

**Programme INSTATCP
for the 3D-computation of temperatures
under transient boundary conditions
using Delphi and Windows**

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Abstract

The [PC computer programme INSTATCP](#) written in Borland Pascal for Borland Delphi under Windows 98/NT performs the transient heat transfer analysis of three-dimensional structures subjected to surface heat flux, convective and radiative heat transfer, internal heat generation and temperature boundary conditions. The non-linearity may be due to either temperature dependent material properties or non-linear boundary conditions. The program is applicable to structures comprised of one or more materials. It uses a network of cubic or prismatic volume elements, finite-volume method and a very efficient predictor-corrector differential equation system solver for stiff problems to facilitate consideration of non-linearity, radiation heat transfer between triangular/square areas, latent heat in the calculation of temperature in materials such as freezing of water into ice or humid concrete and convection heat transfer in flow through tubes and ducts. Colour graphics are represented in VGA on screen or can be printed using PostScript/PCL on colour/laser printer or into a file. By [worked examples](#) the application area of the PC computer program INSTATCP is demonstrated.

Table of content

	Seite
1 Introduction	4
2 Programme INSTATCP	4
3 Data input	4
4 Graphical output	4
5 Data output	5
6 Range of application	5
7 Computing time and examples of application	5
8 Literature	6
8.1 Background of the programme	6
8.2 Building Physics	6
8.3 Thermal bridges	6
8.4 Chimneys	7
8.5 Fire protection	7
8.6 Special problems	8
9 Example 1 : Chimney construction	9
10 Example 2 : Freezing underneath an ice skating rink	12
11 Example 3 : Steel beam supporting a concrete floor and penetrating through a glass wall to the outside	15
12 Example 4 : 12 x 24 cm square reinforced concrete beam with three-sided exposure to fire following the standard temperature/time curve for 90 minutes and evaporation of humidity at 100 °C	22
13 Example 5 : Hermetic cable penetration through the containment shell with an exposure of 800 °C due to fire in the reactor building annulus	25
13.1 Hermetic cable penetration – Node plane 1	28
13.2 Hermetic cable penetration – Node plane 2	30
13.3 Hermetic cable penetration – Node plane 3	31
13.4 Hermetic cable penetration – Node plane 4	32
13.5 Hermetic cable penetration – Node plane 5	34
13.6 Hermetic cable penetration – Node plane 6	36
13.7 Hermetic cable penetration – Node plane 7	38
13.8 Hermetic cable penetration – Node plane 8	39
13.9 Hermetic cable penetration – Node plane 9	40
13.10 Hermetic cable penetration – Calculated temperatures	42

1 Introduction

Experimental investigations are increasingly replaced by numerical analyses and computer simulations on all sectors. Besides savings in time and costs, it is possible to perform parameter variations and optimisations of constructions with little effort already in the design stage. In the past calculations for the assessment of fire protection and thermal insulation of complicated building constructions were a domain only for supercomputers or workstations and therefore could only be done by universities and scientific institutes.

2 Programme INSTATCP

The finite volume programme INSTATCP [1-8] for transient boundary conditions developed by BAM using Borland Delphi/Object Pascal is a tool for practical working staff which allows the solution of geometrical complicated 3D-problems for the assessment of fire protection and thermal insulation already on a PC under Windows 98 with at least 64 MB RAM. In the latest version the number of unknown node temperatures which depends only on the amount of RAM and the tolerable CPU time is 131040. The programme uses prismatic (two parallel triangles stretched in space form the volume element) and cubic elements with nodes in the edges. For the simplification of node numbering and a substantial reduction of computation time an optimisation of the band width with the RCM-method corresponding to Cuthill McKee [4, 5] was integrated into the programme. The modified, very fast calculating multi-step method using predictor-corrector formulas with automatic time-step control for the integration delivers reliable results even if thicknesses and thermal conductivities of the materials are very different (i.e. in case of stiff differential equations). Particularity for the simulation of fluid flow this method has the advantage of calculating very fast, especially in the case of air as fluid with its at a factor 1000 lower heat capacity compared to other materials or fluids (very stiff problem). Algorithms for the consideration of radiation heat transfer, fluid flow and phase change are also available. Spot-wise heat generation is provided as well.

3 Data input

The programme allows the generation of node coordinates on circular arcs as polar coordinates and the assignment of materials to tube structures using a starting index, an incremental value and an end index. Furthermore, a generation of 6 node elements with triangular base in direction of the z-axis is possible, as well as a generation of 8 node elements with rectangular base in the front plane and the planes beyond by indication of the thicknesses in the x/y-front plane and in direction of the z-axis. The data are read from an input file which has to be created by use of a text editor or any preprocessor programme.

4 Graphical output

For checking purposes of the subdivision into elements and the assignment of the elements to materials and to heat transfer regions a colour presentation of the mesh in VGA mode with the ability of zooming is integrated into the programme. It is possible to interactively display on the colour screen isotherms, calculated temperatures, node numbers and additional information by mouse-click on the nodes. The construction can be shown as full-scale or as standardized presentation. The latter allows the presentation

of layers with different thicknesses as layers all with the same thickness which is particularly useful in case of rectangular elements. As in fast motion it is possible either to show for a specified plane, e.g. the front plane, the temperatures as function of time or to leaf through the planes parallel to the front plane in forward or backward direction at any specified time. A colour or black/white presentation on the screen of the node temperatures as function of the z-axis at a specified time or as function of time for a specified plane in z-direction is also provided. The results are stored in an output file or can be printed in high resolution as colour or black/white graphics (Postscript, PCL, PCX).

5 Data output

The most important input data and the calculated values as temperatures, heat fluxes, ratios of phase change are stored in an output file.

6 Range of application

The application range of the programme is far reaching. It can be used for the calculation of fire exposed structures taking into account evaporation of humidity [2, 8, 20, 21, 23, 24], for almost all kinds of 3D-problems with thermal bridges [7-17], for the simulation of insulation [26, 27], freezing and thawing [23, 25, 26], fluid flow which is not only found in pipelines, radiant floor heating systems, subterranean or overhead water and district heating pipes, ventilation ducts exposed to fire, smoke ducts, chimneys [2, 3, 15, 18, 19], but also in technical heat exchangers and geothermal applications [28].

7 Computing time and examples of application

The CPU time depends on the PC processor, the fineness of the mesh, the bandwidth, i.e. the number of nodes and the numbering of the nodes, the time of simulation, the thermal conductivities and specific thermal capacities of the used materials and media and the velocity of flow. As the CPU time depends on the considered problem general remarks can not be done. Under Windows 98 and Borland Delphi/Object Pascal the computing time for the Finite-Volume-Programme INSTATCP is however relatively small. The computation took for example on a 300 MHz-Pentium-PC

- 1084 s for a chimney construction corresponding to [example 1](#) (see fig. 1a - 1c) assuming smoke flow in the inner duct and stationary boundary conditions for 100 h,
- 2.5 s for an ice skating rink corresponding to [example 2](#) (see fig. 2a – 2c) during one year continuous operation to investigate the risk of freezing in the soil,
- 18 s for a steel beam supporting a concrete floor which penetrates through a glass wall to the outside corresponding to [example 3](#) (see fig. 3a – 3g) with stationary boundary conditions for 100 h,
- 91 s for a 12 x 24 cm square reinforced concrete beam corresponding to [example 4](#) (see fig. 4a – 4c) with three-sided exposure to fire following the standard temperature/time curve for 90 minutes and evaporation of humidity at 100 °C and
- 53 s for an hermetic cable penetration through the containment shell corresponding to [example 5](#) (see fig. 5a - 5s) with an exposure of 800 °C due to fire in the reactor building annulus for 30 minutes.

8 Literature

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8.4 Chimneys

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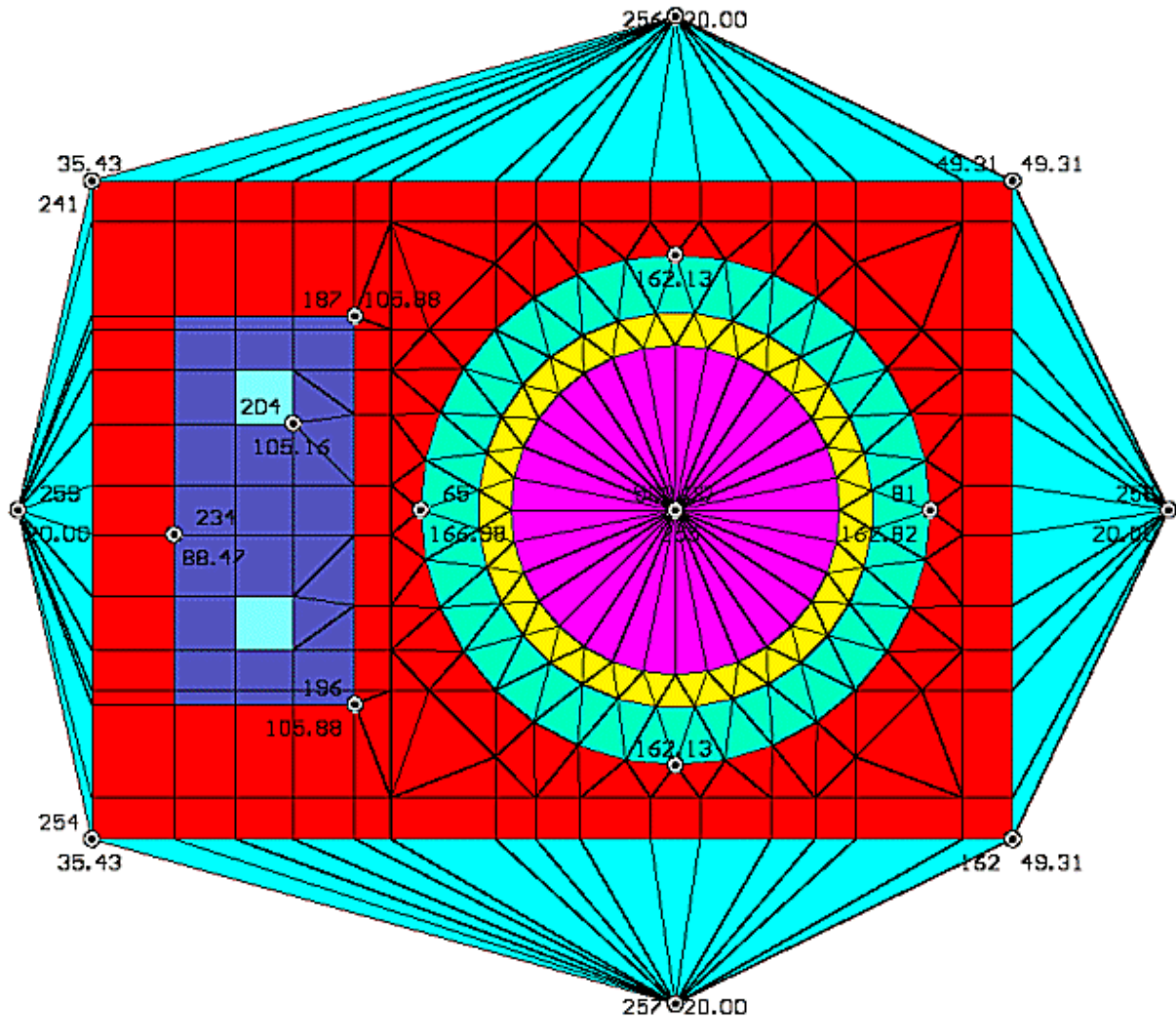
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Hochbau (KWH), Sept. 1992

9 Example 1: Chimney construction

BAM - INSTATGR - SCHIED1A - 14.12.98 14:54:28 - NKN = 259



WAERMEBRUECKE3D, MANTELST SJH20/2ROHRE, 100ORHOL, G, SCHIED1A.DA-E=1, TAU= 100.00 h

K= 255, NKS=2072, X=0.00000, Y=0.00000, Z=0.00000 m, T=500.0 °C








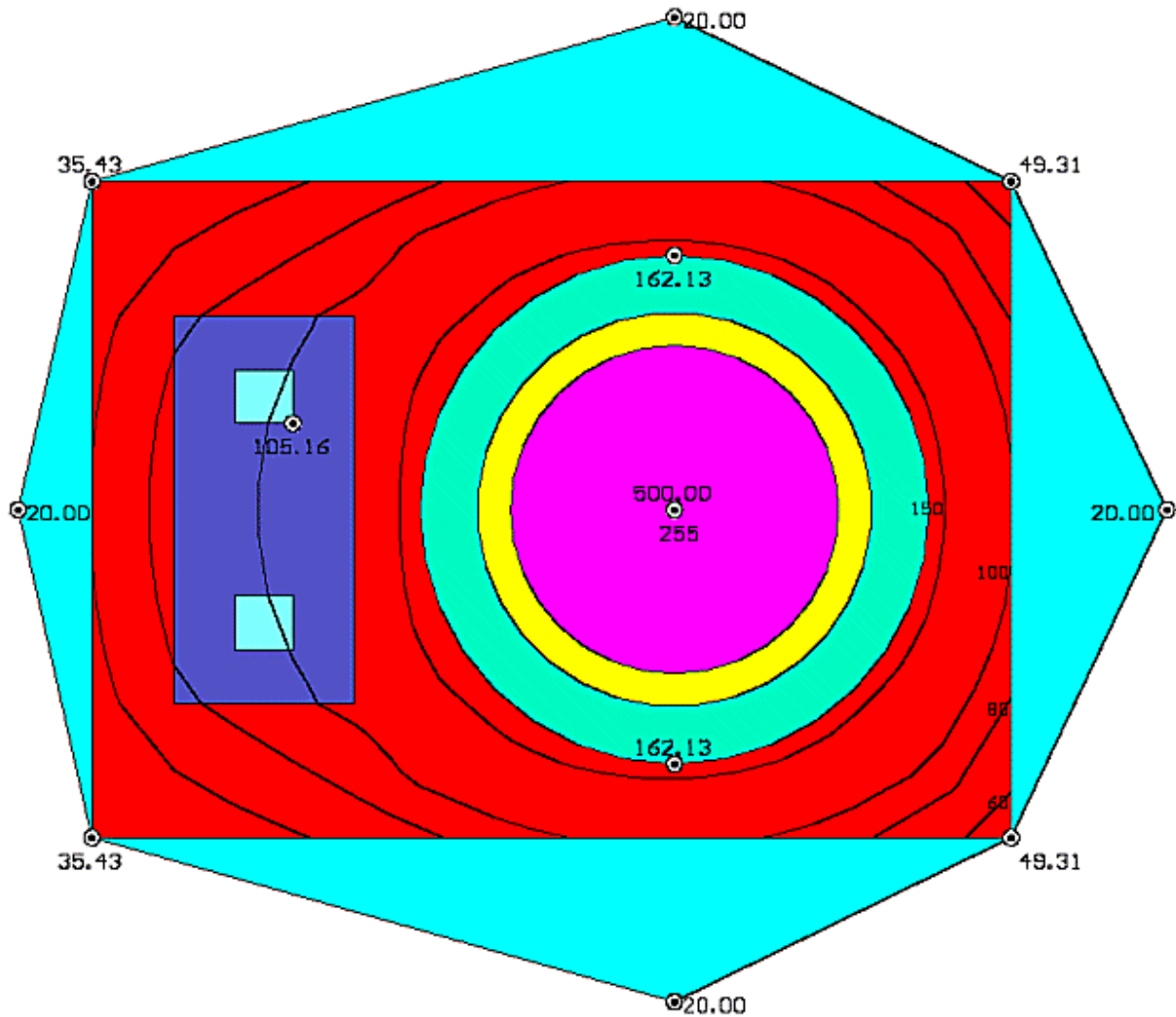
	2, WUE_AUSSEN	--> AL=5.880 W/(m²K)
	5, MANTELSTEIN, LAM	--> LA=0.450 W/(m K)
	8, DAEMMSTOFF, LAM	--> LA=FK(T)
	11, SCHAMOTTE, LAM	--> LA=1.100 W/(m K)
	14, LUFT, LAM	--> LA=FK(T)
	17, SCHAUMSTOFF, LAM	--> LA=0.035 W/(m K)
	20, ABGAS, LAM	--> LA=FK(T)

Fig. 1a: Chimney construction – Mesh of elements for node plane 1 (front plane)

BAM - INSTATGR - SCHIED1A - 14.12.98 14:42:45 - NKN = 259



WAERMEBRUECKE3D, MANTELST SJH20/2ROHRE, 100ORHOL, G, SCHIED1A.DA-E=1, TAU= 100.00 h

K= 204, NKS=2072, X=-0.05250, Y=-0.23250, Z=0.00000 m, T=105.1 °C

2, WUE. AUSSEN	--> AL=5.880 W/(m²K)
5, MANTELSTEIN, LAM	--> LA=0.450 W/(m K)
8, DAEMMSTOFF, LAM	--> LA=FK(T)
11, SCHAMOTTE, LAM	--> LA=1.100 W/(m K)
14, LUFT, LAM	--> LA=FK(T)
17, SCHÄUMSTOFF, LAM	--> LA=0.035 W/(m K)
20, ABGAS, LAM	--> LA=FK(T)

