ORIGINAL

PROGRAMME: REPLACEMENT OF CEA PACKAGING
TITLE: SAFETY DOSSIER - TYPE TN-BGC1 PACKAGING

CHAPTER 6 APPENDIX 3

TEMPERATURES IN THE TNBGCI PACKAGE MODEL DURING NORMAL AND ACCIDENT CONDITIONS OF TRANSPORT

COPY

Summary:

- This appendix presents the hypotheses and methods of calculating external and internal temperatures of sections of TN-BGC1 packaging and their contents.
  This appendix does not present any calculation results, except the benchmark calculations of the model.
  Appendix A6-4 is dedicated to calculation results.

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1. INTRODUCTION

This study aims to define the temperature distribution within the TN-BGCI packaging loaded with its different possible packing methods.

The general conditions taken into account are as follows:

- statutory sunshine <1>,
- package placed horizontally (the most detrimental case),
- accident conditions of fire<1>.

2. METHODOLOGY AND GENERAL HYPOTHESES

2.1 Use of tests

A) Thermal tests on sections of packaging or complete packaging were performed (chapter 6, appendix I):

- Tests on sections determined the thermal conductivity of the resin before and after the fire test.
- The test on the prototype packaging accurately determined the temperature field on different points of the packaging when in a vertical position.
- The test on the manufactured packaging accurately determined the temperature field on different points of the packaging when in a horizontal position.

When we compare results obtained from horizontal and vertical positions, we observe that, when all the other parameters are the same, a horizontal position leads to higher temperatures in the packaging. Therefore, the calculations made in this report all consider the horizontal position.

B) A fire test was carried out on two prototype pieces of packaging that were representative of the production packaging, after these prototypes had been subjected to the statutory drop tests. A report on this fire test is given in chapter 6, appendix 2.

However in this fire test, the ambient temperature at the start of the fire test was 13°C (instead of the statutory 38°C) and the thermal power released by the contents was nil (instead of the 340W in the case of some contents).

Therefore, using the temperatures taken during the fire test, it was necessary to benchmark the results to obtain temperatures that were representative of accident conditions of transport by applying the statutory hypotheses **[1].** It is on the basis of this benchmarking work that the constructed model is validated.

2. 2 Modelling

2.2.1 General approach

The models are performed according to the finite elements method using IDEAS software [2]. The thermal calculations are carried out with the TMG module:

- in a permanent state in normal conditions of transport,
- in a transient state which is representative of accident conditions of transport, with the initial temperature field (t = 0s) being defined by results obtained in normal conditions of transport.

Different calculations were carried out:

- the first modelling involves creating an axisymmetric model in which the content is modelled only according to its thermal power (imposed flow). This model constitutes the basis for the validation of the other hypotheses adopted relating to material characteristics, exchanges, etc. The model used is presented in figure 1 and figure 2.
- the second modelling involves taking the first model and **adding *the most detrimental content modelled to determine the temperature of the containment seals: the C3 packaging***. The model used is presented in figure 9, figure 10 and figure 11.
- The third, more simple, two-dimensional type of modelling, (section model) is performed to determine the maximum temperature of some internal installations: C2.2, C4, C5A, C5B, C11A, C11B and C9B.
- A fourth, three-dimensional type of modelling has to be carried out when there is a lack of symmetry or convergence in 2D, to determine the maximum temperature of some internal installations: C2.1, C7A, C7B, C7C, C8, C9A.

2.2.2 *Meshing*

The geometry of the TN-BGC1 packaging model shown in figure 1 results from [3].

<u>Contents</u>

Each packaging studied (content) requires a specific modelling indicated below. The different meshing and thermal calculations have been archived [7].

The characteristics of the different packings represented are detailed in chapter 3 of the present safety dossier.

2.3 Hypotheses common to all calculations

For all the calculations, the packaging is in a horizontal position. Indeed, the test results showed that this configuration was the most detrimental one.

The aluminium cage of the packaging is neglected.

2.3.1 Conduction

Conduction through the packaging is defined by the thermal conductivity of each material (described in table 1).

Conduction through the packaging is defined by the thermal conductivity (λ) of each material. The conductive exchanges are automatically calculated by TMG. In the air spaces (gaps) with a thickness of e, this is defined using an exchange coefficient $h_{conductive} = \lambda_{air}(T)/e$.

Due to the fact that there are shock absorbers filled with wood at each end of the casing, exchanges at the ends are neglected.

2.3.2 Free Convection

Free convection is taken into account by laws relating to outer surfaces (vertical plates and horizontal cylinders). These laws are described in document **[4]** for fire conditions (turbulent regime):

- $h = 1.22 \times (\Delta T)^{0.33}$ W/m^2.K for horizontal cylindrical surfaces,
- $h = 1.28 \times (\Delta T)^{0.33}$ W/m^2.K for vertical flat surfaces,

Free convection between the outer shell of the packaging and the ambient air is imposed.

2.3.3 Radiation

All the packaging surfaces that open onto the ambient air are considered as radiating surfaces. In the spaces, a radiation exchange is considered.

2.3.4 Ambient temperature

The ambient temperature equals 311 K (38°C) in normal conditions, before and after the fire. In accident conditions of transport, this varies over time. The variation law is indicated hereafter.

2.3.5 Thermal threshold conditions

2.3.5.1 Normal conditions

The solar flux applied on the outer surfaces of the shell are for horizontal cylindrical surfaces and vertical flat surfaces:

$\Phi_{Horiz} = 0.45{,}400\ W/m^2 = 180\ W/m^2$
$\Phi_{Vertic} = 0.45{,}200\ W/m^2 = 90\ W/m^2$

Temperature imposed (ambient):

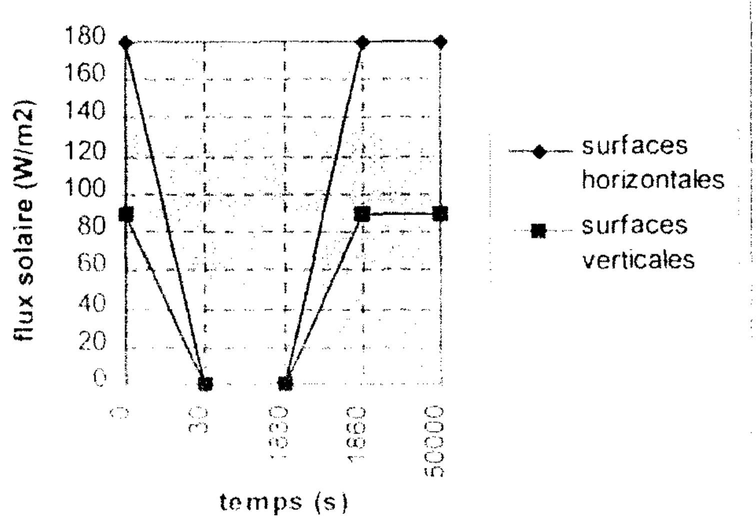
T = 38 □

2.3.5.2 Accident conditions

The initial temperature field of the package is the one determined in the corresponding normal conditions calculation.

The density of the solar flux received by the outer surfaces of the packaging shell is:

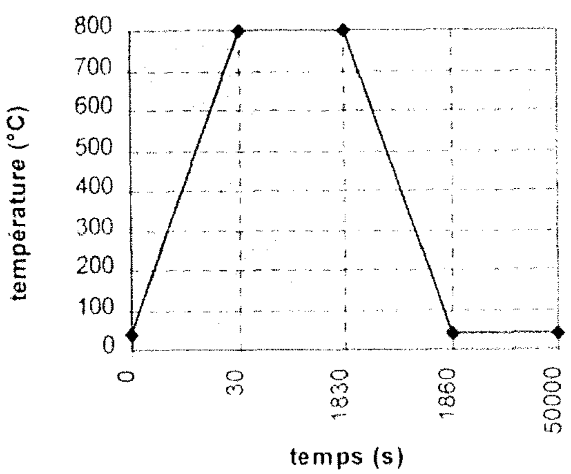
A t = 0s	$\Phi_{Horiz} = 180\ W/m^2$	$\Phi_{Vertic} = 90\ W/m^2$
A t = 30s	$\Phi_{Horiz} = 0\ W/m^2$	$\Phi_{Vertic} = 0\ W/m^2$
A t = 1830s	$\Phi_{Horiz} = 0\ W/m^2$	$\Phi_{Vertic} = 0\ W/m^2$
A t = 1860s	$\Phi_{Horiz} = 180\ W/m^2$	$\Phi_{Vertic} = 90\ W/m^2$
A t = 50000s	$\Phi_{Horiz} = 180\ W/m^2$	$\Phi_{Vertic} = 90\ W/m^2$



flux solaire (W/m2)	solar flux (W/m2)
temps (s)	time (s)
surfaces horizontales	horizontal surfaces
surfaces verticales	vertical surfaces

- Imposed fire temperatures (ambient):

A t = 0s	T = 38□
A t = 30s	T = 800□
A t = 1830s	T = 800□
A t = 1860s	T = 38□
A t = 50000s	T = 38□



température (C°)	temperature
temps (s)	time (s)

3. VALIDATION OF THE FINITE ELEMENTS MODEL

The finite elements model (TN-BGC 1 packaging, figure 1) was benchmarked according to the conditions and results of the fire test carried out by the CEA/DMT.

3.1 Testing conditions

The tests were carried out with no sunshine and in an ambient temperature of 13°C as described in appendix 2.

The average temperature of the fire and the duration of the fire test under consideration are based on analysis of ambient temperature variation charts and the temperature of the packaging outer shell, presented in appendix 2:

- Thus, after smoothing the curve of figure 4 in appendix 2, we can consider that the outer temperature of the package varies between 600°C at the start of the fire and 900°C at the end of the fire (with a peak of over 1000°C); we can note that the temperature of the flames exceeds these values. These latter results as well as the curve of figure 3 (appendix 2) show that the temperature of the fire during the test was higher than 800°C on average, despite these variations.

- Moreover, measurement of the duration of the test took account of the fact that the ambient temperature did not instantly rise to 800°C.

Therefore, we considered that the fire test corresponded to an average fire temperature of 800°C during a period of 30 minutes.

As we mentioned earlier, the outer shell of the packaging reached a relatively high temperature. In the axisymmetric model benchmark calculation, we considered the maximum temperatures reached at the outer shell during the test. Therefore, the fact that both packages are placed side by side above the fire has no impact on the calculations made.

During the test, part of the structure supporting the specimens broke and the specimens fell into the layer of fuel with the lid side first. At this end of the packaging there is a cap to absorb shocks (falls) and for insulation (thermal). Initially there was a layer of fuel of about 143 mm (see appendix 2). As the packaging fell after 10 min. and 25 min. the thickness of this layer at the time of the fall and after the fall was therefore lower (10 min.) and even very lower (25 min.) than the initial value. According to the photographs taken after the fire test, we estimate that the packaging was at an angle of 45° with the horizontal. In fact, only a very small part of the caps were lying in the layer of fuel during the fire test. For this reason and insofar as this was a thermally shielded area, the fact that this part of the packaging was not subjected to the worst conditions has very little impact on the test results. Therefore, the benchmark calculations did not take this event into account.

Consequently, the calculation conditions corresponding to the test are:

- no solar flux;
- even initial temperature of 13°C;
- ambient temperature before and after fire of 13°C;
- average temperature of fire of 800°C;
- duration of fire - 30 minutes;
- thermal power in the packaging - nil.

3.2 Materials

The characteristics of the materials selected are presented in table 1. It should be noted that if the thickness of the burnt resin considered afterwards in the model is taken as 13 mm, the results are benchmarked according to a thickness of 10 mm of burnt resin (maximum thickness of burnt resin measured after the fire test, see appendix 2).

3.3 Results obtained

The results obtained using the finite elements model under the conditions corresponding to the fire test are presented in table 2. Figure 6 presents the packaging isotherms under test conditions at the end of the fire (t = 1830s).
The following table gives the different maximum temperatures within the packaging and compares them with the test results.

	CALCULATED Tmax (°C) and t (s)	TEST Tmax (°C) and t (s)	Figure
Base of shell Thermocouple 6 Node 606	T = 211 t = 1,838	T = 210 t = 2,100	figure 7
Outer shell Thermocouple 3 Node 742	T = 778 t = 1,828	T = 1020 t = 1,800	figure 8
Inner shell Thermocouple 2 Node 746	T = 176 t = 5,810	T = 176 t = 4,000	figure 8
Top of shell Template Node 451	T = 131 t = 15,690	T — 132 -	figure 7

The model results are similar to the test results.

This allows us to consider that the general hypotheses adopted in the model to describe thermal exchanges are representative of the thermal behaviour of the packaging, and to use this model to map the model of the TN BGC1 packaging in normal and accident conditions of transport.

4. TEMPERATURES IN THE MODEL OF THE TNBGCI PACKAGE DURING NORMAL AND ACCIDENT CONDITIONS OF TRANSPORT

Below, we present the temperatures of the packaging and internal installations obtained

from the general hypotheses presented in section 2 and validated in section 3 and the different models detailed below.

The different packing methods studied are indicated in chapter 3 of the present safety dossier. As the study was conducted for normal and accident conditions of transport, in most cases we have taken the dimensions that correspond to the minimum gap.

The characteristics of the packaging materials are given in table 1. The characteristics of the materials used for internal installations and contents are given in table 3.

4.1 TNBGC1 packaging loaded with type C3 packing

4.1.1 Hypotheses and modelling

The content selected is the one that leads to maximum temperatures in the lid area (so as to determine the maximum temperatures of the seals and locking ring of the lid). This is plutonium oxide powder packed in a TN 90 (C3 packing) for which:

- the internal power is maximum (340 W),
- the content is the closest to the lid of the packaging and its height is the lowest (in the case of bars and plates of metal plutonium, the content and internal power are distributed throughout the entire height of the spacer set E4).
- the low thermal conductivity and low value of the product of the density and the specific heat of the content (p.Cp) respectively lead to high temperatures of the content in normal and accident conditions of transport.

Other detrimental hypotheses concerning C3 packing were considered:

- the spacer E1 is in contact with the inner side of the packaging lid,
- the spacer E2 (and possibly the basket Pl) are respectively in contact with the lid and plug of the TN90,
- following the statutory drop tests, we consider that the internal plug of the TN 90 is in contact with the lid of the TN 90 (figure 10 and figure 11) and the packaging is punched.

As the basket Pl is only made up of a part of circular shell, we made two calculations; one calculation with the basket Pl and a second calculation without the basket Pl, in order to determine the most detrimental case.

4.1.2 Internal power

The exchange height is estimated according to the diameter of the aluminium cans and the maximum density of the PuO_2powder, which corresponds to the lowest exchange height.

$$p = \frac{M}{V} = \frac{M}{\pi . r^2 . H}$$

$$H = \frac{M}{\pi . r^2 . H}$$

M = 19.25 kg (density corresponding to the maximum power acceptable)
r = 44.5 mm (radius of cans)
p = 3500 kg/ m3
thus H = 0.884 m

Therefore, a power of 340 W on a height of 0.844 m is introduced.

4.1.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for the C3.A axisymmetric model are summarised in the following tables. As the temperatures of models with and without the Pl basket are similar, we have only given curves with the P1 basket in the appendix. The isotherms for normal conditions are indicated in figure 12, figure 13 and figure 14. The isotherms for accident conditions (end of fire t = 1830s) are shown in figure 15, figure 16 and figure 17. Charts showing how temperature varies over time are given in figure 18 and figure 19.

C3.A (content)	**NCT**		**HAC**		
	Maximum temperature (°C)		**Maximum temperature (°C) / element**		**time (s)**
	with P1	**without P1**	**with P1**	**without P1**	**with/without P1**
PuO_2 powder centre	500	494	546 / E56	538	12 010
PuO_2 powder	387	380	441 / E60	432	12 010
PuO_2 aluminium can	369	362	424 / E162	415	12 010 / 11 010
Can	309	300	375 / E214	364	11 010/ 10 010

Pl basket	205	-	295 / E522	-	10 010
TN90 - Shell	163	164	262 / E1861	265	10 010 /9 010
E2 spacer	144	145	247 / E582	250	9 010
E1 spacer	139	139	243 / E642	246	9 010
Top TN90 lid	140	139	244 / E1980	244	15 010 / 14 010
TN90 seal	141	141	245 / E2103	246	14 010 / 15 010
TN90 gas cavity	138	137	242 / E2109	243	14 010

C3.A (packaging)	**NCT**		**HAC**		
	Maximum temperature (°C)		**Maximum temperature (°C) /element or node N**		**Time**
	with P1	**without P1**	**with P1**	**without P1**	**with/without**
Outer shell of packaging	100	100	777 / E954	777	1 830
Burnt resin	103	103	574 / E1442	574	1 840
Resin	123	123	356 / E1443	357	1 710
Inner shell of packaging	127	127	241 / E982	242	5 010
Locking ring of packaging	111	111	225 / E1201	226	19 010
Packaging seal	111.5	111.5	226 / N912	227	18 010
Inner side of packaging lid	128	127	233 / E729	234.5	15 010
Gas in packaging cavity	80	79	215 / E329	220	9 010
Packaging base	70	69	259 / E921	259	1 830

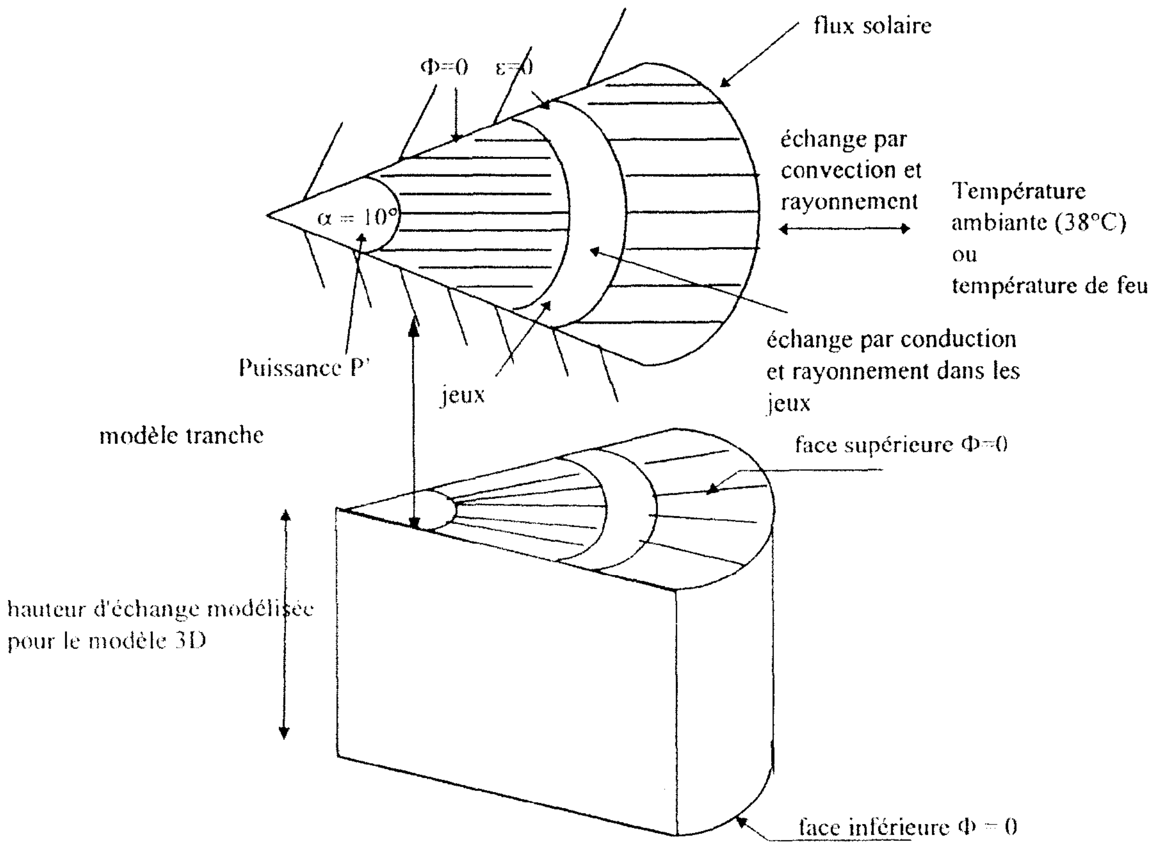
The maximum temperature of the packaging base and the tertiary packing is the same as that of the respective lid.

4.2 TNBGCI packaging loaded with type C2.1 and C2.2 packing

4.2.1 Hypotheses and modelling

Given the different symmetries of the C2.1 and C2.2 packings, only one section of 10° was modelled (see diagram 1 below). The C2.1 meshing is shown in figure 20 and it is a 3D model. The exchange height of the PuO_2 cans was modelled. A 3D model was created.

The meshing for the C2.2 model is 2D with a thickness of 1 mm (see figure 21). For these two models, the density of the PuO_2 powder is taken as equal to 1700 kg/m^3 (average) for the transient state.



Flux solaire	Solar flux
Échange par convection et rayonnement	Exchange via convection and radiation
Température ambiante (38°) ou température de feu	Ambient temperature (38°) or fire temperature
Echange par conduction et rayonnement dans les jeux	Exchange via conduction and radiation in the spaces
Face supérieure	Upper side
Face inférieure	Lower side
Hauteur d'échange modélisée pour le modèle 3D	Exchange height modelled for 3D model
Modèle tranche	Model of section
Jeux	spaces
Puissance P	Power P'

Diagram 1: Thermal threshold conditions of the models C2.1 and C2.2

4.2.2 Internal power

The power introduced in the model varies according to the angle modelled (a = 10°) and the real exchange height of the product releasing heat. In this packing, the product's exchange height is the total height of the stainless steel cans containing the PuO_2 powders.

$$P' = \frac{P}{\frac{360}{\alpha}.H_{exchange}} \quad with P = 340W$$

Packing	C2.1.	C2.2.
Real $H_{exchange}$ (mm)	1175	940
Power P' (W)	9.44	0.0100473
Modelled $H_{exchange}$ (mm)	1175	1

4.2.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for model C2.1 and model C2.2 are summarised in the following tables.

The isotherms for normal conditions are shown in figure 22 for the C2.1 packaging and figure 25 for the C2.2 packaging.

The isotherms in accident conditions (end of fire t = 1830s) are shown in figure 23 for packing C2.1 and figure 26 for packing C2.2. Charts showing how temperature varies over time are presented in figure 24 for packing C2.1 and figure 27 for packing C2.2.

C2.1.	**NCT**	**HAC**	
	Maximum temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
PuO_2 powder centre	413	465 / E417	16 010
PuO_2 powder	321	383 / E405	15 010
PuO_2 stainless steel can	294	359 / E122	15 010
AA236	215	296 / El 12	14 010
AA227 - Shell	163	257 /E104	11 010
E1 spacer	150	247 / E125	10 010
Inner shell of packaging	137	240 / E101	7 010
Resin	132	321 / E423	1 660
Burnt resin	108	638 / E369	1 850
Outer shell of packaging	105	781 / E89	1 830

C2.2.	**NCT**	**HAC**	
	Maximum temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
PuO_2 powder centre	445	503 / E80	22 010
PuO_2 powder	335	406 / E68	20 010
Stainless steel can PuO_2	323	393 / E65	19 010
AA303	245	331 / El 18	19 010
AA227 - Shell	180	280 / E 104	18 010
E1 spacer	164	267 / E125	12 010
Inner shell of packaging	149	255 / E101	8 010
Resin	143	319 /E86	1 610
Burnt resin	114	624 / E5	1 860
Outer shell of packaging	111	752 / E89	1 830

4.3 TNBGC1 packaging loaded with type C4 packing

4.3.1 Hypotheses and modelling

A 3D model was created (figure 28). In this model, the exchange height was modelled. This packing uses the same aluminium cans as packing C3. Therefore, the exchange height is 0.884 m.

4.3.2 Internal power

The power used in the model depends on the angle chosen (10°).

$$P' = \frac{P}{\frac{360}{\alpha}} \text{ with } P = 340W$$

therefore P' = 9.44 W

4.3.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for model C4 are summarised in the following table.

The isotherms for normal conditions are indicated in figure 29.

The isotherms for accident conditions (end of fire t = 1830s) are presented in figure 30.
A chart showing how temperature varies over time is indicated in figure 31.

C4.C	**NCT maximum temperature (°C)**	**HAC maximum temperature (°C)/ element**	**time (s)**
PuO_2 powder centre	505	563 / E476	13 010
PuO_2 powder	400	468 / E464	12 010
PuO_2 aluminium can	370	440 / E607	12 010
Can	340	414 / E626	12 010
P3 basket	291	371 / E620	12 010
AA204 - shell	247	335 / E614	11 010
E1 spacer	169	289 / E598	7 010
Inner shell of packaging	152	281 I E610	6 010
Resin	147	376 / E428	1 710
Burnt resin	118	582 / E425	1 840
Outer shell of packaging	114	777/ E523	1 830

4.4 TNBGC1 packaging loaded with type C7 packing

4.4.1 Hypotheses and modelling

Given the different symmetries of the C7 packing, it was modelled according to three-dimensional modelling.

Only half the height of spacer E4 separating the bars is modelled. We consider the minimum height is equal to 90/2 = 45 mm. A bar is geometrically defined by its diameter and its height. 9 bars are placed in the E4 spacer. In order to determine the most conservative case, we processed the most extreme cases (H_{mini};r_{maxi})and (H_{maxi}; r_{mini}), and an intermediary case ($H_{average}$; $r_{average}$).

The case of (H_{maxi}; r_{mini})

The minimum height of the E4 spacer is equal to 8 x 90 = 720 mm. The effective height of the TN90 is 1397 mm. Therefore, the maximum height of the bars is equal to H maxi = (1397-720)/9 = 75.2 mm. Taking a conservative specific power of plutonium equal to 20 W/kg, the mass of plutonium is equal to:

$$M = \frac{340}{20} = 17kg \ \textit{i.e..for one bar of } 1.88 \text{ kg}$$

$$M = \rho.V = \rho.\pi.r^2_{mini}.H_{maxi}$$

$$r_{mini} = \sqrt{\frac{M}{p.\pi.H_{maxi}}} = \sqrt{\frac{1.88}{19700.\pi.0,07522}}$$

$$r_{mini} = 20.1 \text{ mm}$$

Thus (H_{maxi} ; r_{mini}) = (75.2 mm; 20.1 mm)

The case of (H_{mini};r_{maxi})

The maximum radius of the bar corresponds to the radius of the spacer E4 taken as equal to 116/2 = 58 mm.

Therefore, H_{mini}= 9.1 mm.

And (H_{mini};r_{maxi}) = (9.1 mm; 58 mm).

The case of ($H_{average}$; $r_{average}$).

Given the values obtained above, we can consider the following values ($H_{average}$; $r_{average}$) = (33.9 mm; 30 mm)

The meshing for C 7.A, C 7.B and C 7.C, respectively associated with cases (H_{mini};r_{maxi}), (H_{maxi} ; r_{mini}) and ($H_{average}$; $r_{average}$)are 3D models. They are indicated in figure 32, figure 33 and figure 34.

4.4.2 Internal power

The power used in the model depends on the angle chosen (10°) and the number of bars releasing

heat.

$$P' \frac{P}{\frac{360}{\alpha}.9.2} \text{ with } P = 340W$$

$$P' = 0.52469 \text{ W}$$

4.4.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for models C7 are summarised in the table below.

The isotherms for normal conditions are indicated in figure 35, figure 38 and figure 41.

The isotherms for accident conditions (end of fire t = 1830s) are presented in figure 36, figure 39 and figure 42. Charts showing how temperature varies over time are indicated in figure 37, figure 40 and figure 43.

C7.1.	**NCT**	**HAC**	
	temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Pu bar	224	305 / E1020	15 010
E4 spacer	223	304 / E453	15 010
TN90 - Shell	187	274 / E1261	12 010
E2 spacer	170	263 / E1158	8 010
E1 spacer	165	261 / E 1152	7 010
Inner shell of packaging	149	264 / E1256	4 710
Resin	143	373 / E975	1 710
Burnt resin	116	581 / E972	1 840
Outer shell of packaging	112	777 / E1249	1 830

C7.2.	**NCT**	**HAC**	
	temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Pu bar	174	248 / E453	15 010
E4 spacer	168	2481 El 161	15 010
TN90 - Shell	143	229 / E1261	11 010
E2 spacer	132	225 / El 158	8 010
E1 spacer	129	225 / El 152	7 010
Inner shell of packaging	118	234 / E1256	4 510
Resin	115	355 / E975	1 710
Burnt resin	98	572 / E972	1 840
Outer shell of packaging	96	776 / E1249	1 830

C7.3.	**NCT**	**HAC**	
	temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Pu bar	204	1020	
E4 spacer	198	453	
TN90 - Shell	167	1261	
E2 spacer	152	1158	
E1 spacer	148	1152	
Inner shell of packaging	134	1256	
Resin	130	975	
Burnt resin	108	972	
Outer shell of packaging	104	1249	

The results indicated in the different tables allow us to conclude that model C7.1 is the most detrimental case (the smallest exchange height and the maximum radius)

4.5 TNBGC1 packaging loaded with type C8 packing

4.5.1 Hypotheses and modelling

Half of the plate and E5 spacer was modelled (only 1/8 of the cross-section was modelled). The meshing is indicated in figure 44 and corresponds to a 3D model (for reasons of symmetry). We take a conservative position and consider that the plates are in contact with their packing.

4.5.2 Internal power

We consider the case of 6 stacks of plates with an effective height of 100 mm. The power to enter depends on the number of stacks and angle α (45°).

$$P' = \frac{P}{\frac{360}{\alpha}.6.2} \text{ with } P = 150\,W$$

$$P' = 1.5625\,W$$

4.5.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for model C8 are summarised in the table below.

The isotherms for normal conditions are indicated in figure 45.

The isotherms for accident conditions (end of fire t = 1830s) are presented in figure 46. A chart showing how temperature varies over time is indicated in figure 47.

C8.	**NCT**	**HAC**		
	Maximum temperature	**Maximum temperature (°C) / element**		**time (s)**
Plates	164	245 /	E1019	14 010
E5 spacer	142	223 /	E2514	14 010
TN90 - Shell	116	207 /	E2938	11 010
E2 spacer	108	205 /	E2932	8 010
E1 spacer	106	205 /	E2024	8 010
Inner shell of packaging	100	212 /	E2120	5 010
Resin	98	326 /	E2908	1 710
Burnt resin	88	537 /	E2905	1 850
Outer shell of packaging	86	748 /	E2095	1 830

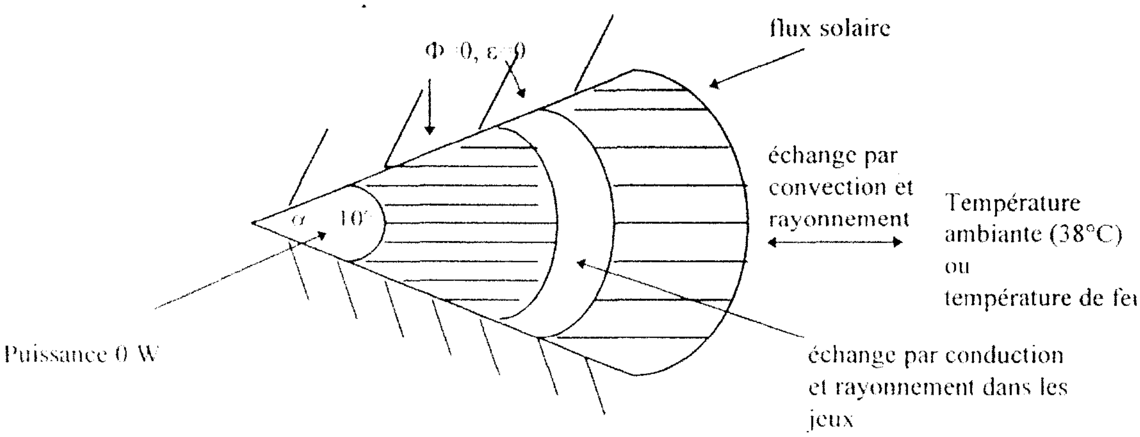
4.6 TNBGCI packaging loaded with type C5 and C11 packing

4.6.1 Hypotheses and modelling

For these two models, the coefficient of exchange via convection results from the experiment and is equal to: 2.3 ΔT0.33 [8].

- For model C5, two contents were studied: uranyl nitrate (C5.A) and UO2 powder (C5.B).
- For model C11, two contents were studied: uranium metal (C11.A) and uranium metal oxide (C11.B).

The contents of packing bottles C5 and C11 releases a negligible power. Part of a section (10°) measuring 1 mm in thickness was modelled (see diagram 2, figure 48 and figure 55). The insulating spacer E3 was not modelled because it is mainly made up of empty space and insulating material.



Flux solaire	Solar flux
Échange par convection et rayonnement	Exchange via convection and radiation
Température ambiante (38°) ou température de feu	Ambient temperature (38°) or fire temperature
Echange par conduction et rayonnement dans les jeux	Exchange via conduction and radiation in the spaces
Puissance 0 W	Power 0 W

Diagram 2: Thermal threshold conditions of the models C5 and C11

4.6.2 Internal power

We consider the case of 6 stacks of plates with an effective height of 100 mm. The power to enter depends on the number of stacks and the angle a (45°).

4.6.3 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for models C5 and C11 are summarised in the following tables.

The isotherms for normal conditions are indicated in figure 49 for C5.A, figure 52 for C5.B and figure 56 for C11.B.

The isotherms in accident conditions (end of fire t = 1830s) are presented in figure 50 for C5.A, figure 53 for C5.B and figure 57 for C11.B. Charts showing how temperature varies over time are indicated in figure 51 for C5.A, figure 54 for C5.B and figure 58 for C11.B. As the results of model C11.A were similar to those of model C11.B, the isotherms and variation charts for model C11.A are not presented.

C5.A	**NCT**	**HAC**

	Maximum temperature (°C)	**maximum temperature (°C) / element**	**time (s)**
Uranyl nitrate	55	97 /E86	26 010
LDPE bottle	55	97 / E193	23 010
P2 basket	55	103 / E206	8 010
TN90 - Shell	55	126 / E200	7 010
Inner shell of packaging	59	241/ E196	4 410
Resin	59	376 / E56	1 890
Burnt resin	59	533 / E53	1 510
Outer shell of packaging	59	772 / E115	1 830

C5.B	**NCT**	**HAC**	
	Maximum temperature (°C)	**maximum temperature (°C) / element**	**time (s)**
UO_2 powder	45	147 /E86	17 010
HDPE bottle	45	147 / E193	17 010
P2 basket	46	147 / E206	16 010
TN90 - Shell	47	148 / E200	14 010
Inner shell of packaging	57	240/ E196	14 010
Resin	58	376 / E56	1 900
Burnt resin	58	533 / E53	1 510
Outer shell of packaging	58	772 / E115	1 830.

