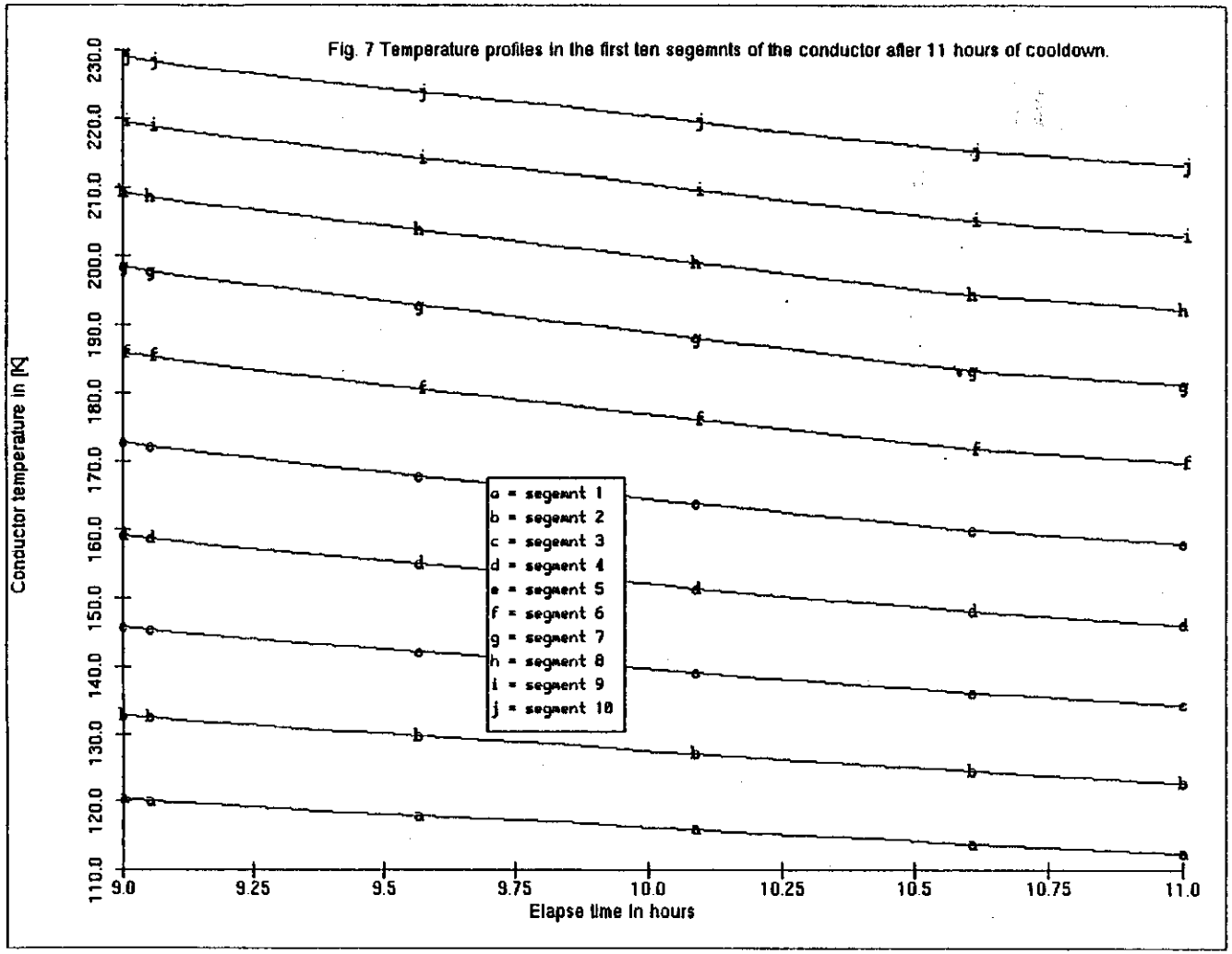


Fig. 7 Temperature profiles in the first ten segemnts of the conductor after 11 hours of cooldown.
Conductor temperature in [K]
230.0
220.0
210.0
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
9.0
9.25
9.5
9.75
10.0
10.25
10.5
10.75
11.0
Elapse time in hours
a = segemnt 1
b = segemnt 2
c = segemnt 3
d = segment 4
e = segment 5
f = segment 6
g = segment 7
h = segment 8
i = segment 9
j = segment 10