Fig. 1b: Chimney construction – Isotherms for node plane 1 after 100 h

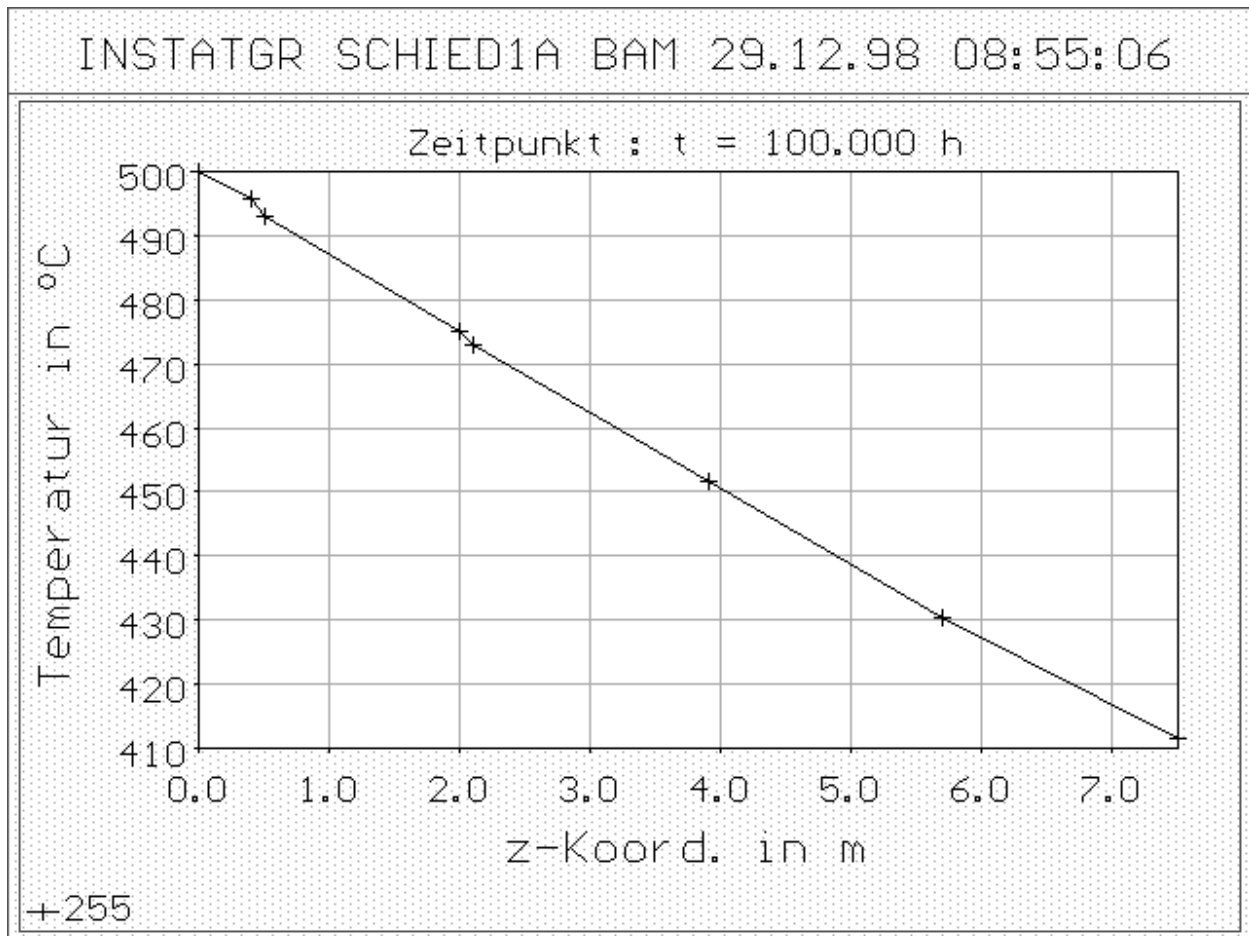


Fig. 1c: Chimney construction – Temperatures calculated at the surface of the inner duct also considering the flow of smoke as function of the z-coordinates from the bottom to the top (0 ... 7,5 m, 8 node planes)

10 Example 2: Freezing underneath an ice skating rink

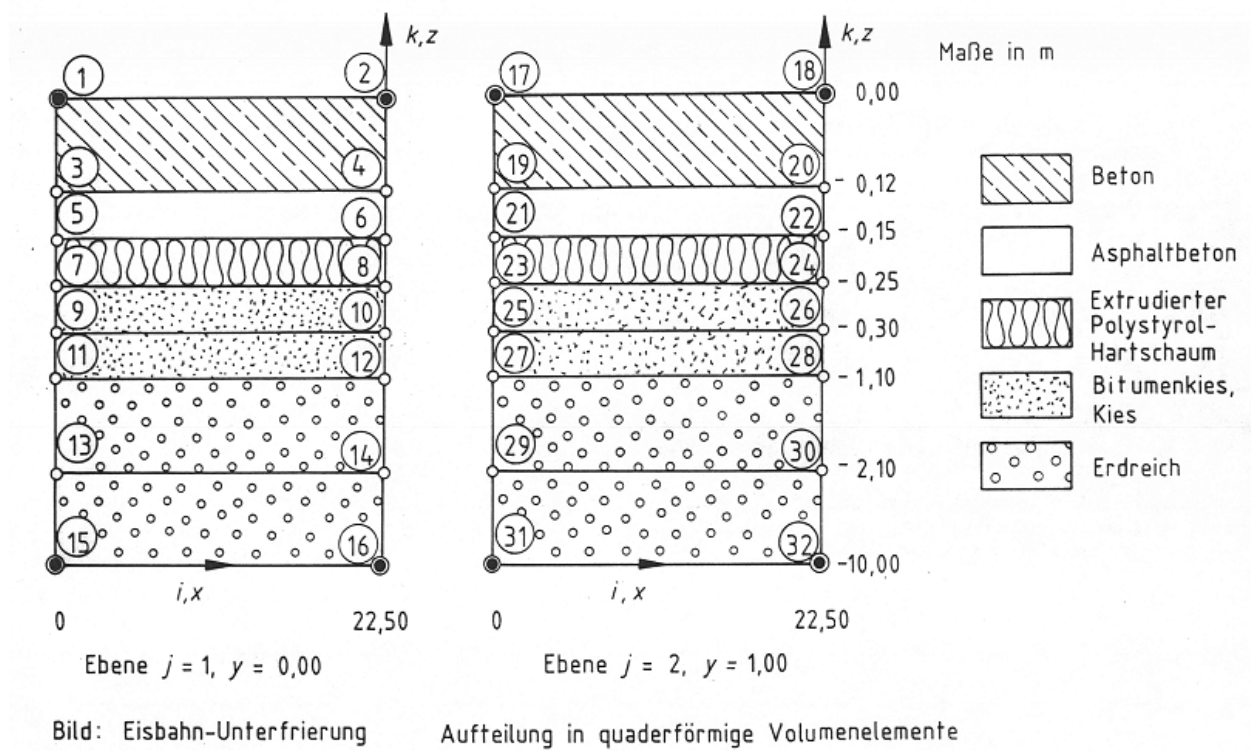
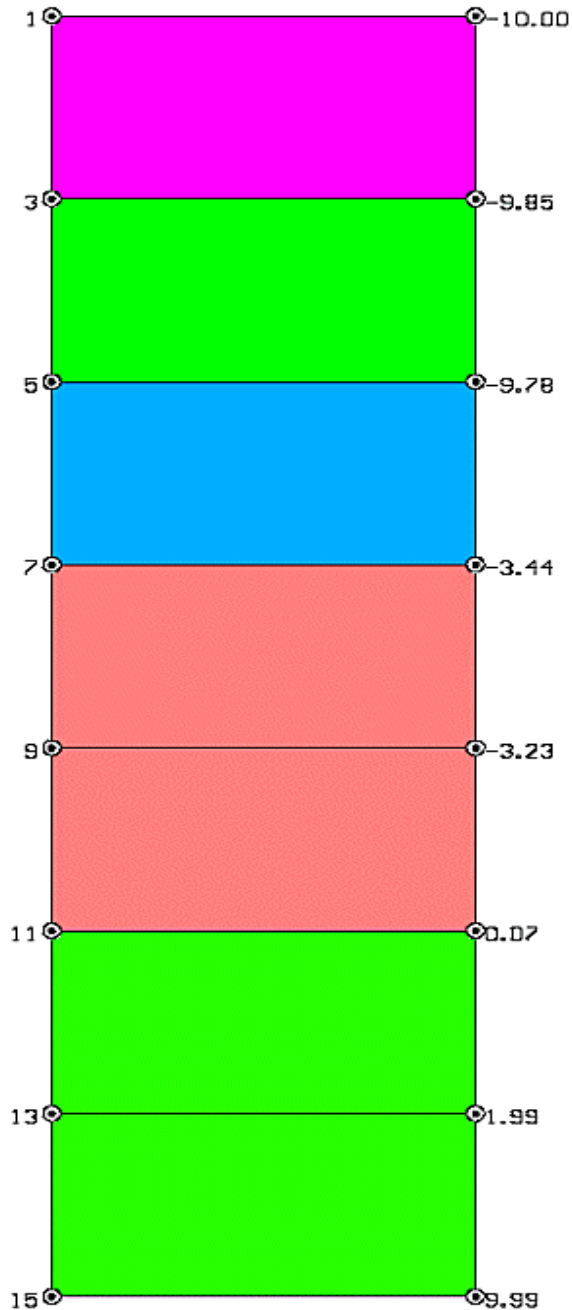


Fig. 2a: Ice skating rink – Subdivision into elements

BAM - INSTATGR - EISBREI1J - 29.12.98 09:05:48 - NKN = 17



EISBAHNUNTERFRIERUNG MIT WAERMED/KIESKOFFER, 1 J, EISBREI1J.DAT-E=1, TAU= 215.00 d
 K=11, NKS=34, X=1.10000, Y=0.00000, Z=0.00000 m, T=0.07 °C

1	STAHLBETON	LAM	--> LA=2.330 W/(m K)
4	ASPHALT-BETON	LAM	--> LA=1.370 W/(m K)
7	EXTR. POLYST.-HARTSCH.	LAM	--> LA=0.046 W/(m K)
10	BITUMENKIES, KIES	LAMO	--> LA=0.700 W/(m K)
18	ERDREICH	LAMO	--> LA=1.400 W/(m K)

Fig. 2b: Ice skating rink – Temperatures underneath the ice skating rink after 215 days (standardized presentation)

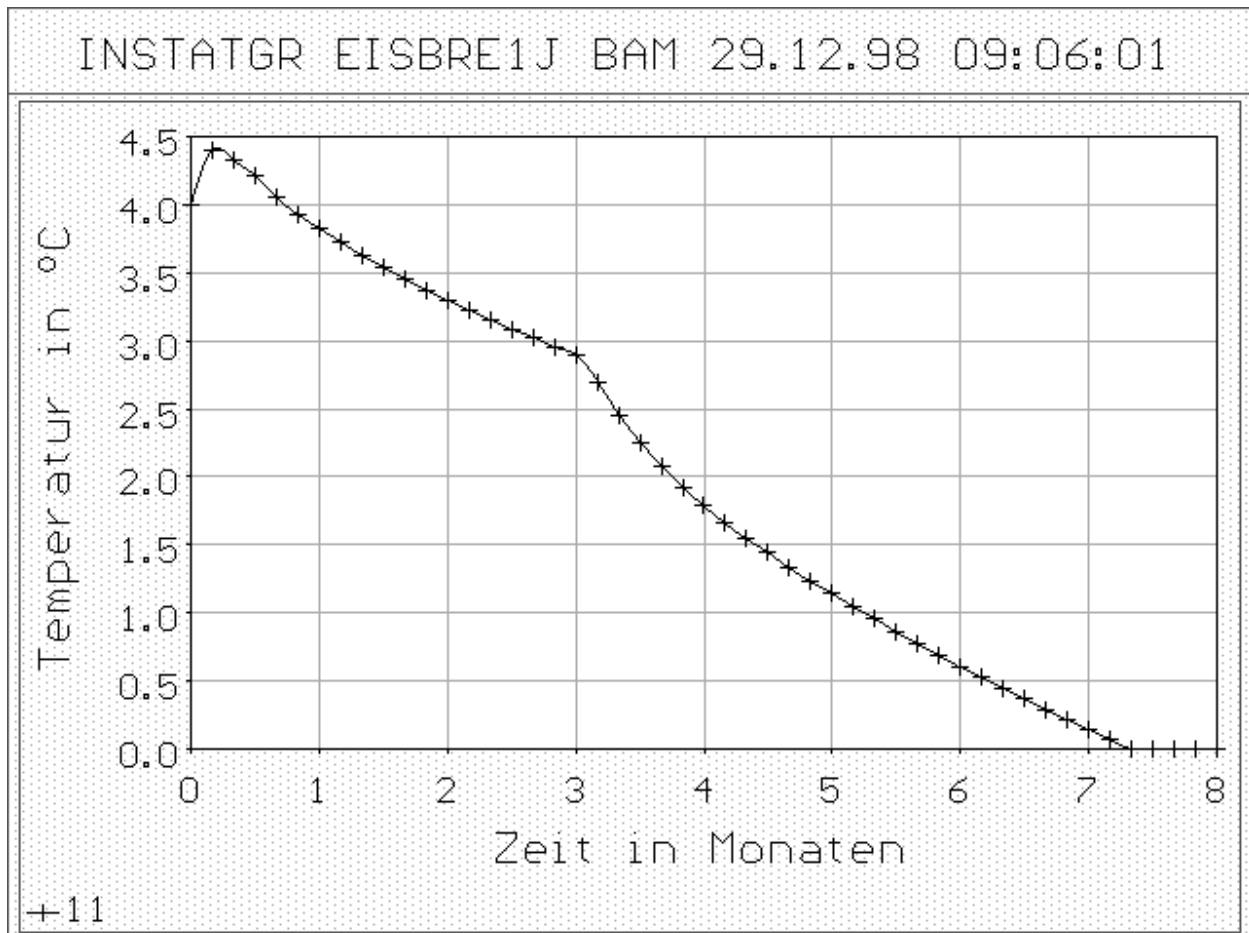


Fig. 2c: Ice skating rink – Calculated temperature of node 11 beneath the gravel bed vs. time for a period of 8 month

11 Example 3: Steel beam supporting a concrete floor and penetrating through a glass wall to the outside

BAM - INSTATGR - TR100H - 29.12.98 09:20:33 - NKN = 126

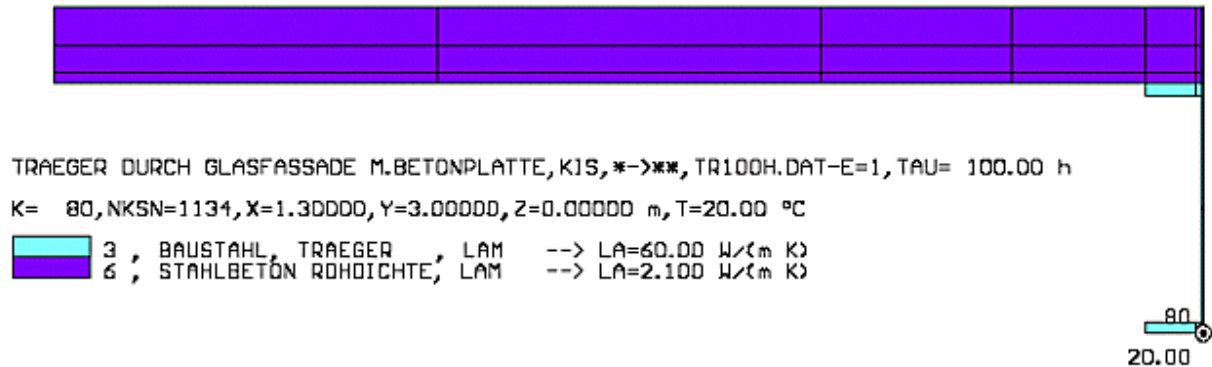


Fig. 3a: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Subdivision into elements of node plane 1 at the inside as full-scale presentation without surface heat transfer elements