C11.A	**NCT**	**HAC**	
	Maximum temperature	**Maximum temperature (°C)/ element**	**time (s)**
Uraniferous material (U metal)	41	115 /E86	25 010
LDPE bottle	41	115 / E193	24 310
Tinplate can	48	117 / E206	22 810
TN90 - Shell	48	157 / E200	6 910
Inner shell of packaging	57	240/ E196	4 410
Resin	58	375 / E56	1 890
Burnt resin	58	533 / E53	1 510
Outer shell of packaging	58	772 / E115	1 830

C11.B	**NCT**	**HAC**	
	Maximum temperature	**Maximum temperature (°C) / element**	**time (s)**
Uraniferous material (UO_2 metal)	41.5	120 / E86	24 110
LDPE bottle	41.5	120 / E193	22 910
Tinplate can	42	120 / E206	21 210
TN90 - Shell	48	160 / E200	6 910
Inner shell of packaging	57.5	241 / E196	4 410
Resin	58	376 / E56	1 890
Burnt resin	58	533 / E53	1 510
Outer shell of packaging	58.5	772 / E115	1 830

The temperatures of models C5.B, C11.A and C11.B are very detrimental. Indeed, we created a 2D model and this implied an over-estimation of temperatures due to the absence of flux on the lower and upper sides.

4.7 TNBGC1 packaging loaded with type C9 packing

4.7.1 Hypotheses and modelling

The thermal threshold conditions are those indicated in diagram 1.

Given the different packing methods, 3 models (C9A, C9B and C9C) were created. The meshings are indicated in figure 59, figure 60 and figure 61.

For packing C9, there are different packing methods depending on the mass of plutoniferous matter (see chapter 3 of this safety dossier).

We have:

- $M \leq 3$ kg and 100 mm $< D \leq 119.5$ mm

- $M \leq 4$ kg and 36 mm $< D \leq 100$ mm
- $M > 4$ kg and $D < 36$ mm

in which M is the mass of plutoniferous matter and D is the inner diameter of the container in which the matter is packed.

We consider the following cases:

- M = 3 kg and Φ = 60 W (given a specific power of 20 W/kg).

We will study two cases: D= 119.5 mm (1) and D = 100 mm (2)

- M = 4 kg and Φ = 80 W

We will study two cases: D = 100 mm (3) and D = 36 mm (4)

- M = 7.5 kg and Φ = 150 W

We will study the case: D = 36 mm (5)

We calculate the exchange heights in the following manner:

$$P = \frac{M}{V} = \frac{M}{\pi . r^2 . H_{exchange}}$$

$$H_{exchange} = \frac{M}{\pi . r^2 . p}$$

in which r is the radius of the matter and p is the density of the matter.

$$P' = \frac{P}{\frac{360}{\alpha . H_{exchange}}} \quad with\ \alpha = 10°$$

thus:

(1) $H_{exchange}$= 13.5 mm; D =119.5 mm; P = 60 W
P' = 0.12346 W for 1 mm of height C9.C

(2) $H_{exchange}$ = 19.4 mm; D =100 mm; P = 60 W
P' = 0.08591 W for 1 mm of height

(3) $H_{exchange}$ = 25.8 mm; D =100 mm; P 80 W
P' = 0.08613 W for 1 mm of height C9.A

(4) $H_{exchange}$ = 199.5 mm; D = 36 mm; P = 80 W
P' = 0.01114 W for 1 mm of height C9.B

(5) $H_{exchange}$= 374.0 mm; D = 36 mm; P = 150 W
P' = 0.01114 W for 1 mm of height C9.B

We chose models (1), (3) and (4). Indeed, we observed that model (1) is more detrimental than model (2), owing to a higher linear power density. Model (4) covers the case of model (5). Therefore, there remain models (1),(3) and (4) to be studied for which we cannot provide an answer a priori.

Model (4) is a 2D model (see diagram 1). However, for models (1) and (3), a 3D model has to be produced, because the radial flow no longer predominates the axial flow, indeed r > $H_{exchange}$. The different meshings are indicated in figure 59, figure 60 and figure 61. The conditions at the thermal thresholds of the different models are those in diagram 1. For models (1) and (3), the exchange height of spacer E7 was modelled. There is one further radiation condition between the metal plutonium and the E7 spacer for model (3), and one radiation condition between the plutonium and the TN 90 for model (1), because the diameter of the E7 spacer is that of the TN90.

4.7.2 Results

The maximum temperatures noted in normal conditions of transport (NCT) and accident conditions of transport (HAC) for models C9 are summarised in the following tables.

The isotherms for normal conditions are indicated in figure 62, figure 65 and figure 68.

The isotherms for accident conditions (end of fire t = 1830s) are presented in figure 63, figure 66 and figure 69. Charts showing how temperature varies over time are indicated in figure 64, figure 67 and figure 70.

C9.A	**NCT**	**HAC**	
	Maximum temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Plutonium	127	226 / E483	10 010
E7 spacer	95	199 / E551	10 010
TN90 - Shell	91	195 / E564	9 010
E2 spacer	87	193 / E545	9 010
E1 spacer	86	193 / E539	8 010
Inner shell of packaging	83	201 / E559	4 610
Resin	82	335.5 / E429	1 710
Burnt resin	77.5	562 / E426	1 840
Outer shell of packaging	77	775 / E487	1 830

C9.B	**NCT**	**HAC**	
	Maximum temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Plutonium	225	304 / E146	14 010
E7 spacer	220	301 / E291	14 010
TN90 - Shell	201	285 / E307	12 010
E2 spacer	182	271 / E285	9 010
E1 spacer	176	268 / E279	8 010
Inner shell of packaging	158	271 / E302	4 510
Resin	152	378 / E83	1 710
Burnt resin	121	584 / E80	1 840
Outer shell of packaging	117	777 / E153	1 830

C9.C	NCT	**HAC**	
	Maximum temperature (°C)	**Maximum temperature (°C) / element**	**time (s)**
Plutonium	163	258/ E420	9 010
TN90 - Shell	116	222 / E564	8 010
E2 spacer	82	200 / E545	8 010
E1 spacer	81	199 / E539	8 010
Inner shell of packaging	79	202 / E559	5 010
Resin	78	334 / E365	1 710
Burnt resin	75	562 / E362	1 840
Outer shell of packaging	75	775 / E487	1 830

The results given in the previous three tables allow us to conclude that model C9.B is the most detrimental, i.e. H = 199.5 mm; D = 36 mm and P=80 W or H = 374 mm; D=36 mm and P= 150 W.

5. CONCLUSIONS

The results presented in the previous paragraphs demonstrate that the materials of the contents, interior installations and packaging are not forced beyond their maximum temperature of use.

6. REFERENCES

[1] IAEA ST-1 Safety Series - Regulations for the Safe Transport of Radioactive material 1996 edition

[2] Software for the calculation of finite elements: I-DEAS Master Series V4.0 developed by SDRC La Défense combined with TMG, the thermal analysis module

[3] TN-BGC1 Packaging - Packaging, whole concept plan: Plan 9990-65 ind. C. Packaging, assembled plug: Plan 9990-117 ind. B

[4] Heat transmission — WI-1 Mc Adams. Chapter VII

[5] I-DEAS - TMG Reference Manual.

[6] TN-BGC1 Packaging safety dossier - Chapter 2 and appendices, Chapter 6 and appendices.

[7] Archive note 3648-V-3, archive cartridge 3648-4 file: ie351554/THERMIQUE/viroleC10.arc ie351554/THERMIQUE/TNBGC1.arc

[8] Touloukian - Specific heat (volume 5 - p.190), (volume 4 - p. 167)

[9] New Treatise on Inorganic Chemistry - Paul PASCAL - Volume XV – third fascicle - Transuranium - Masson et Cie - p. 261, 262 - 1962.

[10] Handbook of Chemistry and Physics - David R. LIDE - 73 'e' edition - p. 13131 — 1992-1993.

[11] J. F Sacadura - Introduction to heat transfer - Lavoisier - p. 430 - p. 433 1983.

[12] J. Bost - Plastics - Volume 1 - Chemistry Applications - Techniques and Documentation - p. 219 - 1982.

[13] New Treatise on Inorganic Chemistry - Paul PASCAL - Volume XV – first fascicle - uranium - Masson et Cie - p. 290 - 1960.

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TABLE 1: CHARACTERISTICS OF PACKAGING MATERIALS

Items	Materials	λ (W/m.K)	Cp (J/kg.K)	Emissivity coefficient	absorptivity	p (kg/m^2)
1	Stainless steel	15	500	0.26 before fire 0.5 after fire	0;45	7850
2	Unburnt resin	0.66	1400	-	-	1330[(a)]
3	Burnt resin (thickness 13mm) (see fig.A6-3.3)	0.66 before fire 0.094[(b)] end of fire (λe)	1400	-	-	1000[(c)]
4	Polyethylene	0.42	1800	-	-	920
5	Poplar (lower part) (see fig. A6-3.4)	0.95 before fire 0.95 end of fire (1830s) 0.03[(d)] end of fire (1860s)	2102 before fire 1000[(c)] end of fire (Cp air)	-	-	360
6	Poplar (upper part) (see fig. A6-3.5)	1.3 before fire 1.3 end of fire (1830s) 0.03[(d)] end of fire (1860s)	2102 before fire 1000[(c)] end of fire (Cp air)	-	-	360

(a) Conservative value, the minimum guaranteed is 1600 kg/m^3
(b) λe deducted from the measurements taken after the fire between the inner and outer shell (λ_o = 0.29) based on:

$$\lambda_0 = \frac{\lambda i.\lambda e.1n\left(\frac{\mathrm{Re}}{Ri}\right)}{\lambda i.1n\left(\frac{\mathrm{Re}}{R'}\right) + \lambda e.1n\left(\frac{R'}{Ri}\right)}$$

with Re: outer radius, Ri: inner radius and Re-R' = thickness of burnt resin.

(c) Value obtained by benchmarking with tests
(d) Based on $\lambda air = 0.025 + 6.86{,}10^{-5}.T$ with T in °C.

TABLE 2:

REPORT ON PACKAGING TEMPERATURES MEASURED DURING THE FIRE TEST AND THOSE DETERMINED FROM THE FINITE ELEMENTS MODEL (THE CASE OF ZERO INTERNAL POWER)

Packaging element	Temperatures (°C)		
	Test	Finite Elements Model	
		Test condition	Accident conditions P = 0 W
Seal	132	131	172
Inner side of lid	132	131	171
Outer shell	1020	778	780
Inner shell	176	176	220
Base(1)	210	211	251

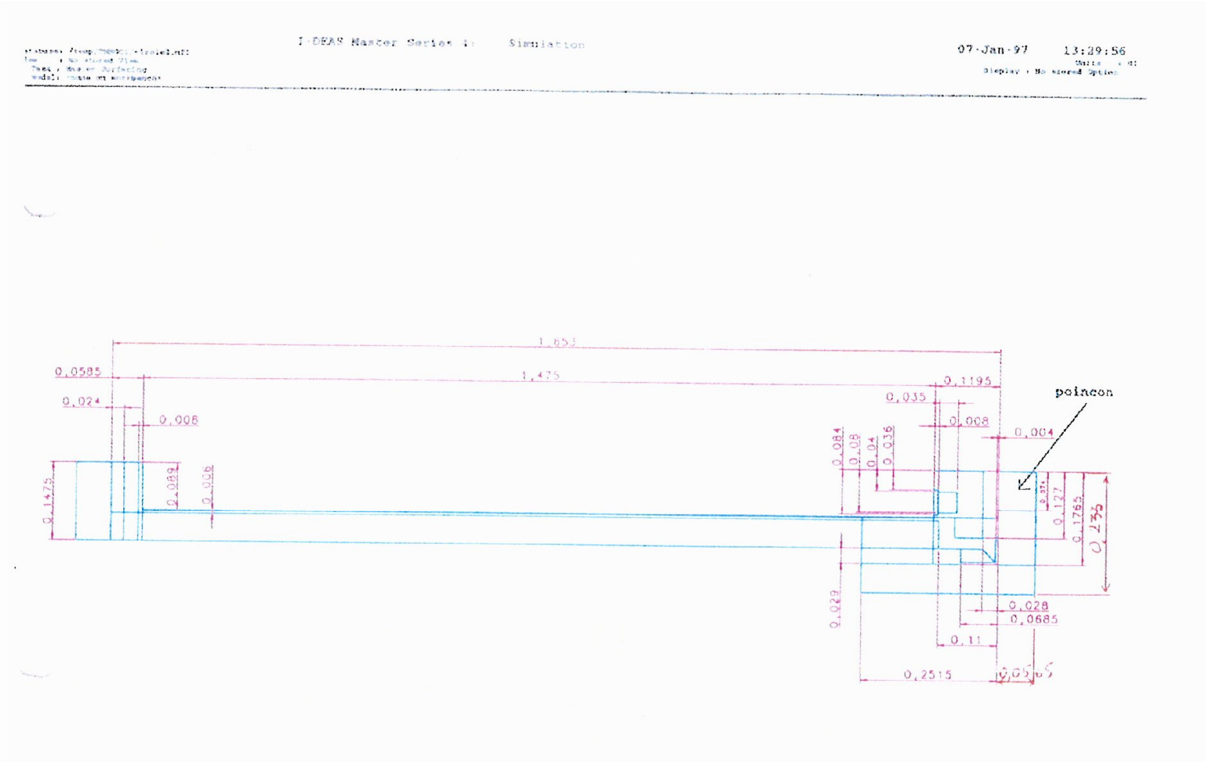
(1)Contact temperature between the resin and casing.

TABLE 3:
CHARACTERISTICS OF THE MATERIAL MAKING UP THE INTERNAL INSTALLATIONS AND CONTENTS

Materials	Conductivity λ (W/m.K)	Specific heat Cp (J/kg.K)	Emissivity coefficient	Density ρ (kg/m^2)
PuO_2 powder	0.07 + 0.375.10^{-3}x T (°C)	251.2 (2)		1 700 (8) 3 500 (1)
Metal plutonium	6.74 (4)	146.55 (2)	0.5 (8)	19 700 (4)
Aluminium	134 (1)	962 (1)	0.55 (1)	2 700 (4)
Uranyl nitrate	0.685 (5)	4250 (5)		945.3 (5)
Air	0.025 + 6.86.10^{-5} x T (°C)	1 000 (5)		1 (5)
LDPE bottle	0.3344 (6)	2 299 (6)	0.92 (9)	920 (6)
HDPE bottle	0.389 (6)	1 881 (6)	0.92 (9)	930 (6)
U metal	27.6 (4)	114.9 (0°C) (7) 118.3 (50°C) 122 (100°C) 126.3 (150°C)	-	19 100 (4)
UO_2 metal	7.315 (3)	236.9 (270C) (3) 262.9 (100°C) 281.8 (200°C)	-	8 000 (3)
UO_2 powder	7.315 (3)	234.1 (270C) (2) 259.2 (127°C) 288.5 (227°C)	-	3 500 (1)

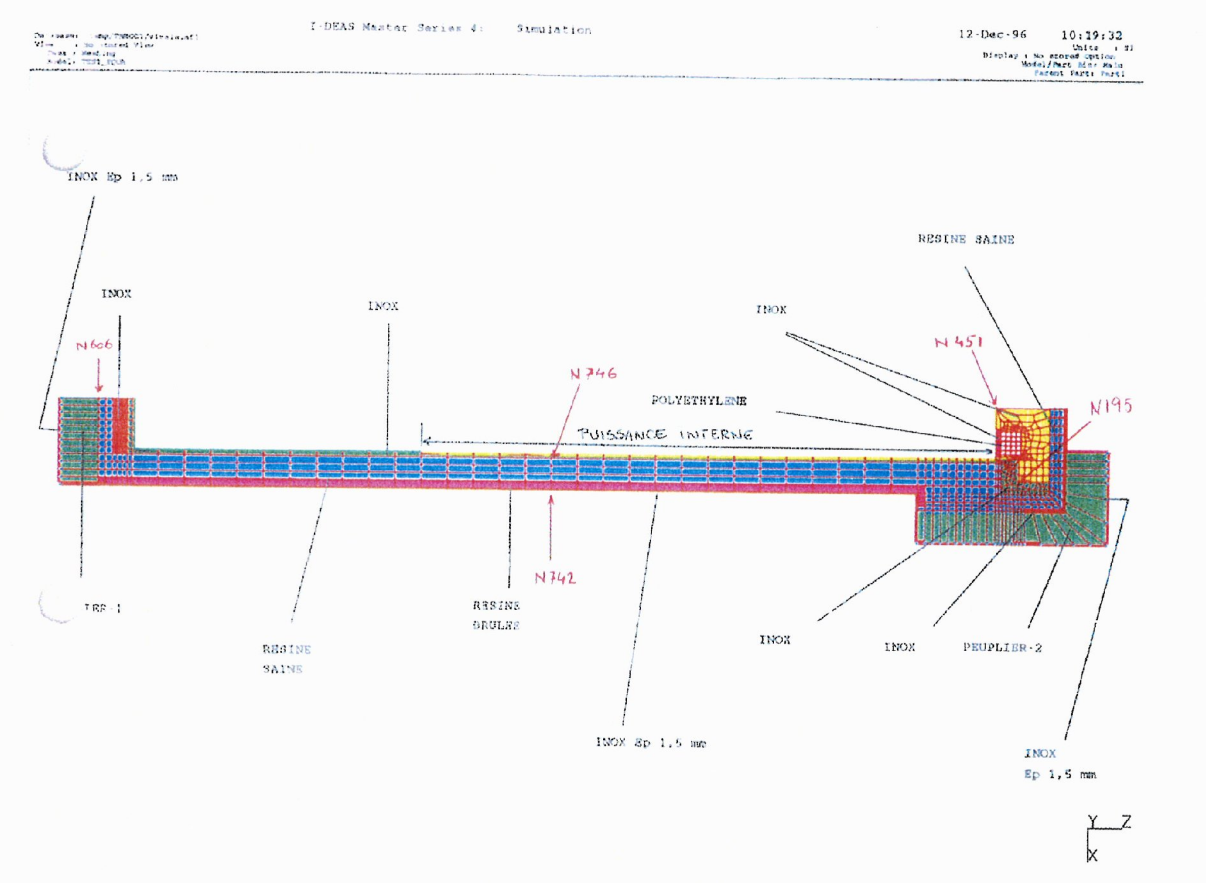
(I) Value from chapter 3
(2) Value from the reference [8]
(3) Value from the reference [9]
(4) Value from the reference [10]
(5) Value corresponding to that of water in the case of the uranyl nitrate from the reference [11]
(6) Value from the reference [12]
(7) Value from the reference [13]
(8) Average value
(9) Value from the reference [11]
* melting point at 108°C LDPE [12]
* melting point at I30°C HDPE [12]

FIGURE 1:
MODEL GEOMETRY



poinçon	punch

FIGURE 2:
MESHING OF FINITE ELEMENTS MODEL



INOX Ep 1,5 mm	1.5 mm stainless steel
INOX	Stainless steel
POLYETHYLENE	Polyethylene
PUISSANCE INTERNE	Internal power
RESINE SAINE	Sound resin
RESINE BRULEE	Burnt resin
PEUPLIER – 2	Poplar -2

FIGURE 3:
THERMAL CONDUCTIVITY OF BURNT RESIN

ρ = 1000 kg / m^3
Cp = 1400 J / kg.K

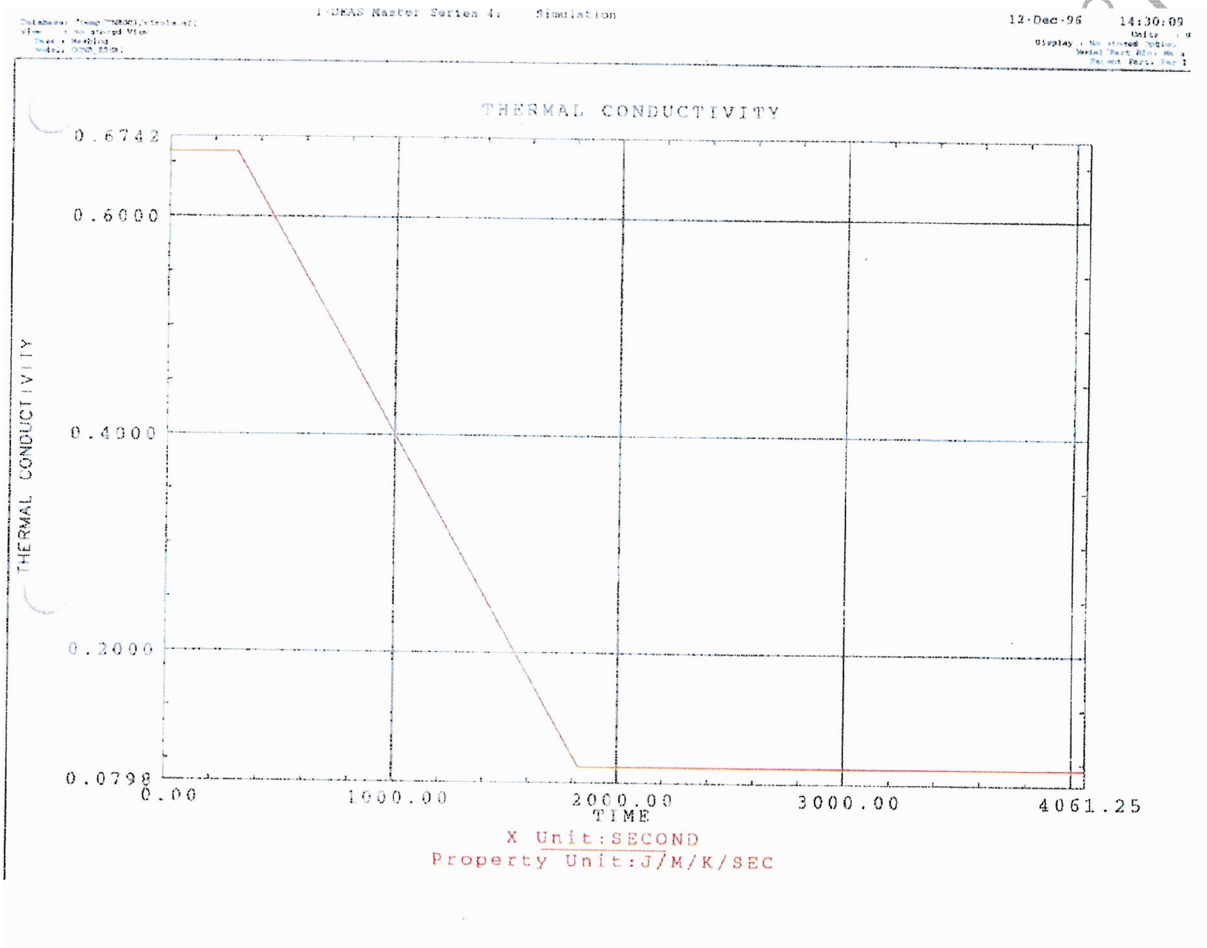


FIGURE 4:
THERMAL CHARACTERISTICS OF POPLAR (BASE)

$\rho = 360\ kg / m^3$

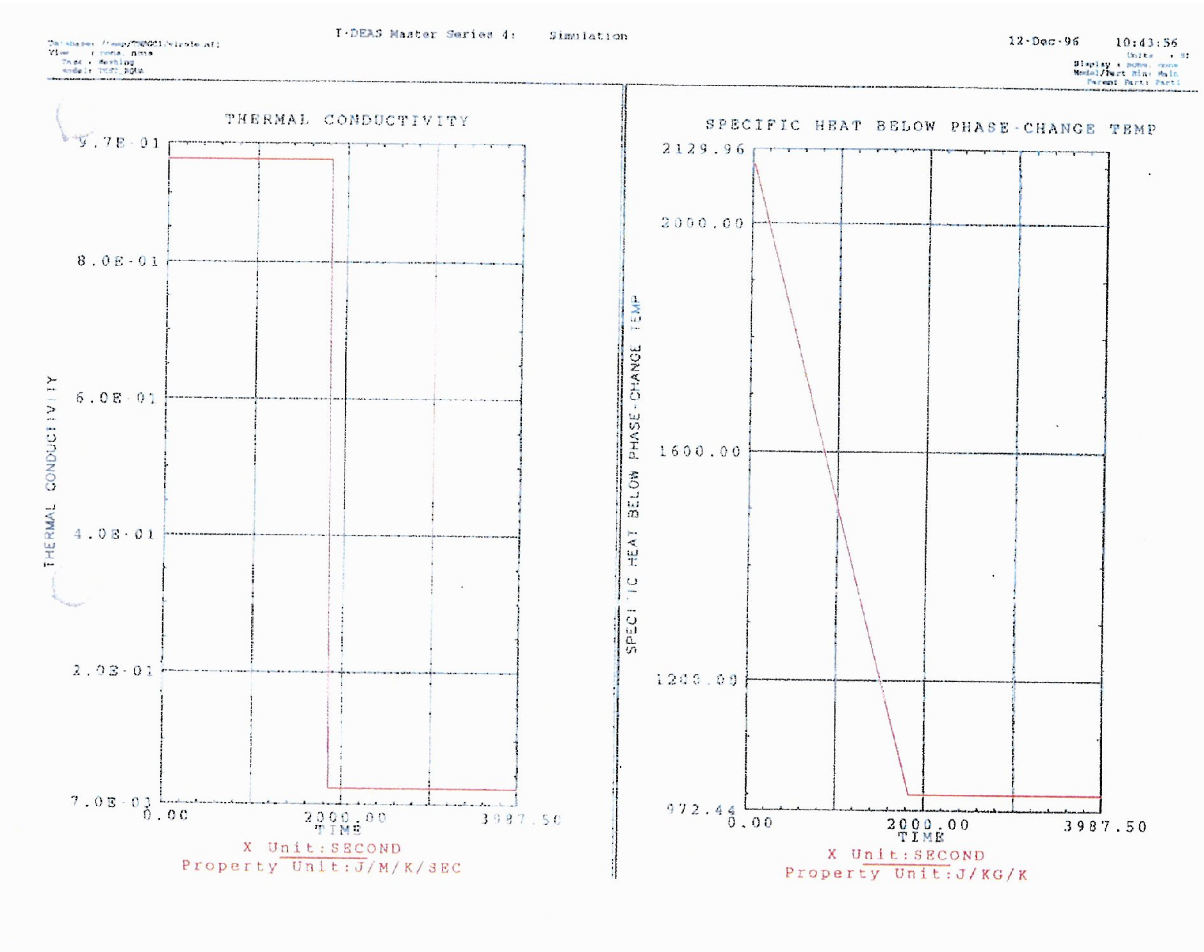


FIGURE 5:
THERMAL CHARACTERISTICS OF POPLAR (PLUG)

ρ = 360 kg / m³

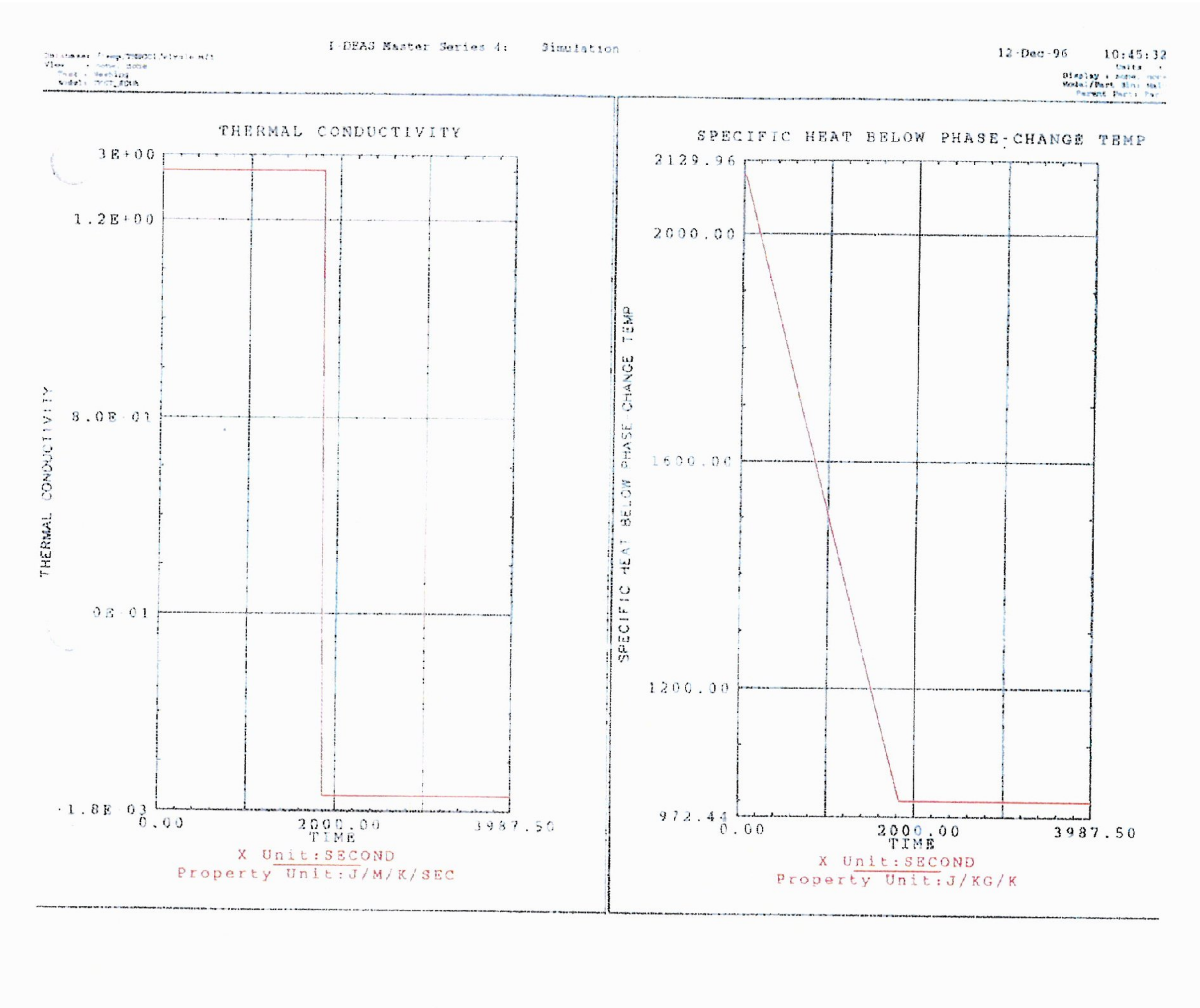


FIGURE 6:
ISOTHERMS OF PACKAGING IN TEST CONDITIONS AT END OF FIRE (T = 1830S)

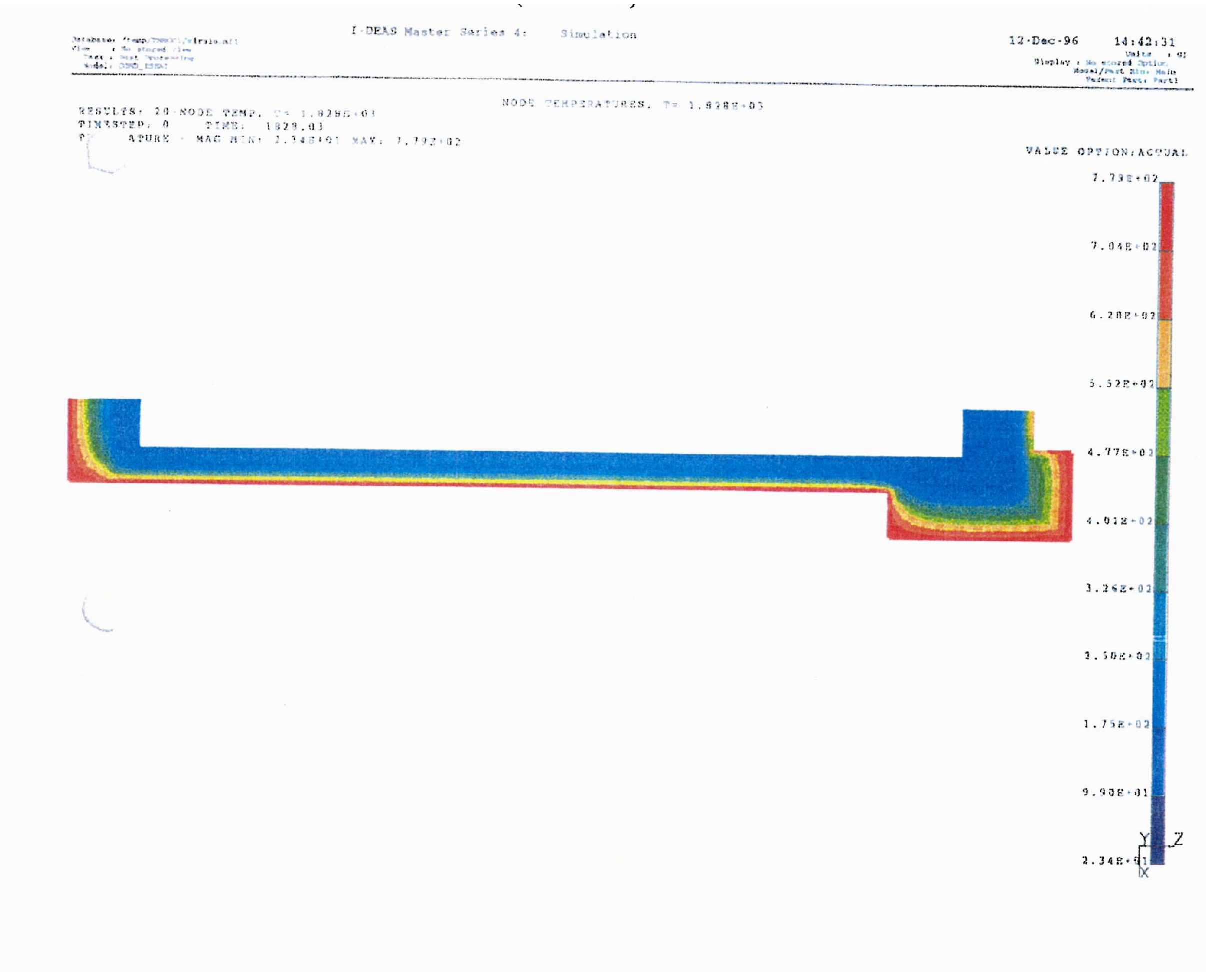


FIGURE 7:
CHART SHOWING HOW TEMPERATURE VARIES OVER TIME AT THE BASE OF THE SHELL (N606) AND AT THE TOP OF THE SHELL (N451) IN TEST CONDITIONS