temp6

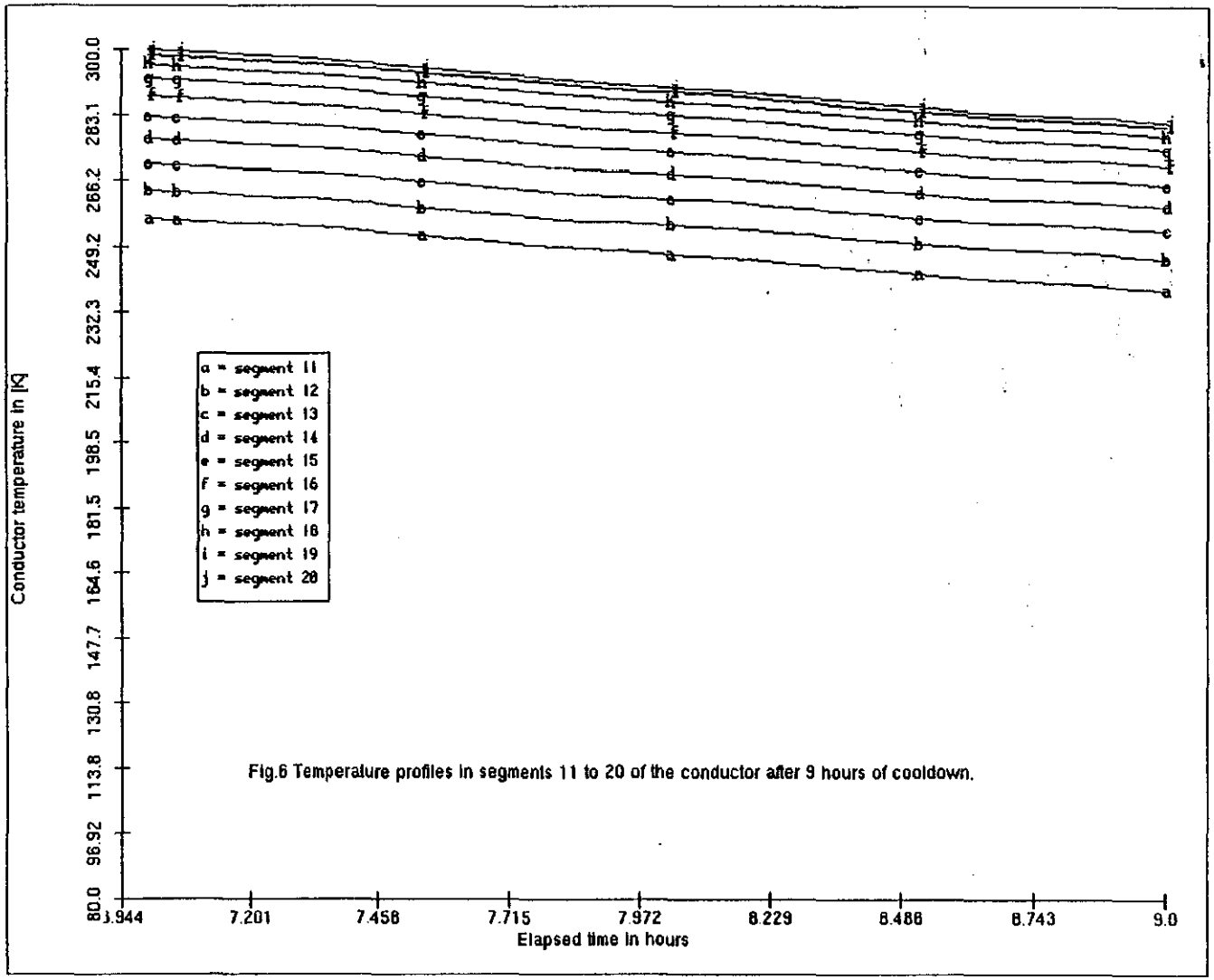


Fig.6 Temperature profiles in segments 11 to 20 of the conductor after 9 hours of cooldown.