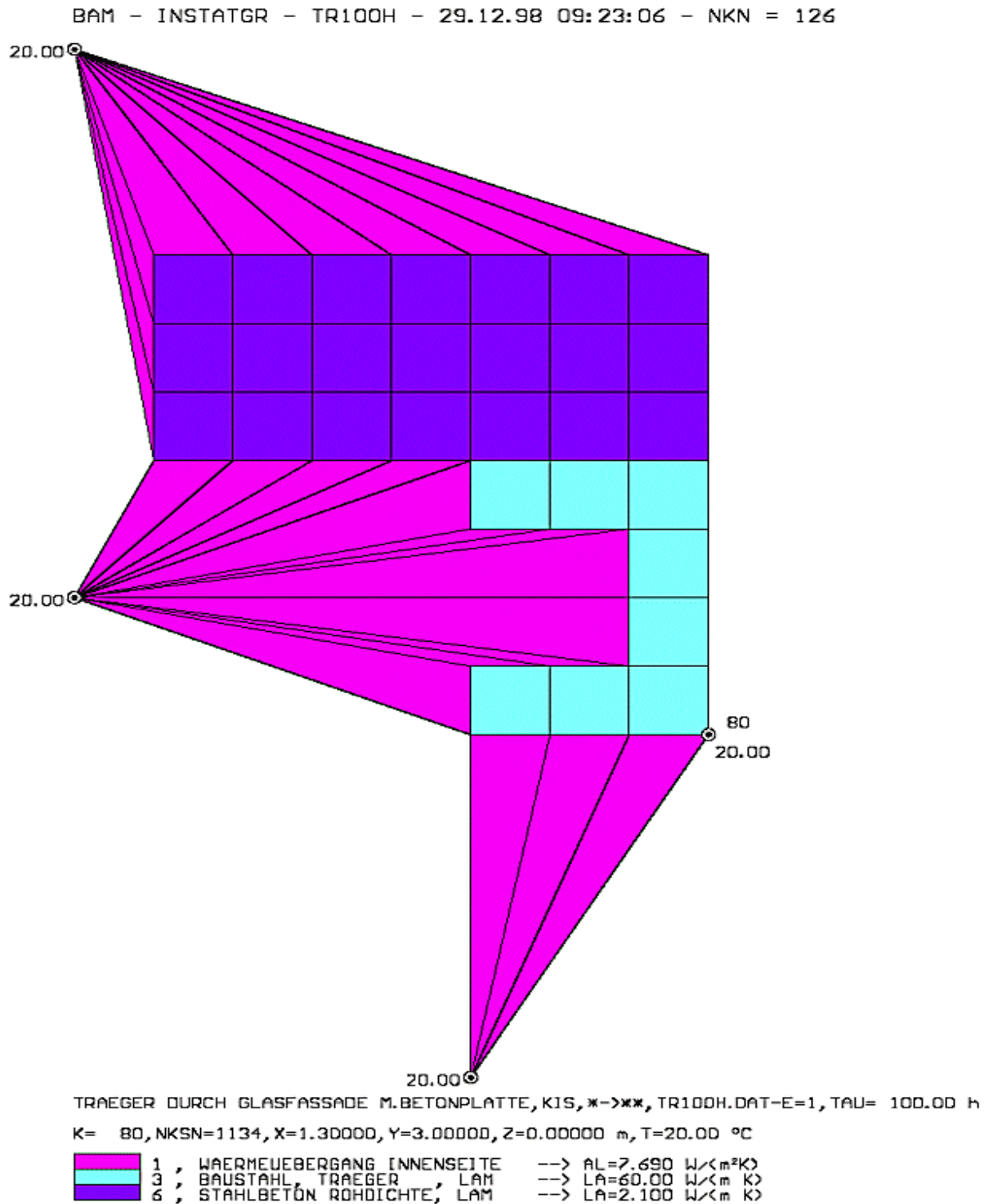
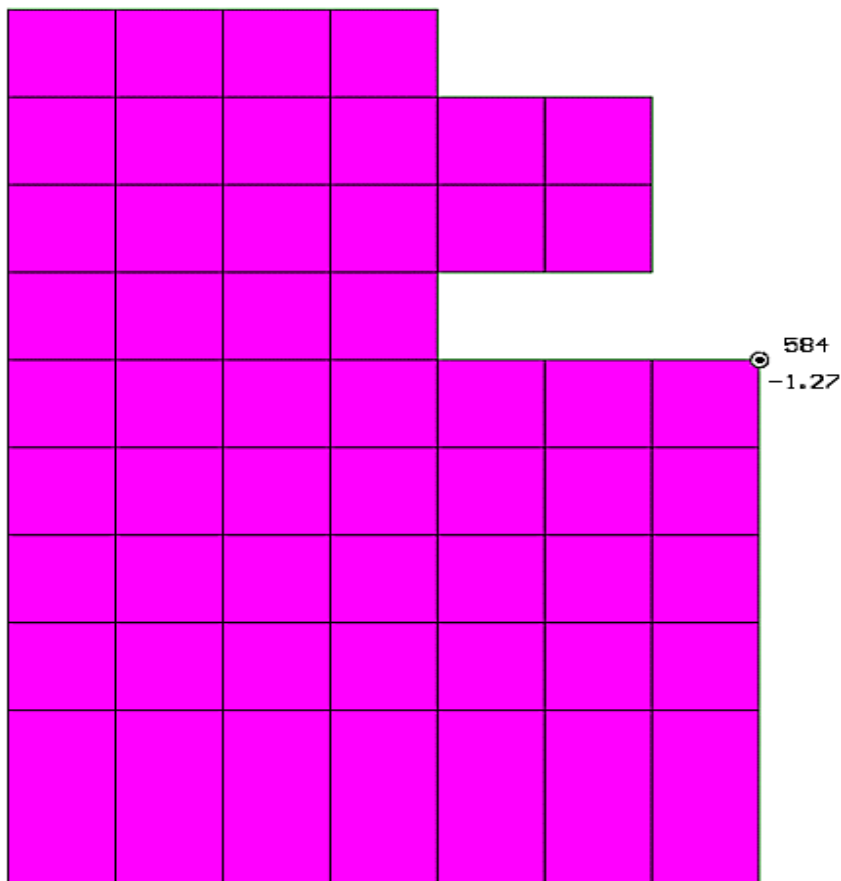
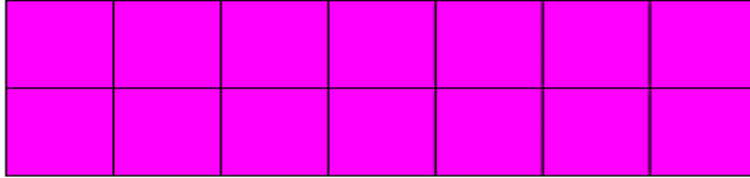


Fig. 3b: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Subdivision into elements of node plane 1 at the inside as standardized presentation with surface heat transfer elements

BAM - INSTATGR - TR100H - 29.12.98 09:27:41 - NKN = 126



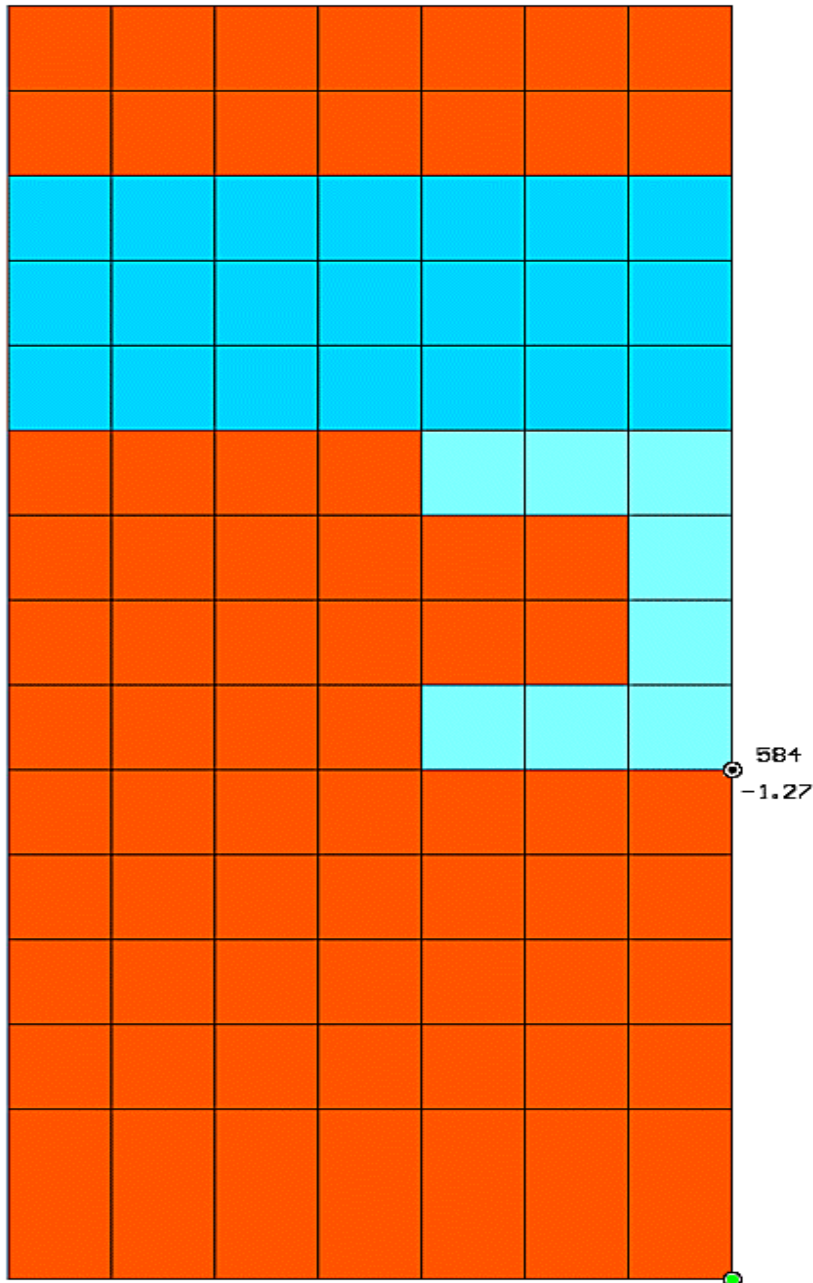
TRAEGER DURCH GLASFASSADE M.BETONPLATTE, K1S, *->**, TR100H.DAT-E=5, TAU= 100.00 h

K= 584, NKS=1134, X=1.30000, Y=3.00000, Z=3.96000 m, T=-1.27 °C

 1 , WAERMEUEBERGANG INNENSEITE --> AL=7.690 W/(m²K)

Fig. 3c: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Surface heat transfer elements vertical to the inner surface of the glass wall (node plane 5) as standardized presentation

BAM - INSTATGR - TR100H - 29.12.98 09:24:14 - NKN = 126



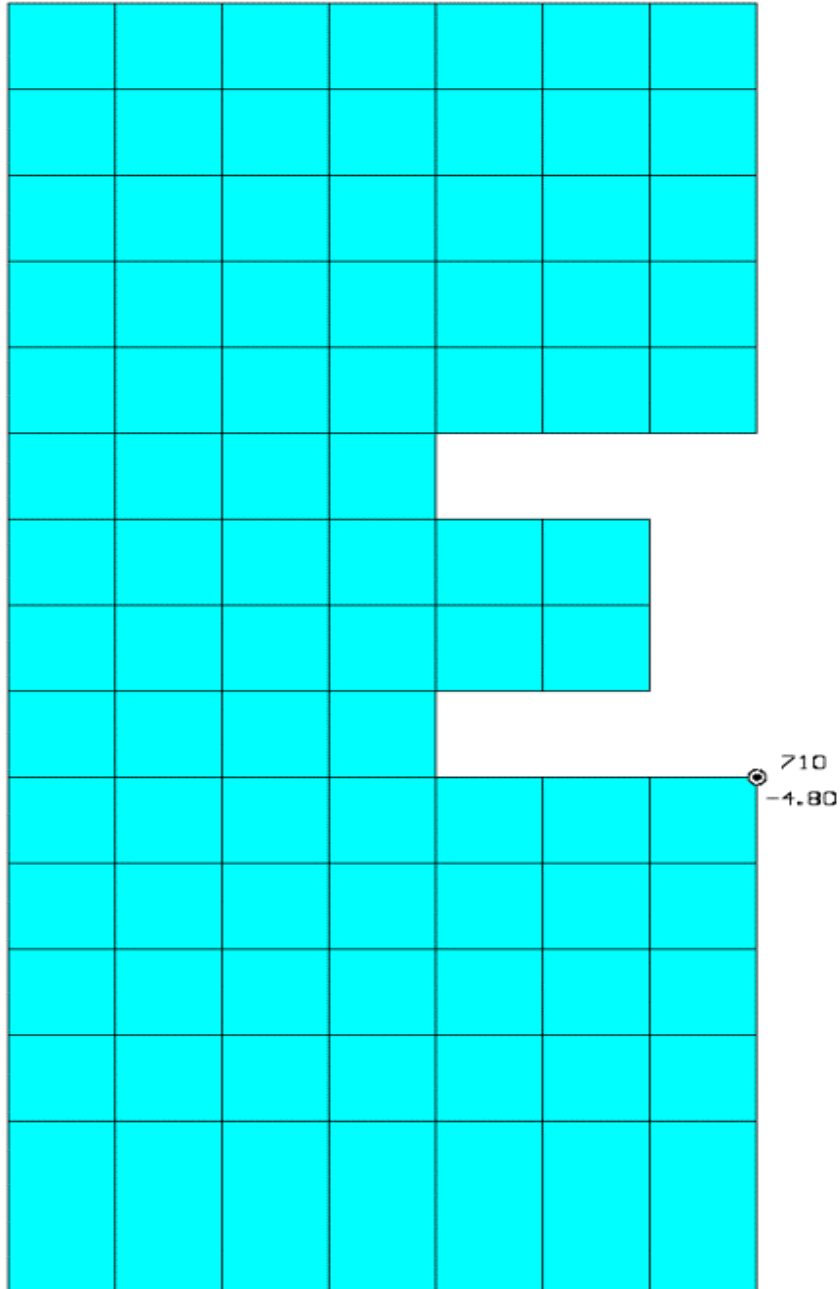
TRAEGER DURCH GLASSASSADE M.BETONPLATTE, KIS, *->** , TR100H.DAT-E=5, TAU= 100.00 h

K= 624, NKS=1134, X=1.95000, Y=3.00000, Z=3.96000 m, T=10.96 °C

3	BAUSTAHL, TRAEGER	LAM	--> LA=60.00 W/(m K)
9	MF-PLATTE	LAM	--> LA=0.040 W/(m K)
12	VERGLASUNG, K-WERT 2.0	LAM	--> LA=0.120 W/(m K)

Fig. 3d: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Subdivision into elements of the glass wall (node plane 5, thickness 4 cm, $U = 2,0 \text{ W}/(\text{m}^2\text{K})$) as standardized presentation

BAM - INSTATGR - TR100H - 29.12.98 09:28:00 - NKN = 126


 TRAEGER DURCH GLASFASSADE M.BETONPLATTE, KIS, *->**, TR100H.DAT-E=6, TAU= 100.00 h
 K= 710, NKS=1134, X=1.30000, Y=3.00000, Z=4.00000 m, T=-4.80 °C


 2 , WAERMEUEBERGANG AUSSENSEITE --> AL=25.00 W/(m²K)

Fig. 3e: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Surface heat transfer elements vertical to the outer surface of the glass wall (node plane 6) as standardized presentation

BAM - INSTATGR - TR100H - 04.01.99 08:17:49 - NKN = 126

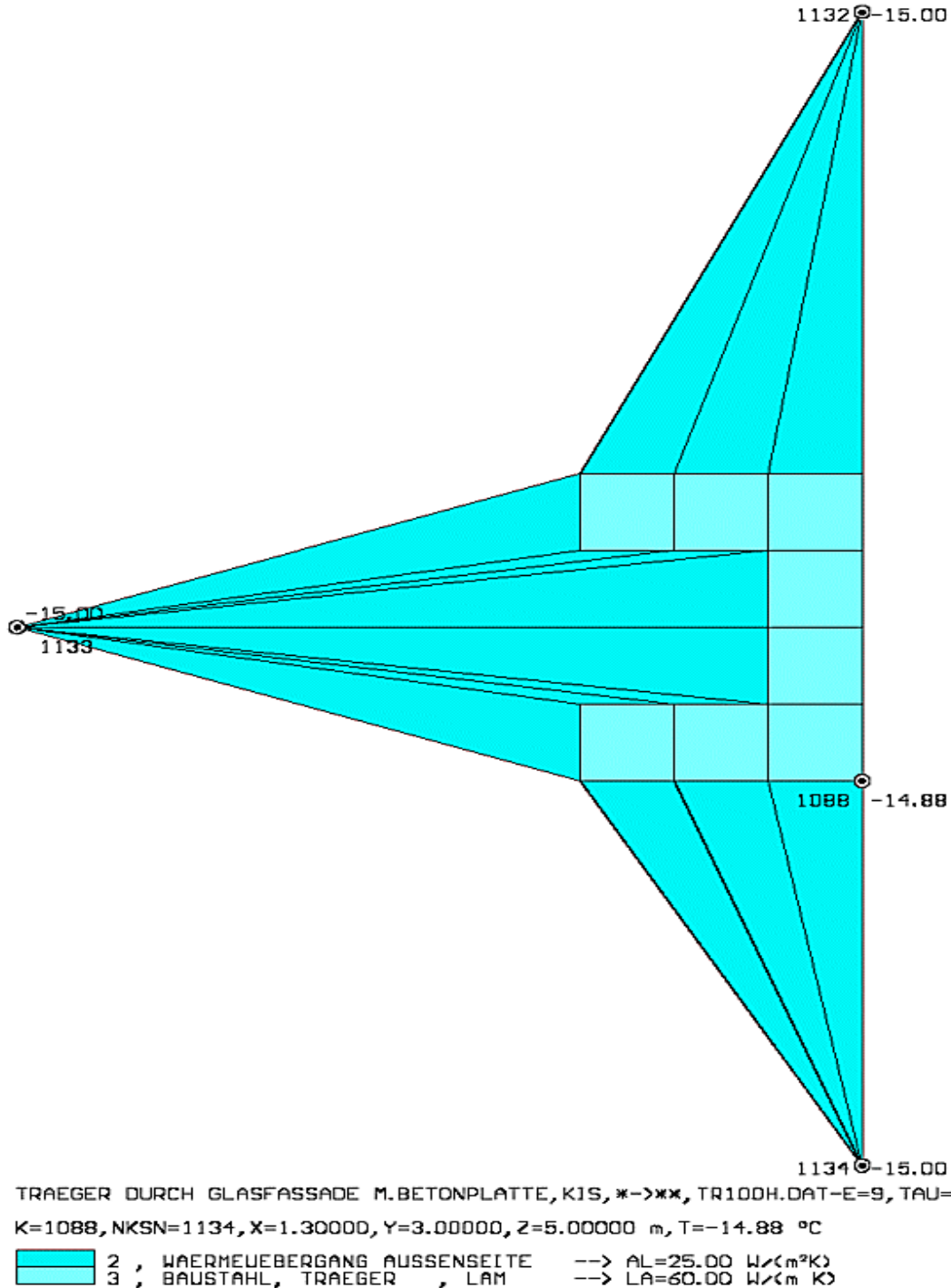


Fig. 3f: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Subdivision into elements of node plane 9 at the outside as standardized presentation with surface heat transfer elements