BASE OF SHELL
T^{max} = 210.9°C
t = 1838 s

TOP OF SHELL
T^{max} = 130.9°C
t = 15690 s

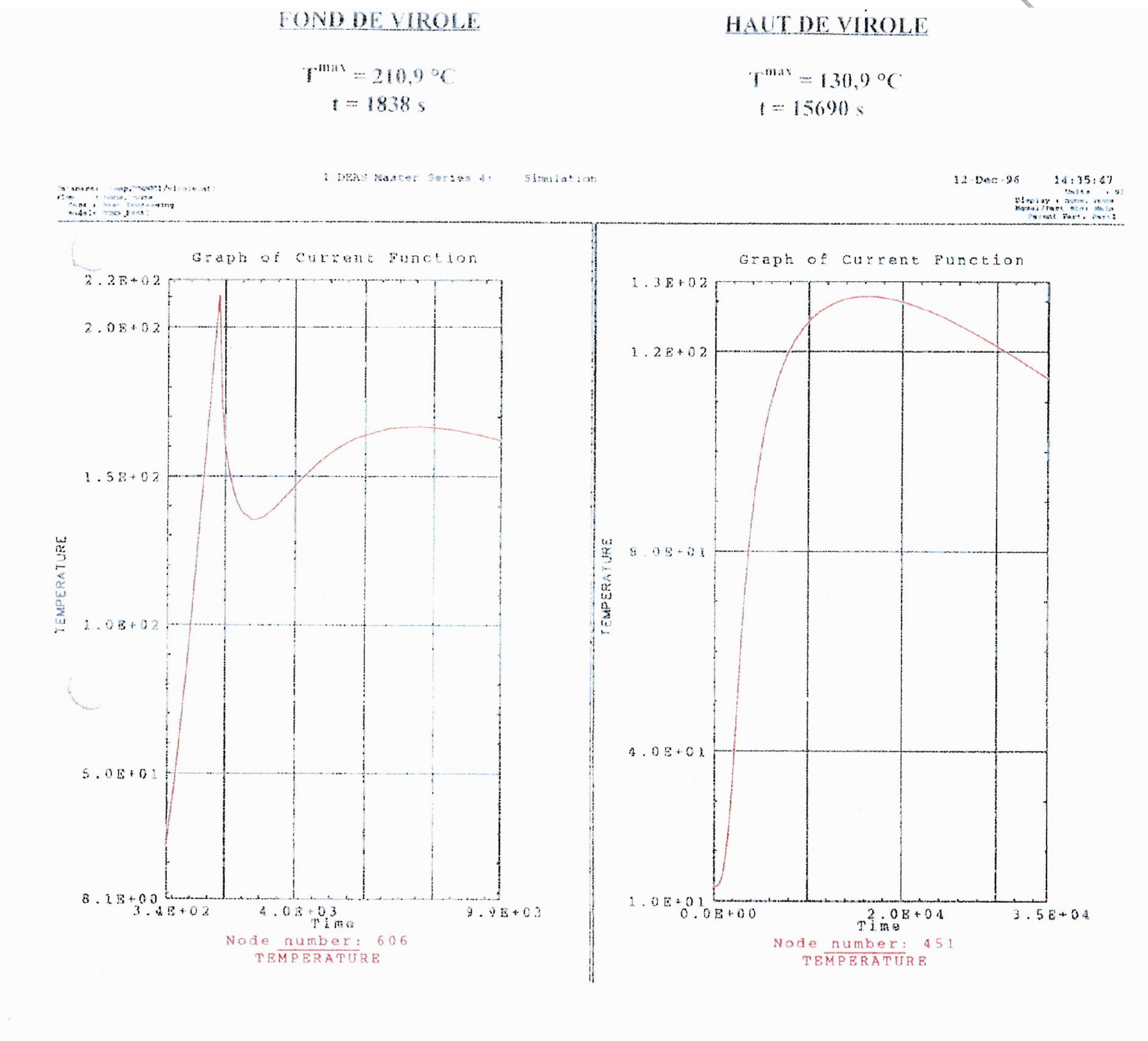


FIGURE 8:
CHART SHOWING HOW TEMPERATURE VARIES OVER TIME AT THE OUTER SHELL (N742) AND THE INNER SHELL (N746) IN TEST CONDITIONS

OUTER SHELL	INNER SHELL
T^{max} = 777.8°C	T^{max} = 176.0°C
t = 1828 s	t = 5810 s

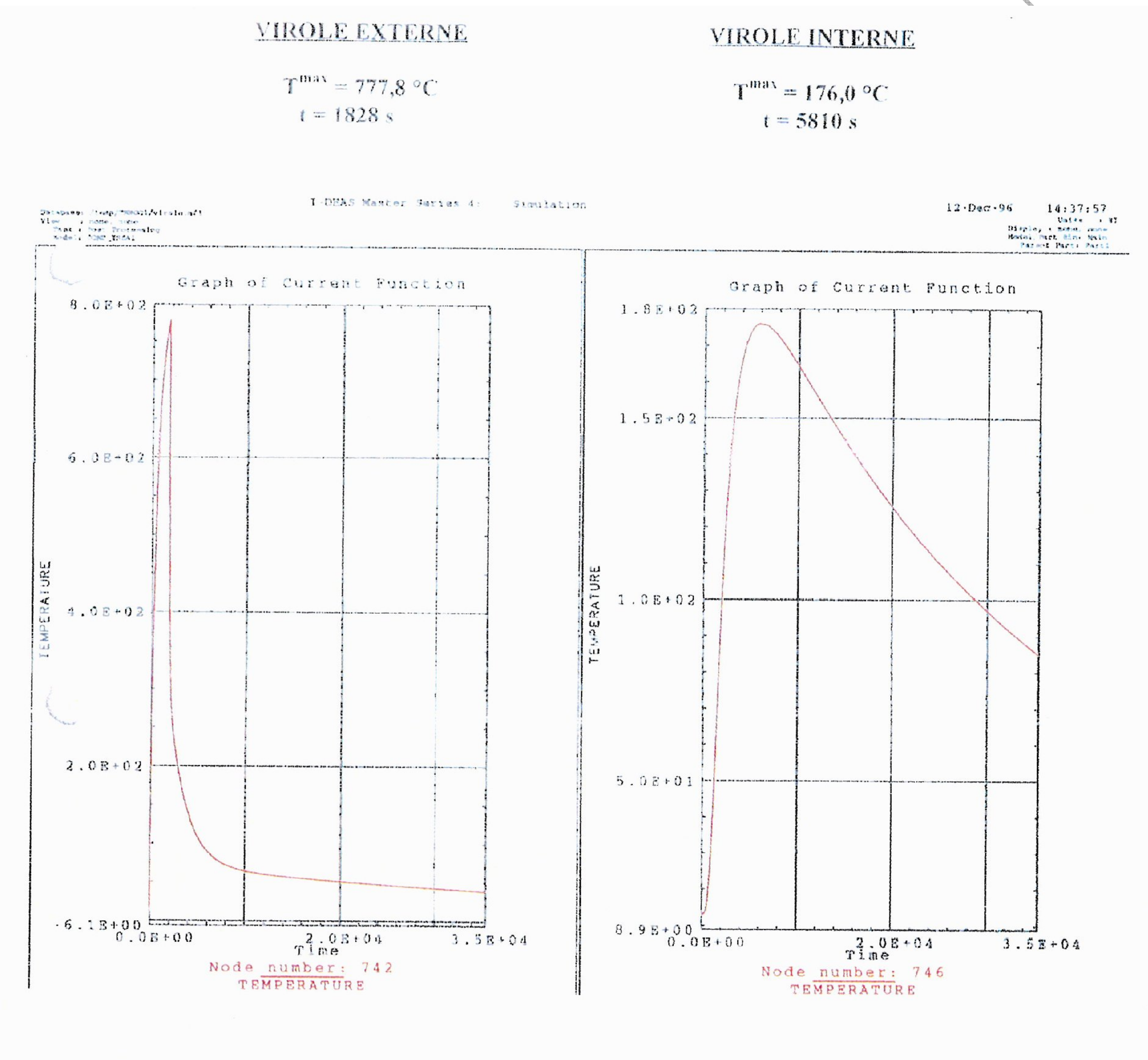


FIGURE 9:
GEOMETRY OF AXISYMETRIC MODEL C3

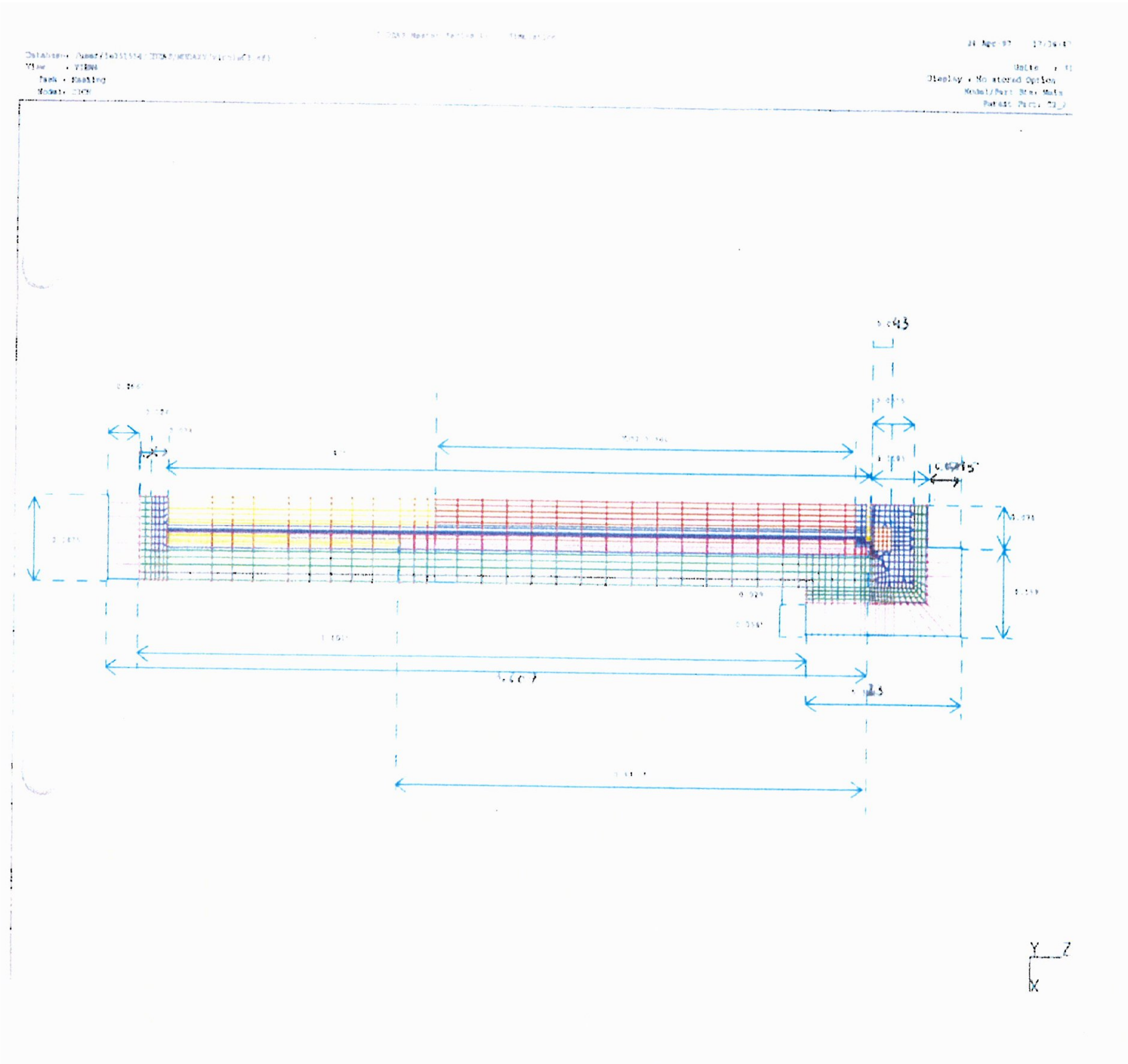
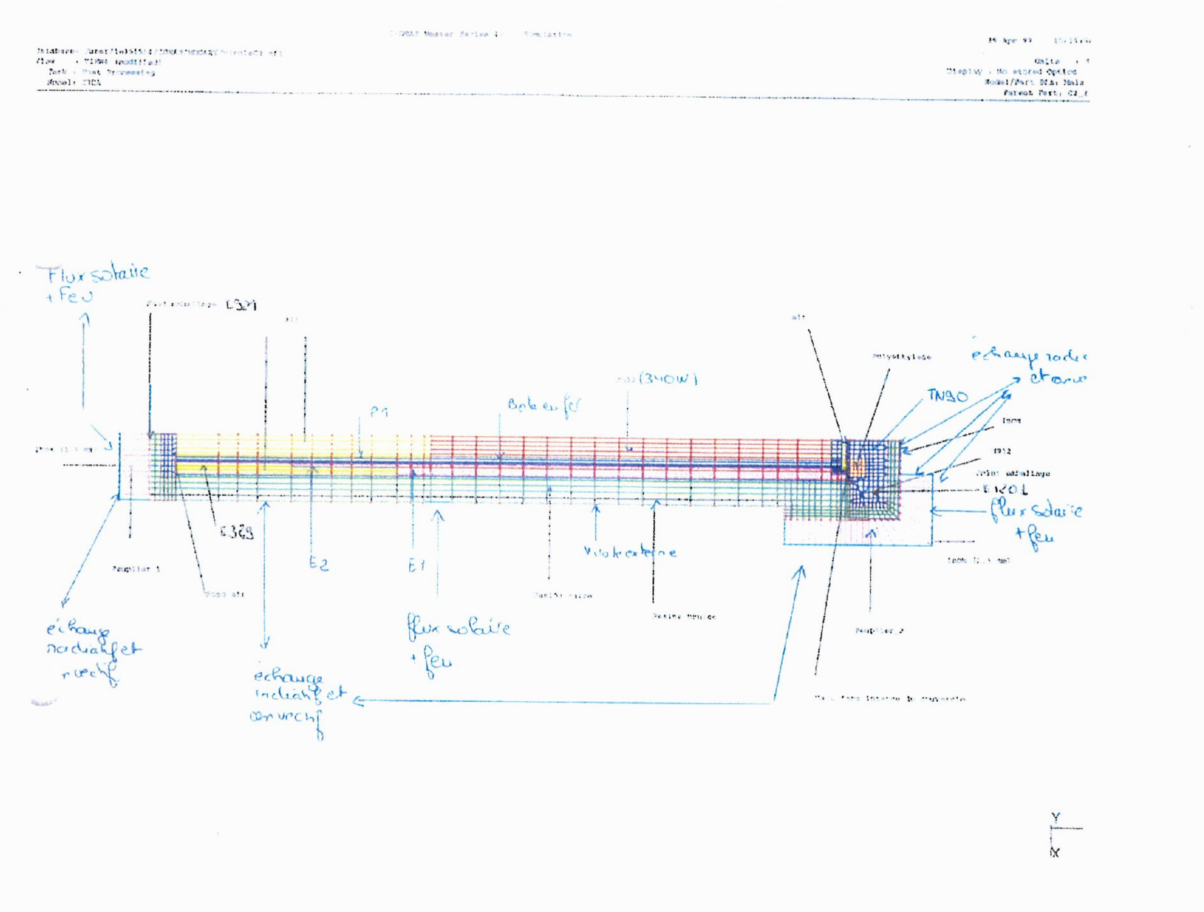
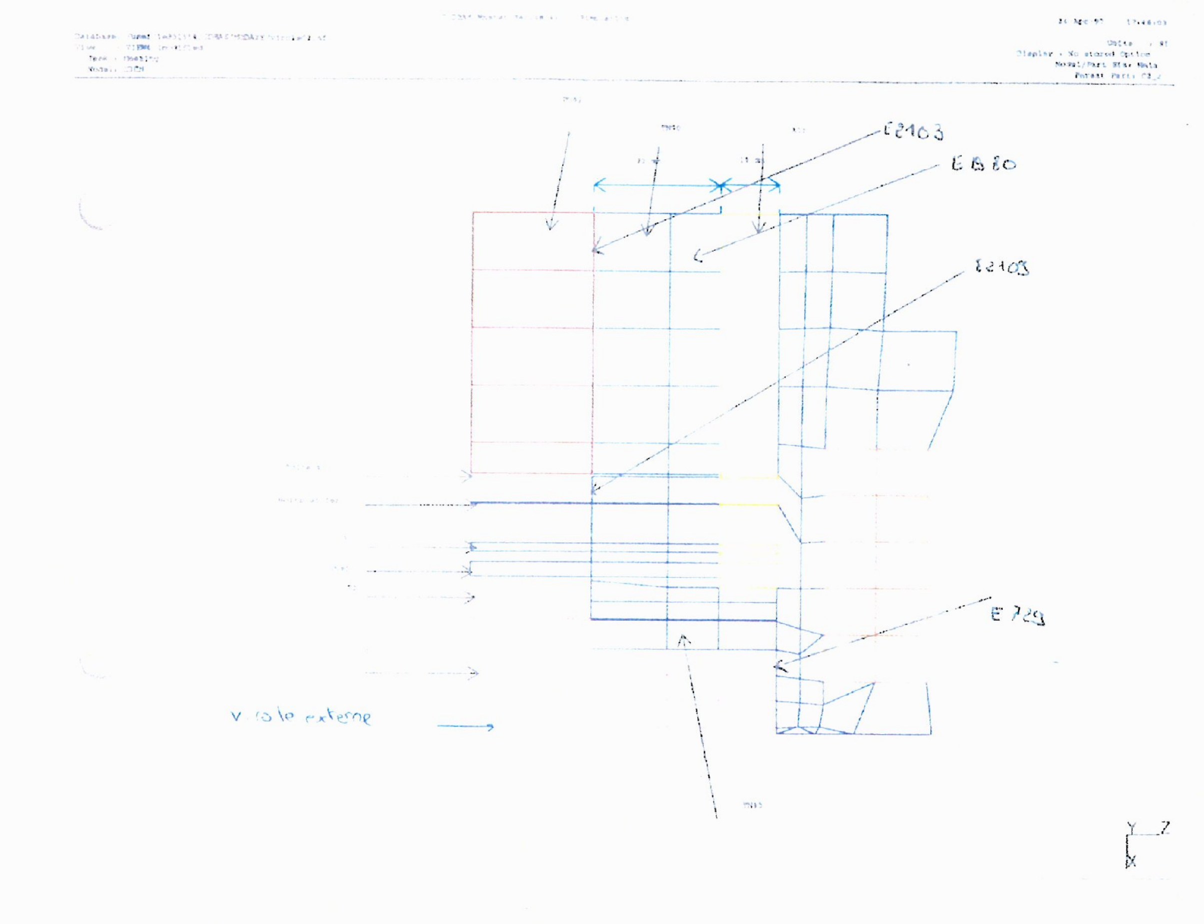


FIGURE 10:
MESHING OF AXISYMMETRIC MODEL C3



Flux solaire + feu	Solar flux + fire
échange radiatif et convectif	Radiative and convectional exchange
Boite en fer	Tin can
Virole externe	Outer shell

FIGURE 11:
MESHING OF AXISYMMETRIC MODEL C3 (TOP OF SHELL)



Virole externe	Outer shell

FIGURE 12:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN NORMAL CONDITIONS OF TRANSPORT

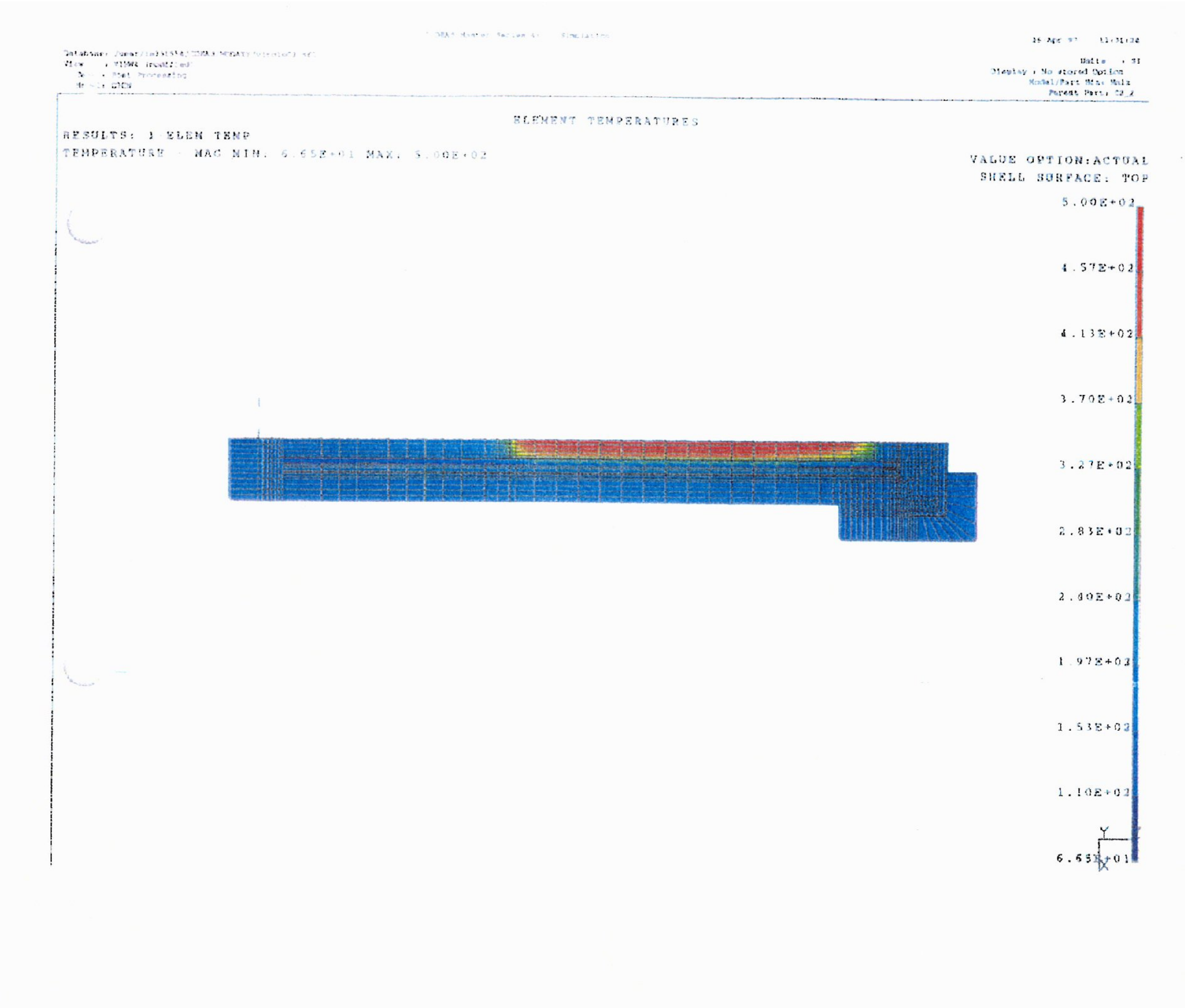


FIGURE 13:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN NORMAL CONDITIONS OF TRANSPORT (TOP OF SHELL)

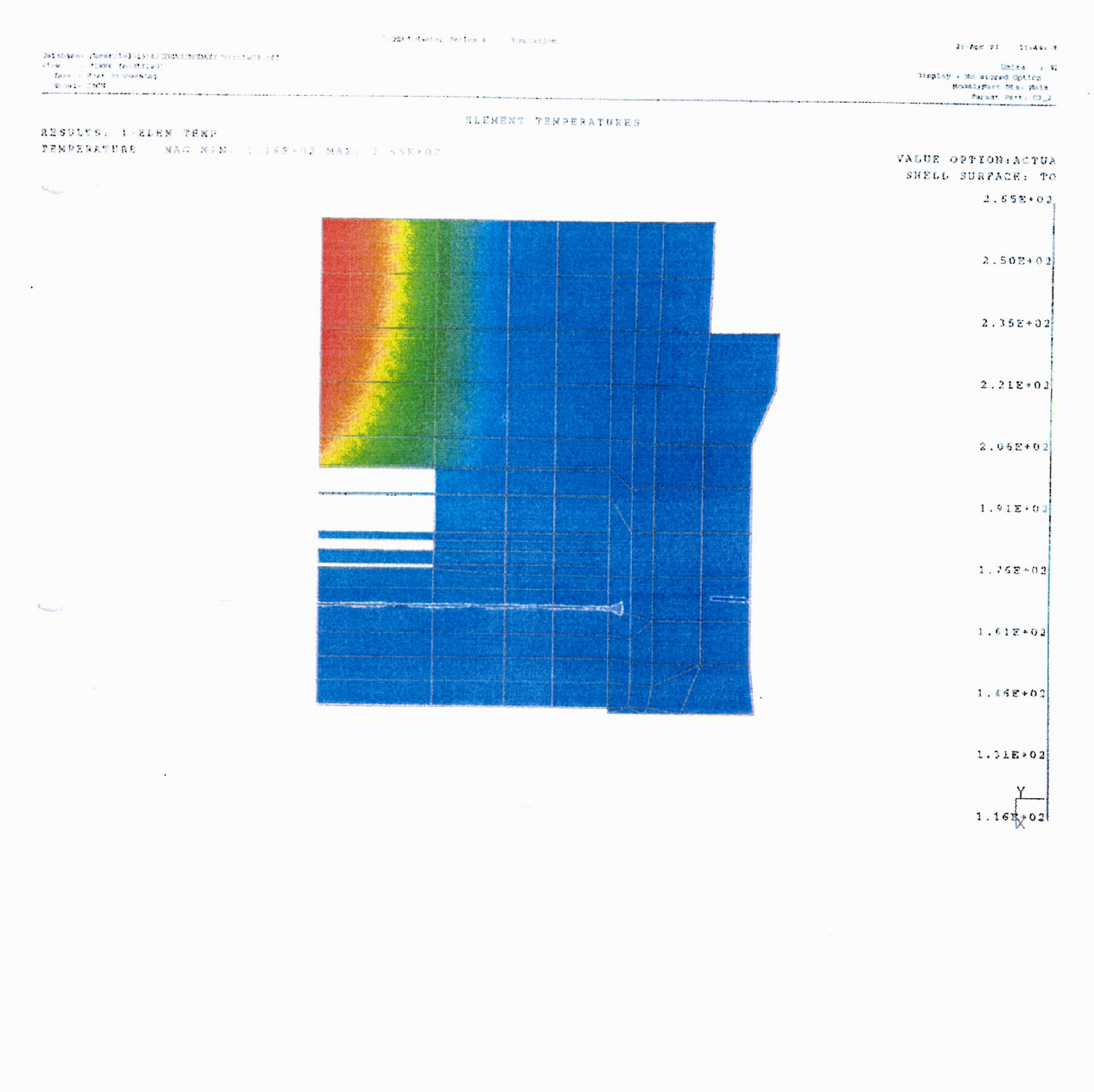


FIGURE 14:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN NORMAL CONDITIONS OF TRANSPORT (MAXIMUM TEMPERATURE)

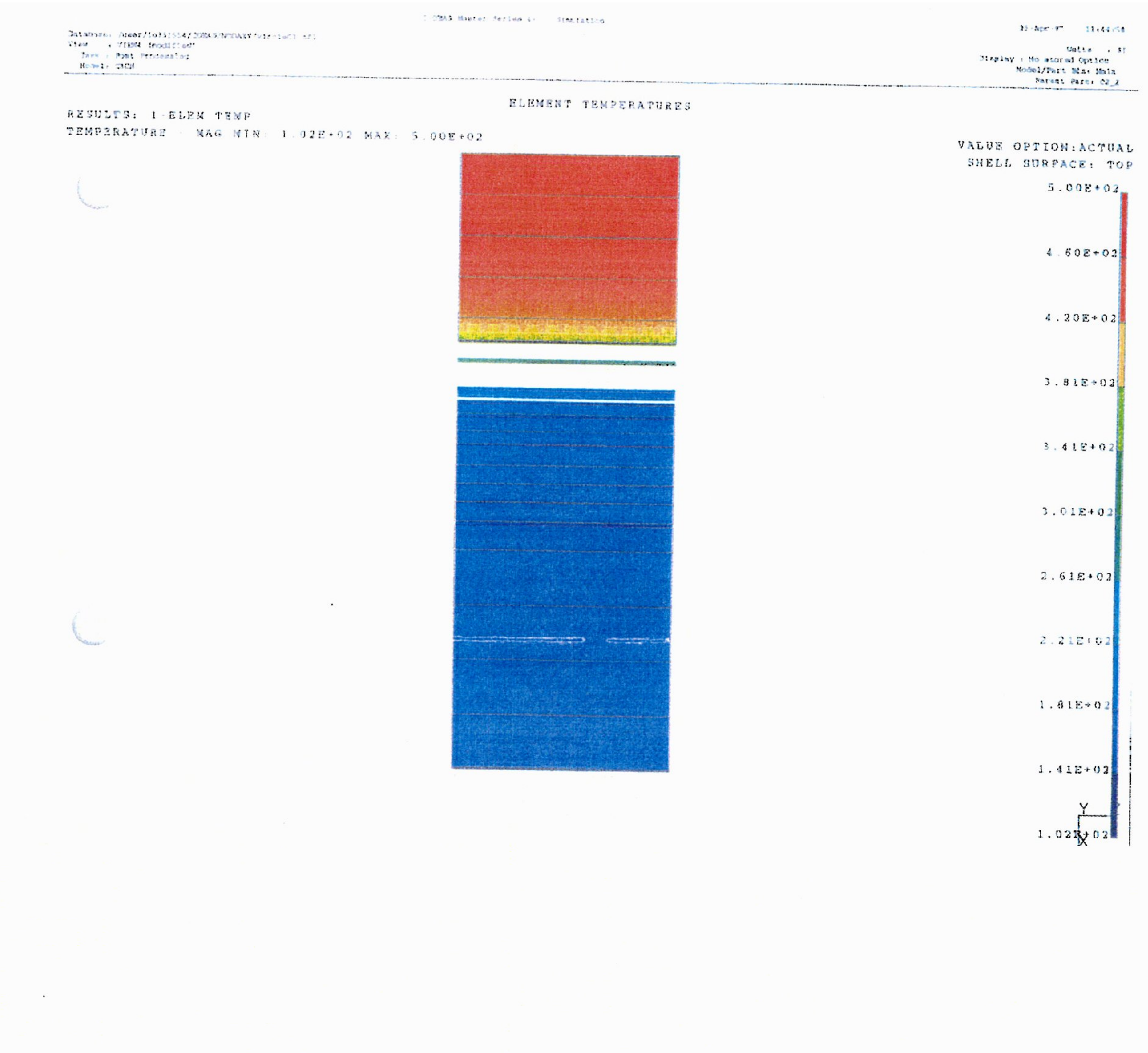


FIGURE 15:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S)

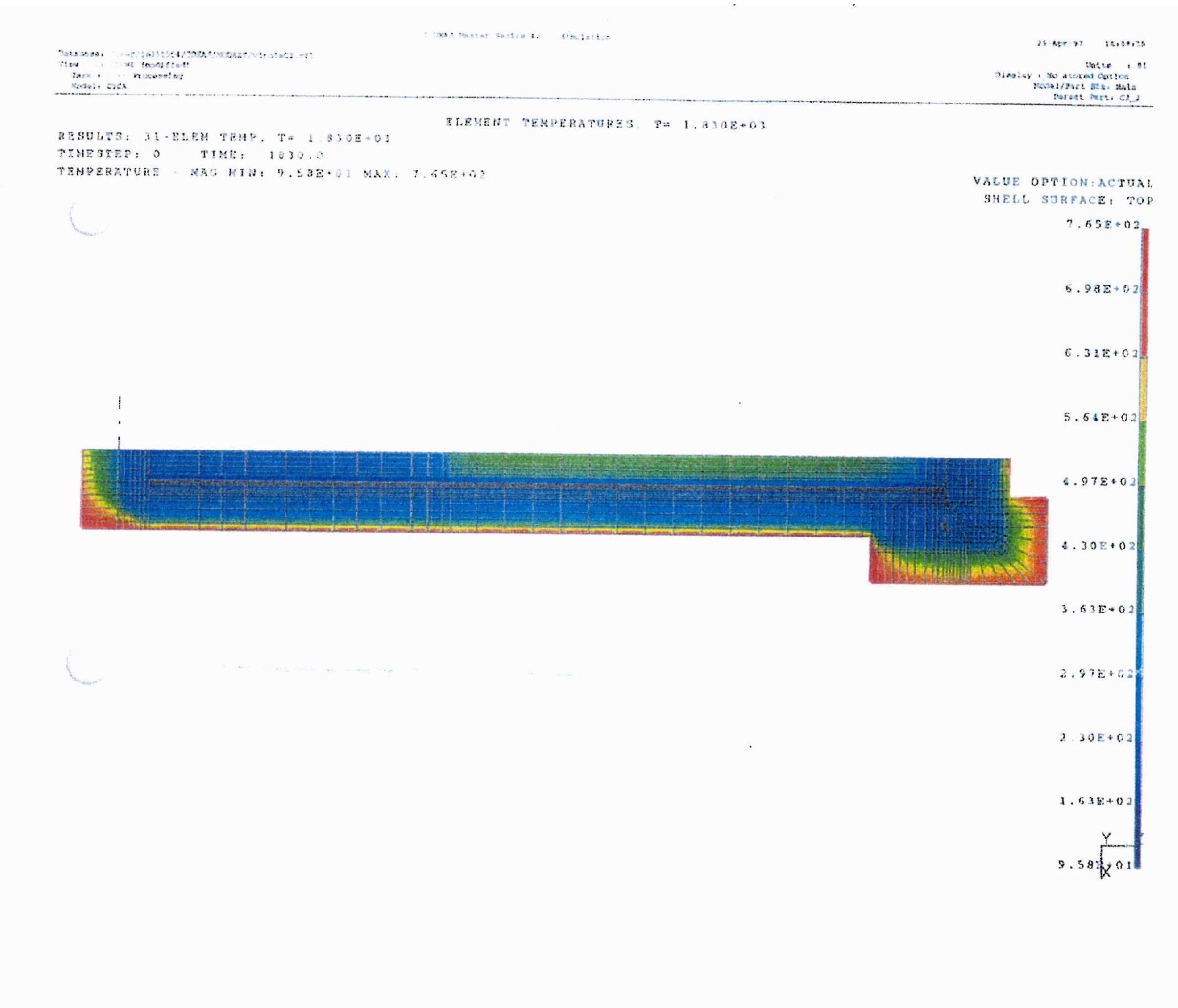


FIGURE 16:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S) (TOP OF SHELL)

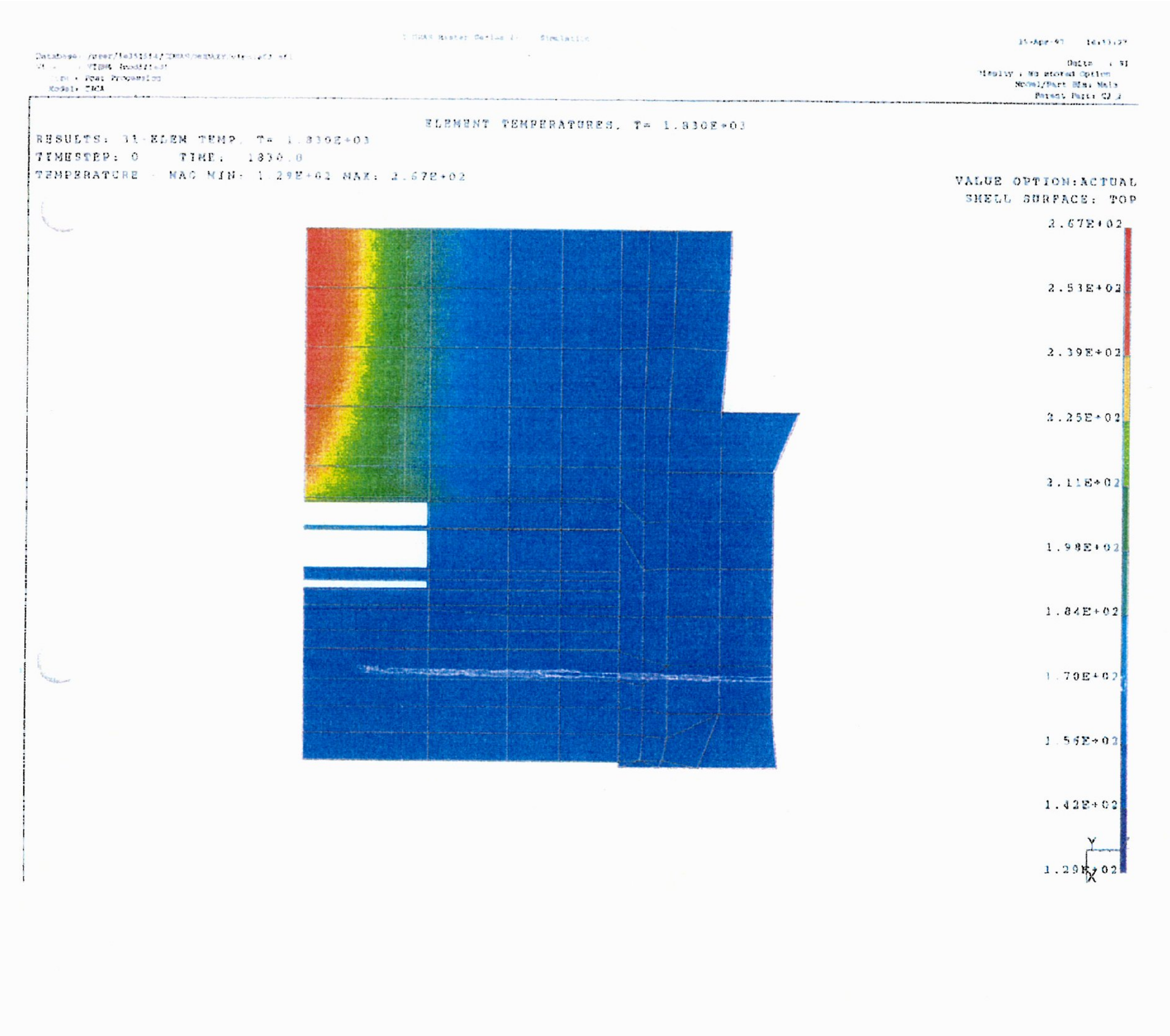


FIGURE 17°:
ISOTHERMS OF AXISYMMETRIC MODEL C3 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S) (MAXIMUM TEMPERATURE)