Fig. 9

Conductor and nitrogen temperature profiles in the last segment after 11 hours of cooldown

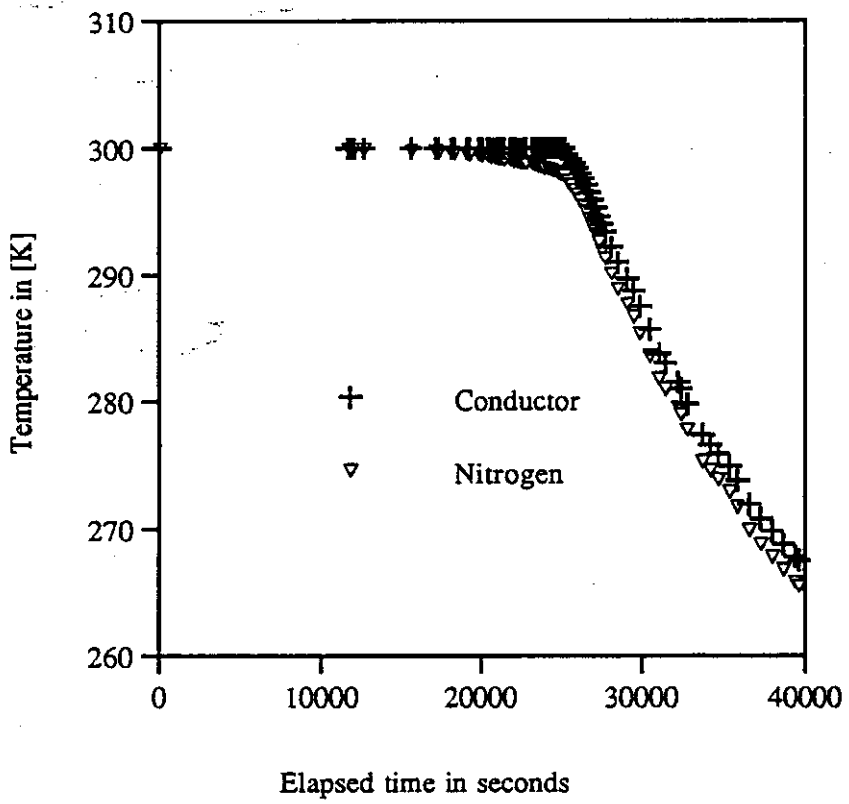
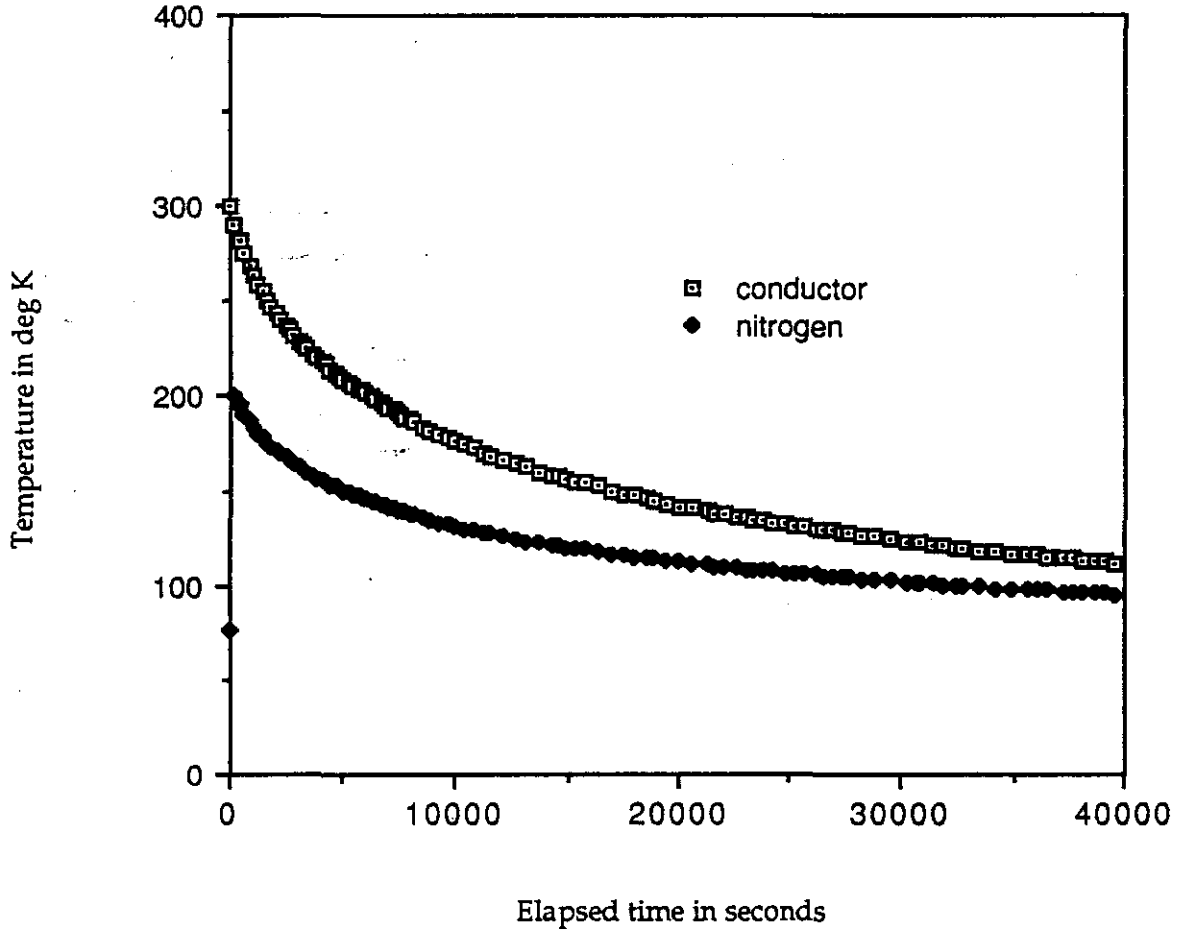