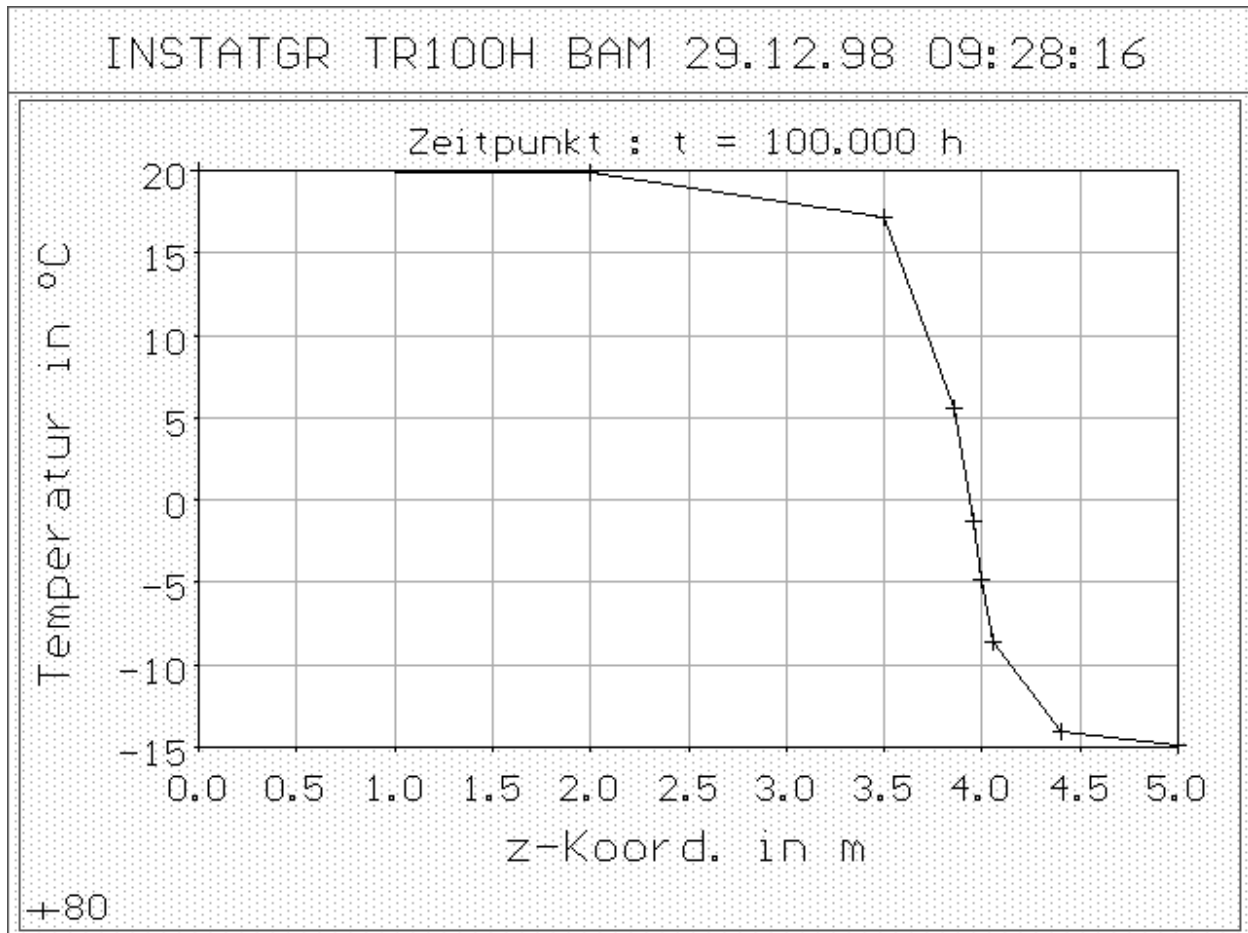


Fig. 3g: Steel beam supporting a 20 cm thick concrete floor and penetrating through a glass wall to the outside (altogether 9 node planes) – Calculated temperatures in the middle of the bottom side of the lower flange along the beam length of 5 m from inside to outside (node 80)

12 Example 4: 12 x 24 cm square reinforced concrete beam with three-sided exposure to fire following the standard temperature/time curve for 90 minutes and evaporation of humidity at 100 °C

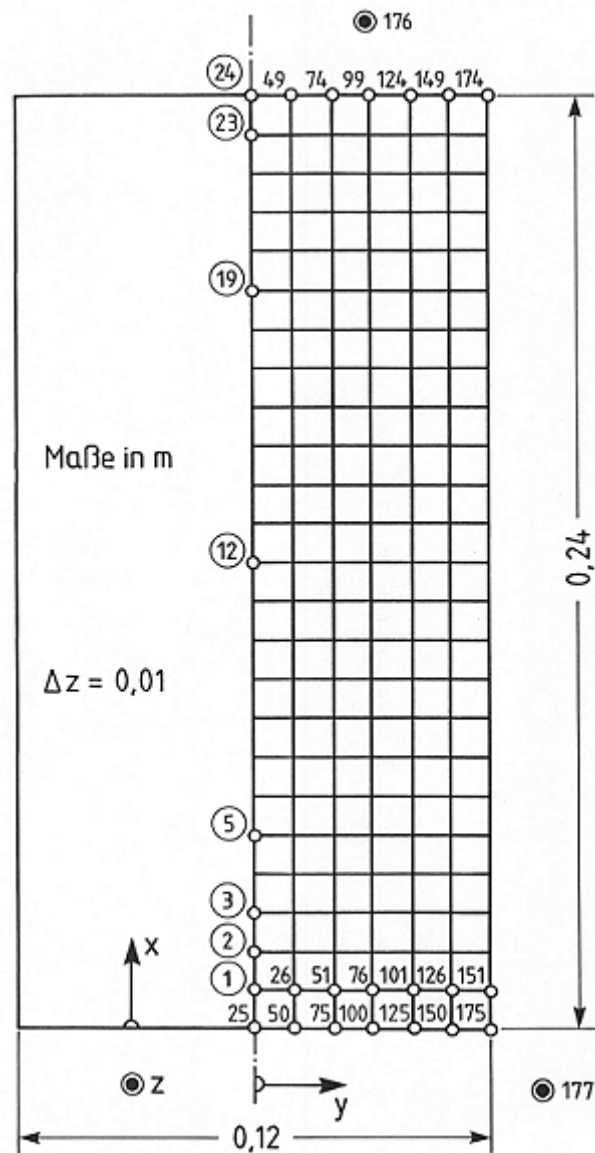


Fig. 4a: 12 x 24 cm square reinforced concrete beam – Subdivision of the first of altogether 2 node planes

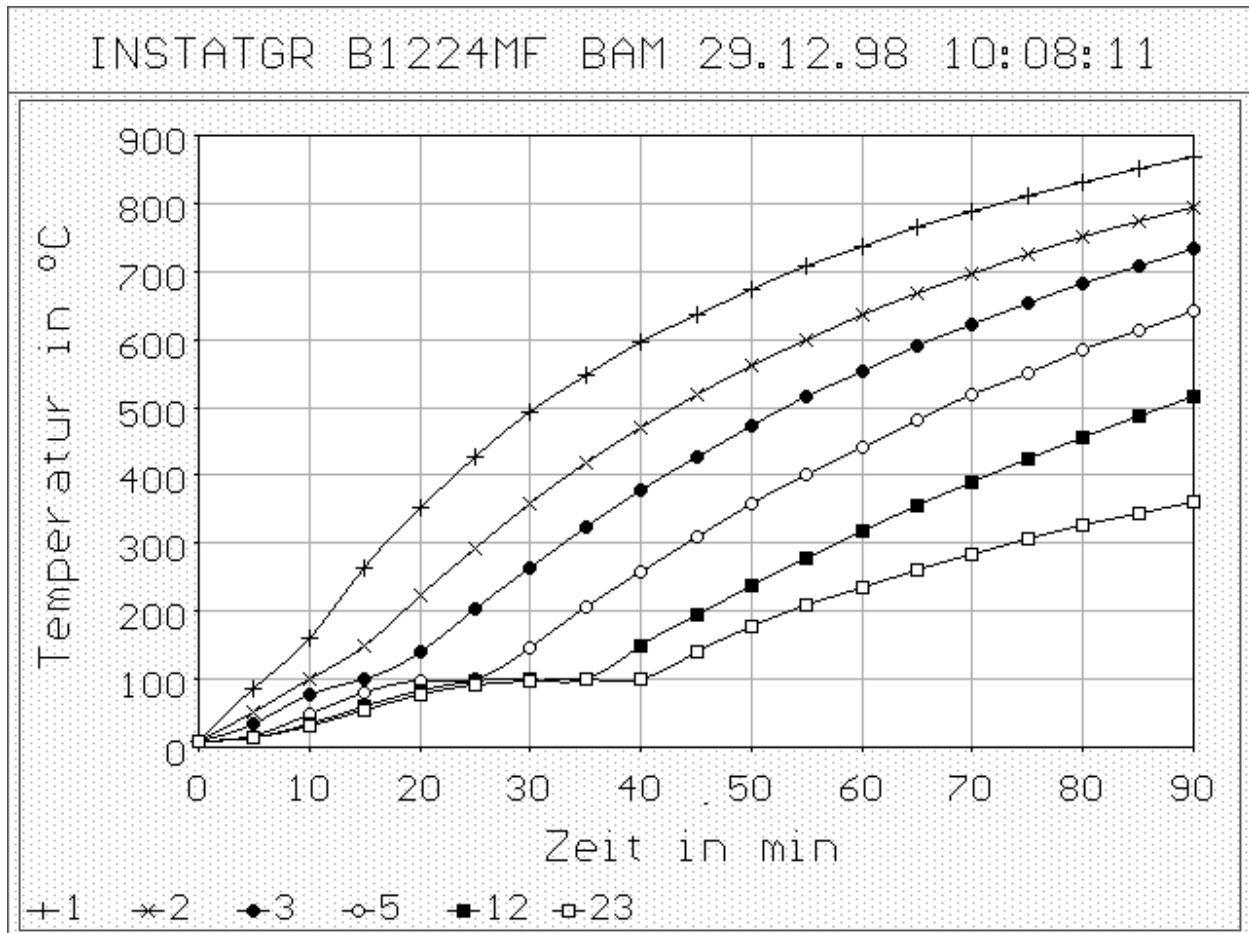


Fig. 4b: 12 x 24 cm square reinforced concrete beam – Temperature/time curves calculated for several nodes along the symmetry axis

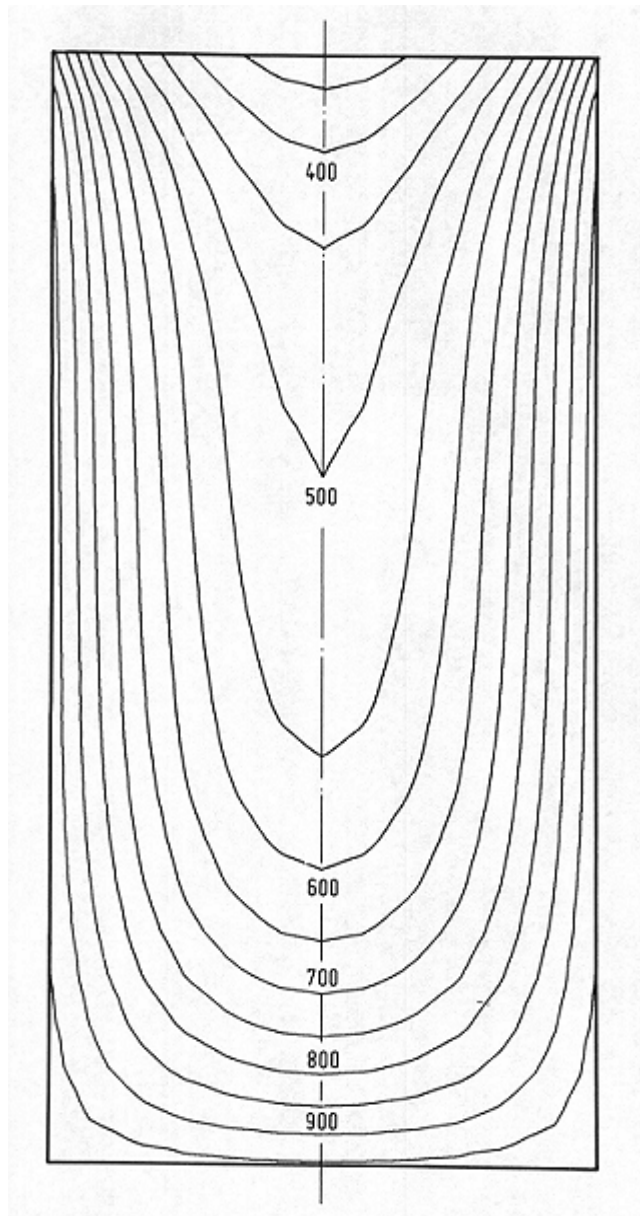


Fig. 4c: 12 x 24 cm square reinforced concrete beam – Isotherms after 90 minutes

13 Example 5: Hermetic cable penetration through the containment shell with an exposure of 800 °C due to fire in the reactor building annulus

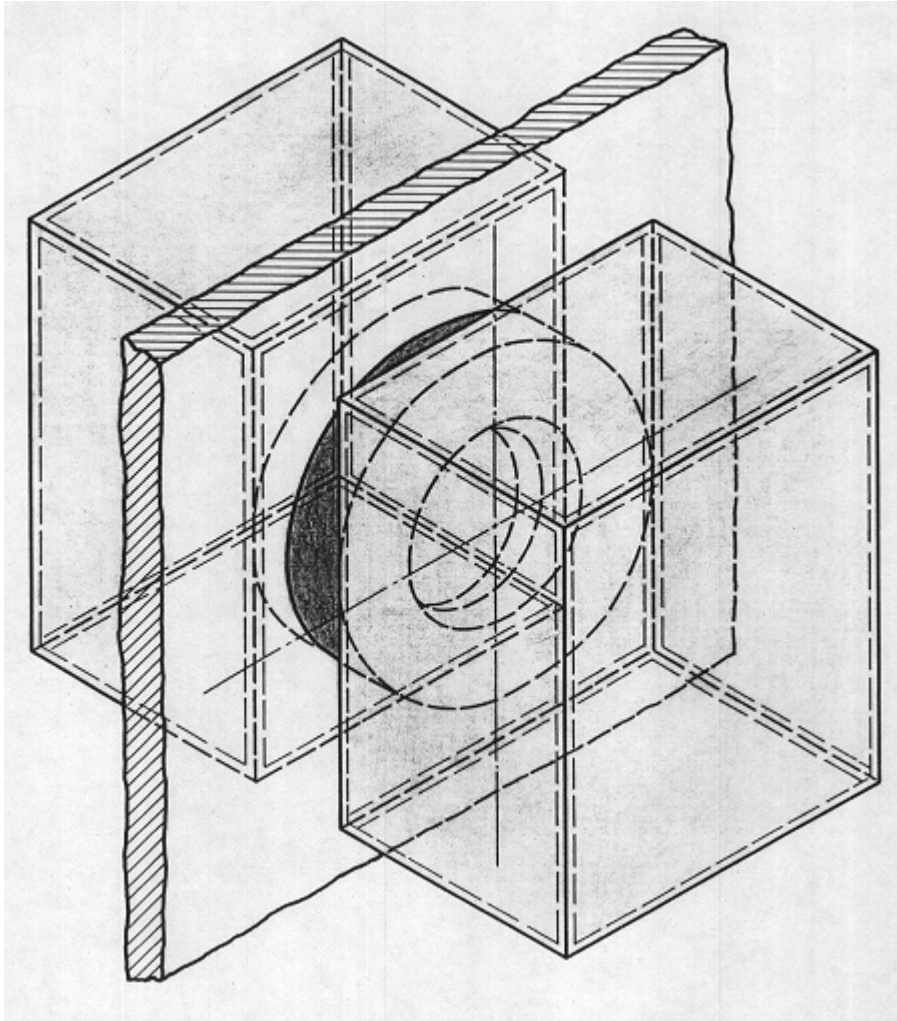


Fig. 5a: Hermetic cable penetration – Perspective representation

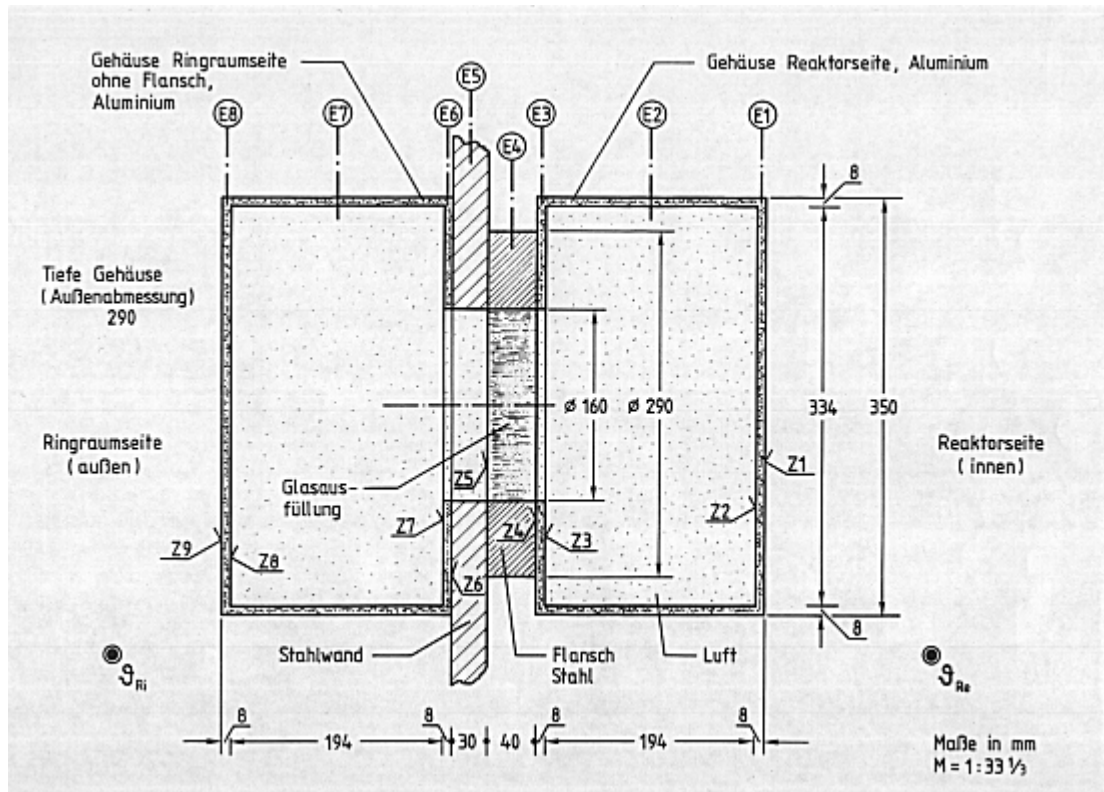


Fig. 5b: Hermetic cable penetration – Cut view with 8 layers (drawn in as E1, ..., E8) and 9 node planes (drawn in as Z1, ..., Z9)