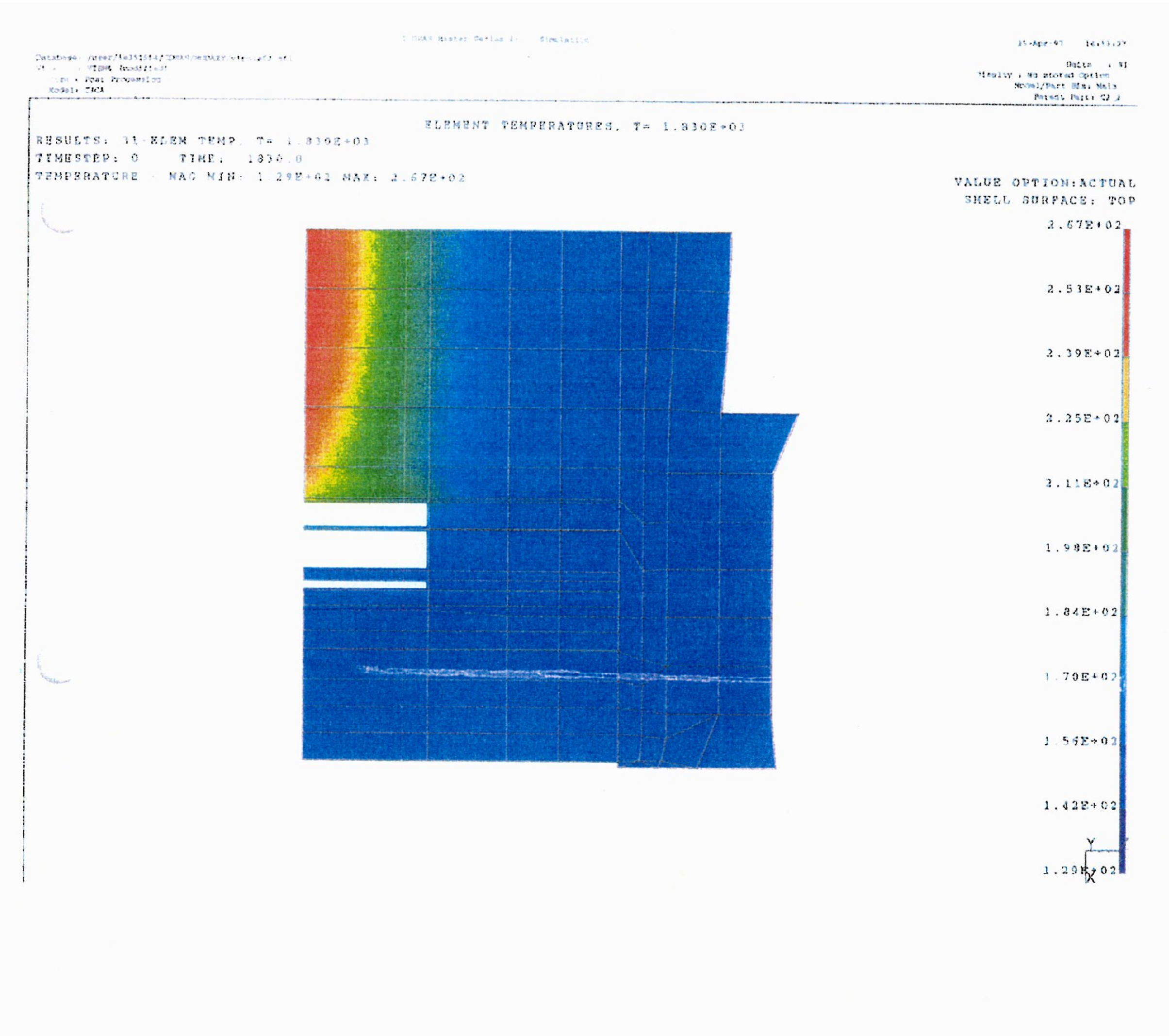


FIGURE 18:
CHART SHOWING HOW MAXIMUM TEMPERATURE VARIES OVER TIME FOR AXISYMMETRIC MODEL C3

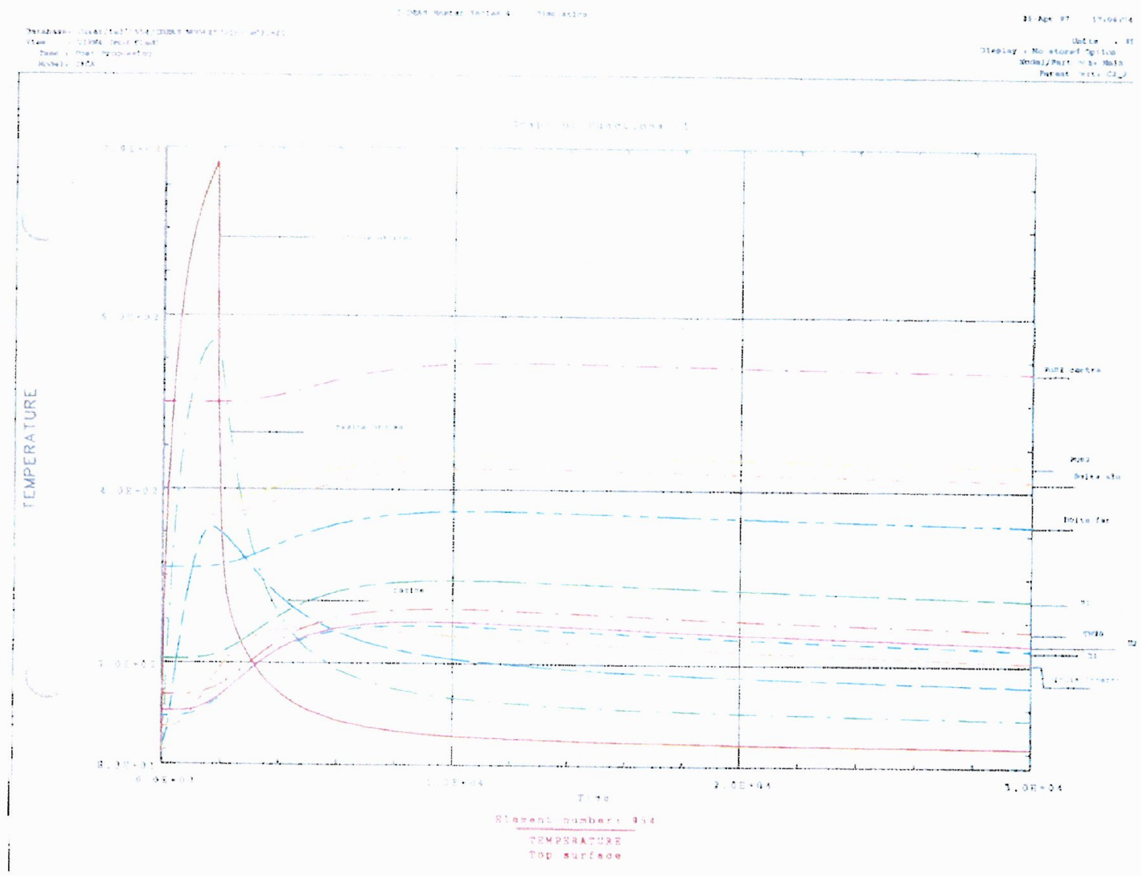


FIGURE 19:
CHART SHOWING HOW TEMPERATURE VARIES OVER TIME AT THE BASE AND TOP OF THE PACKAGING IN ACCIDENT CONDITIONS

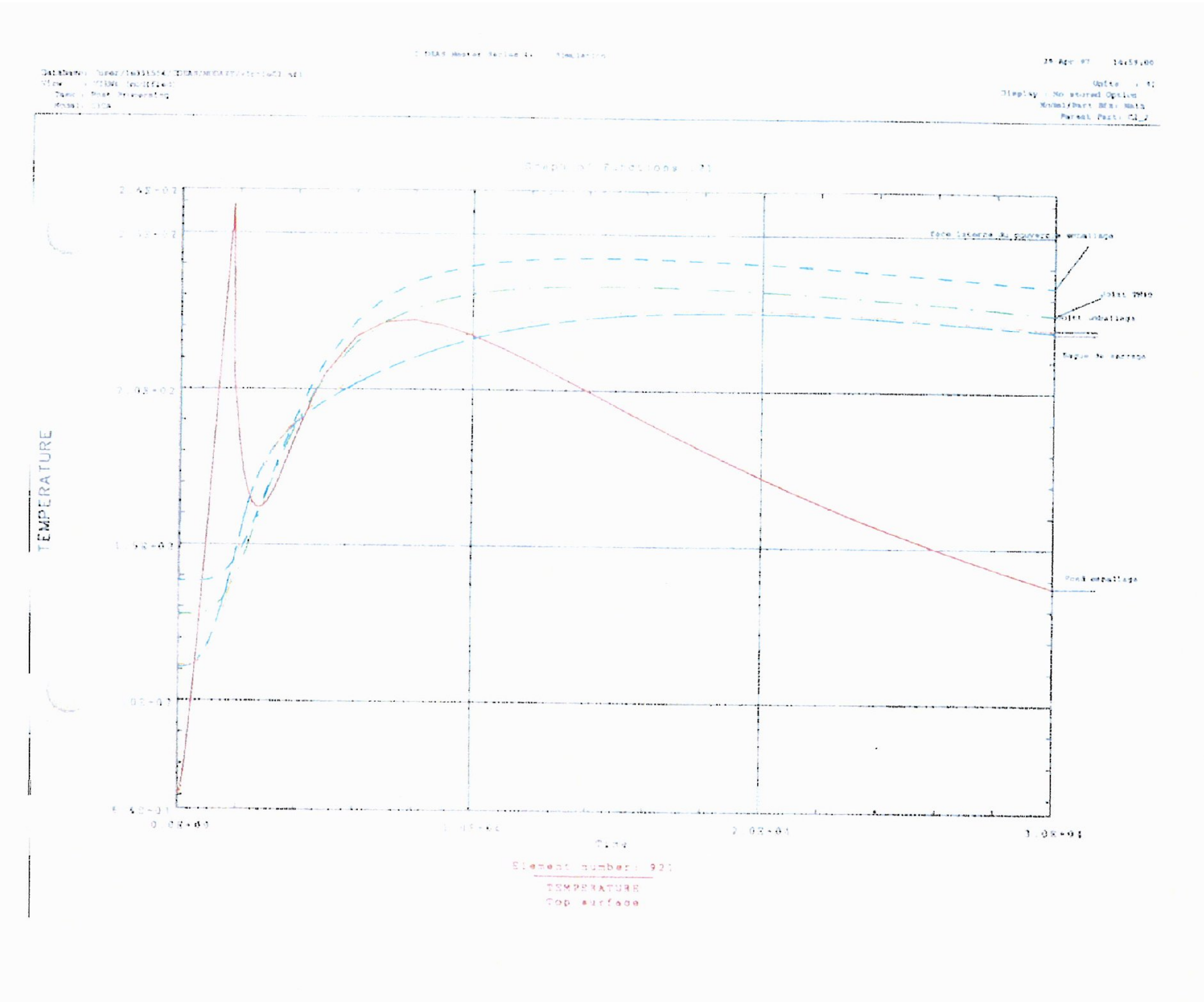


FIGURE 20: MESHING OF MODEL C2.1

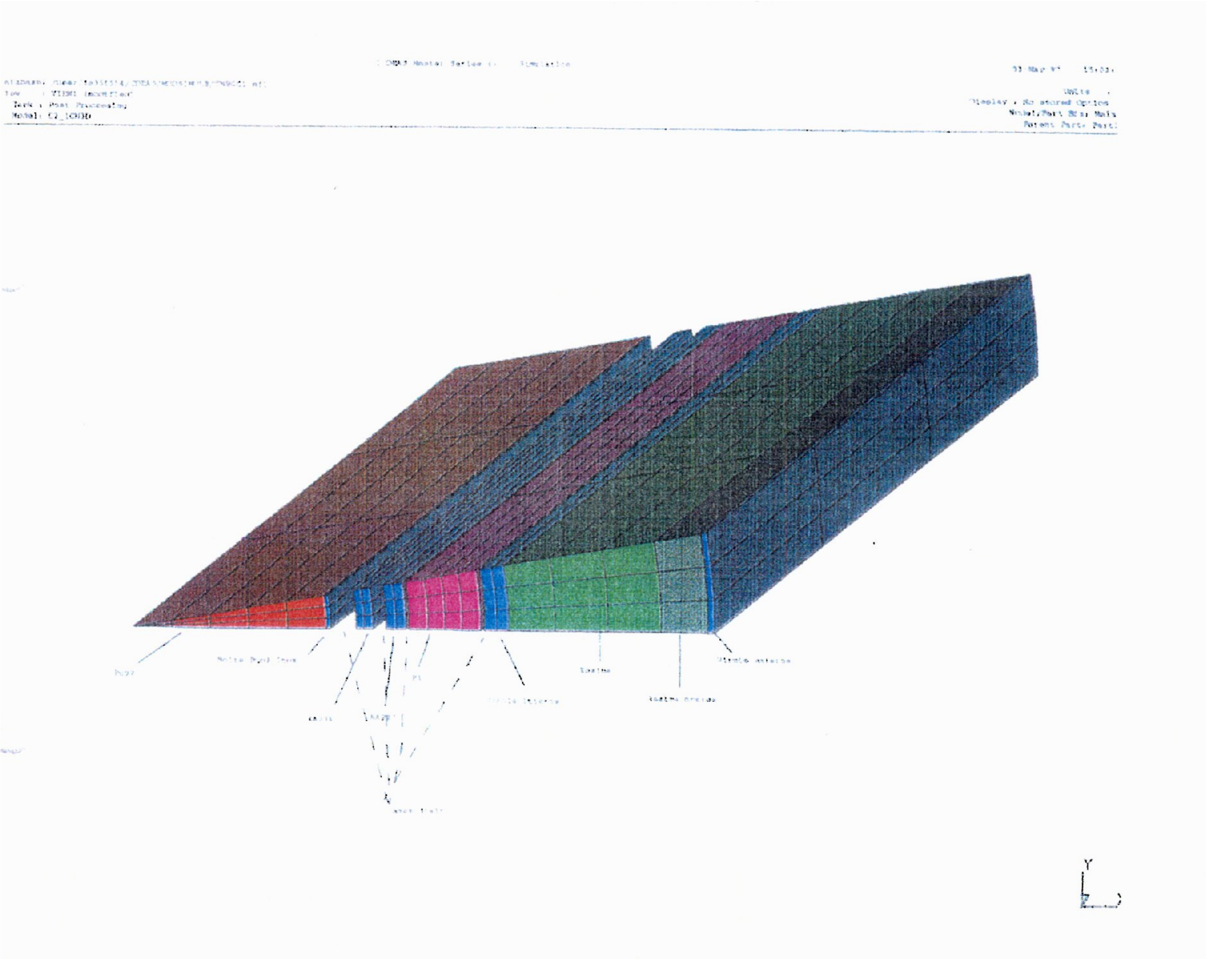


FIGURE 21:
MESHING OF MODEL C2.2

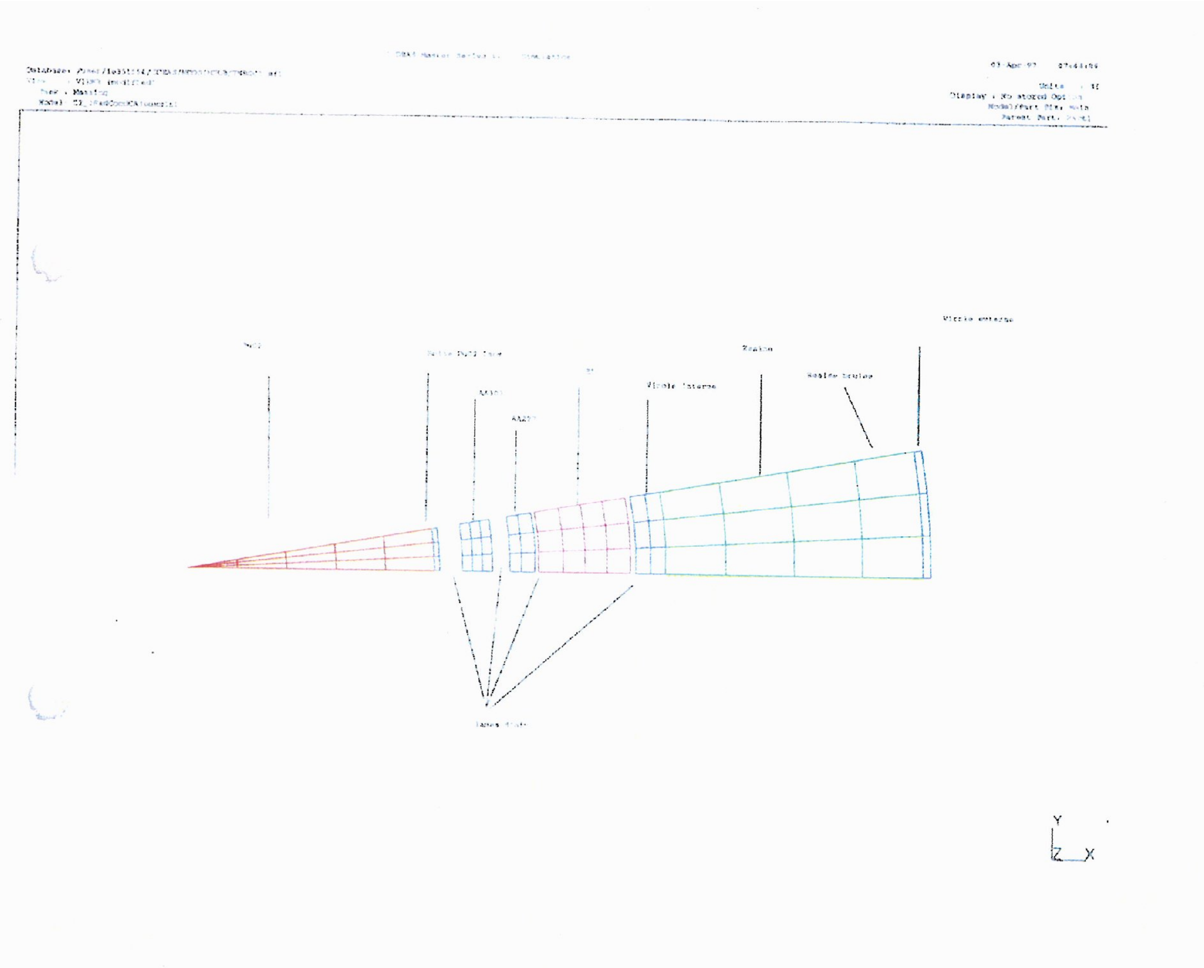


FIGURE 22:
ISOTHERMS OF MODEL C2.1 IN NORMAL CONDITIONS OF TRANSPORT

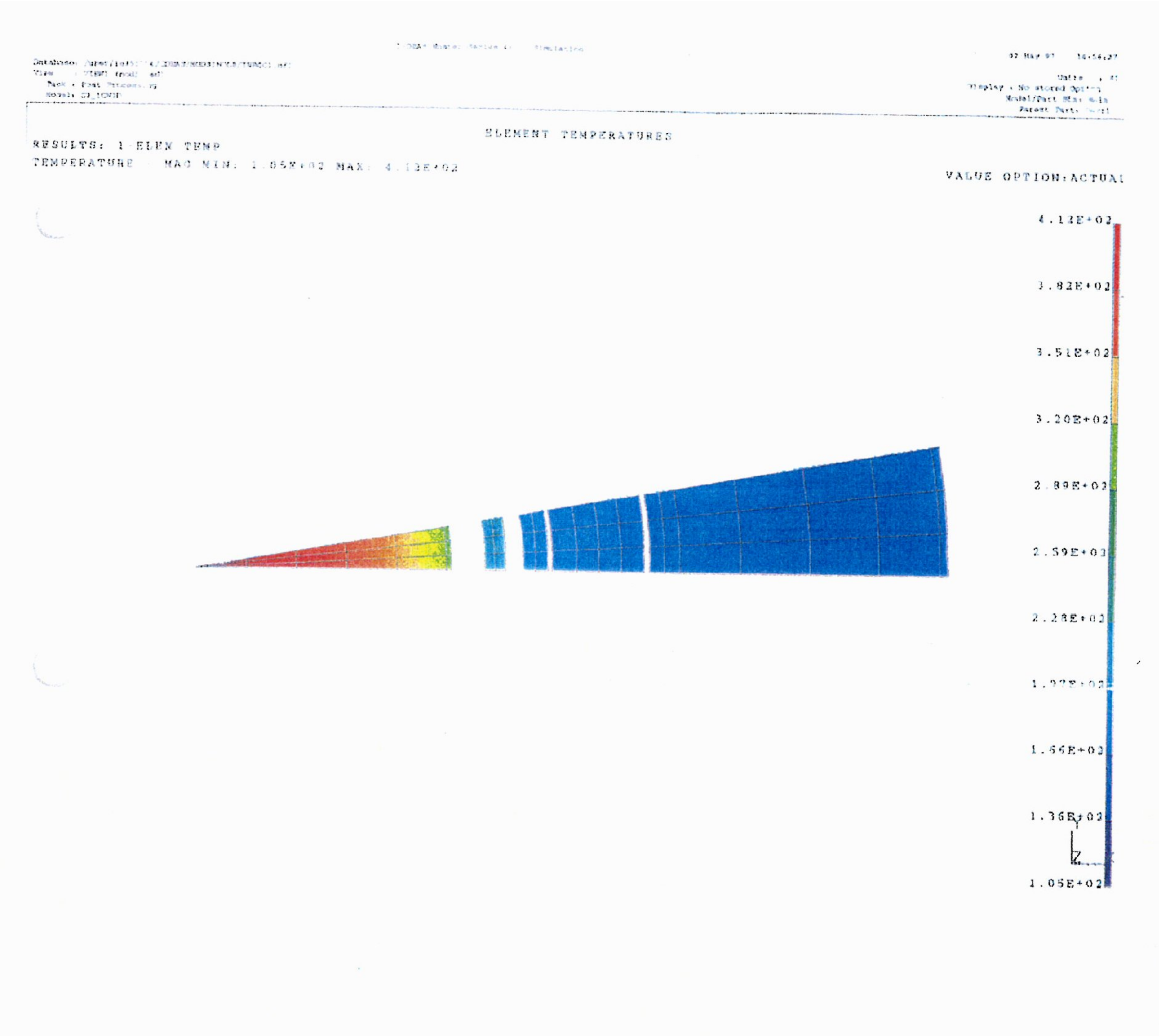


FIGURE 23:
ISOTHERMS OF MODEL C2.1 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S)

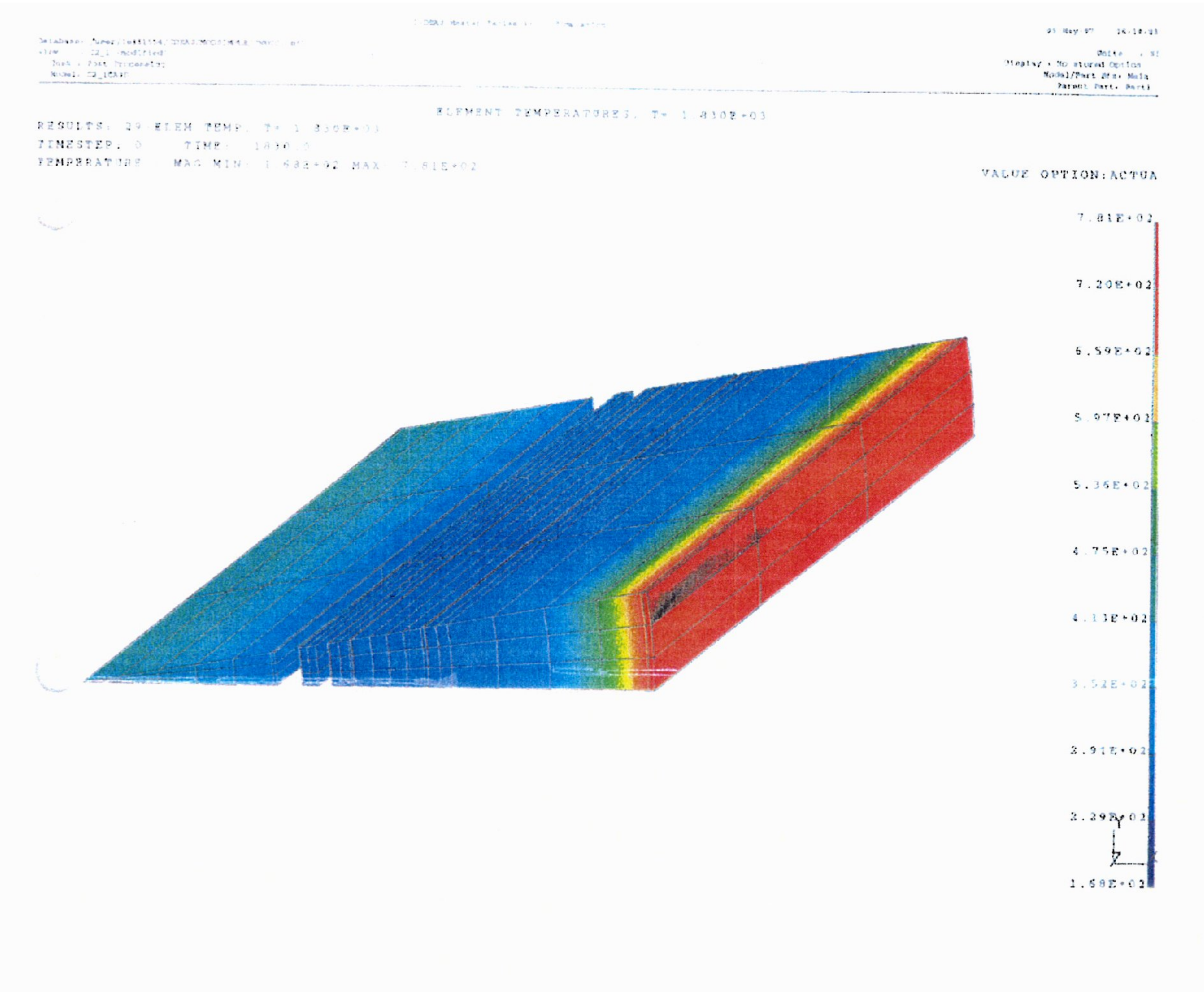


FIGURE 24:
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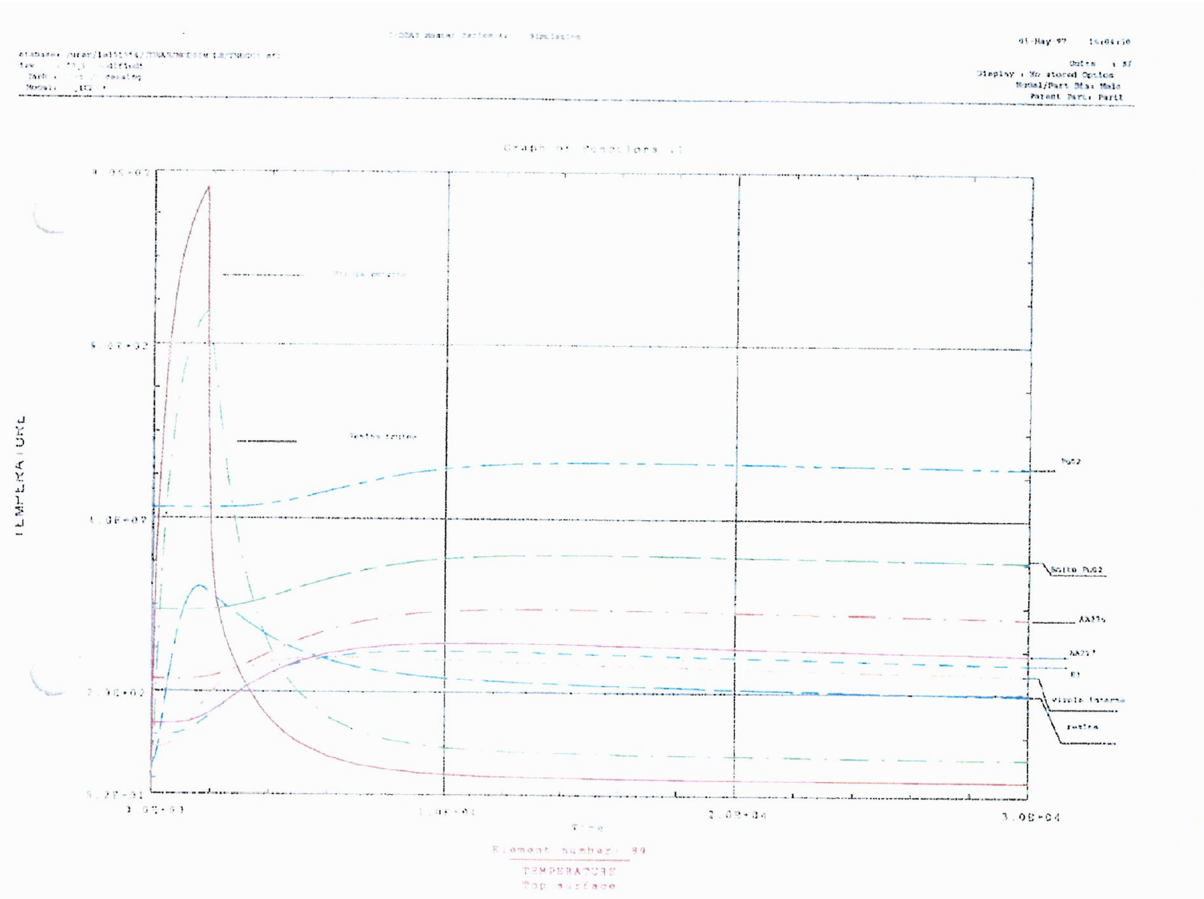