Fig. 10

Conductor and nitrogen temperature profiles in the first segment after 11 hours of cooldown.



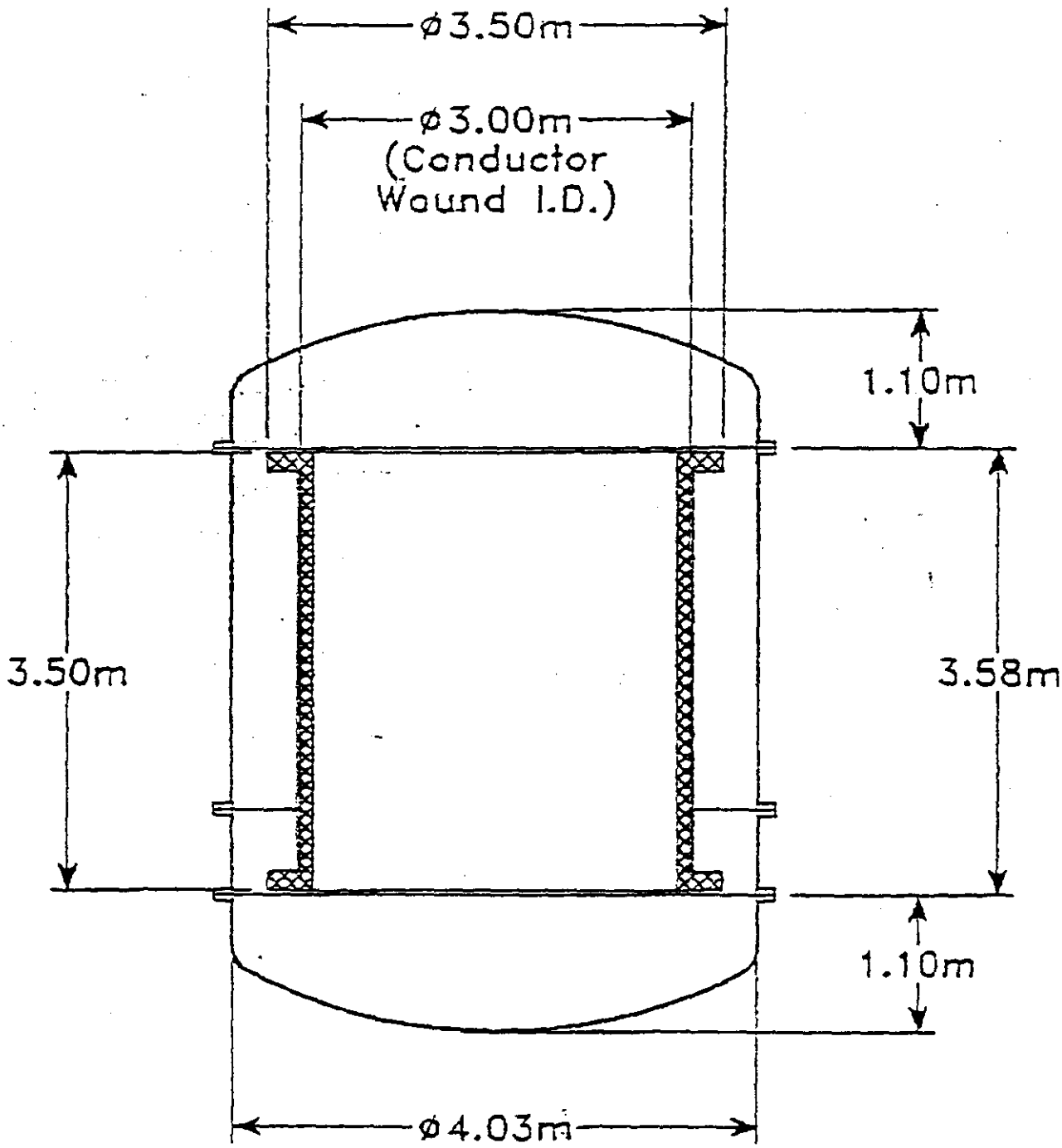


Fig. 11

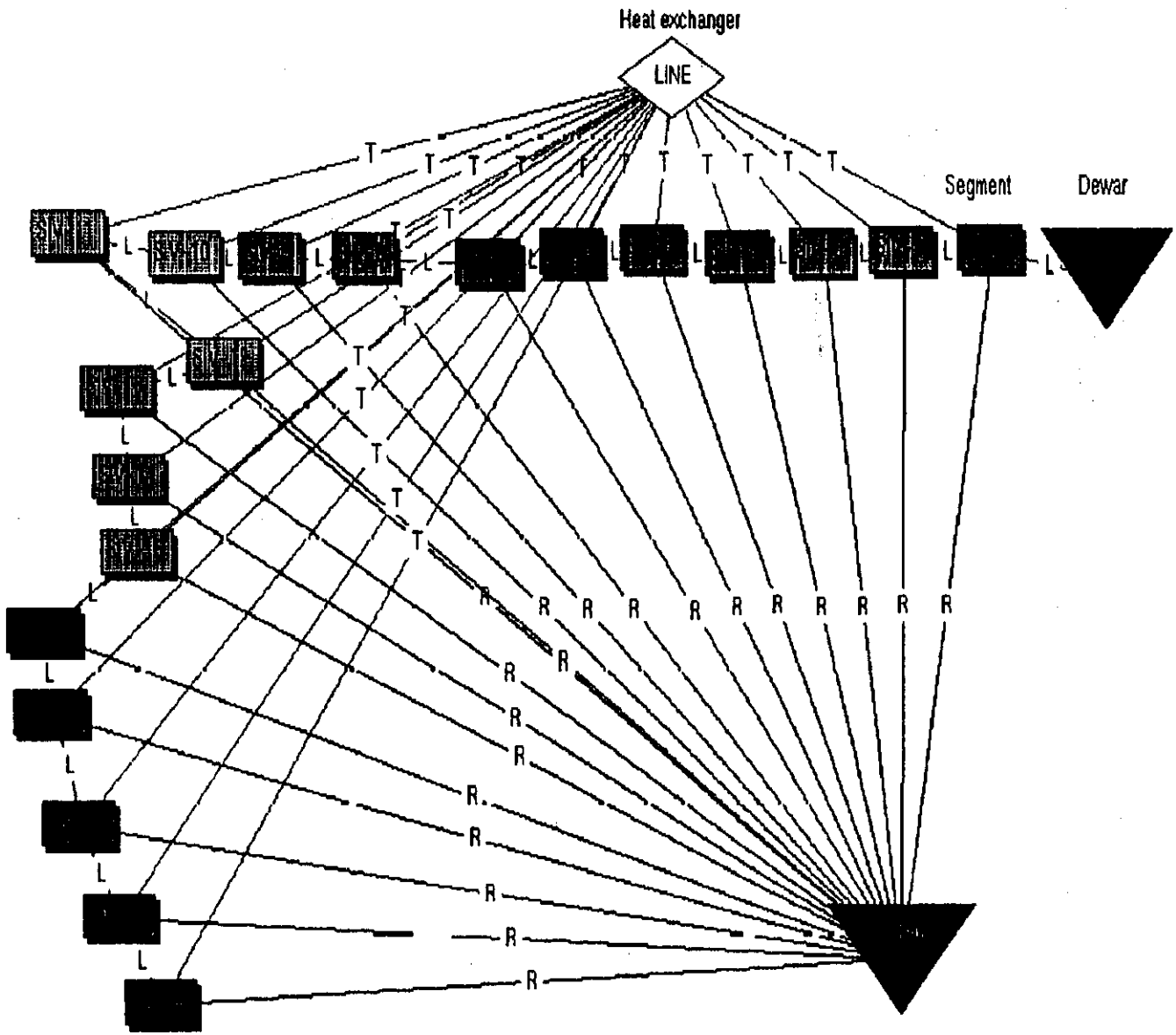


Fig 12 Sinda/Fluind Model