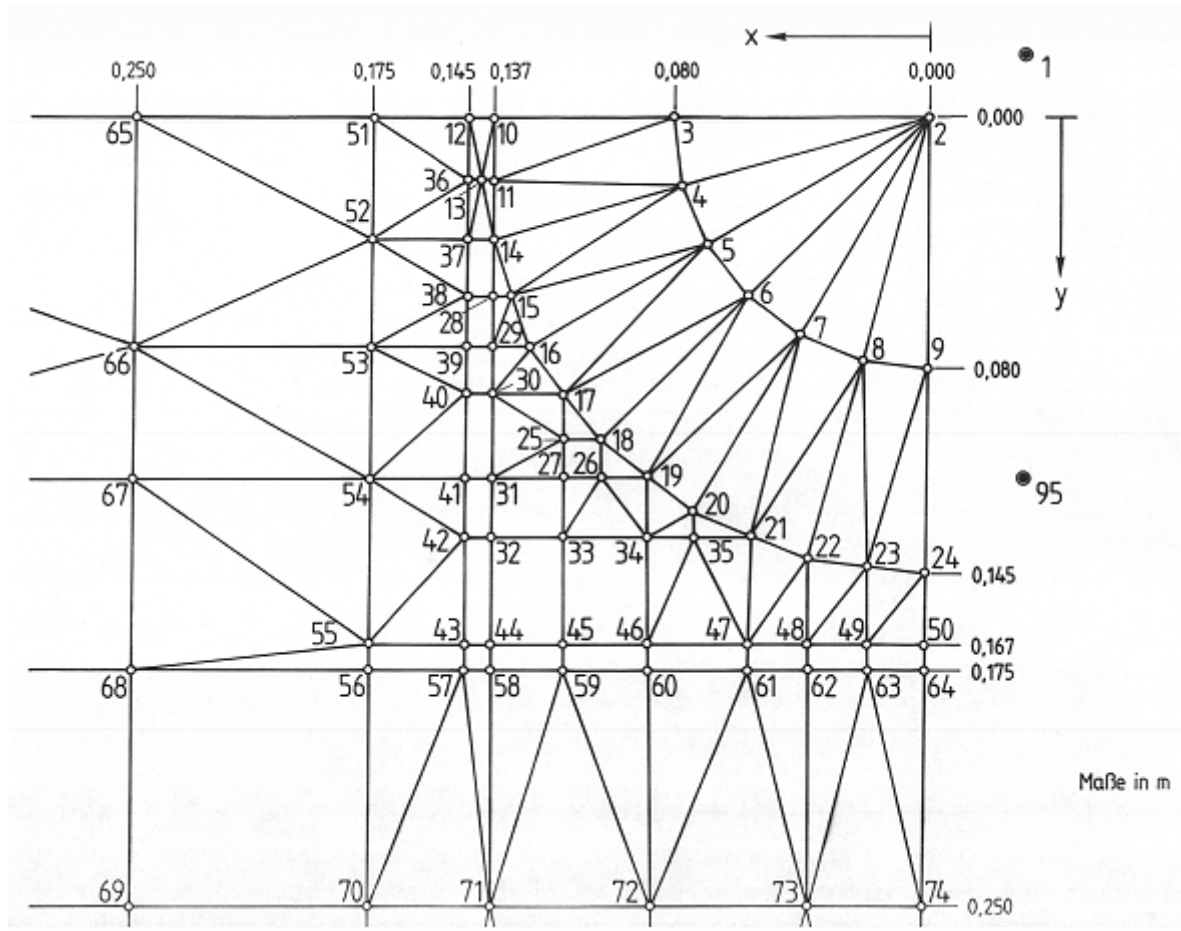
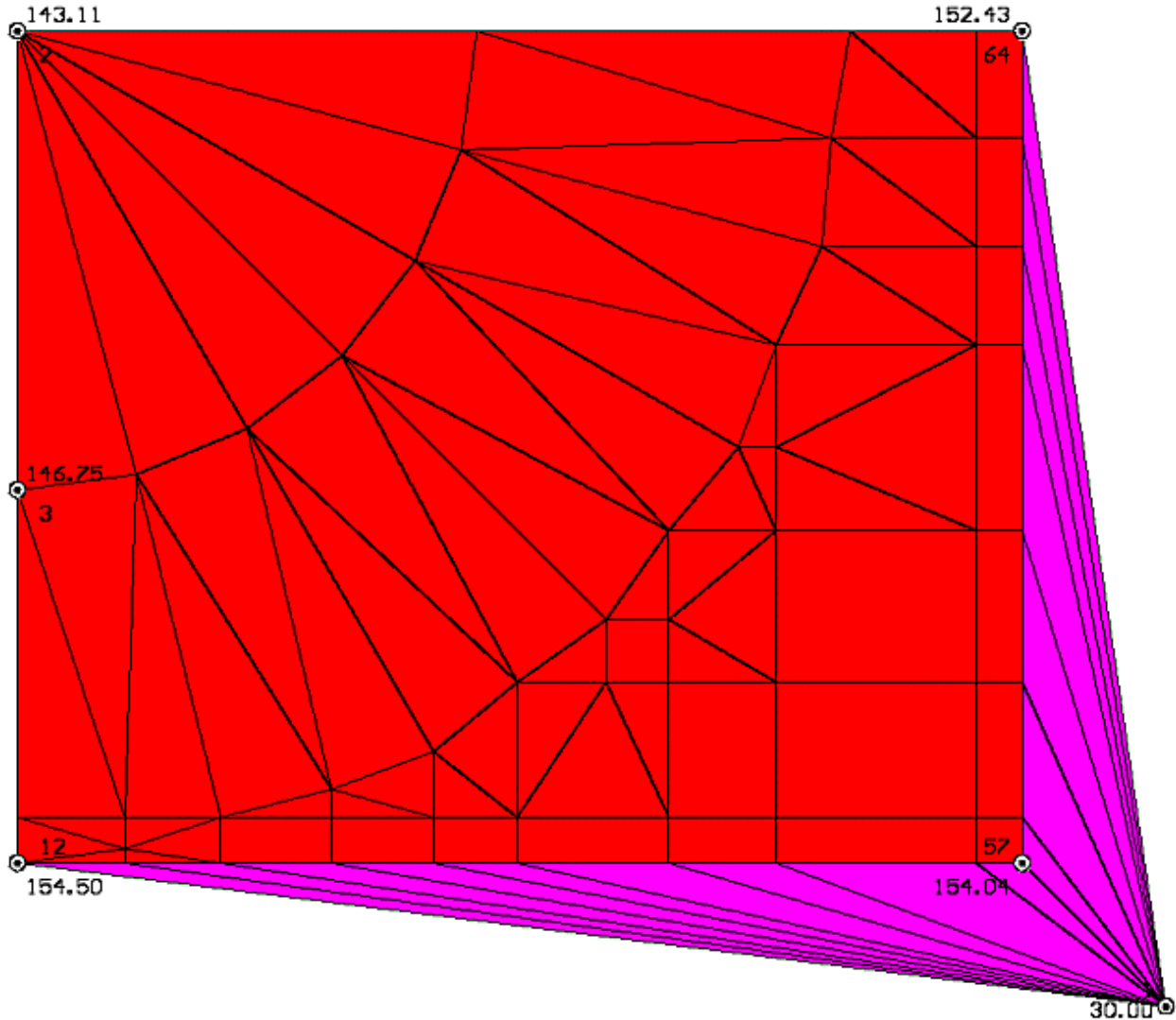


Fig. 5c: Hermetic cable penetration – Clipping of the subdivision into elements of the front plane

13.1 Hermetic cable penetration – Node plane 1

BAM - INSTATGR - DR30MIN - 29.12.98 11:06:15 - NKN = 95



REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEITD.30MIN, DR30MIN.DAT-E=1, TAU= 1800.00 s

K= 1, NKS=855, X=0.17000, Y=0.20000, Z=0.00000 m, T=30.00 °C

 1, WAERMEUEBERGANG REAKTORSEITE --> AL=8.000 W/(m²K)
 6, ALUMINIUM, GEHAEUSE REAKTORSEITE, LAM --> LA=221.0 W/(m K)

Fig. 5d: Hermetic cable penetration – Subdivision into elements of node plane 1 (front plane) with lateral surface heat transfer elements

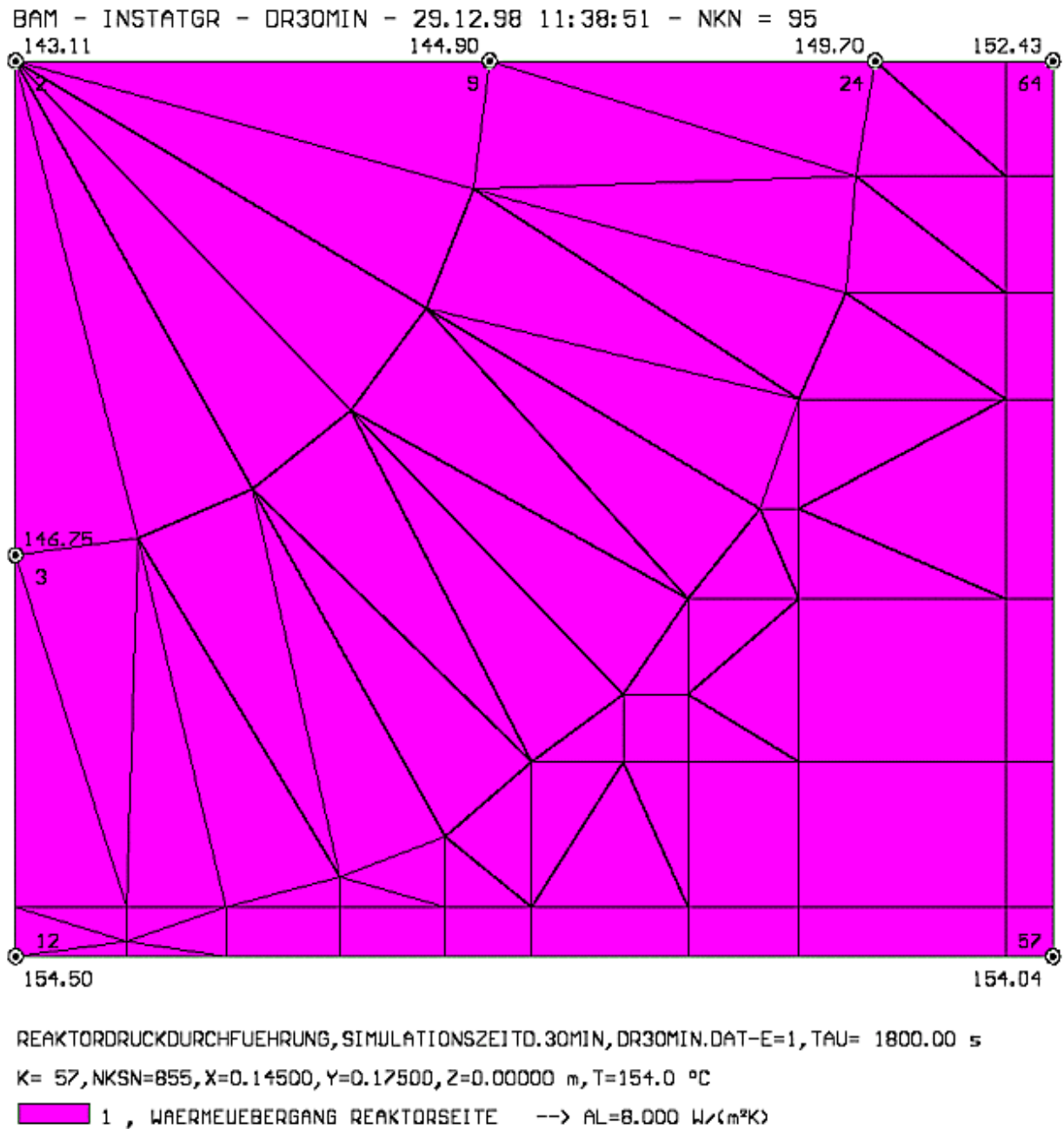


Fig. 5e: Hermetic cable penetration – Subdivision into elements of node plane 1 (front plane) with surface heat transfer elements vertical to the front plane

13.2 Hermetic cable penetration – Node plane 2

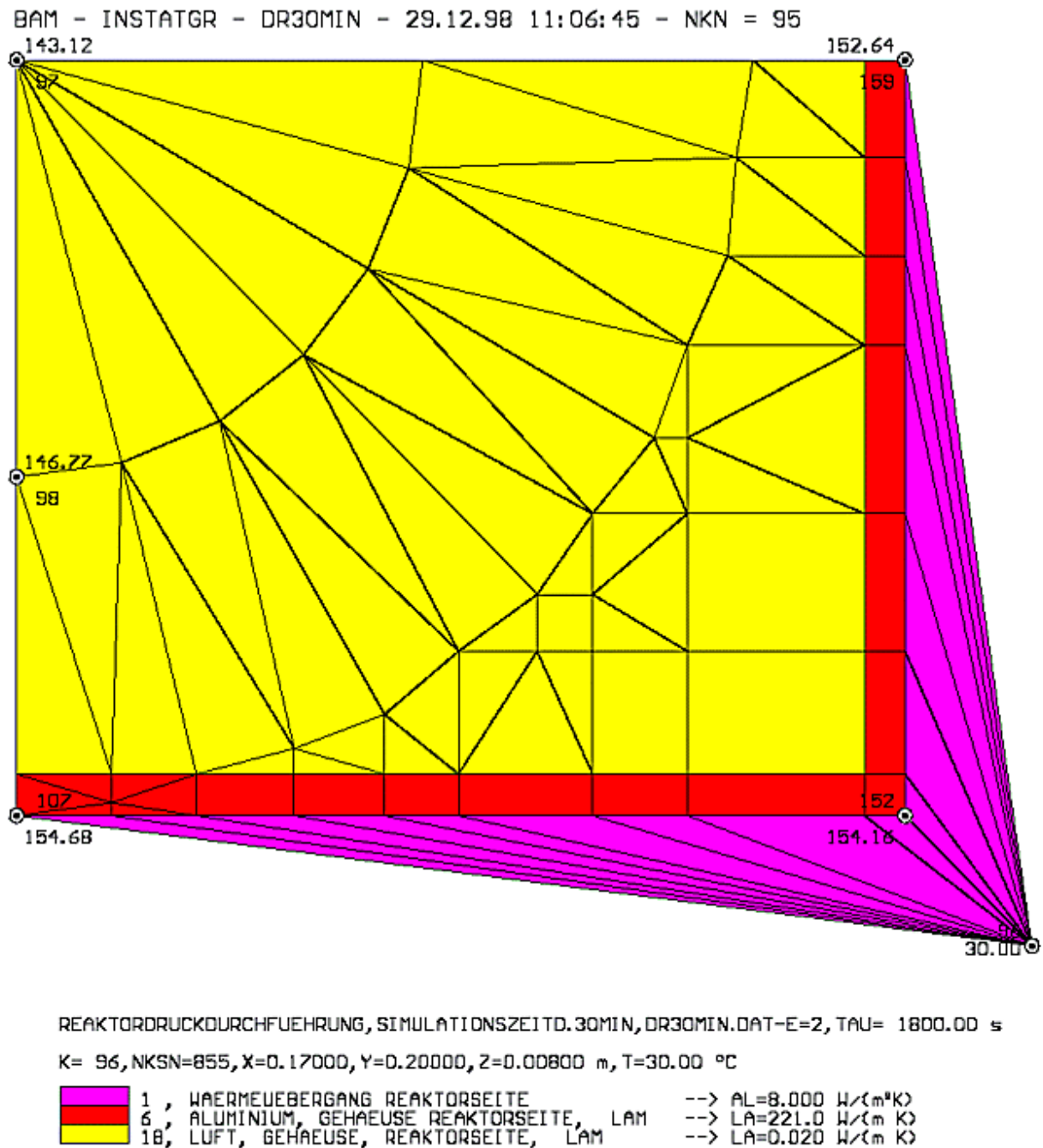
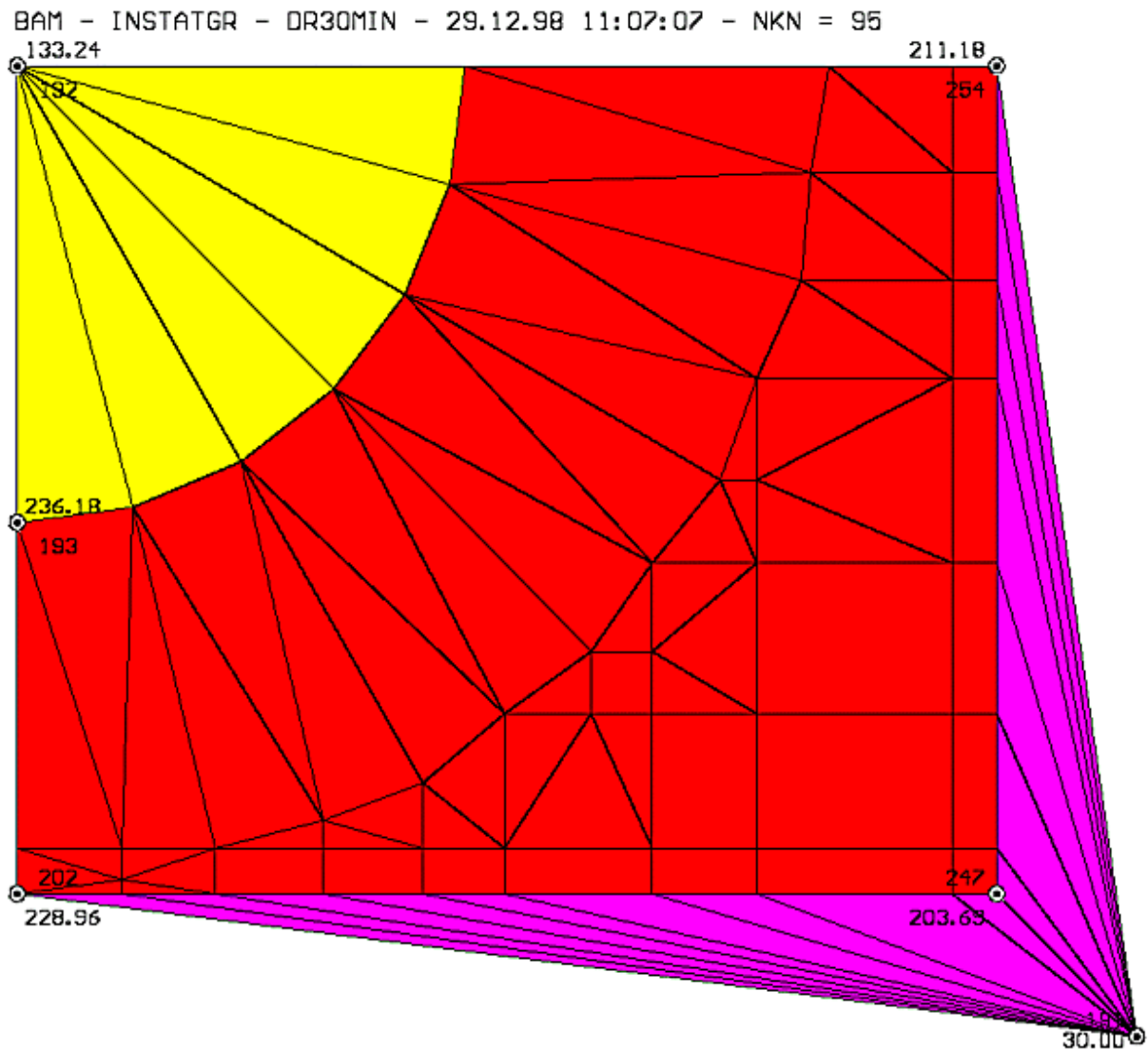