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ISOTHERMS OF MODEL C2.2 IN NORMAL CONDITIONS OF TRANSPORT

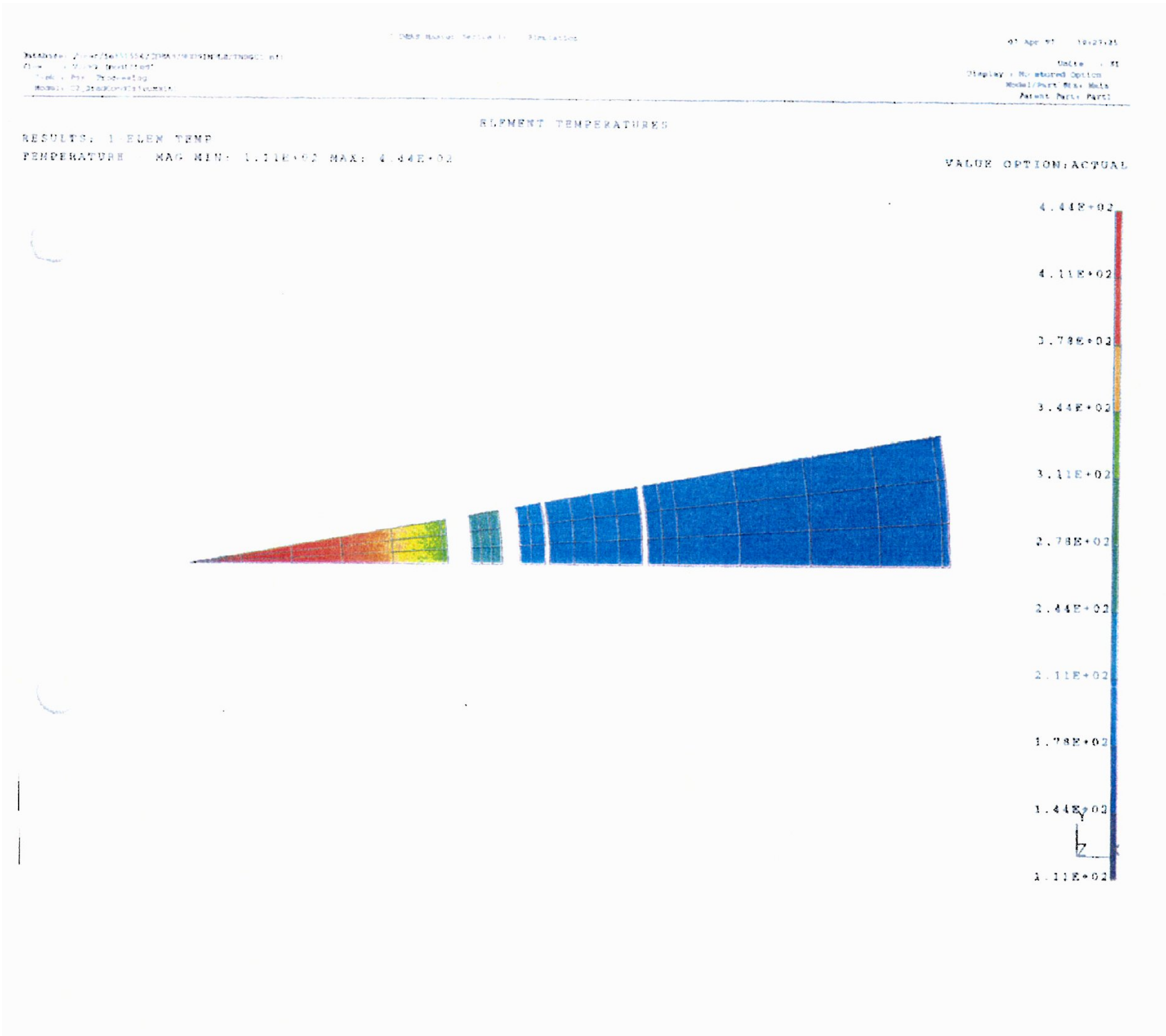
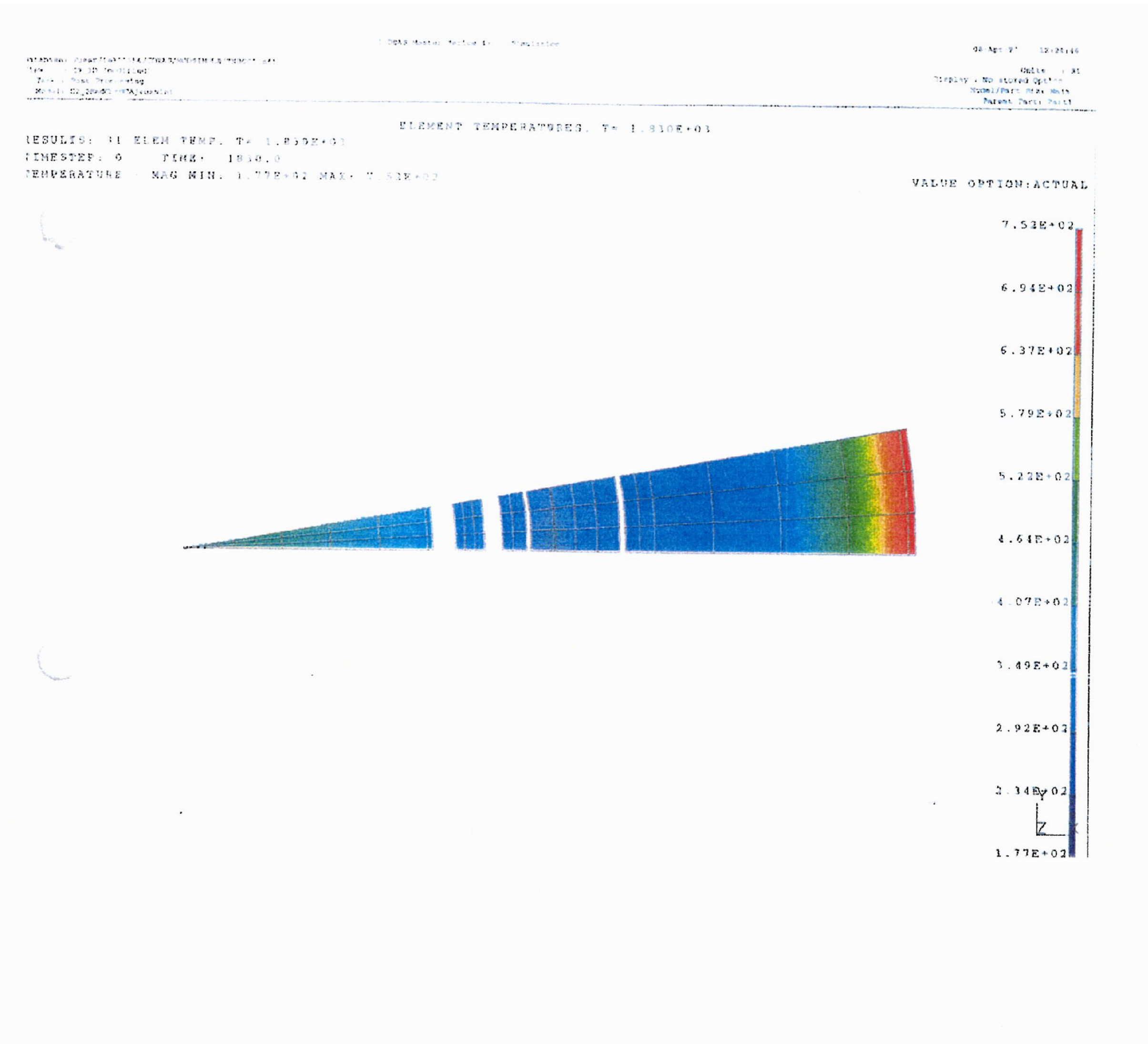


FIGURE 26:
ISOTHERMS OF MODEL C2.2 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S)



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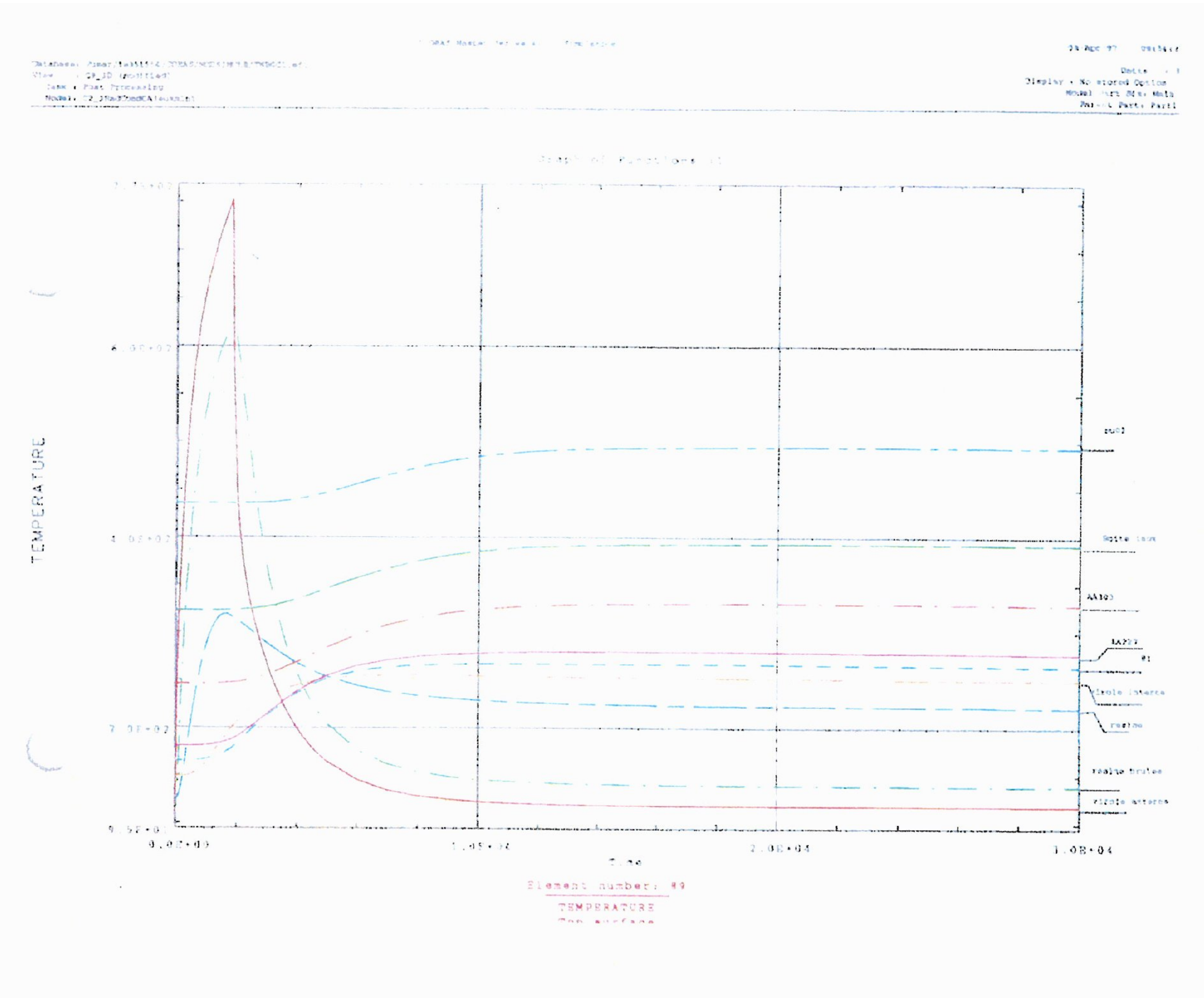

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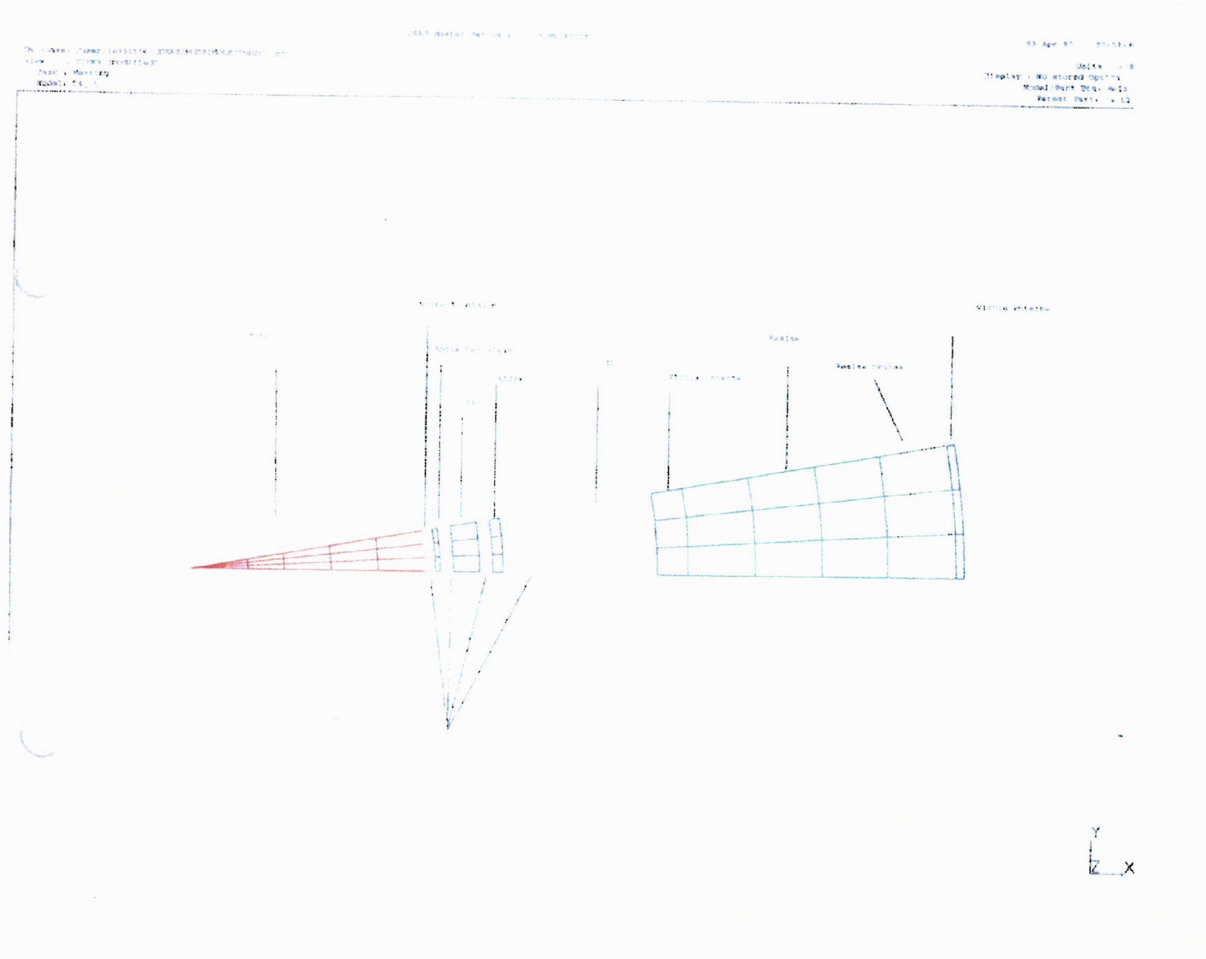

FIGURE 29:
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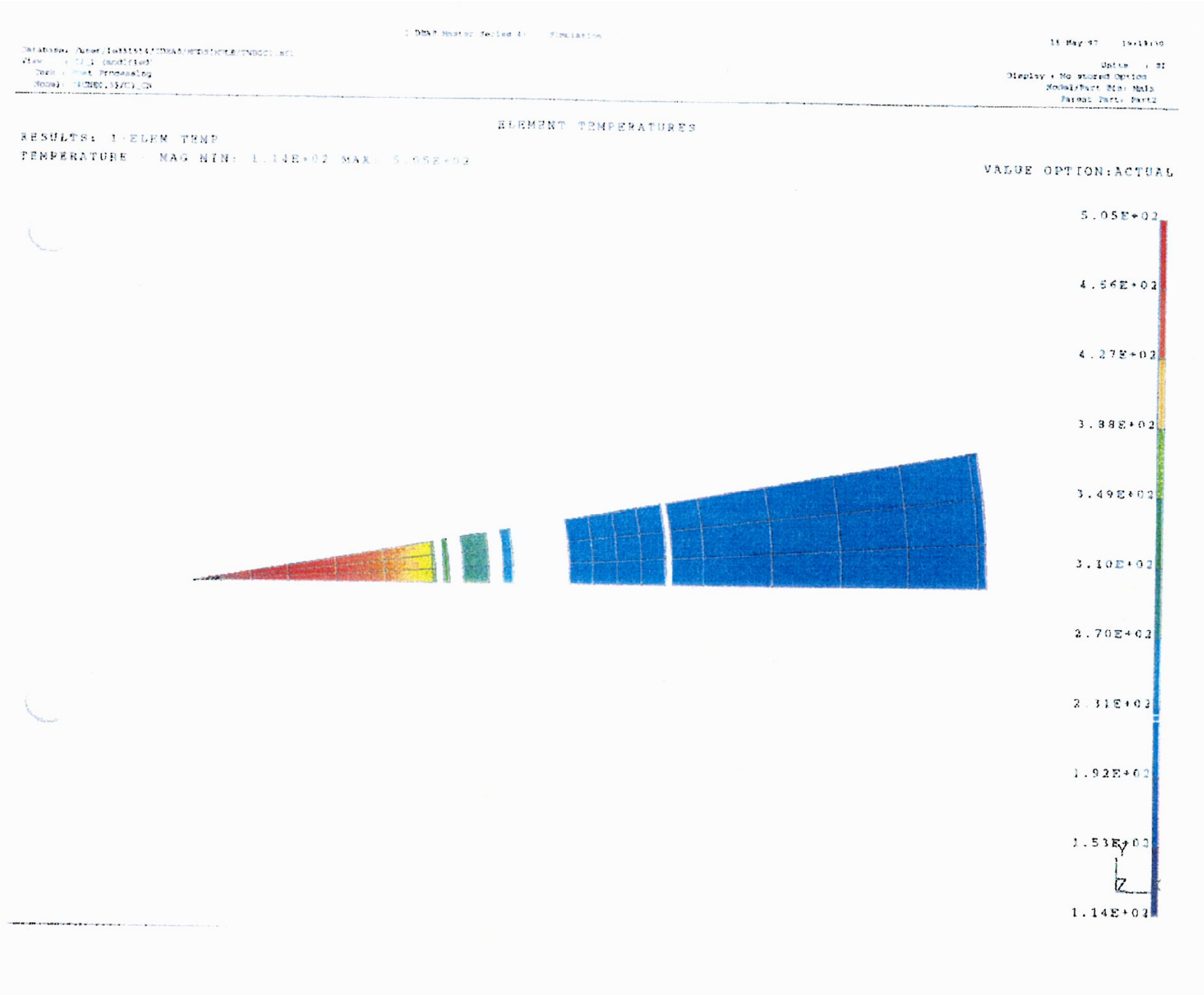

FIGURE 30:
ISOTHERMS OF MODEL C4 IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S)

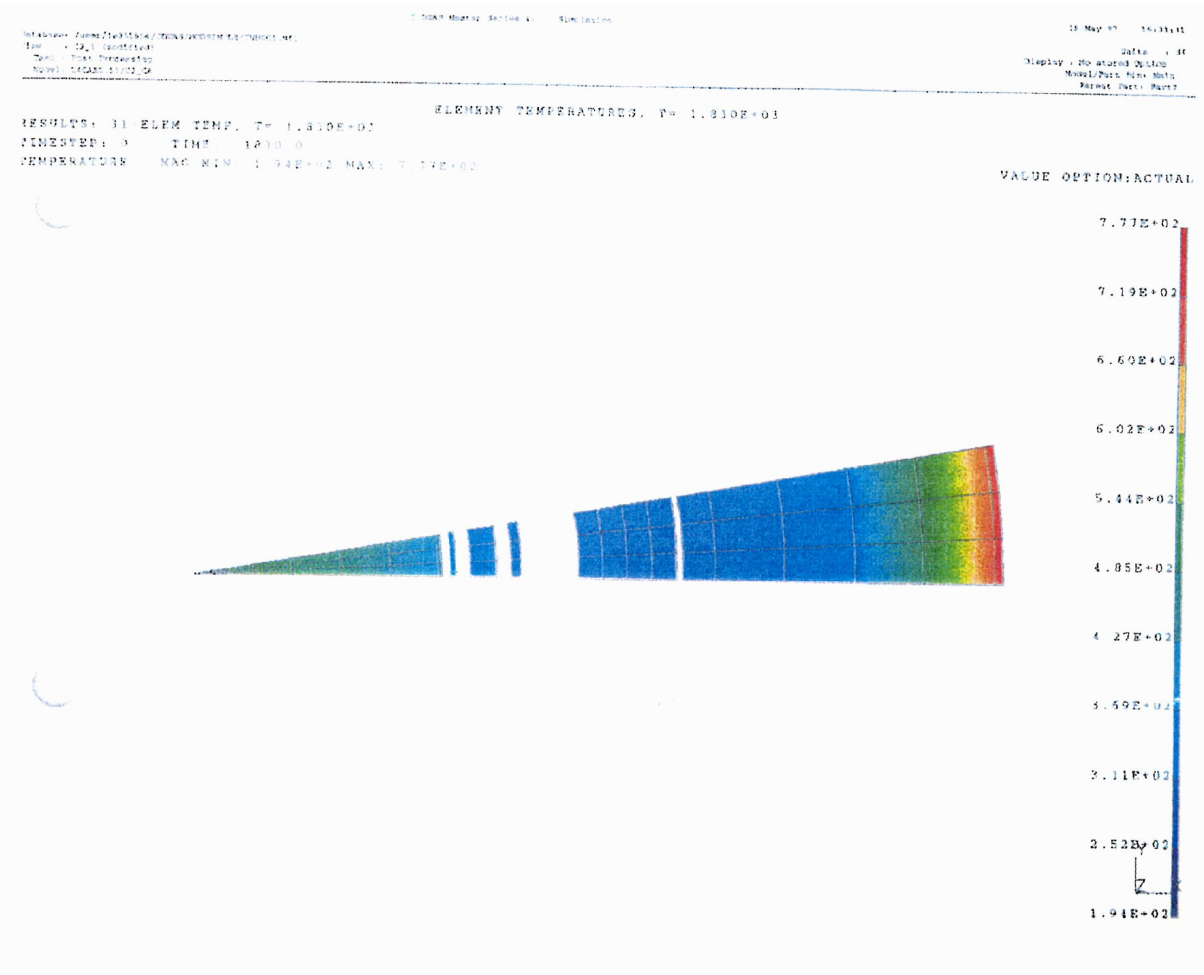

FIGURE 31:
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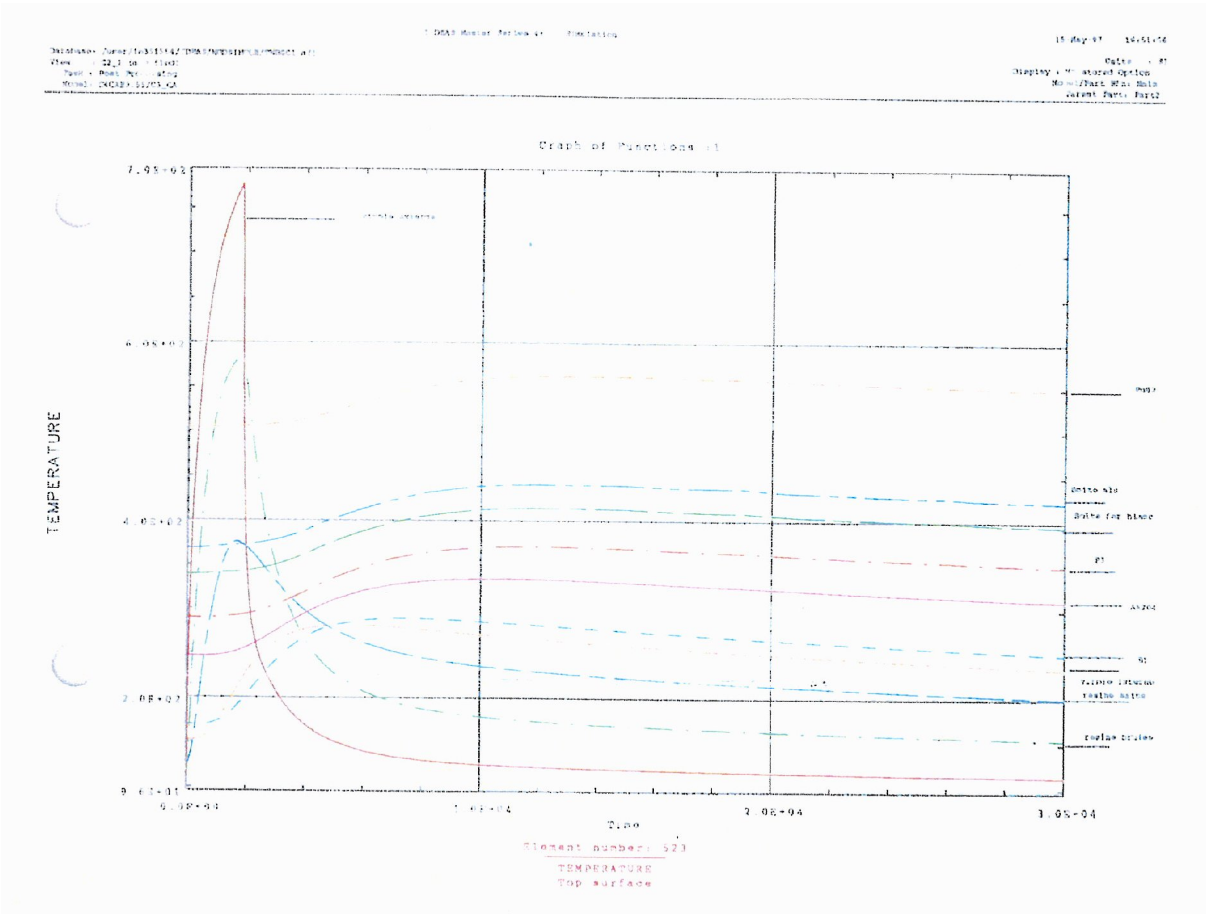

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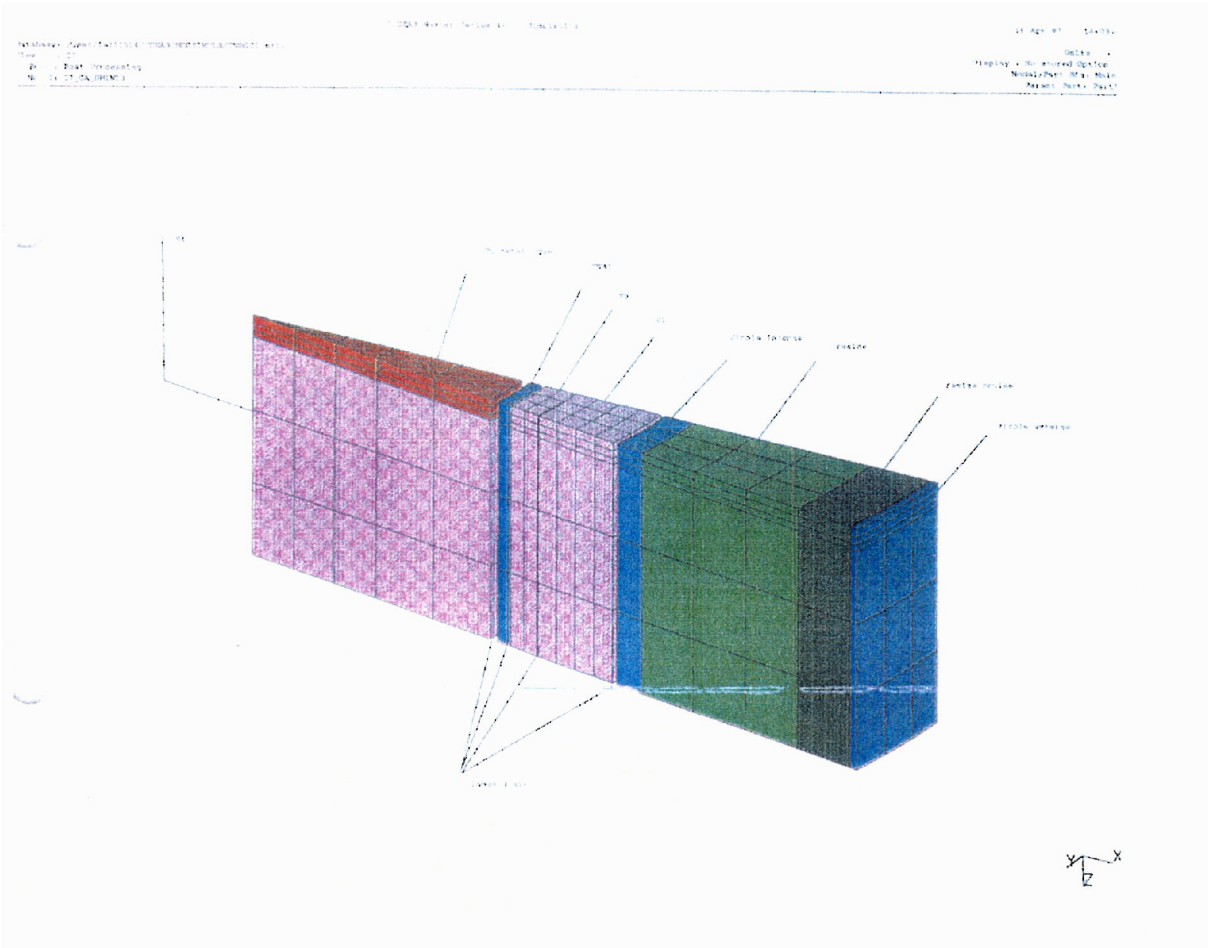

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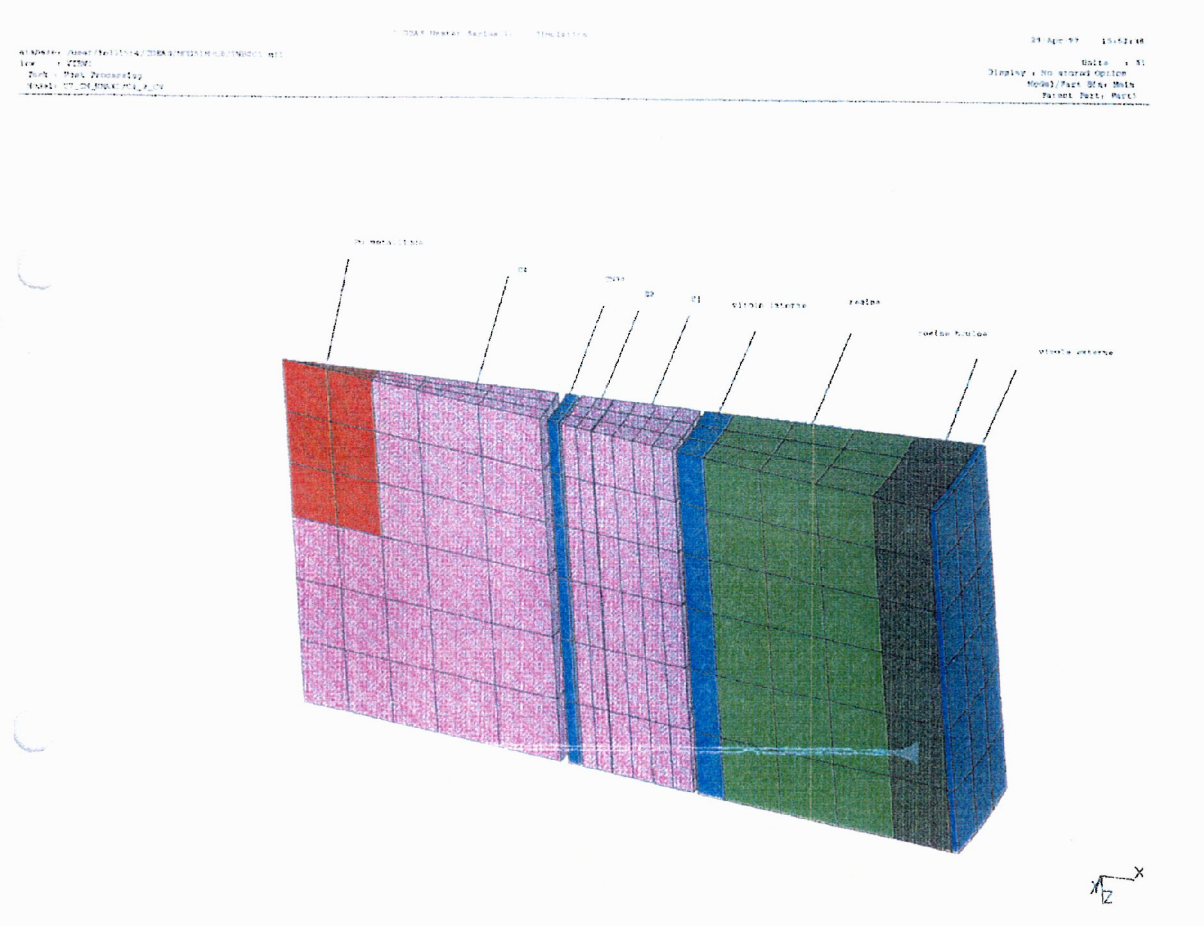

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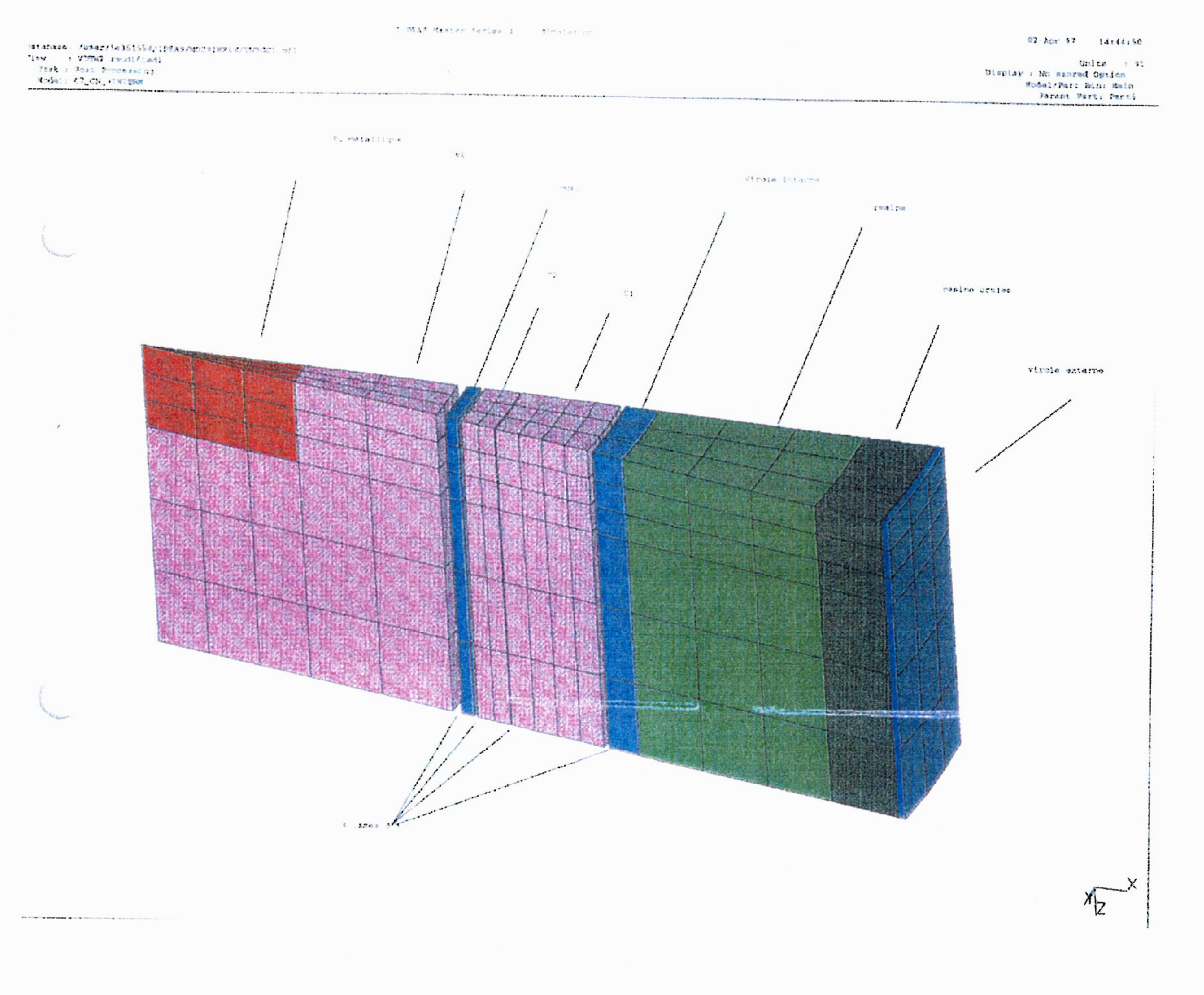