Fig. 5f: Hermetic cable penetration – Subdivision into elements of node plane 2 with lateral surface heat transfer elements

13.3 Hermetic cable penetration – Node plane 3



REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEITD.30MIN, DR30MIN.DAT-E=3, TAU= 1800.00 s

K=191, NKS=855, X=0.17000, Y=0.20000, Z=0.20200 m, T=30.00 °C

	1, WAERMEUEBERGANG REAKTORSEITE	--> AL=8.000 W/(m²K)
	6, ALUMINIUM, GEHAEUSE REAKTORSEITE, LAM	--> LA=221.0 W/(m K)
	18, LUFT, GEHAEUSE, REAKTORSEITE, LAM	--> LA=0.020 W/(m K)

Fig. 5g: Hermetic cable penetration – Subdivision into elements of node plane 3 with lateral surface heat transfer elements

13.4 Hermetic cable penetration – Node plane 4

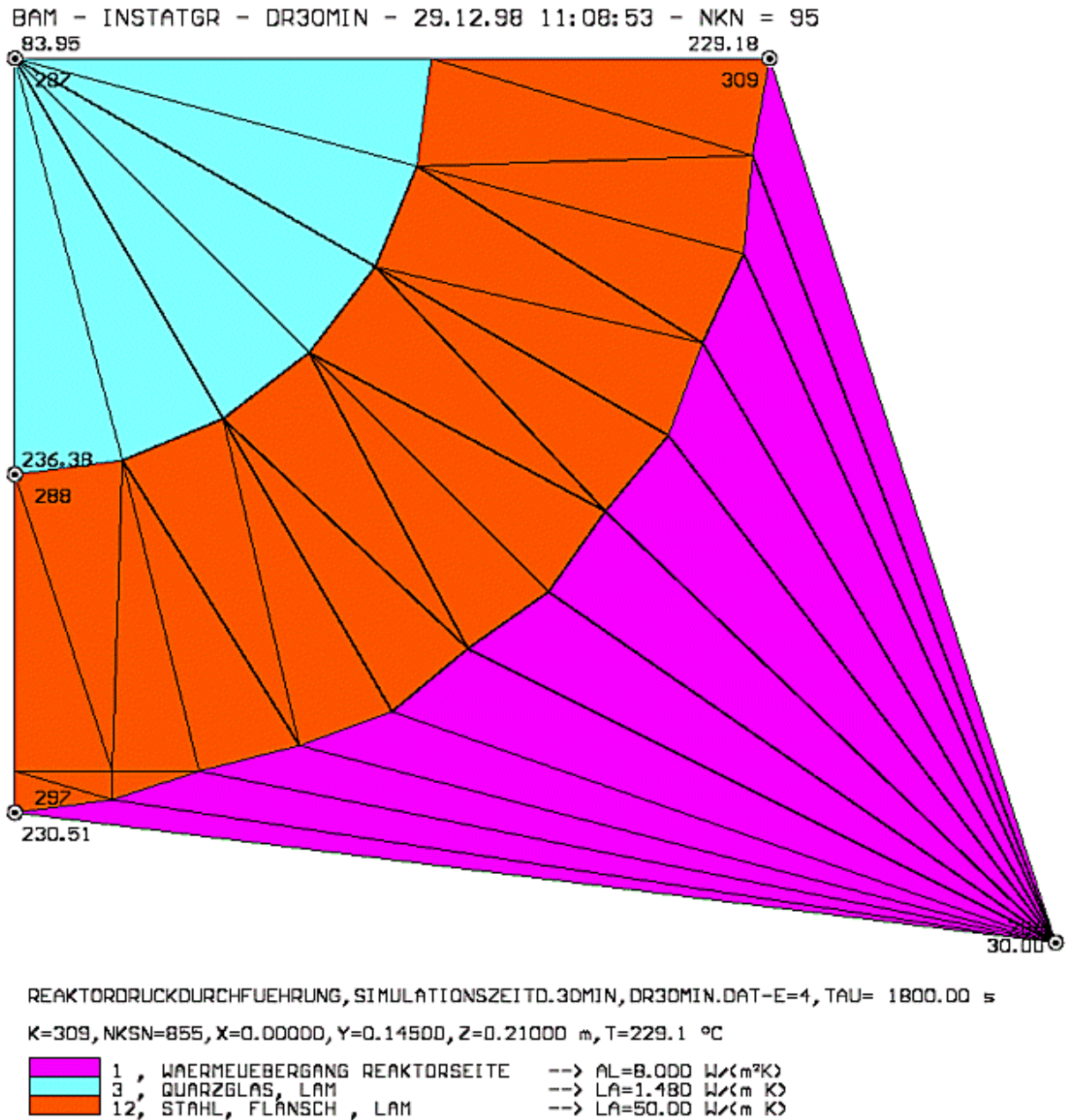
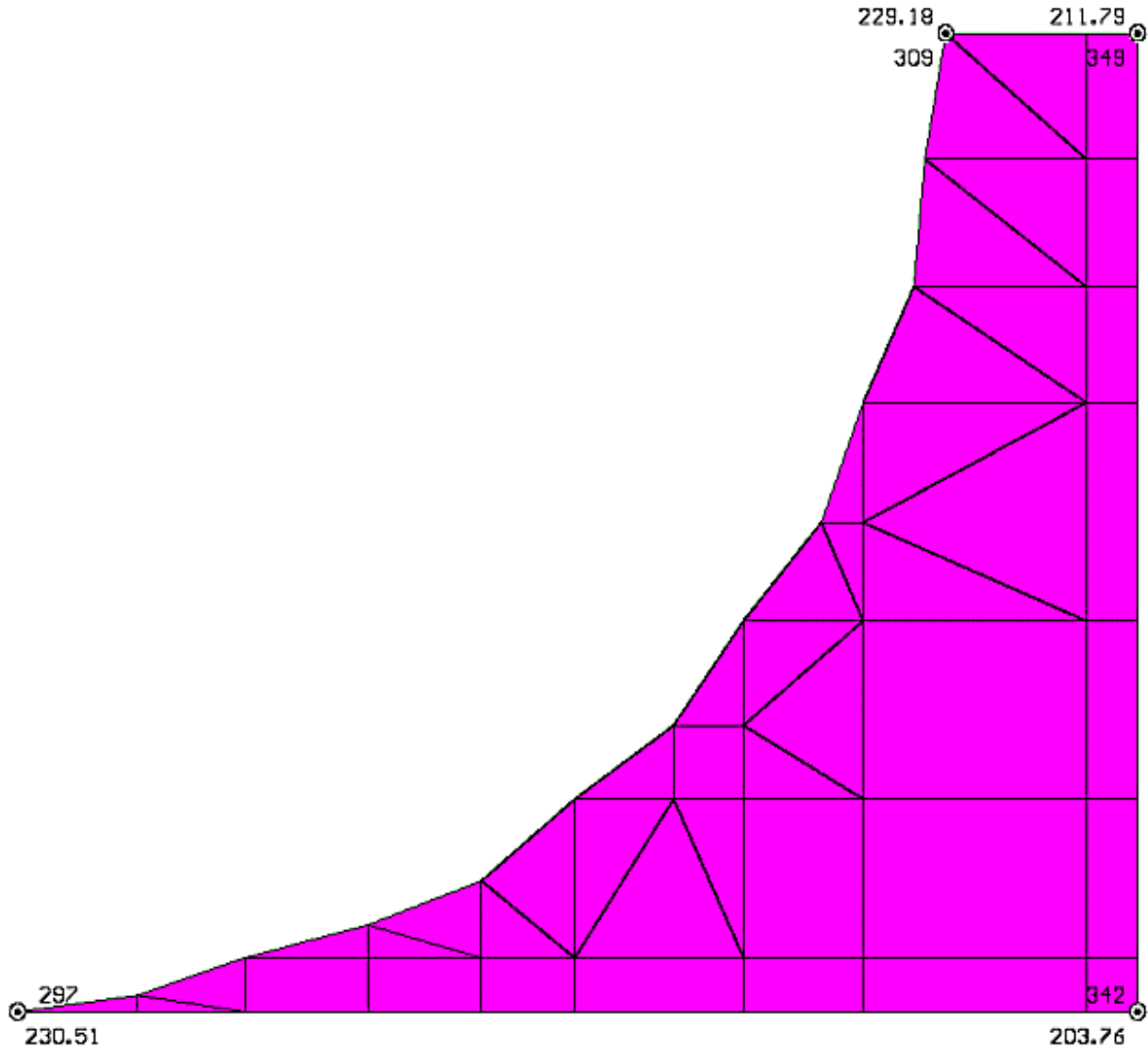


Fig. 5h: Hermetic cable penetration – Subdivision into elements of node plane 4 with lateral surface heat transfer elements

BAM - INSTATGR - DR30MIN - 29.12.98 11:41:16 - NKN = 95



REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEITD.30MIN, DR30MIN.DAT-E=4, TAU= 1800.00 s

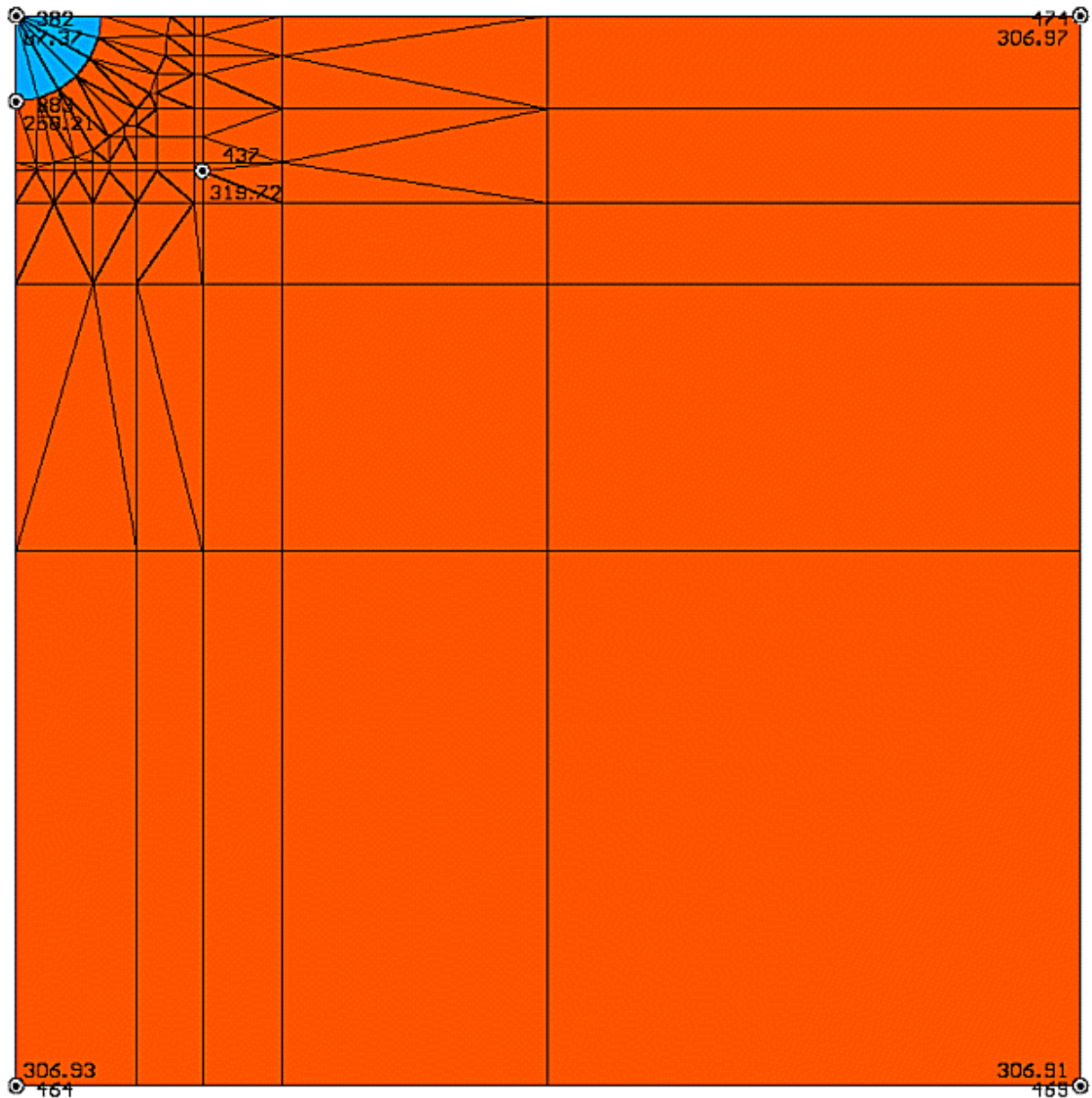
K=342, NKS=855, X=0.14500, Y=0.17500, Z=0.21000 m, T=203.7 °C

1 , WAERMEUEBERGANG REAKTORSEITE --> AL=8.000 W/(m²K)

Fig. 5j: Hermetic cable penetration – Subdivision into elements of node plane 4 with surface heat transfer elements vertical to the plane

13.5 Hermetic cable penetration – Node plane 5

BAM - INSTATGR - DR30MIN - 29.12.98 11:12:01 - NKN = 95



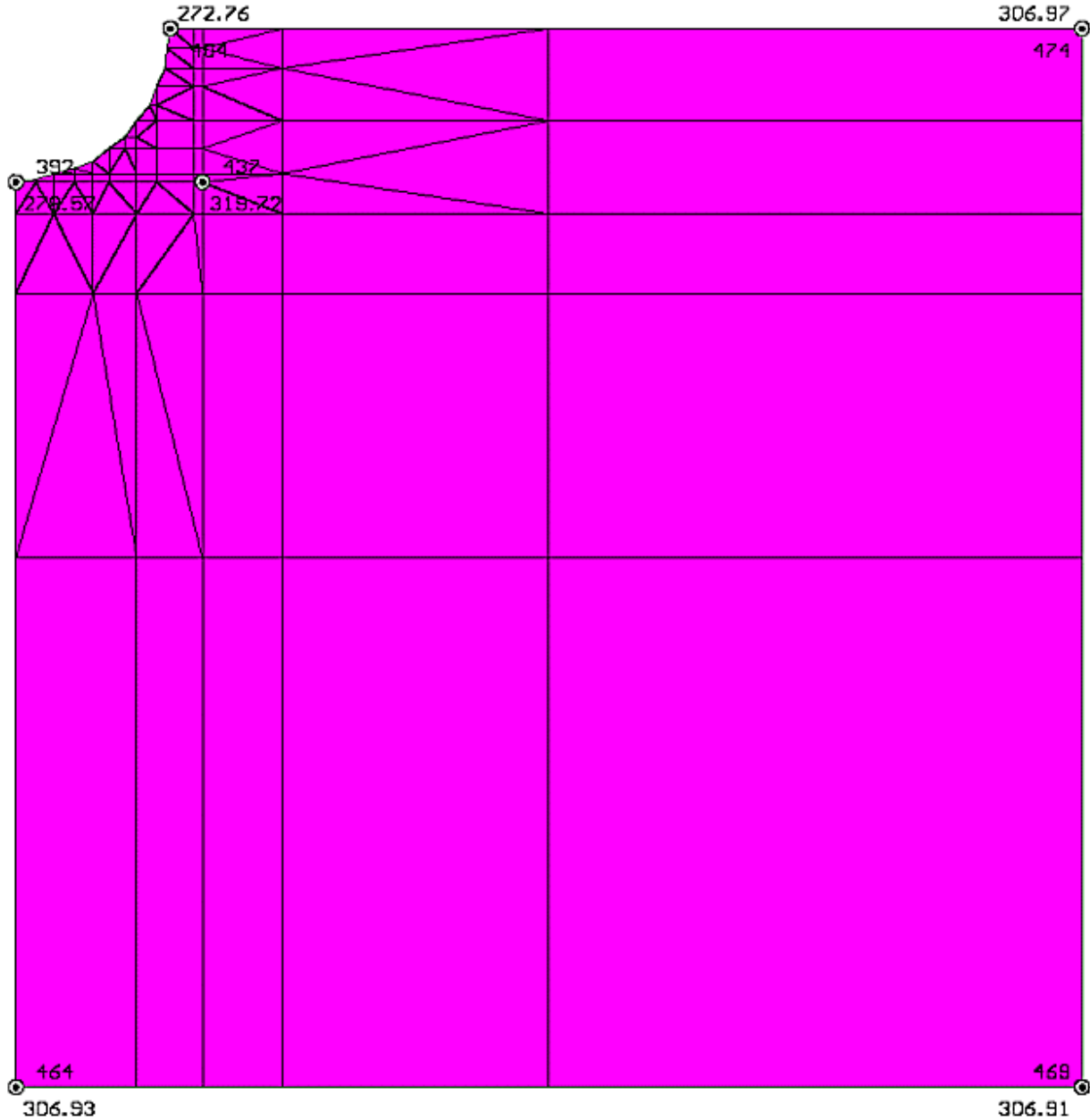
REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEIT 0.30MIN, DR30MIN.DAT-E=5, TAU= 1800.00 s

K=469, NKS=855, X=1.00000, Y=1.00000, Z=0.25000 m, T=306.9 °C

	15, STAHL, WAND, LAM	--> LA=50.00 W/(m K)
	21, LUFT, GEHAEUSE, RINGRAUMSEITE, LAM	--> LA=0.020 W/(m K)

Fig. 5j: Hermetic cable penetration – Subdivision into elements of node plane 5

BAM - INSTATGR - DR30MIN - 29.12.98 11:45:59 - NKN = 95



REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEITD.30MIN, DR30MIN.DAT-E=5, TAU= 1800.00 s

K=469, NKS=855, X=1.00000, Y=1.00000, Z=0.25000 m, T=306.9 °C

1 , WAERMEUEBERGANG REAKTORSEITE --> AL=8.000 W/(m²K)

Fig. 5k: Hermetic cable penetration – Subdivision into elements of node plane 5 with surface heat transfer elements vertical to the plane

13.6 Hermetic cable penetration – Node plane 6

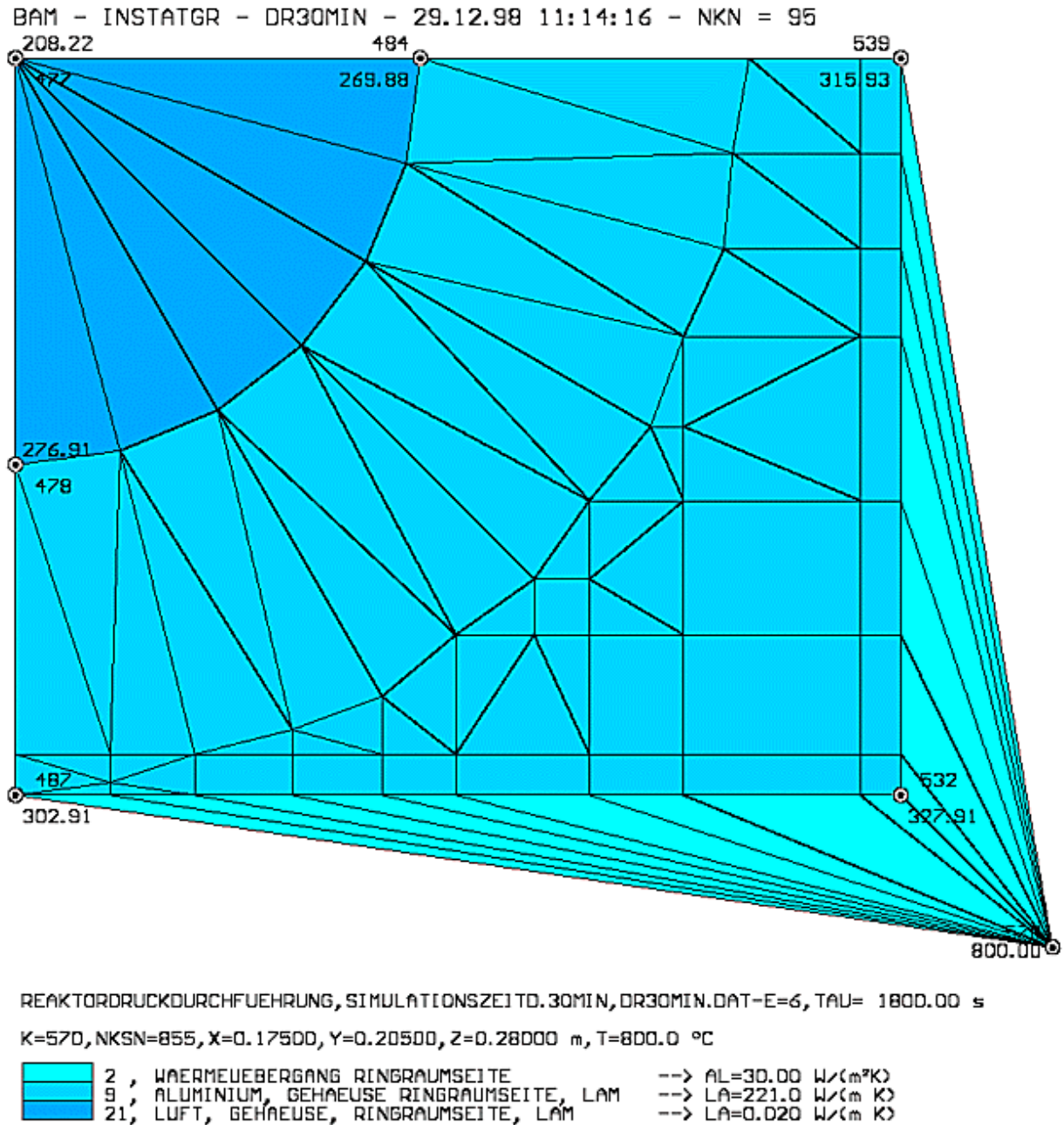
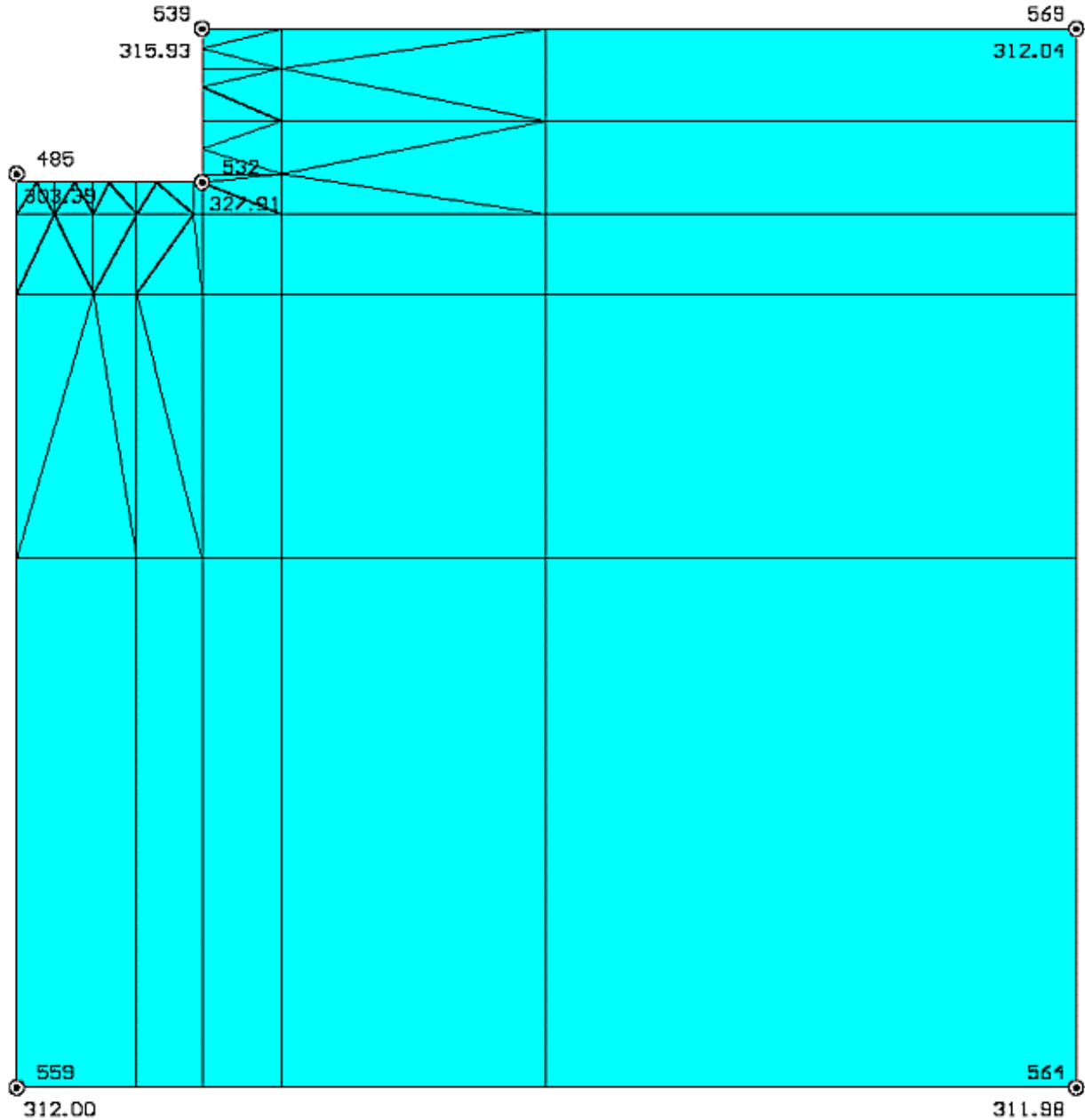


Fig. 51: Hermetic cable penetration – Subdivision into elements of node plane 6 with lateral surface heat transfer elements

BAM - INSTATGR - DR30MIN - 29.12.98 12:01:39 - NKN = 95



REAKTORDRUCKDURCHFUEHRUNG, SIMULATIONSZEIT 0.30MIN, DR30MIN.DAT-E=6, TAU= 1800.00 s

K=564, NKS=855, X=1.00000, Y=1.00000, Z=0.28000 m, T=311.9 °C

2 , WAERMEUEBERGANG RINGRAUMSEITE --> AL=30.00 W/(m²K)

Fig. 5m: Hermetic cable penetration – Subdivision into elements of node plane 6 with surface heat transfer elements vertical to the plane

13.7 Hermetic cable penetration – Node plane 7

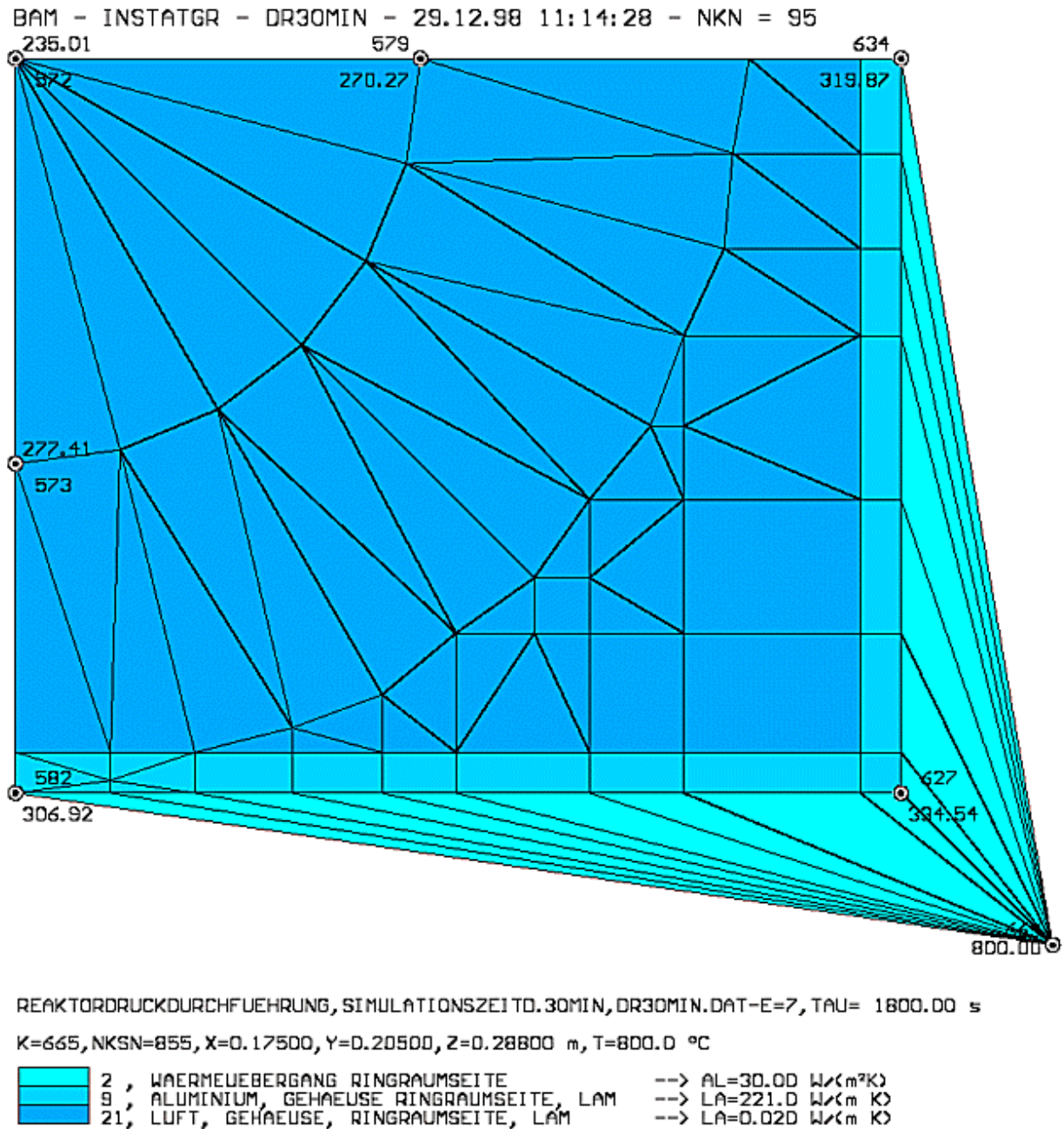


Fig. 5n: Hermetic cable penetration – Subdivision into elements of node plane 7 with lateral surface heat transfer elements

13.8 Hermetic cable penetration – Node plane 8

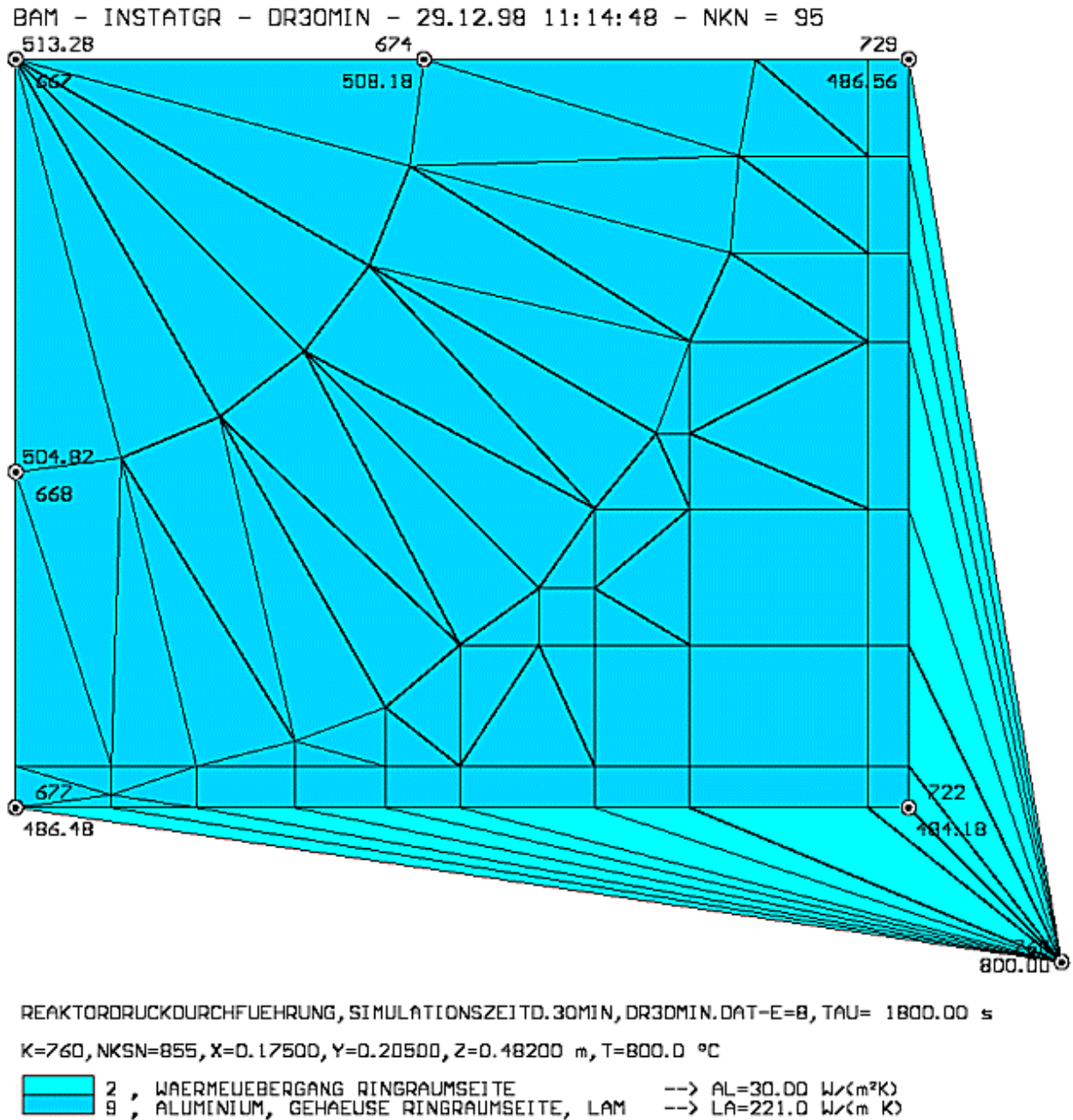


Fig. 50: Hermetic cable penetration – Subdivision into elements of node plane 8 with lateral surface heat transfer elements