FIGURE 35:
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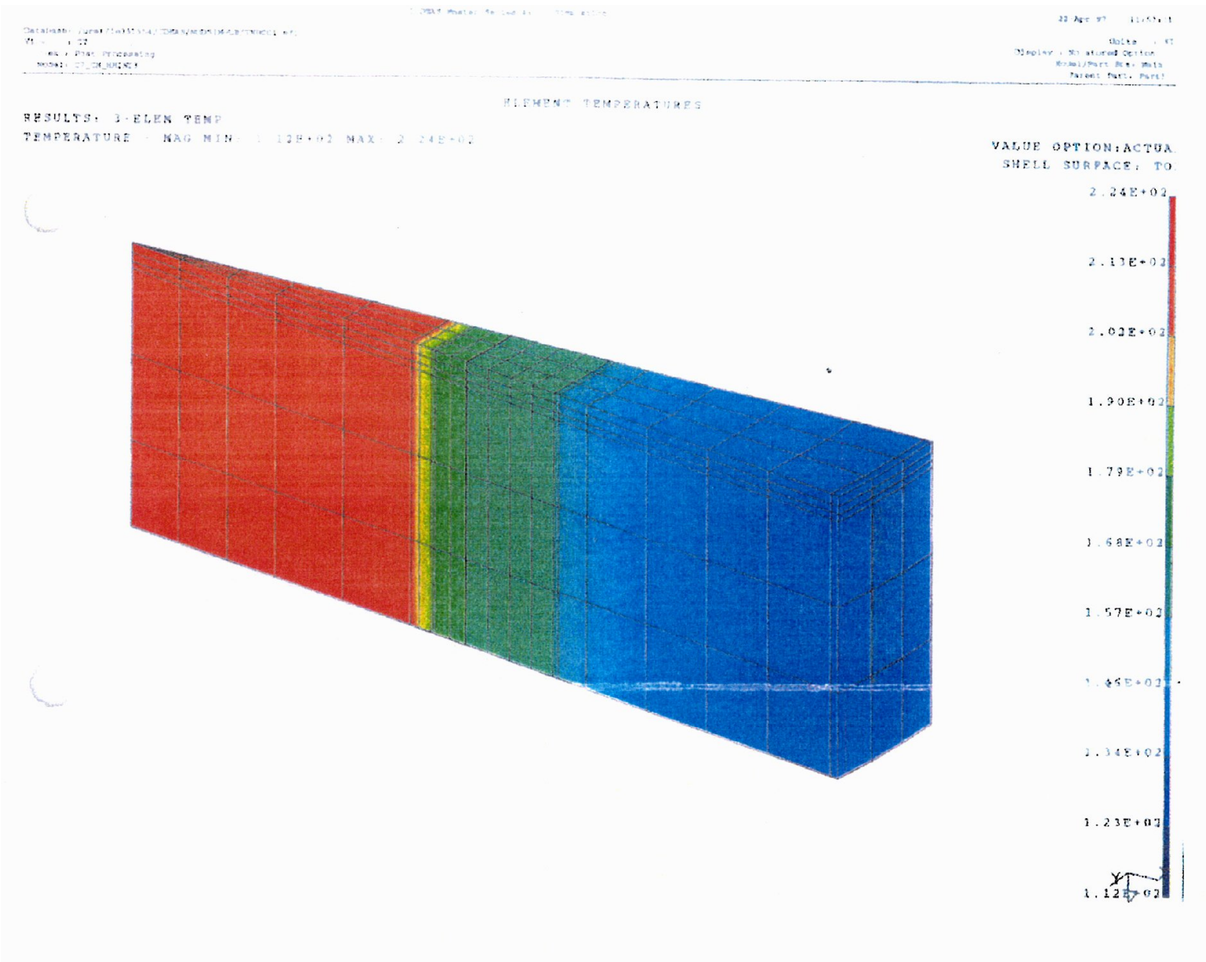

FIGURE 36:
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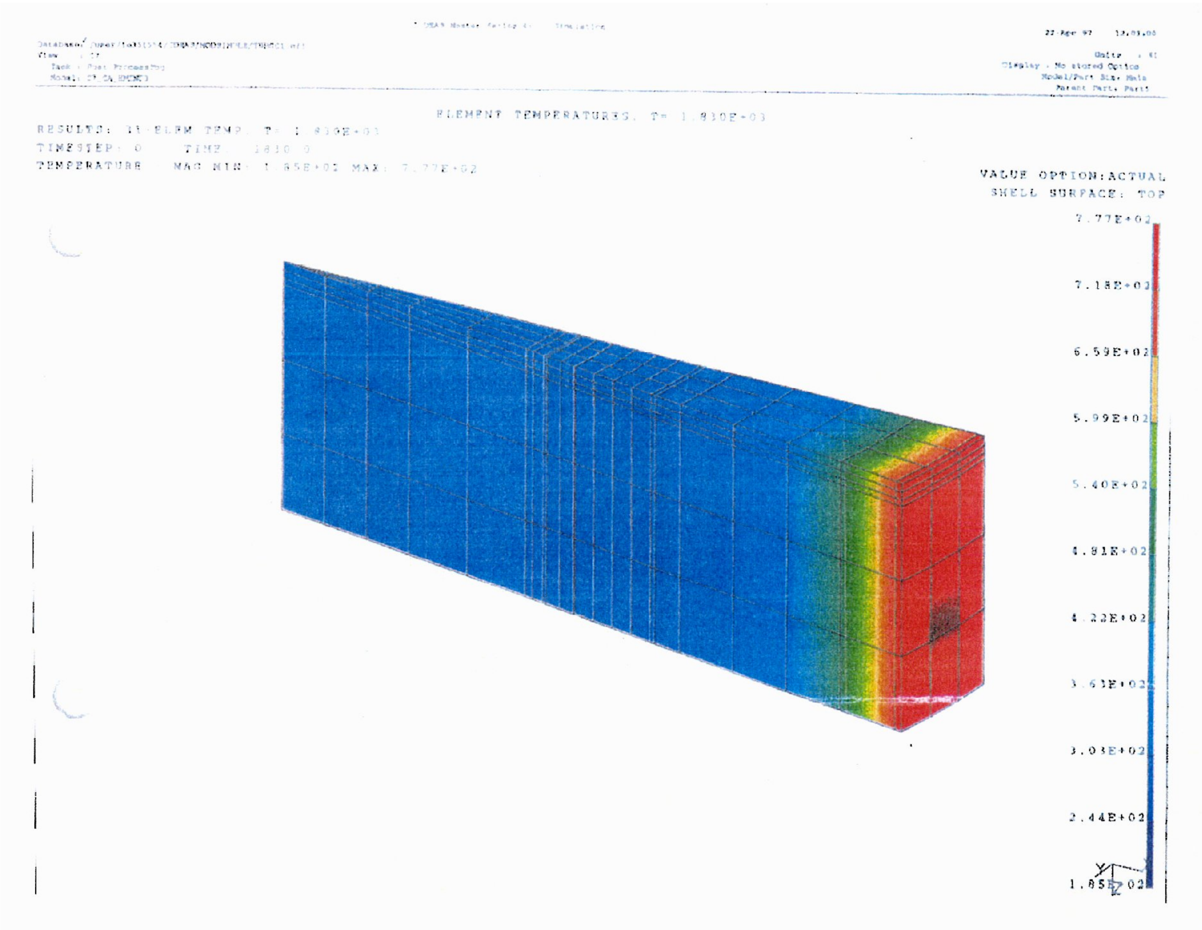

FIGURE 37:
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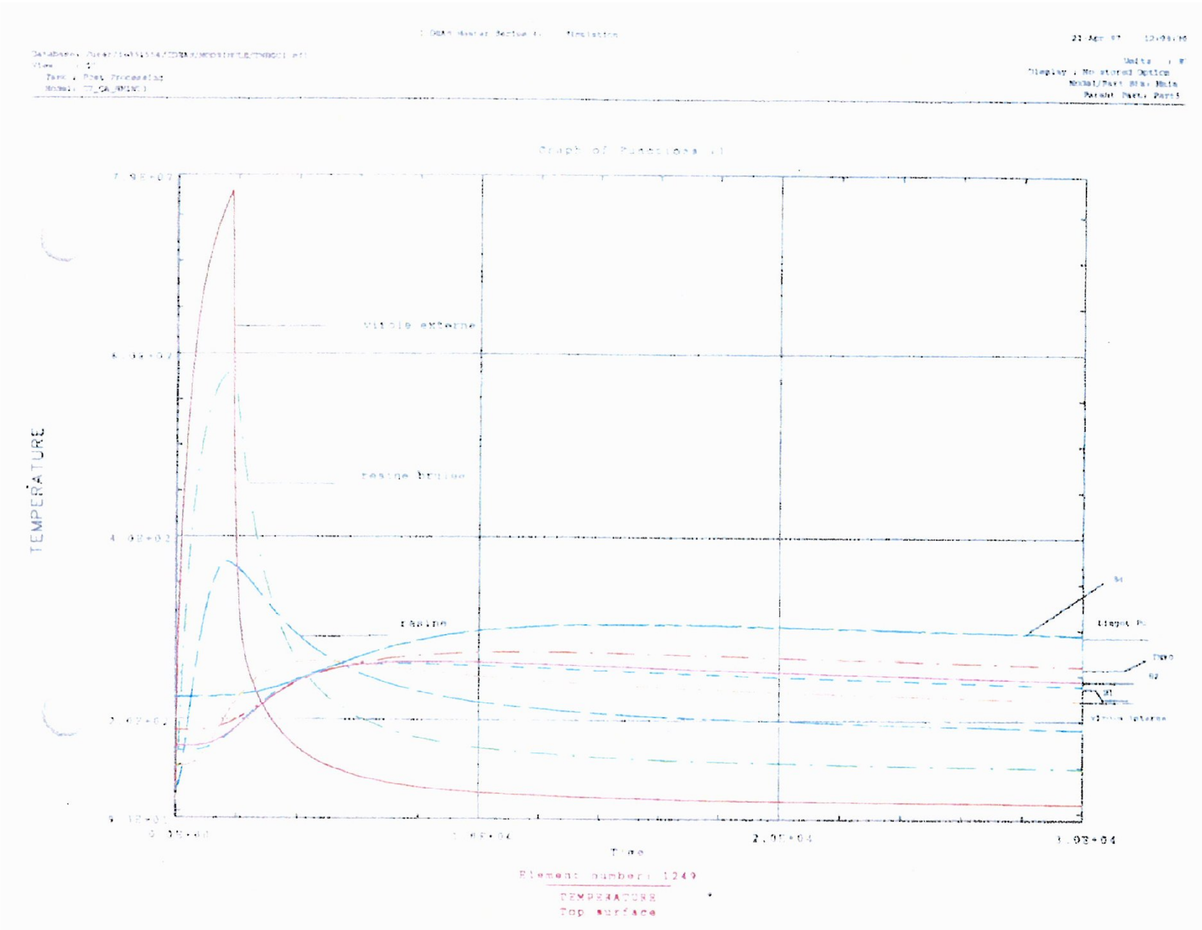

FIGURE 38:
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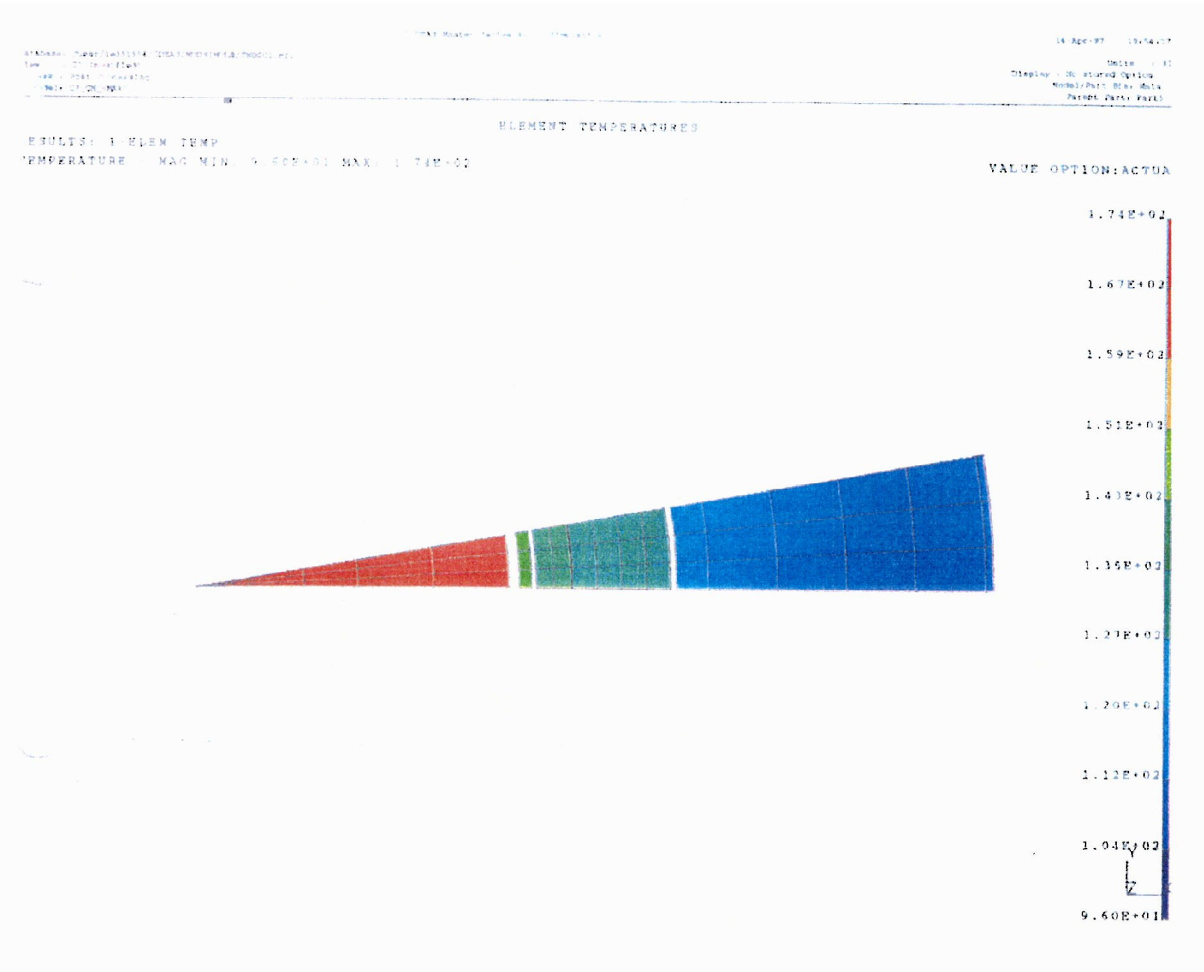

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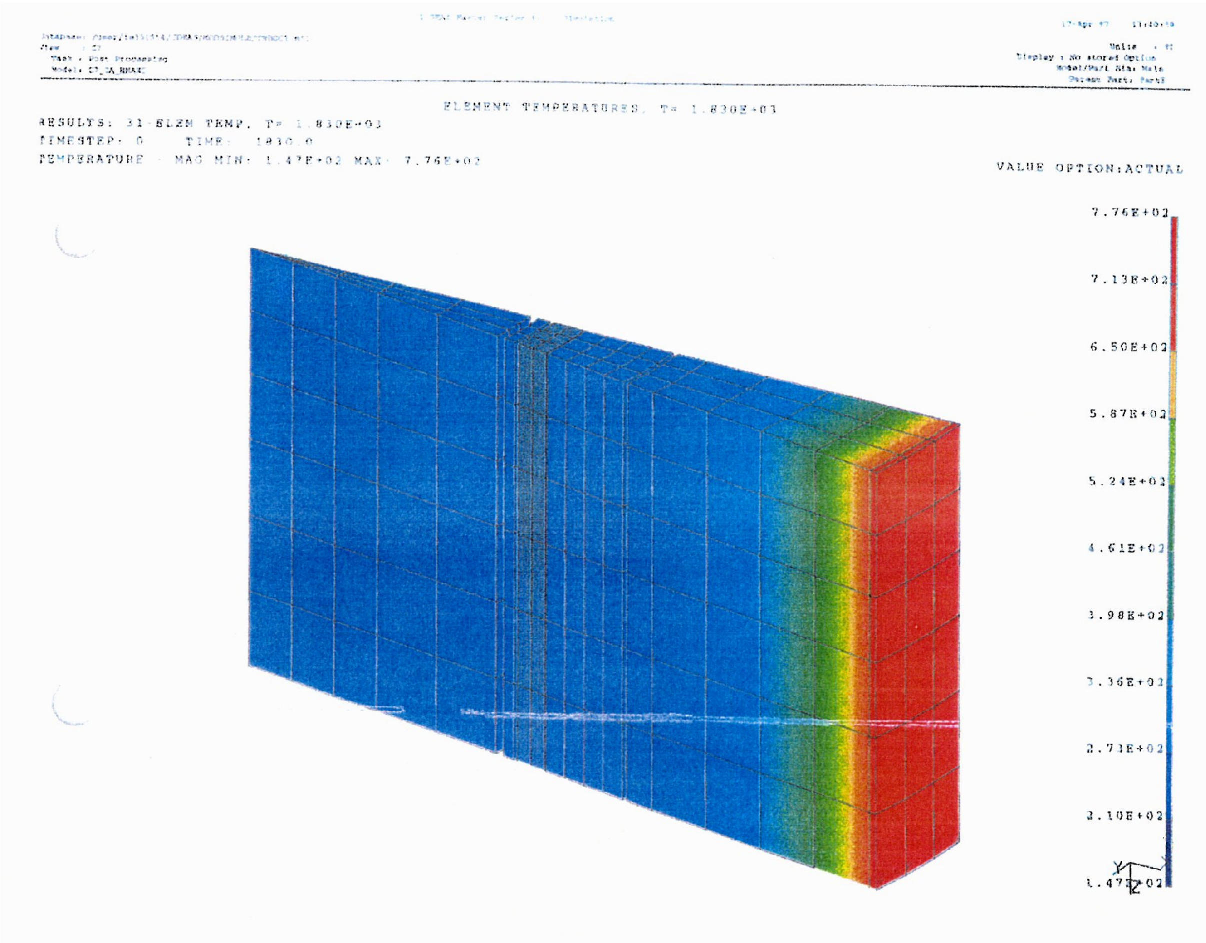

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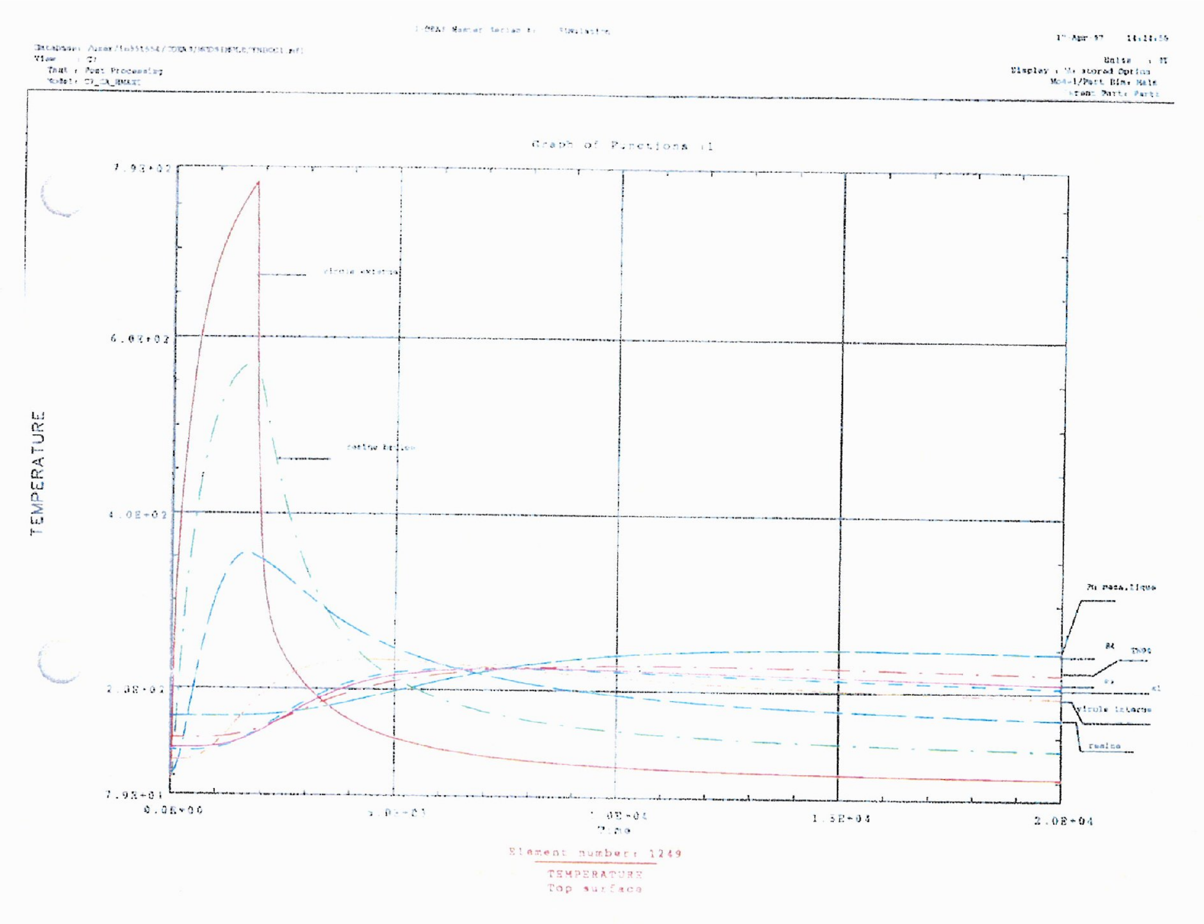

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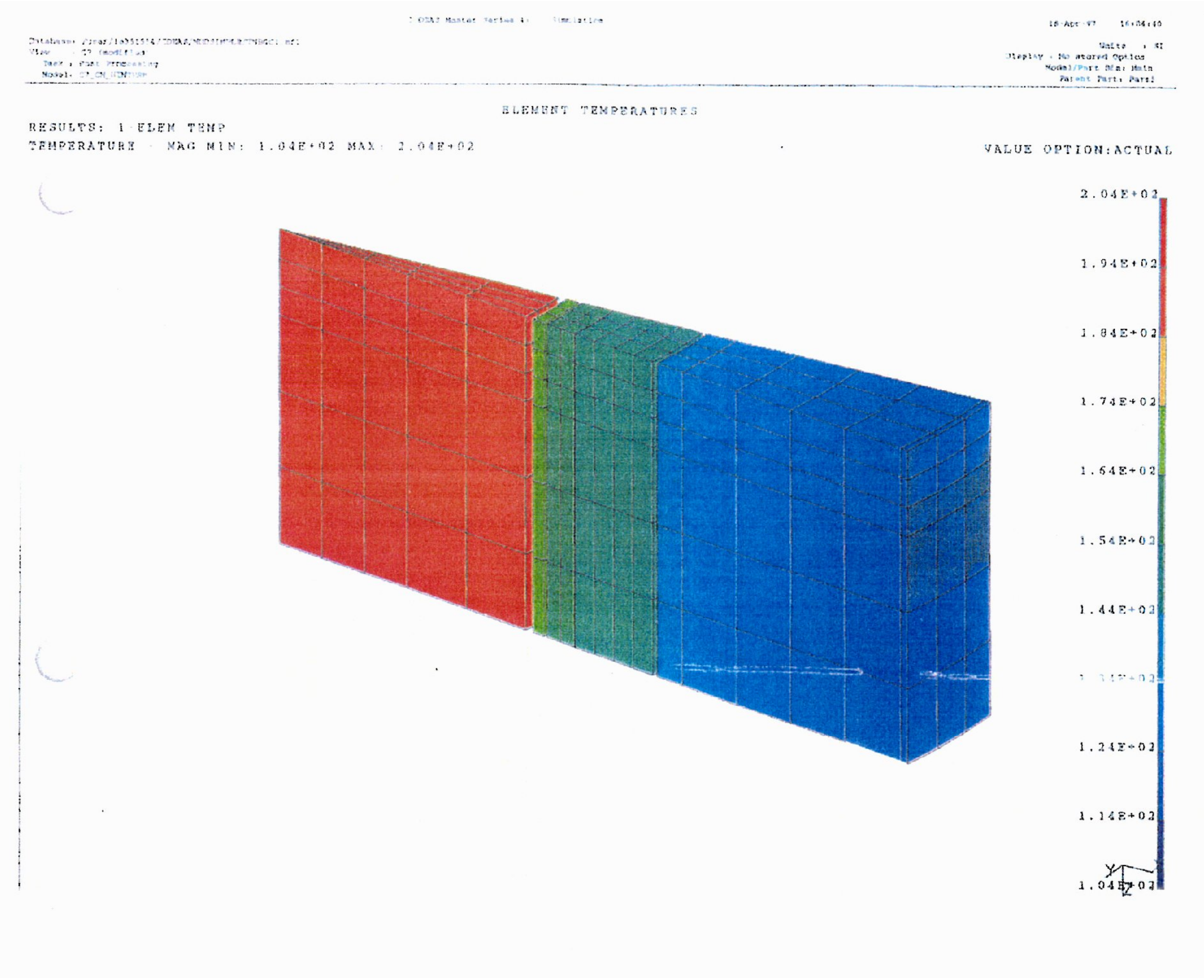

FIGURE 42:
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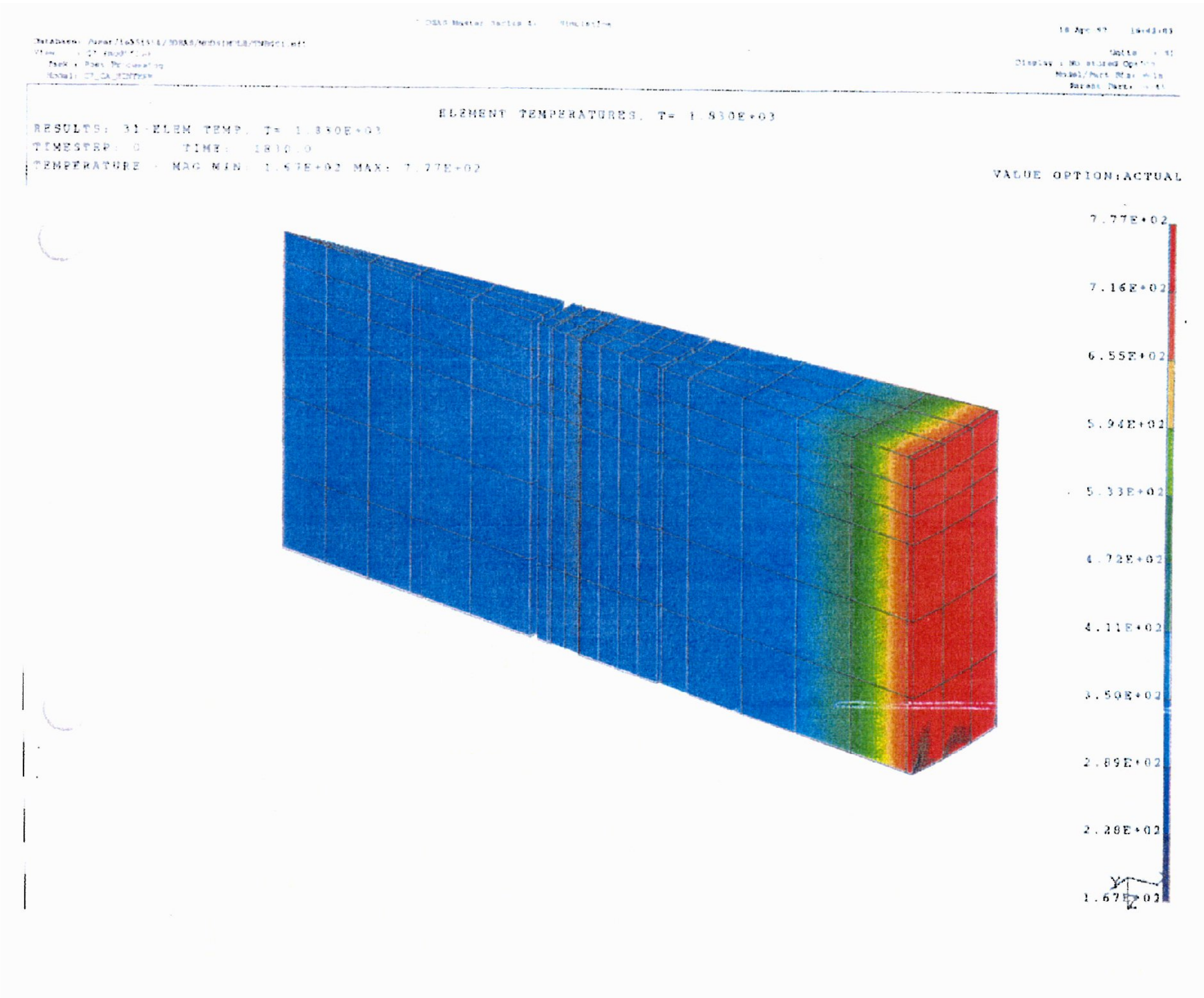

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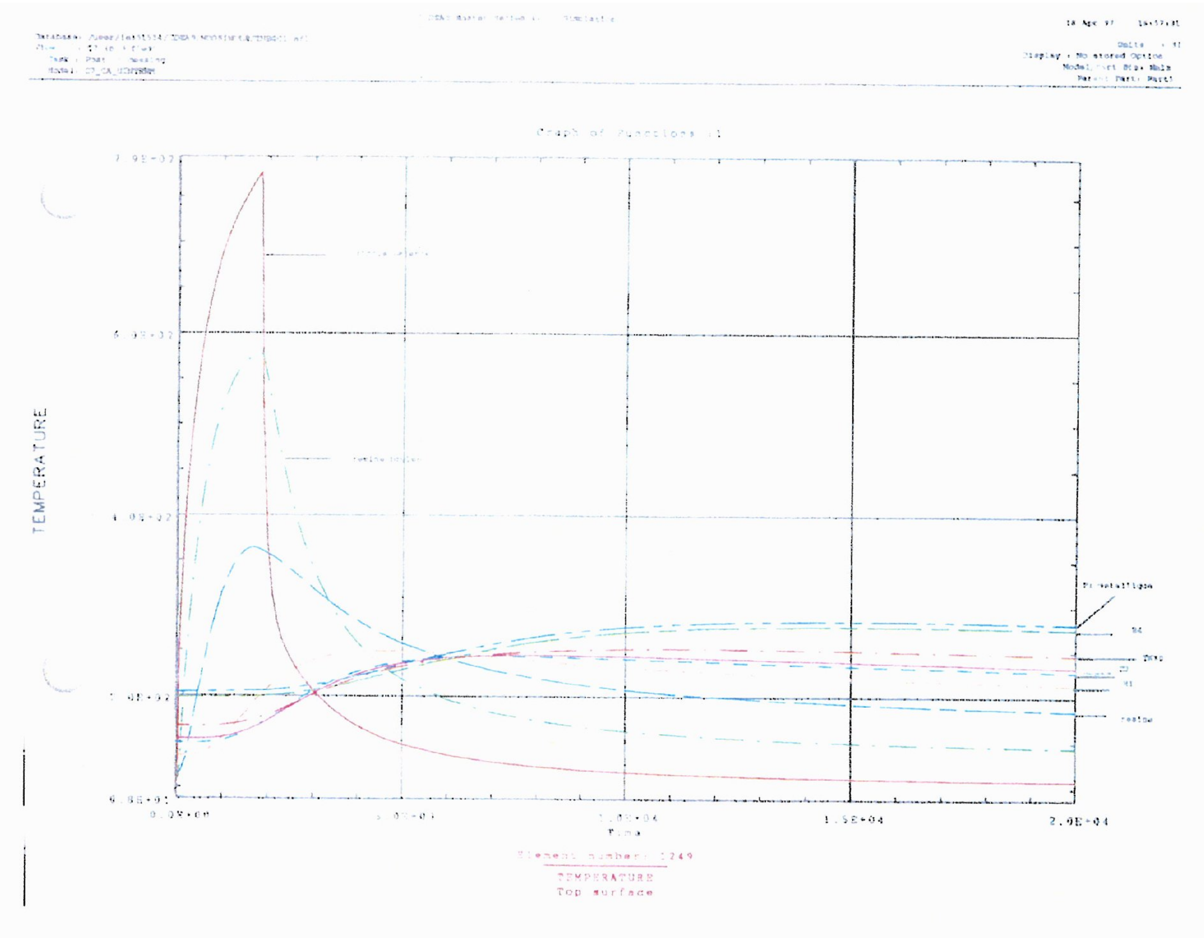

FIGURE 44:
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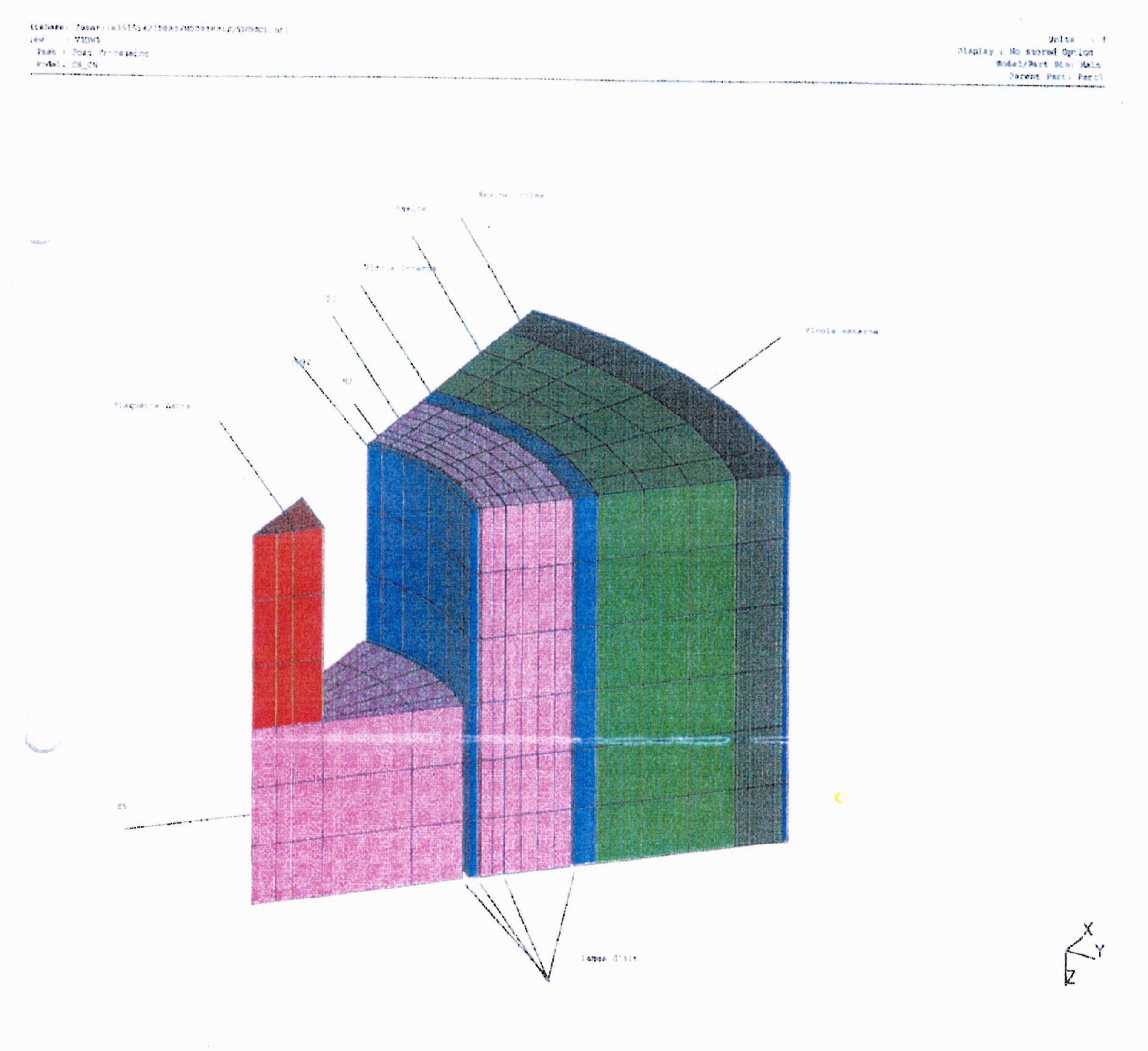

FIGURE 45:
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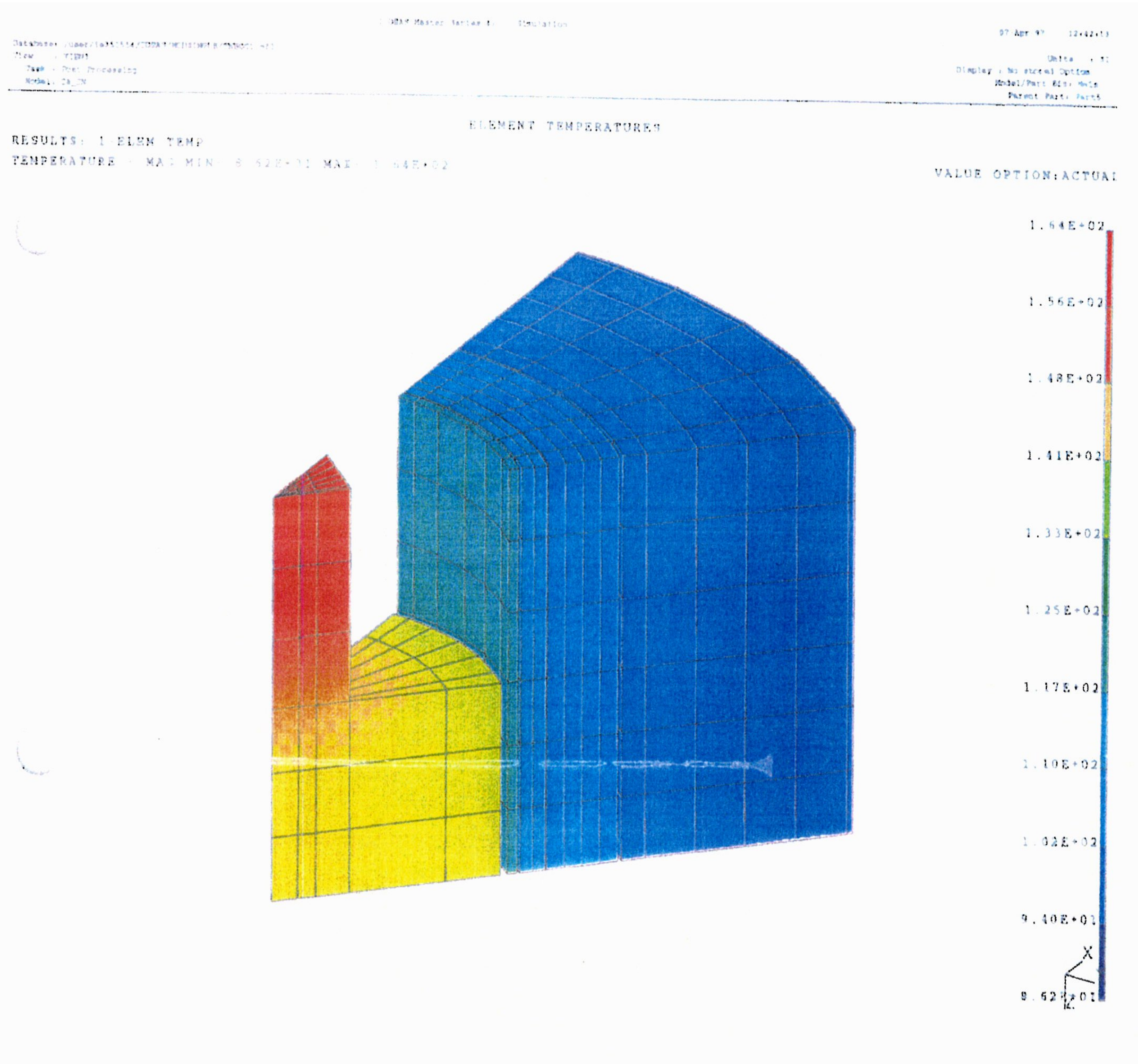

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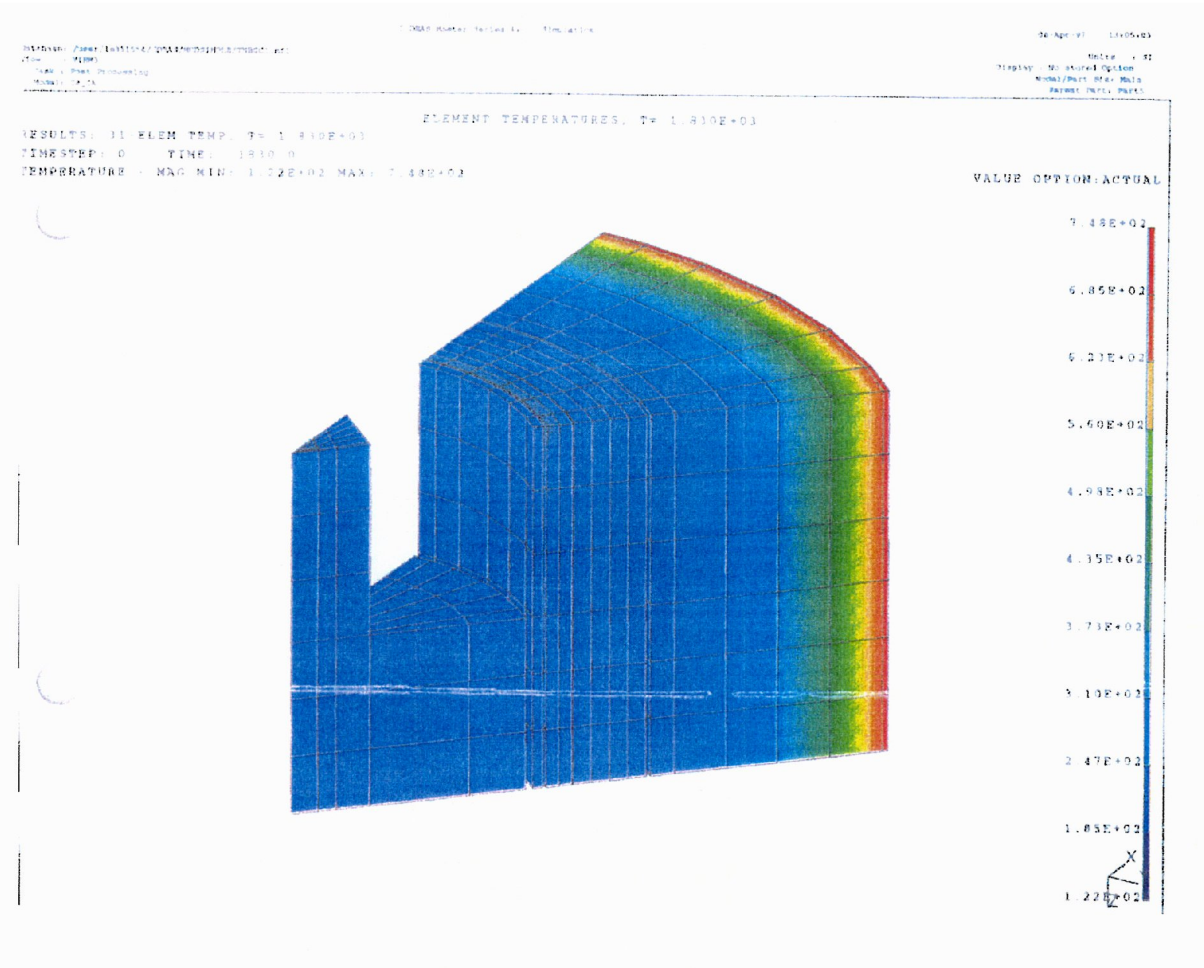
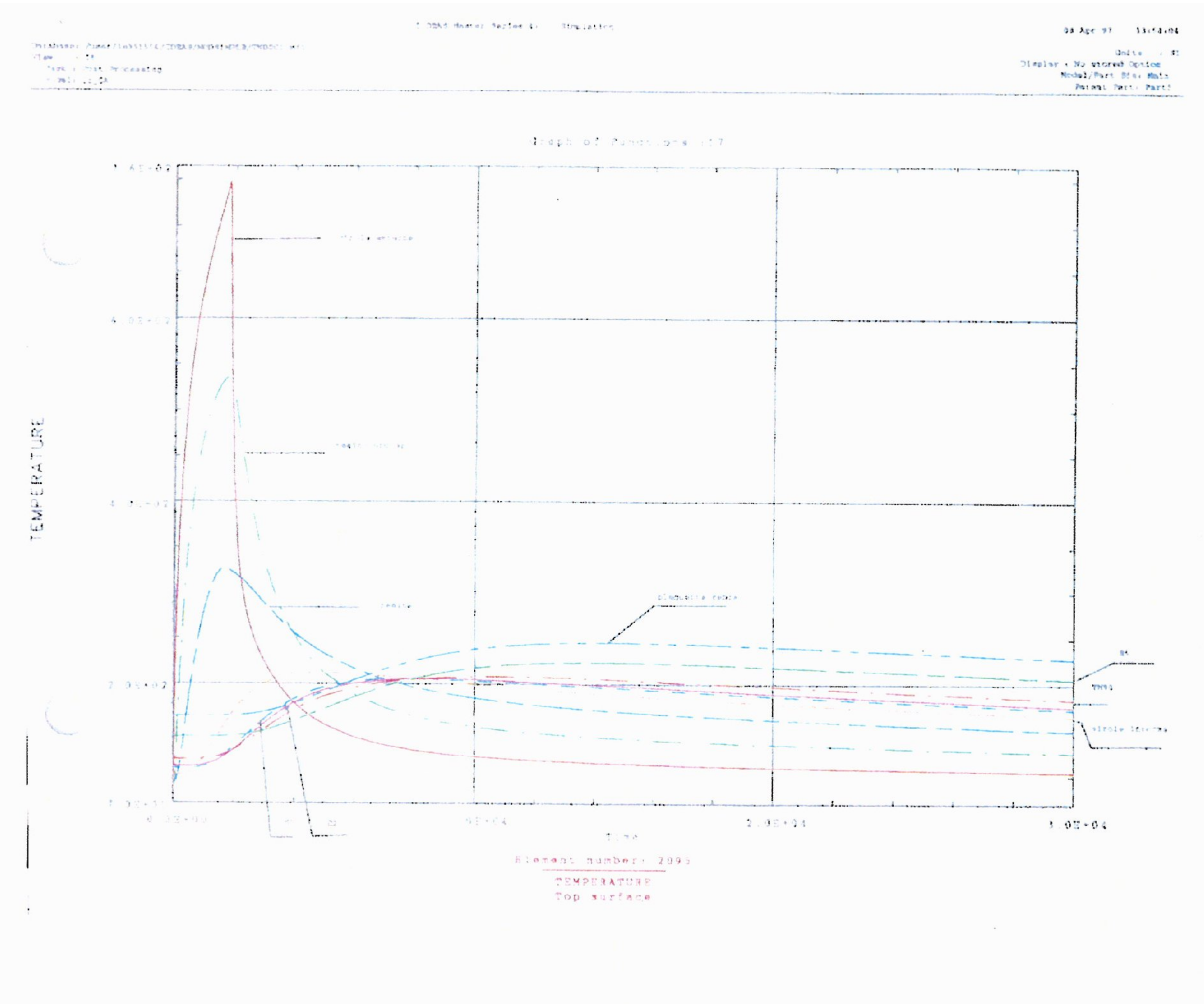


FIGURE 47:
CHART SHOWING HOW TEMPERATURE VARIES OVER TIME FOR MODEL C8



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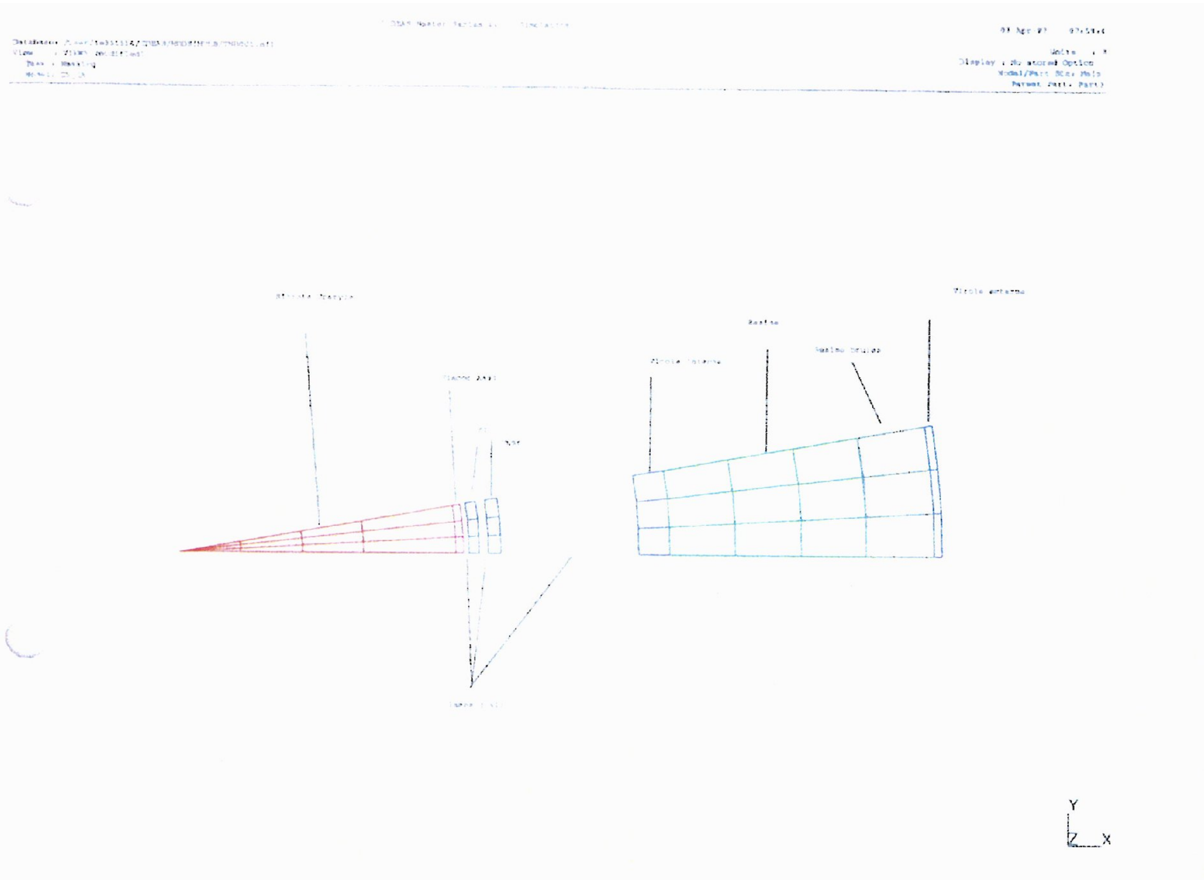

FIGURE 49:
ISOTHERMS OF MODEL C5.A IN NORMAL CONDITIONS OF TRANSPORT

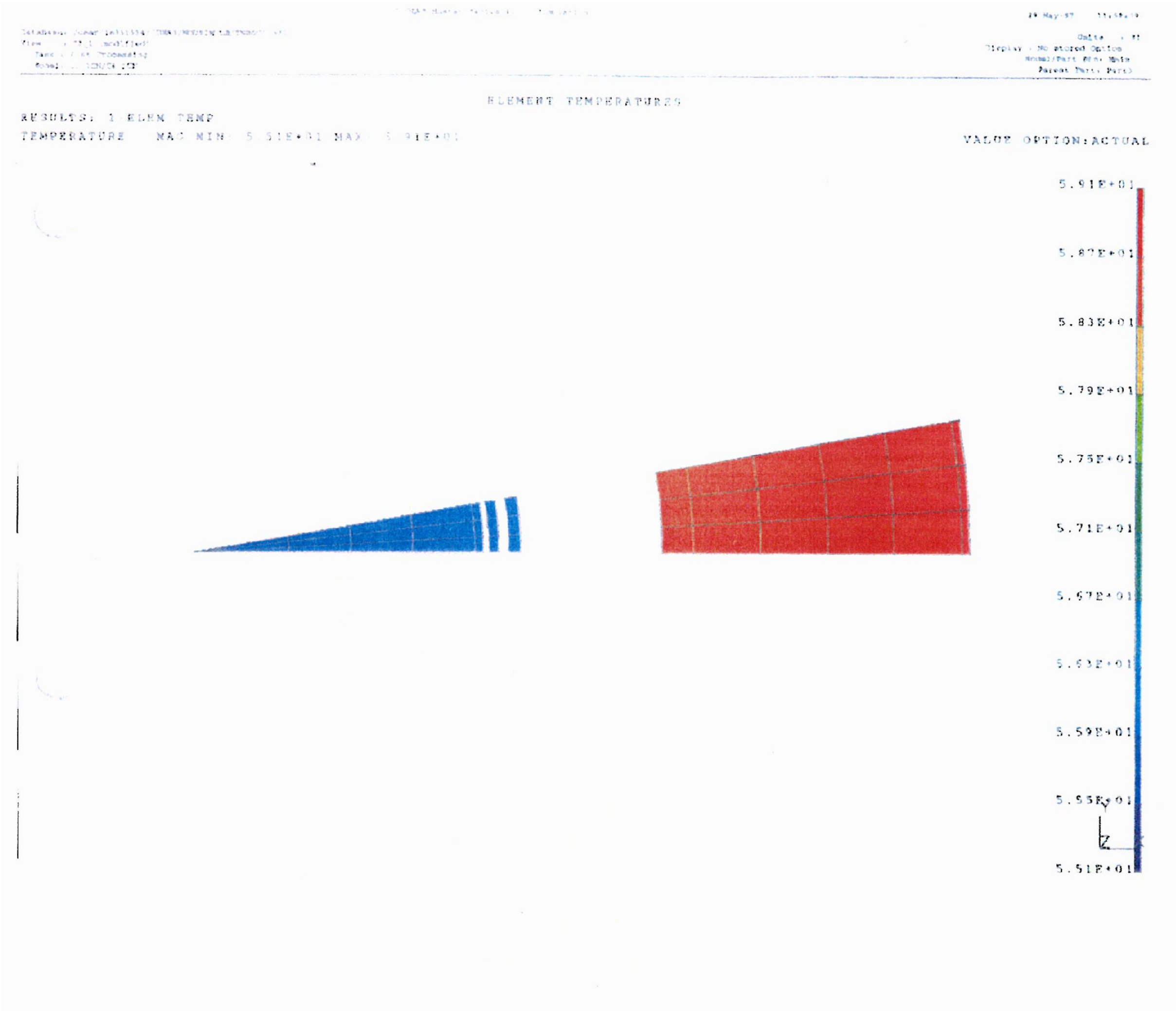

FIGURE 50:
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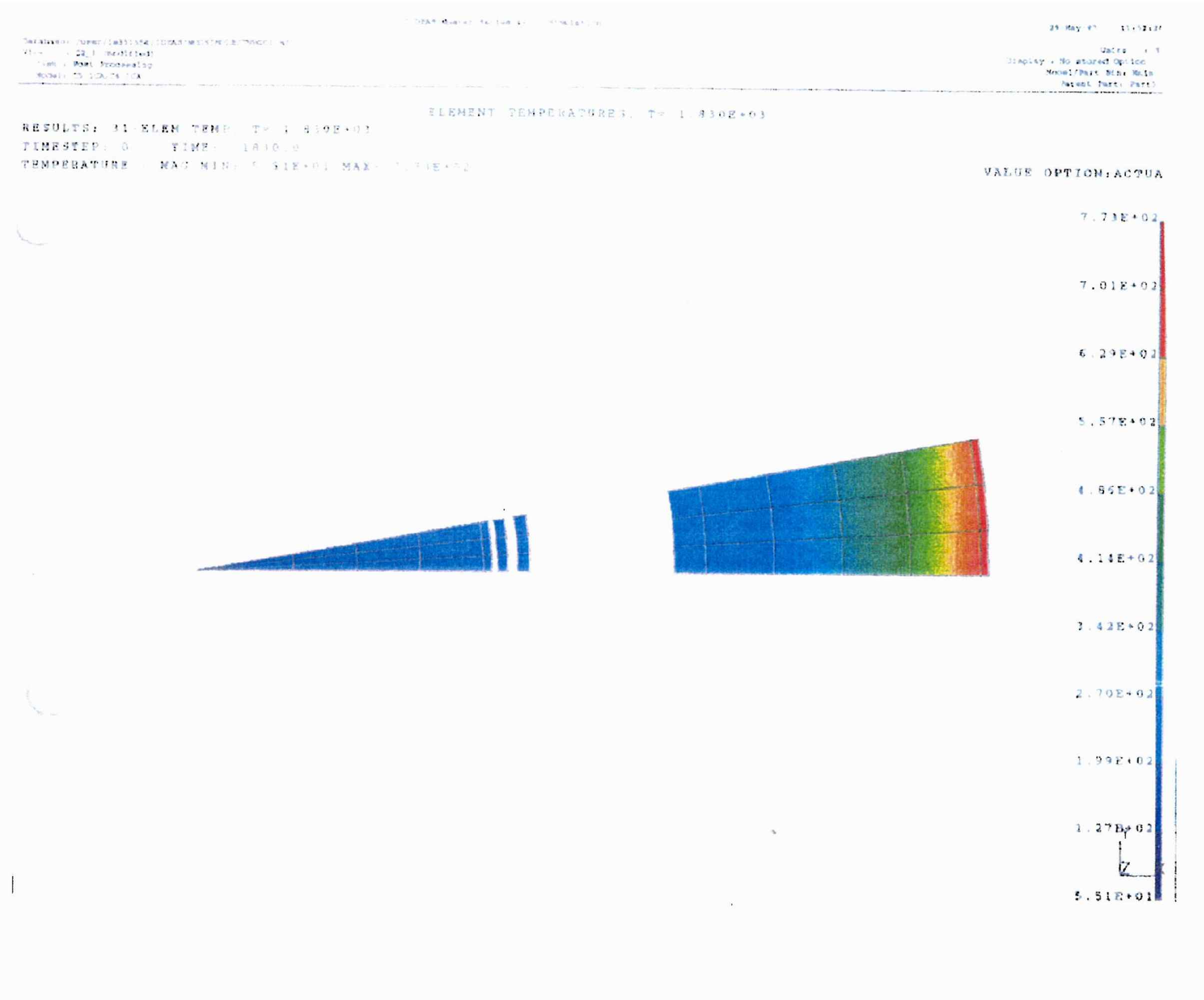

FIGURE 51:
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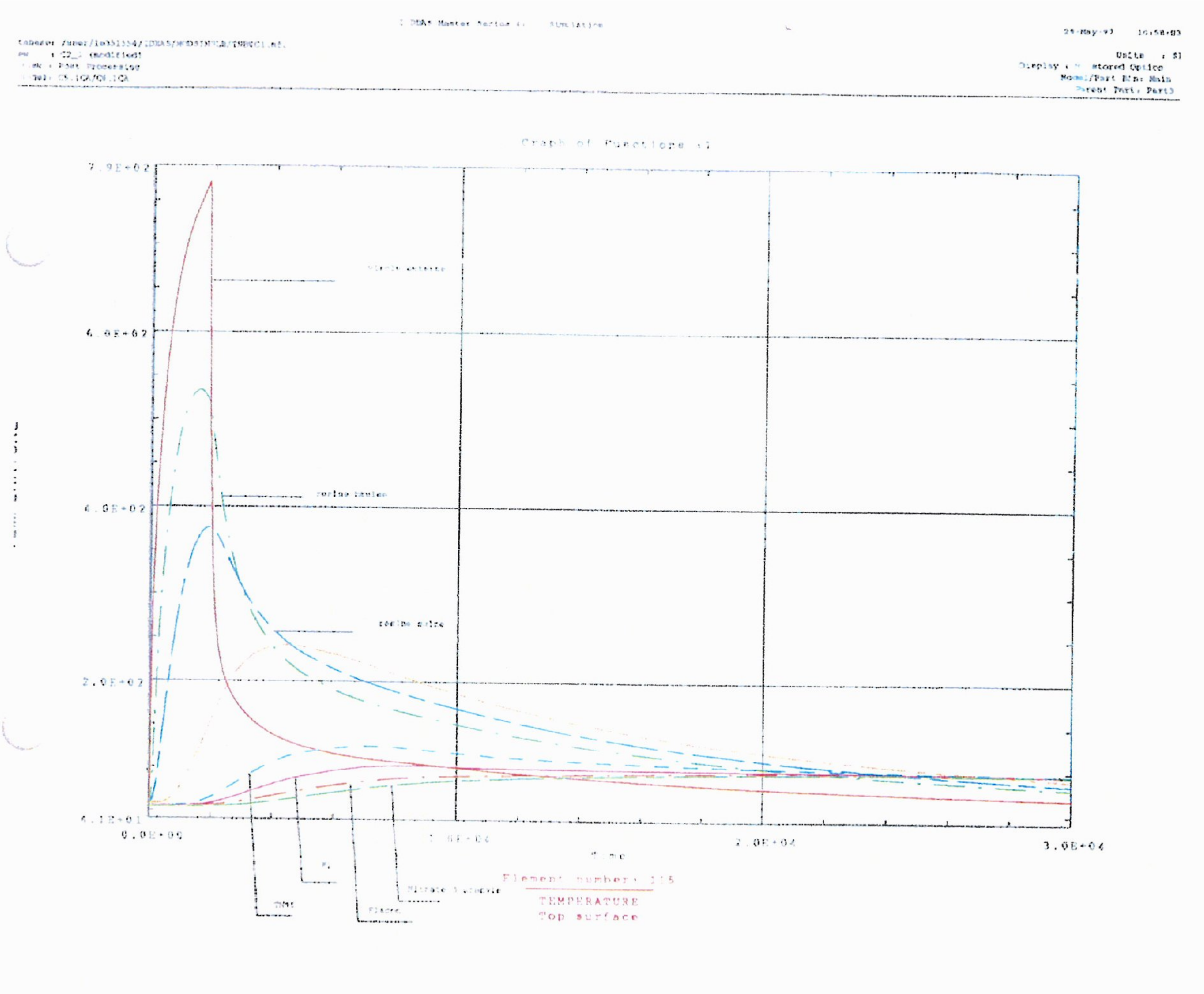

FIGURE 52:
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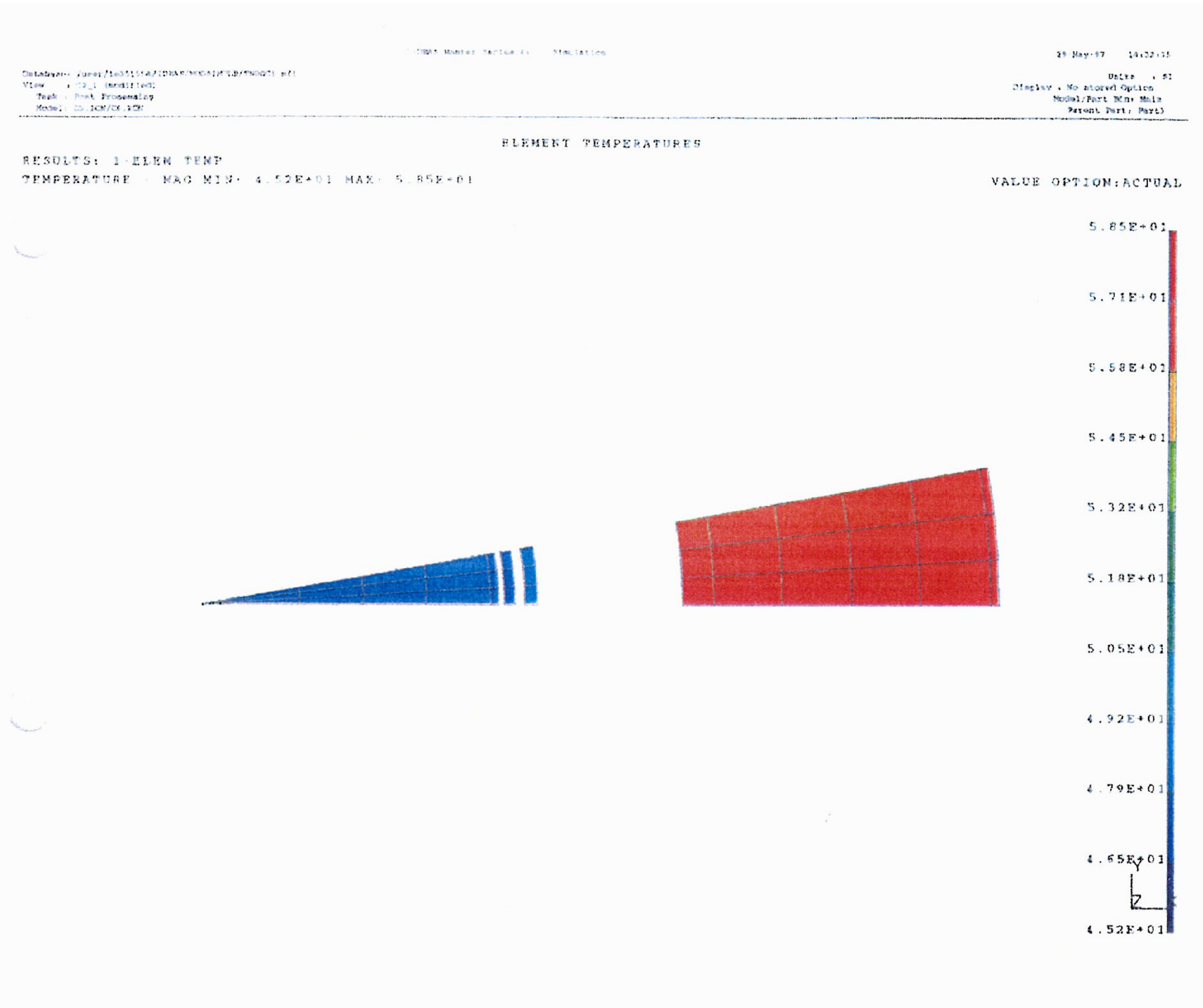

FIGURE 53:
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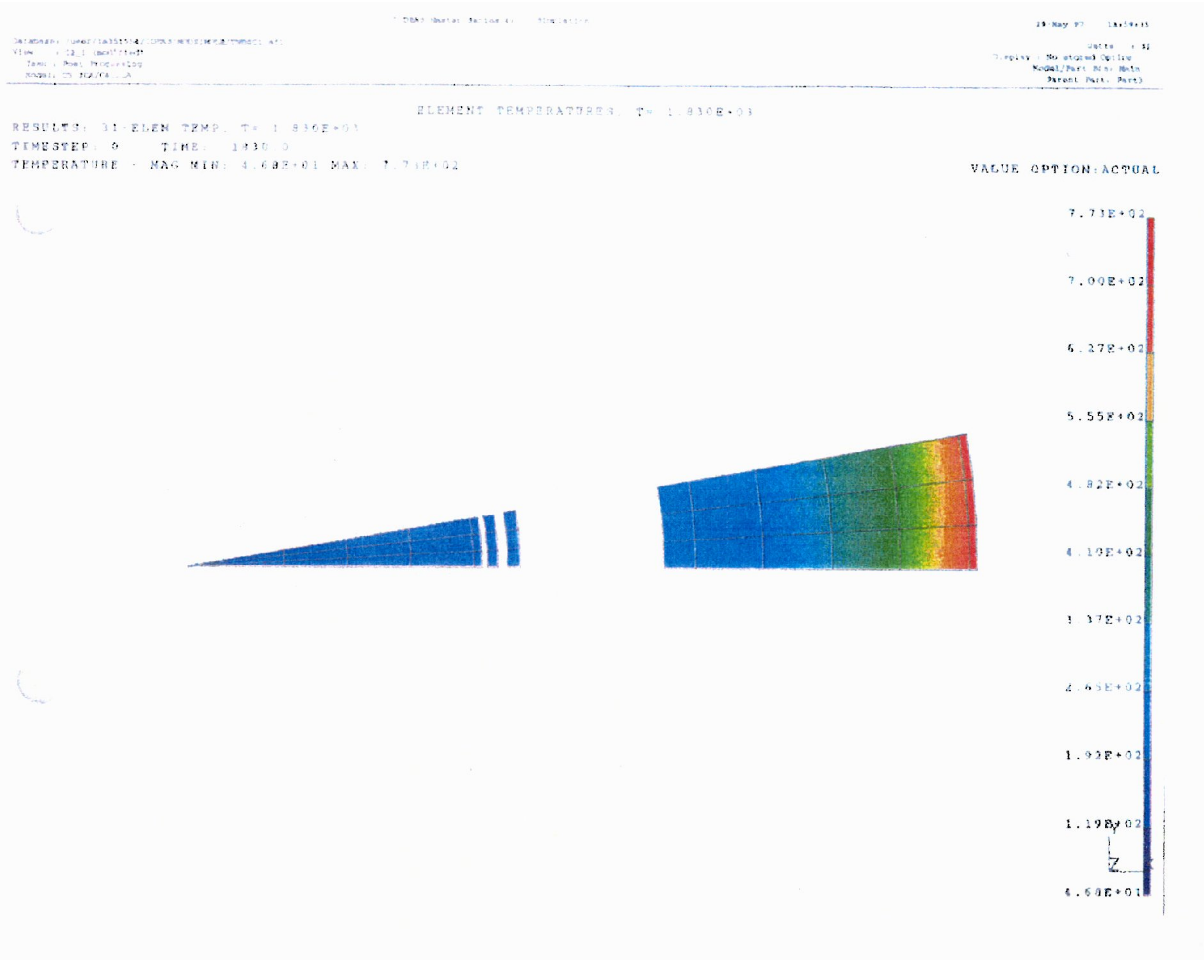

FIGURE 54:
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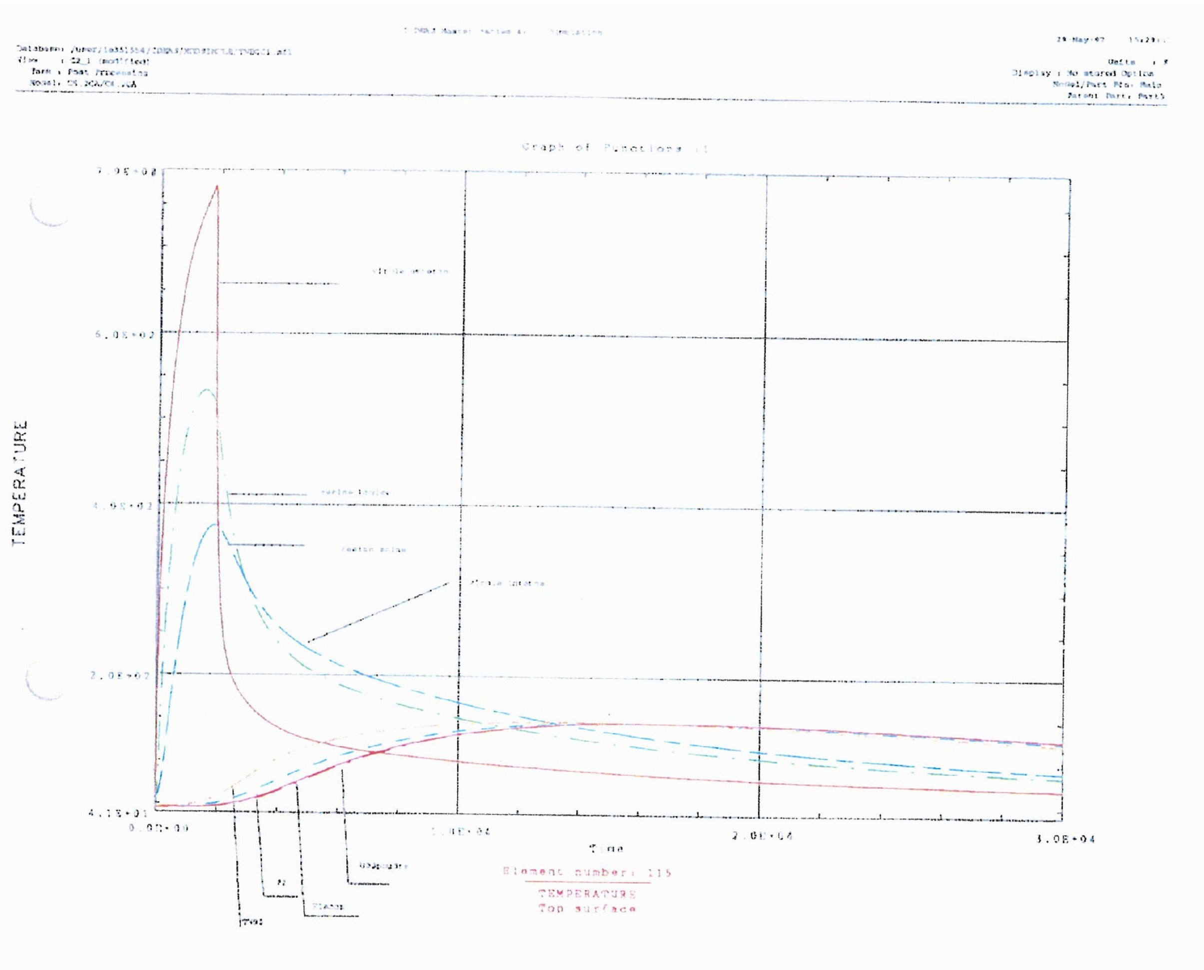