13.9 Hermetic cable penetration – Node plane 9

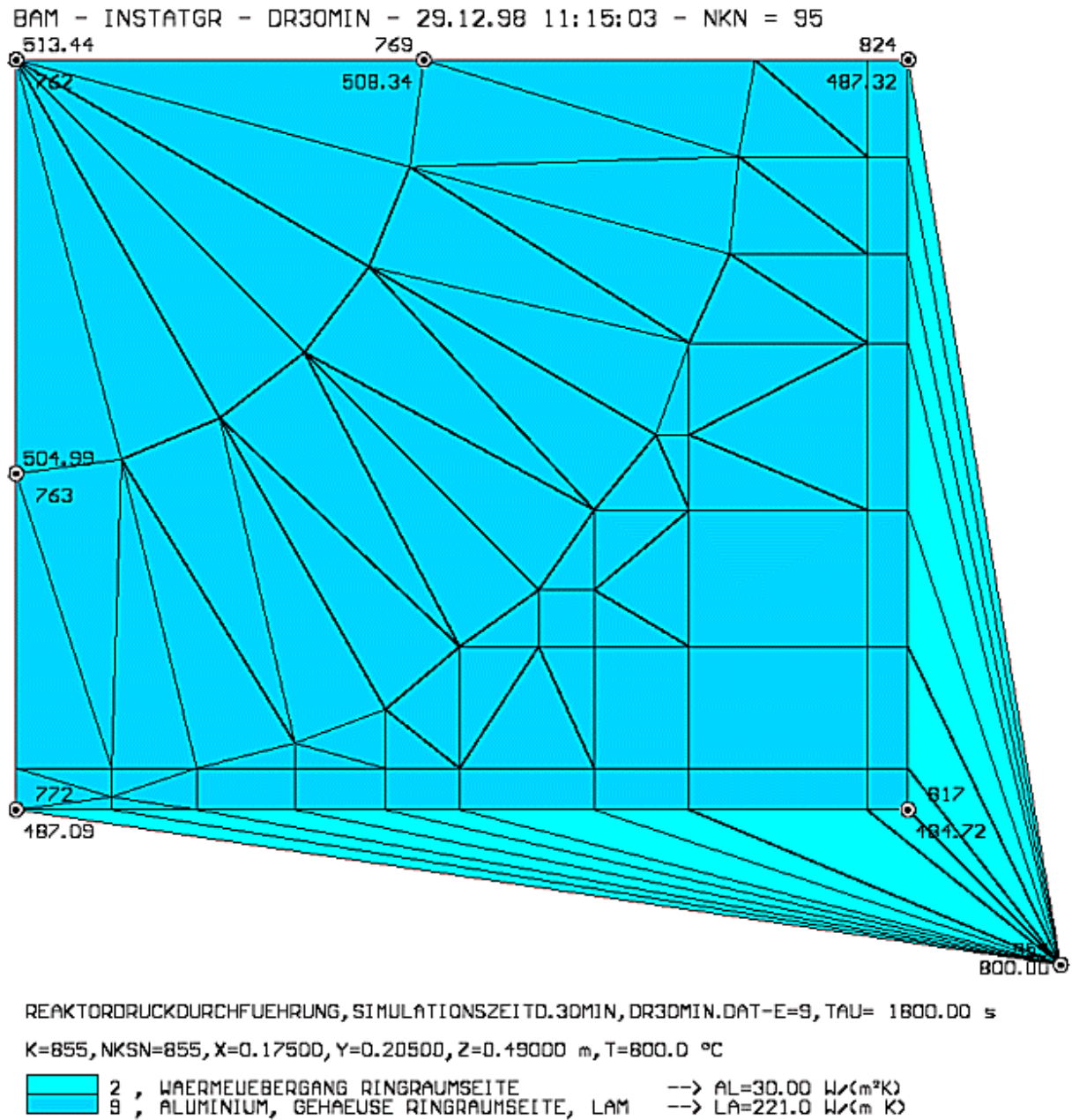


Fig. 5p: Hermetic cable penetration – Subdivision into elements of node plane 9 with lateral surface heat transfer elements

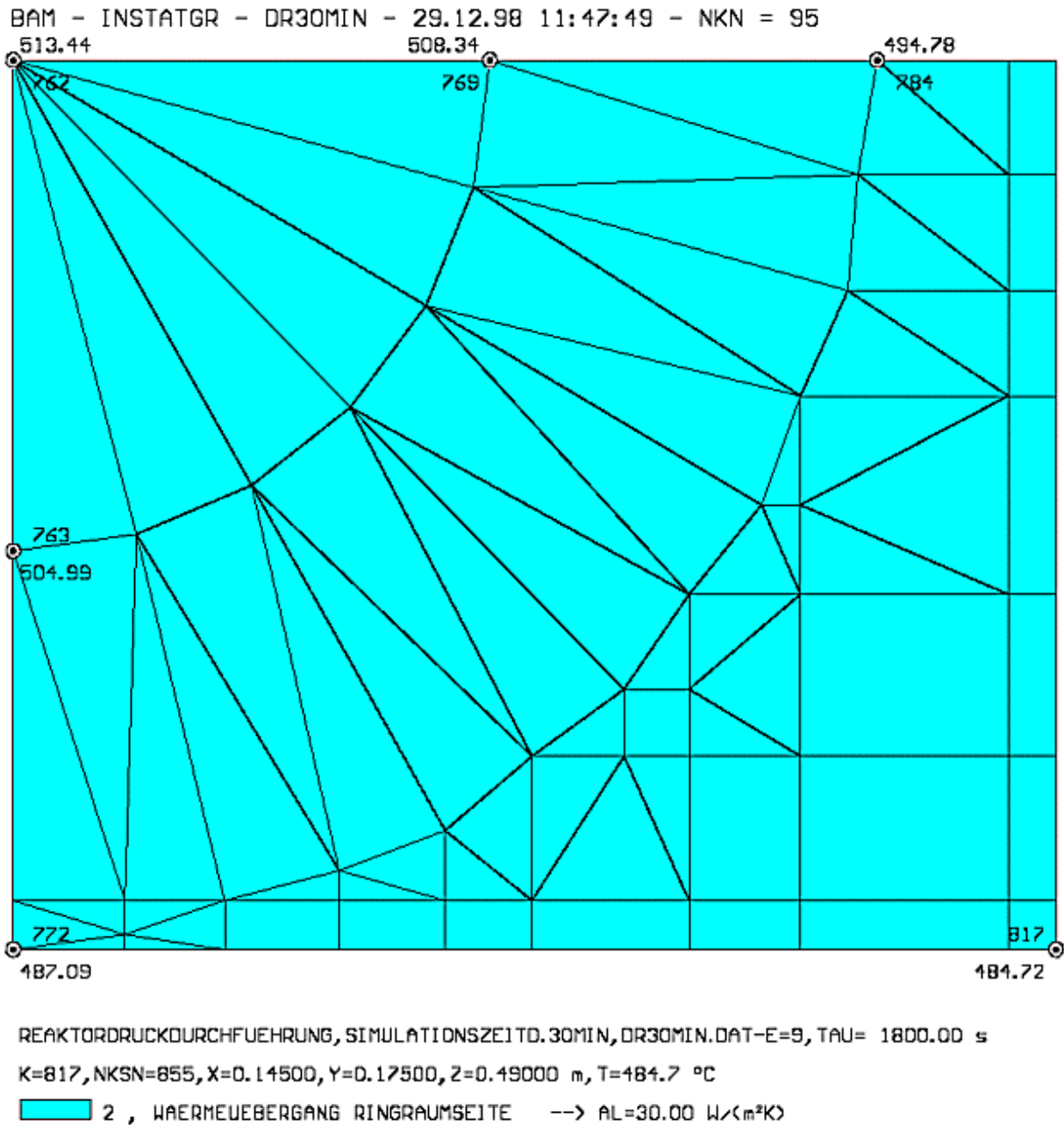


Fig. 5q: Hermetic cable penetration – Subdivision into elements of node plane 9 with surface heat transfer elements vertical to the plane

13.10 Hermetic cable penetration - Calculated temperatures

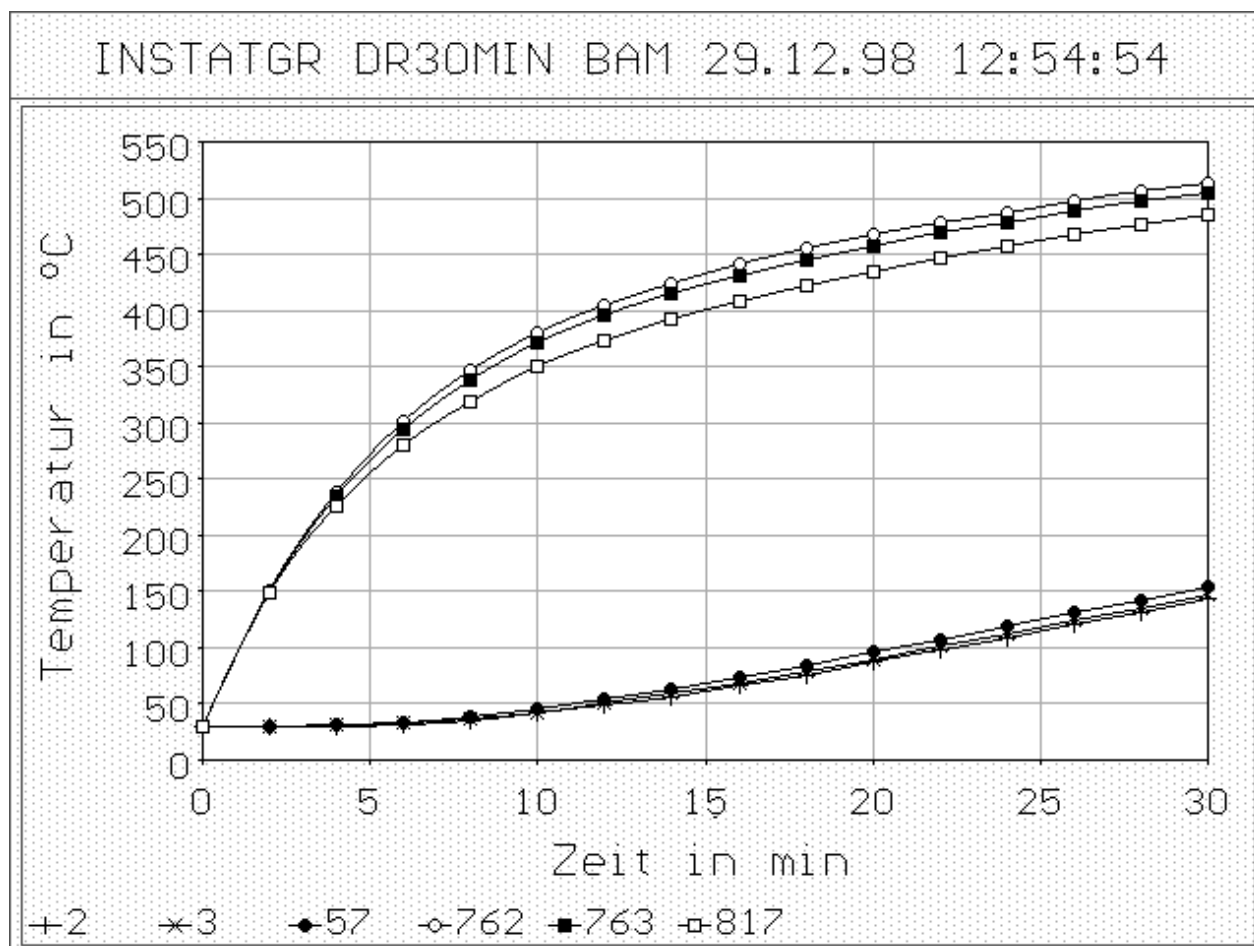


Fig. 5r: Hermetic cable penetration – Calculated temperatures of nodes 2, 3 and 57 (reactor building annulus) and of nodes 762, 763 and 817 (inner side of the containment shell) vs. time

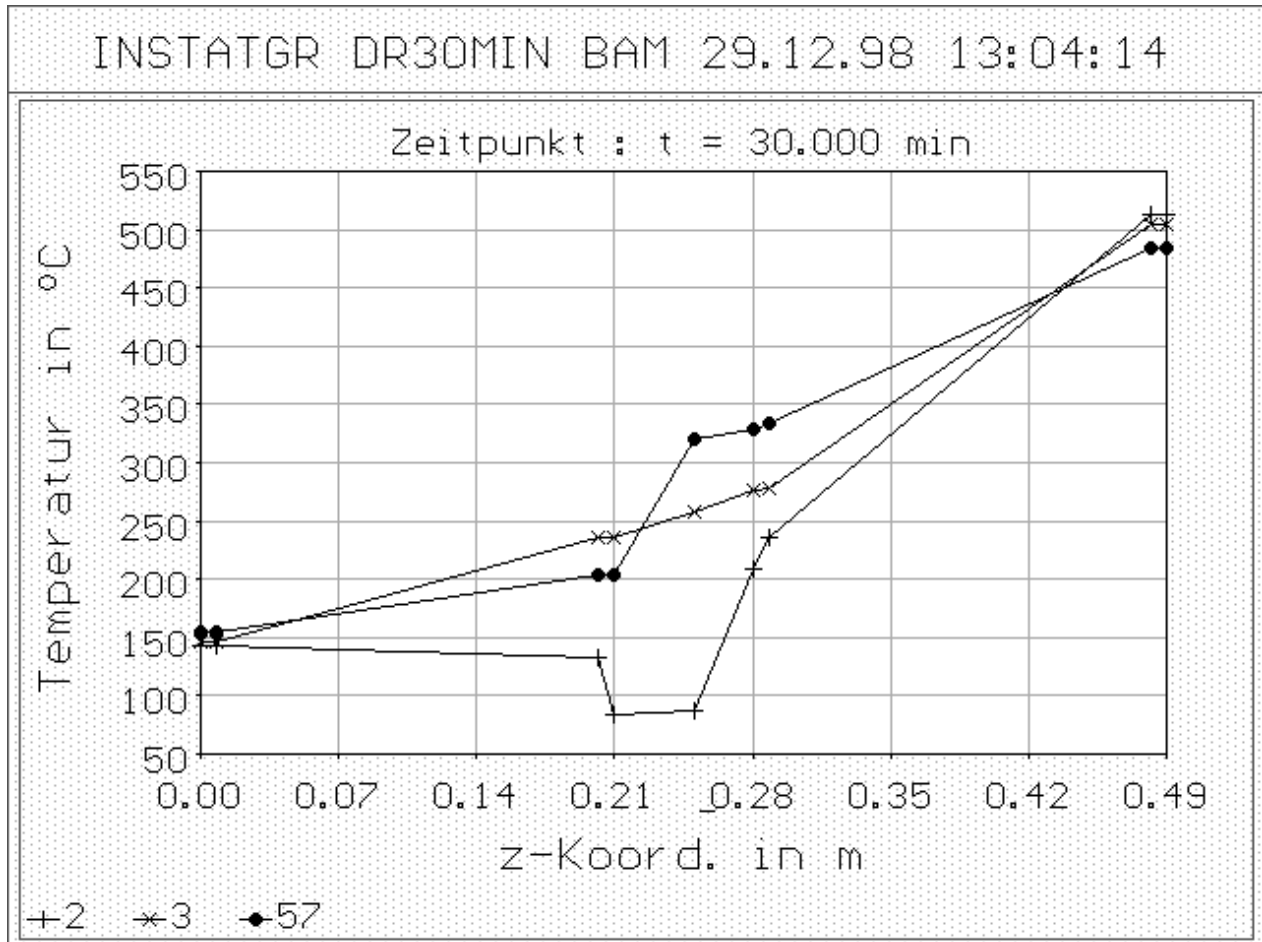


Fig. 5s: Hermetic cable penetration – Temperatures along the z-axis from the reactor building annulus to the containment at the nodes 2, 3 and 57 after an exposure of 800 °C due to fire in the reactor building annulus lasting 30 minutes