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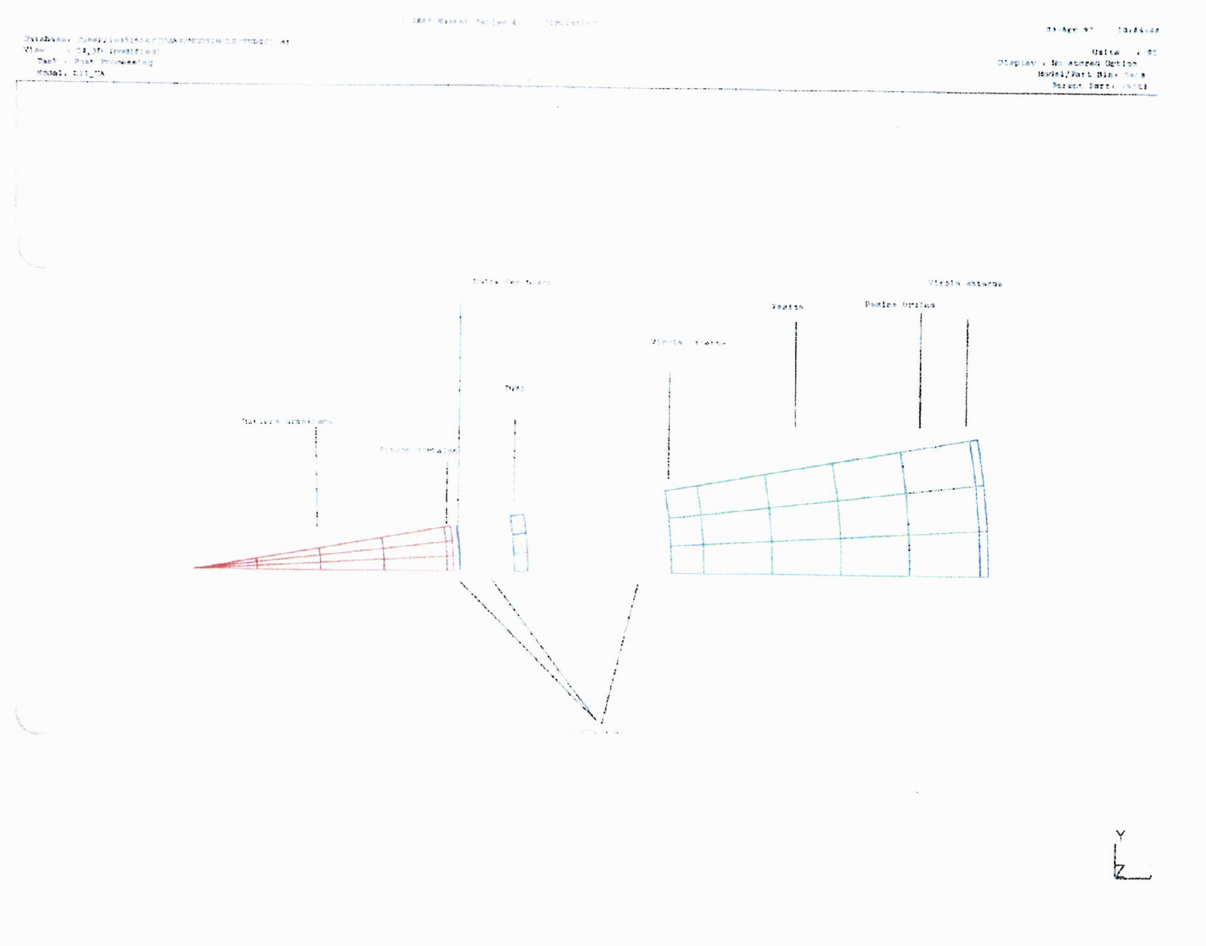

FIGURE 56:
ISOTHERMS OF MODEL C11.B IN NORMAL CONDITIONS OF TRANSPORT

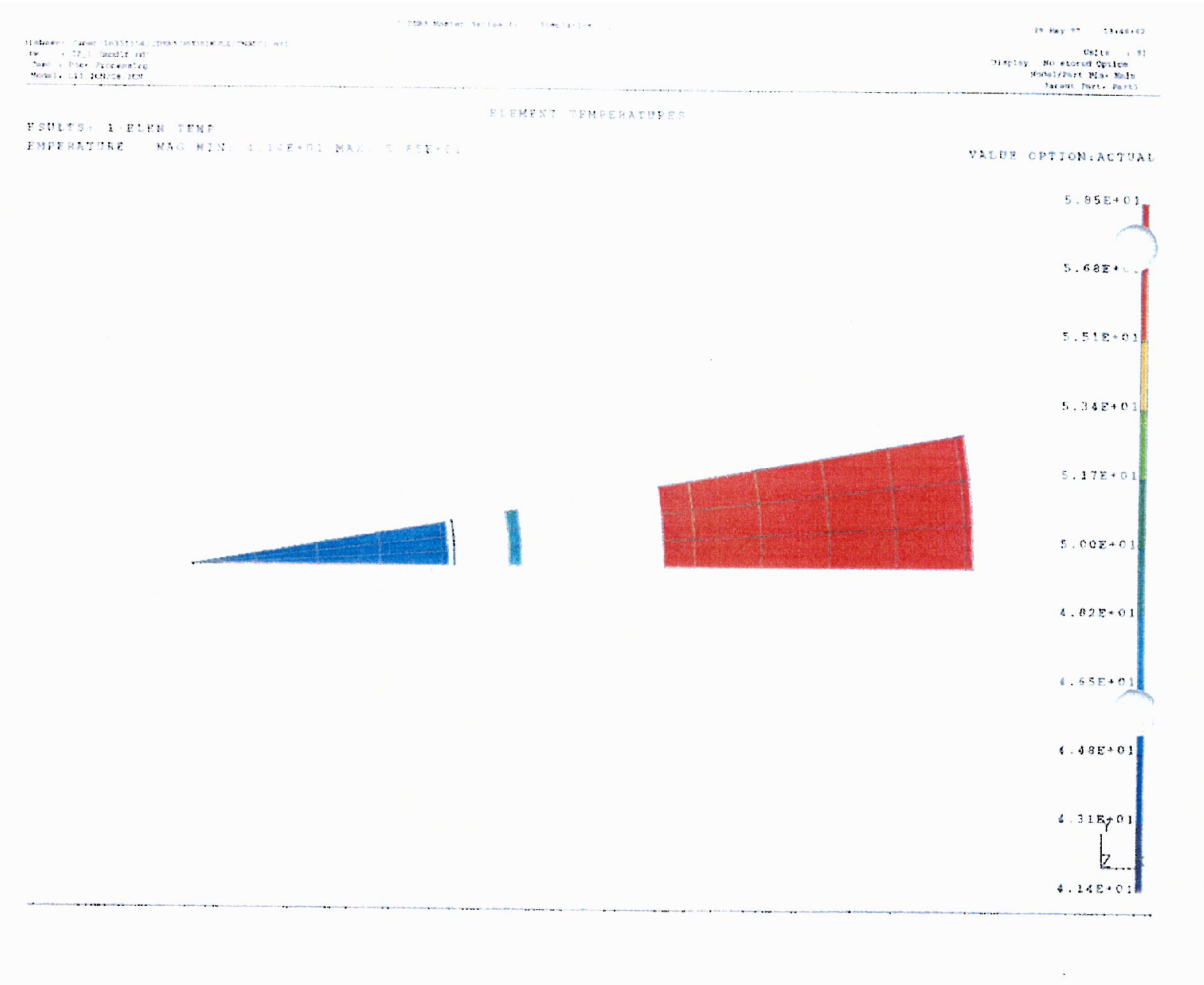

FIGURE 57:
ISOTHERMS OF MODEL C11.B IN ACCIDENT CONDITIONS OF TRANSPORT (T = 1830S)

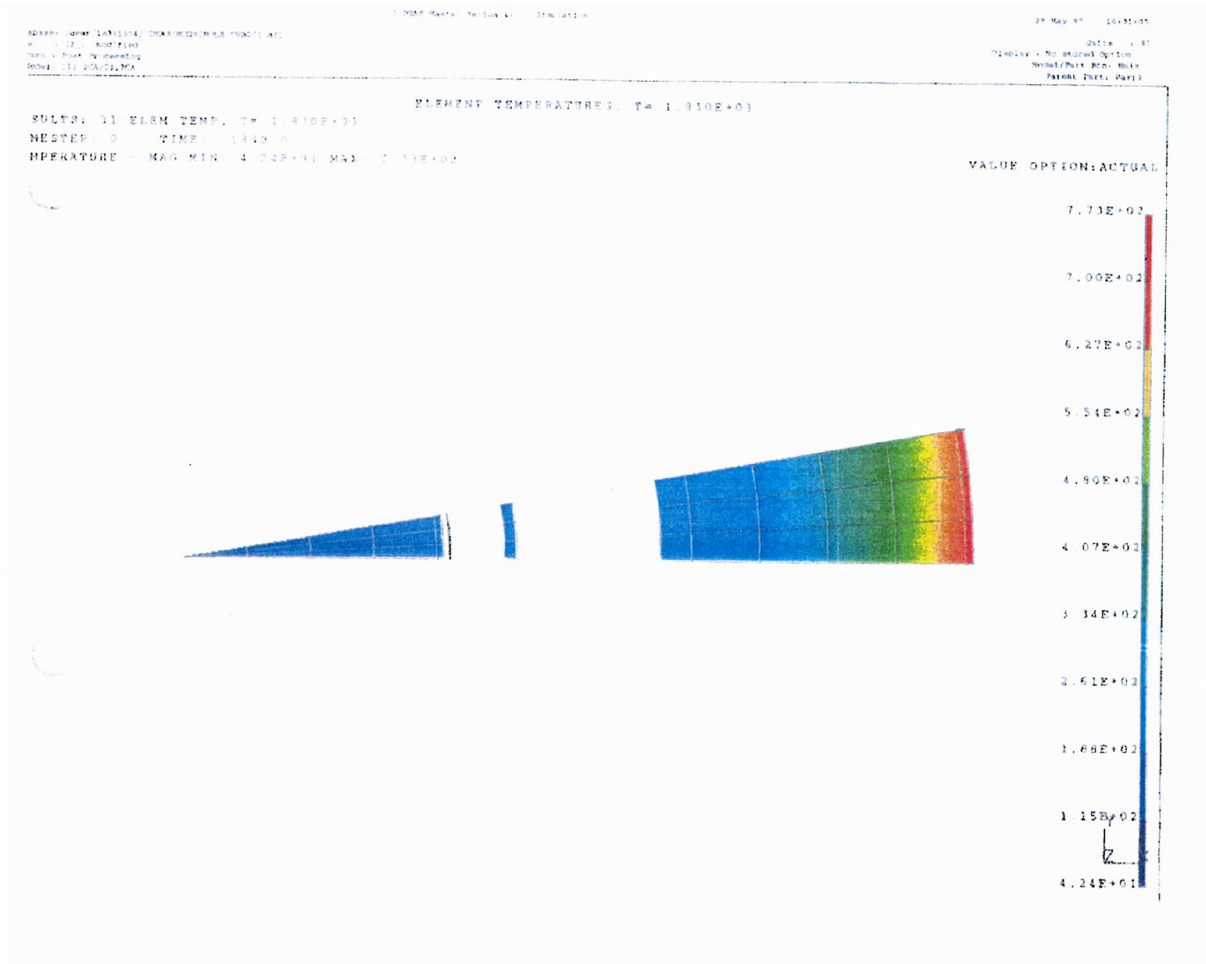

FIGURE 58:
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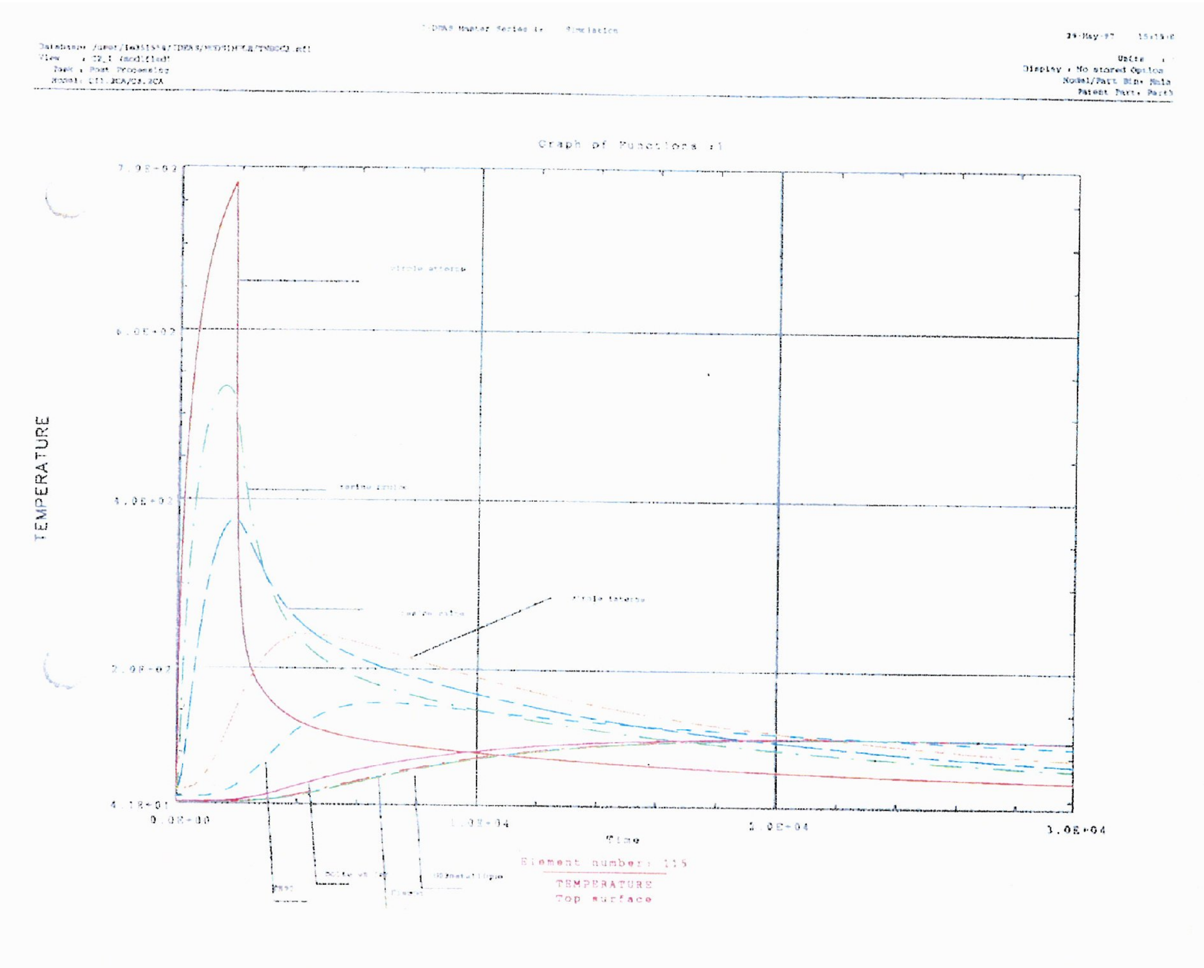

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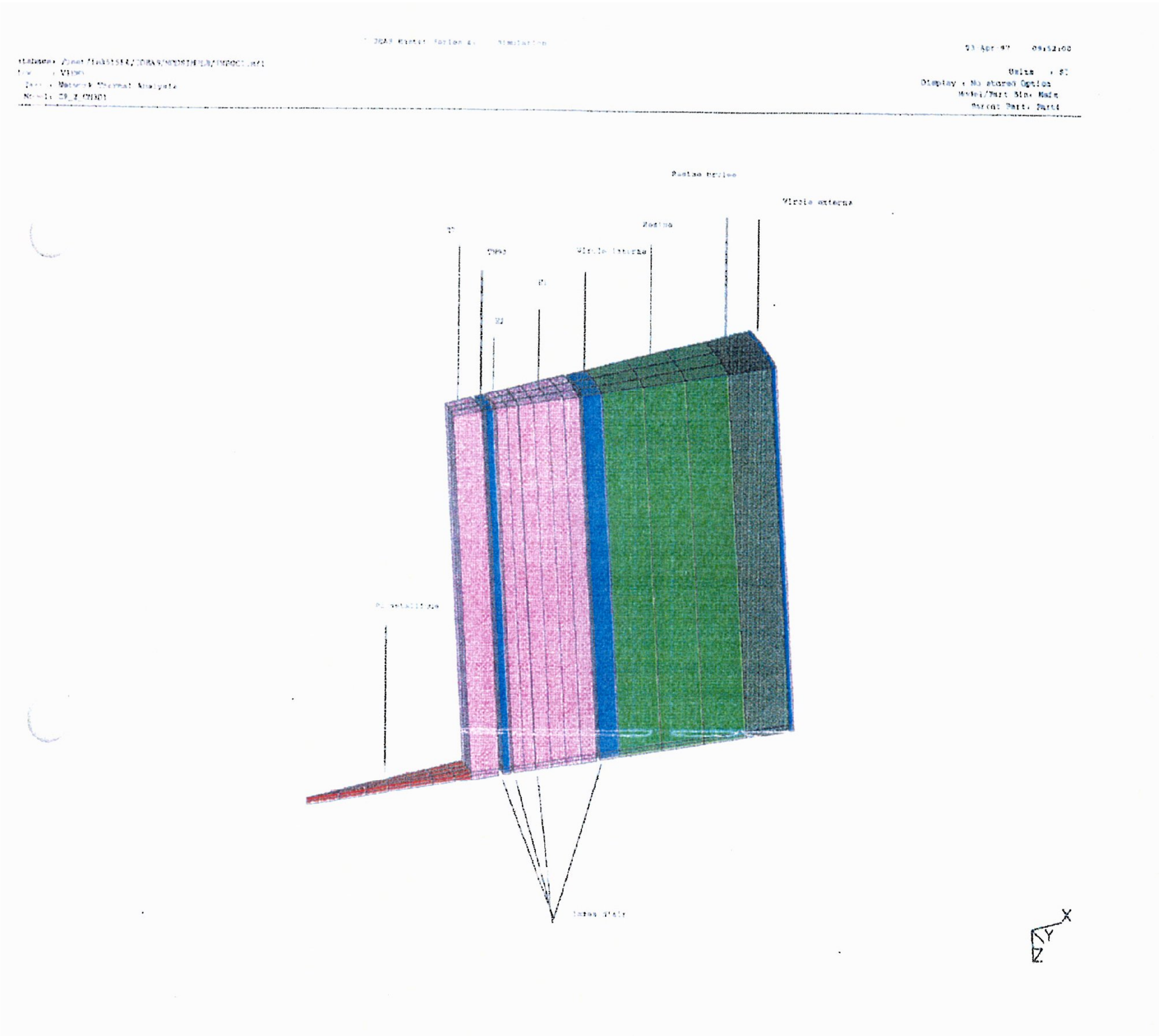

FIGURE 60:
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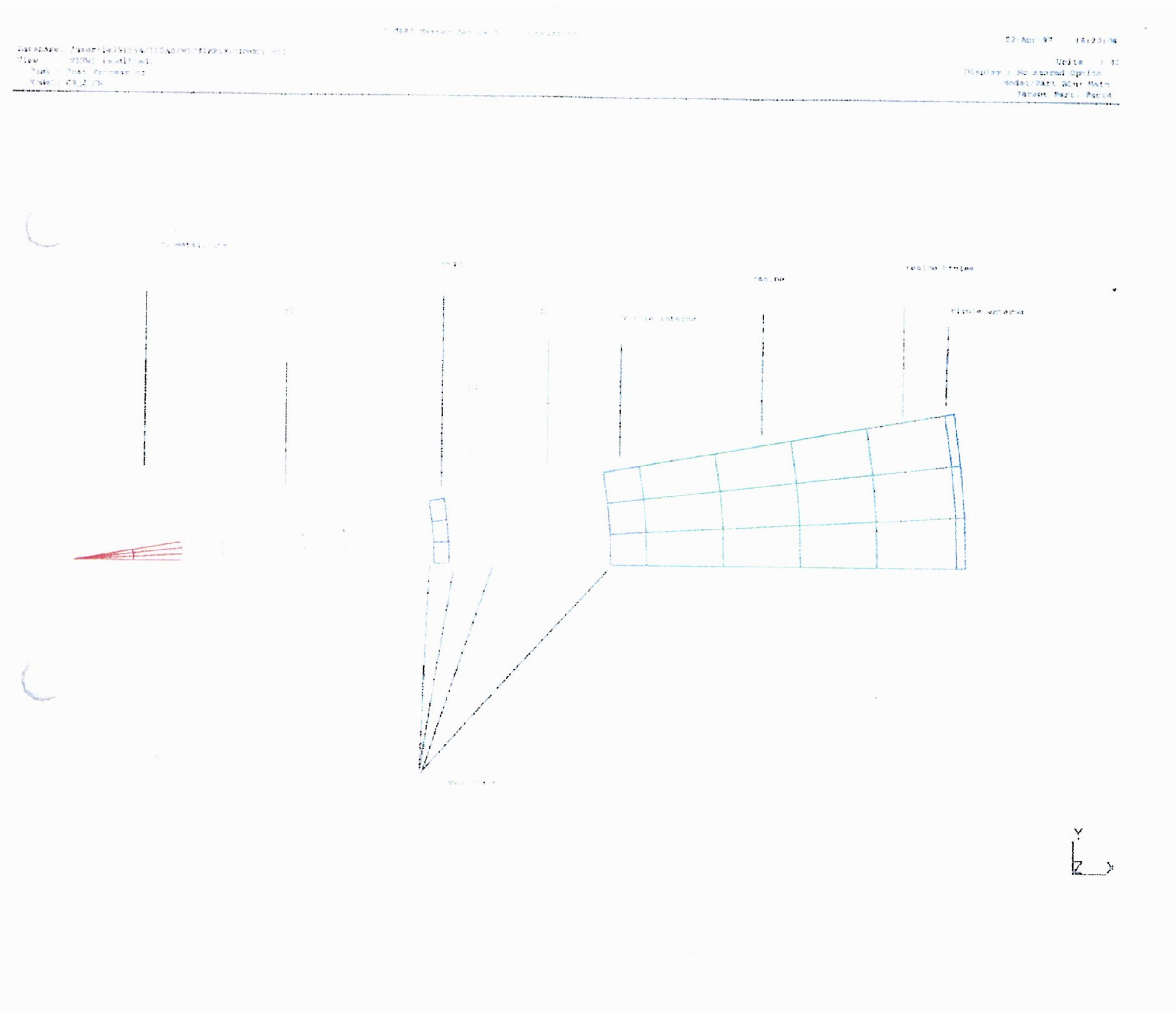

FIGURE 61:
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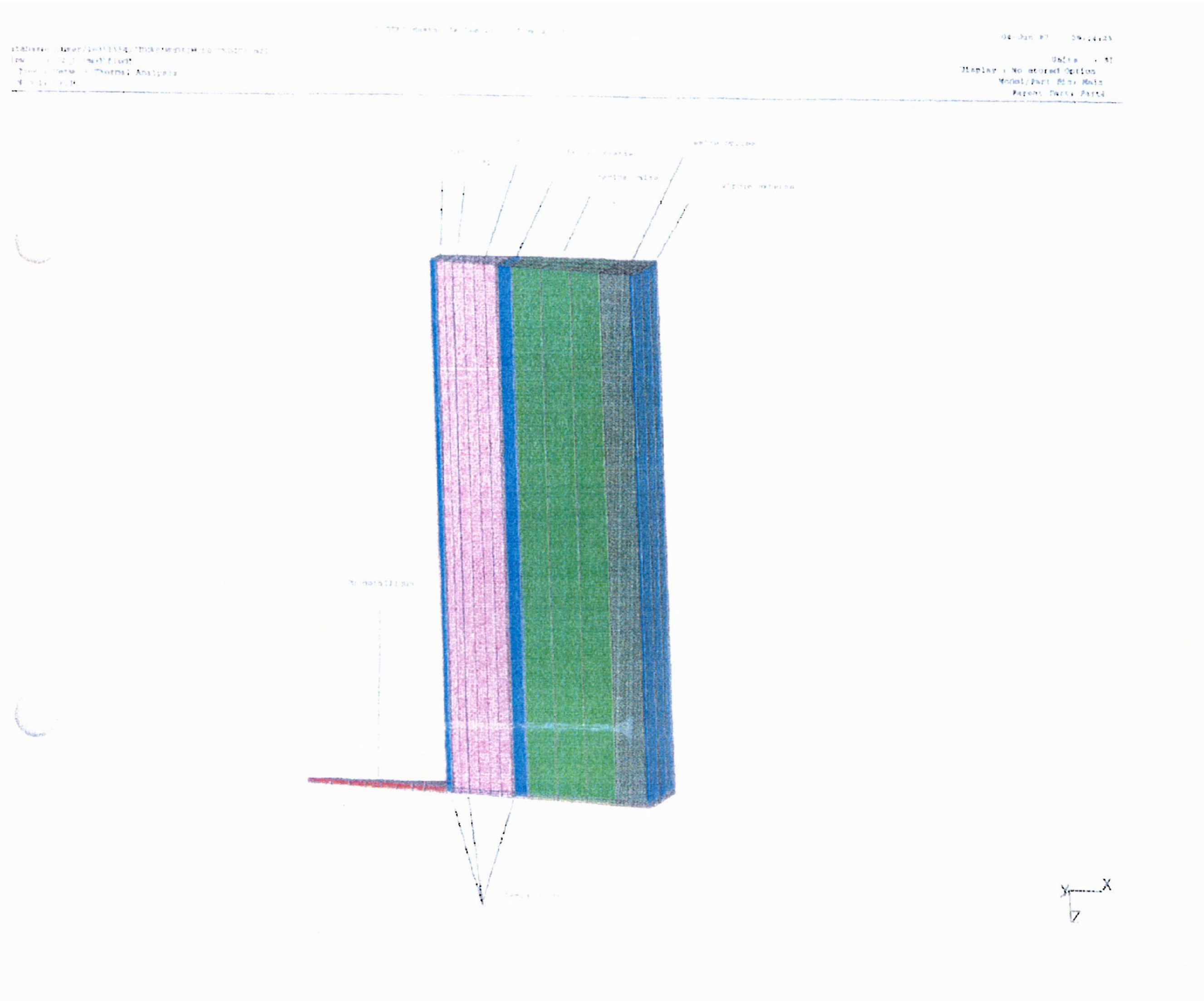

FIGURE 62:
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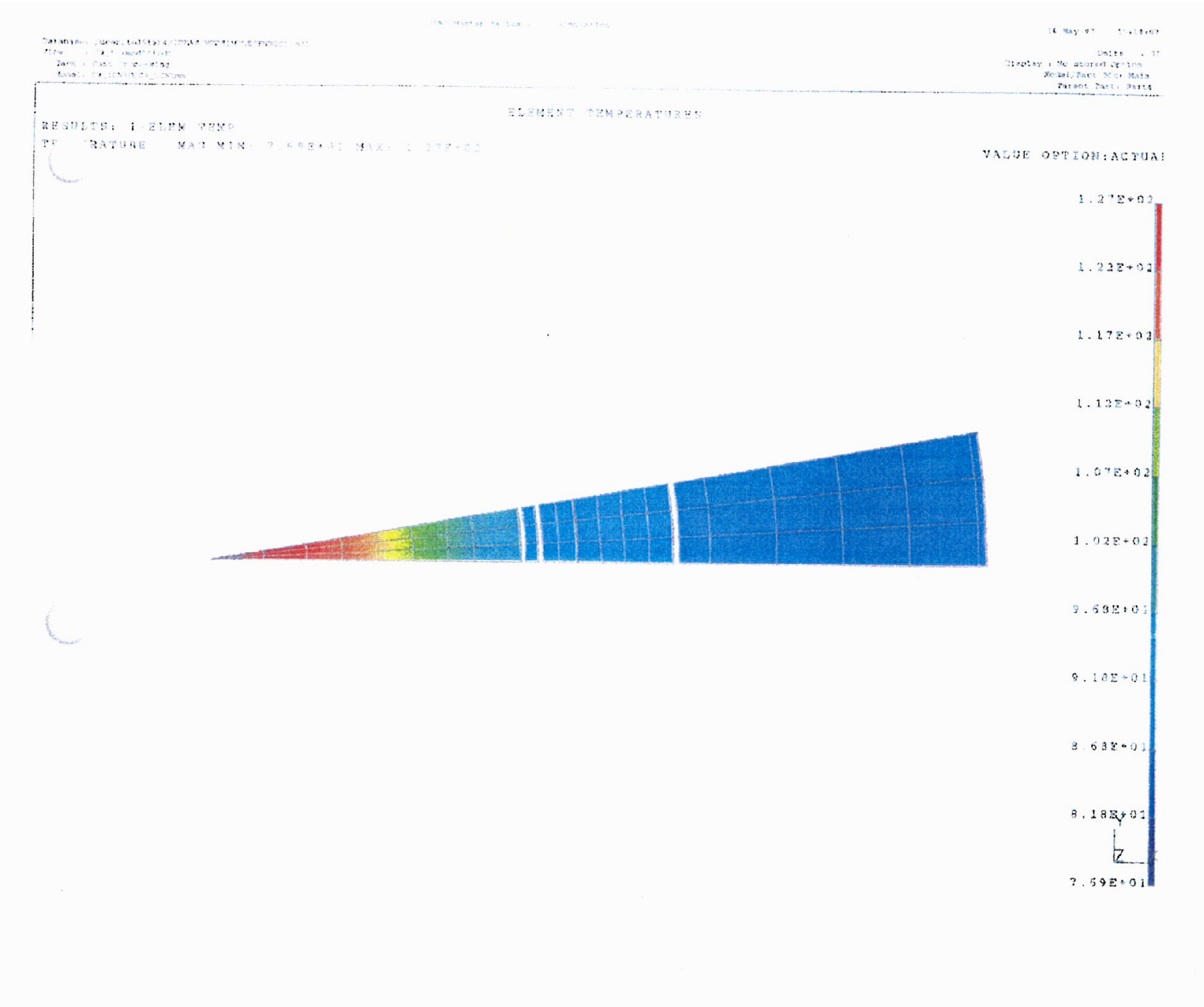

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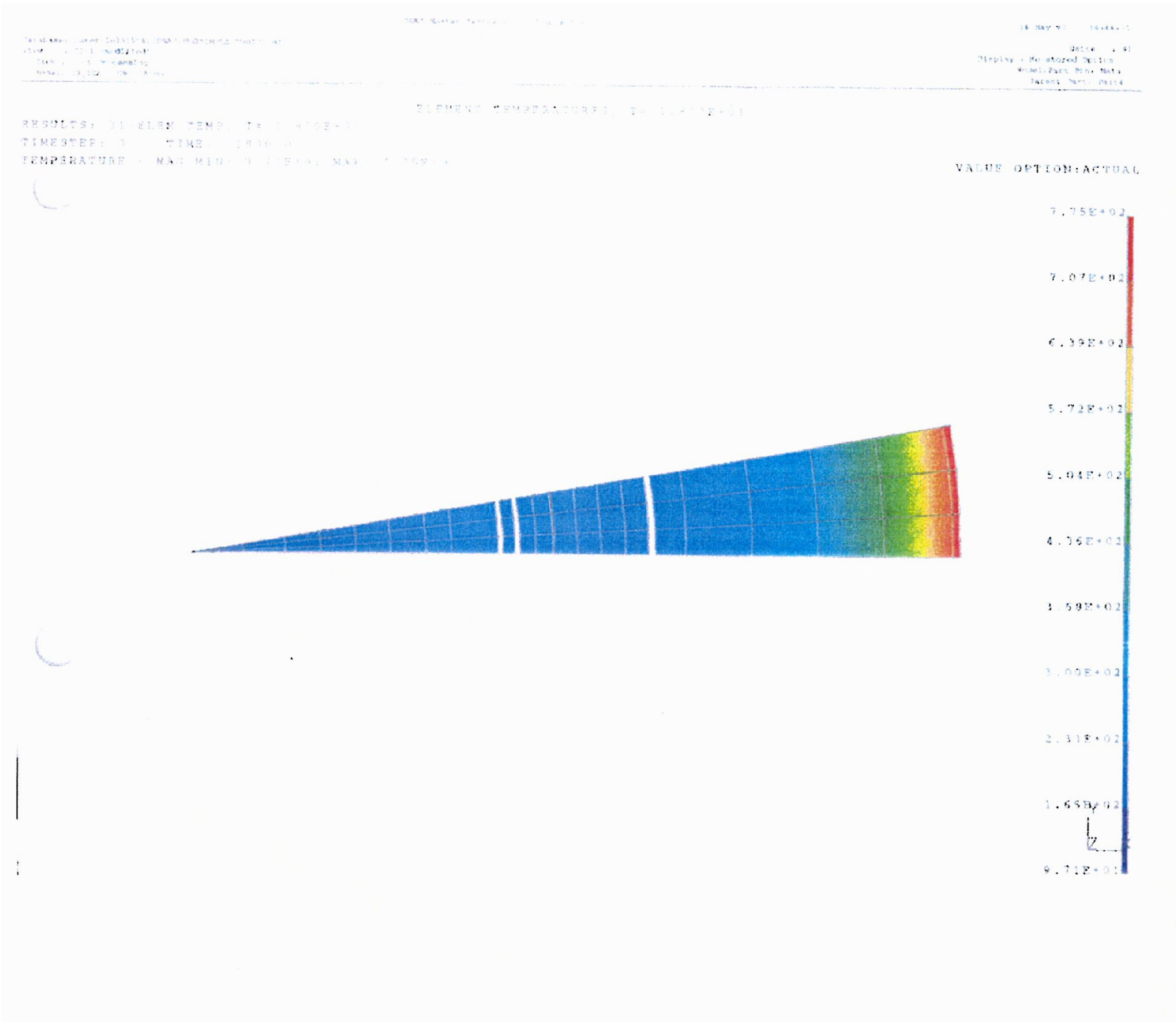

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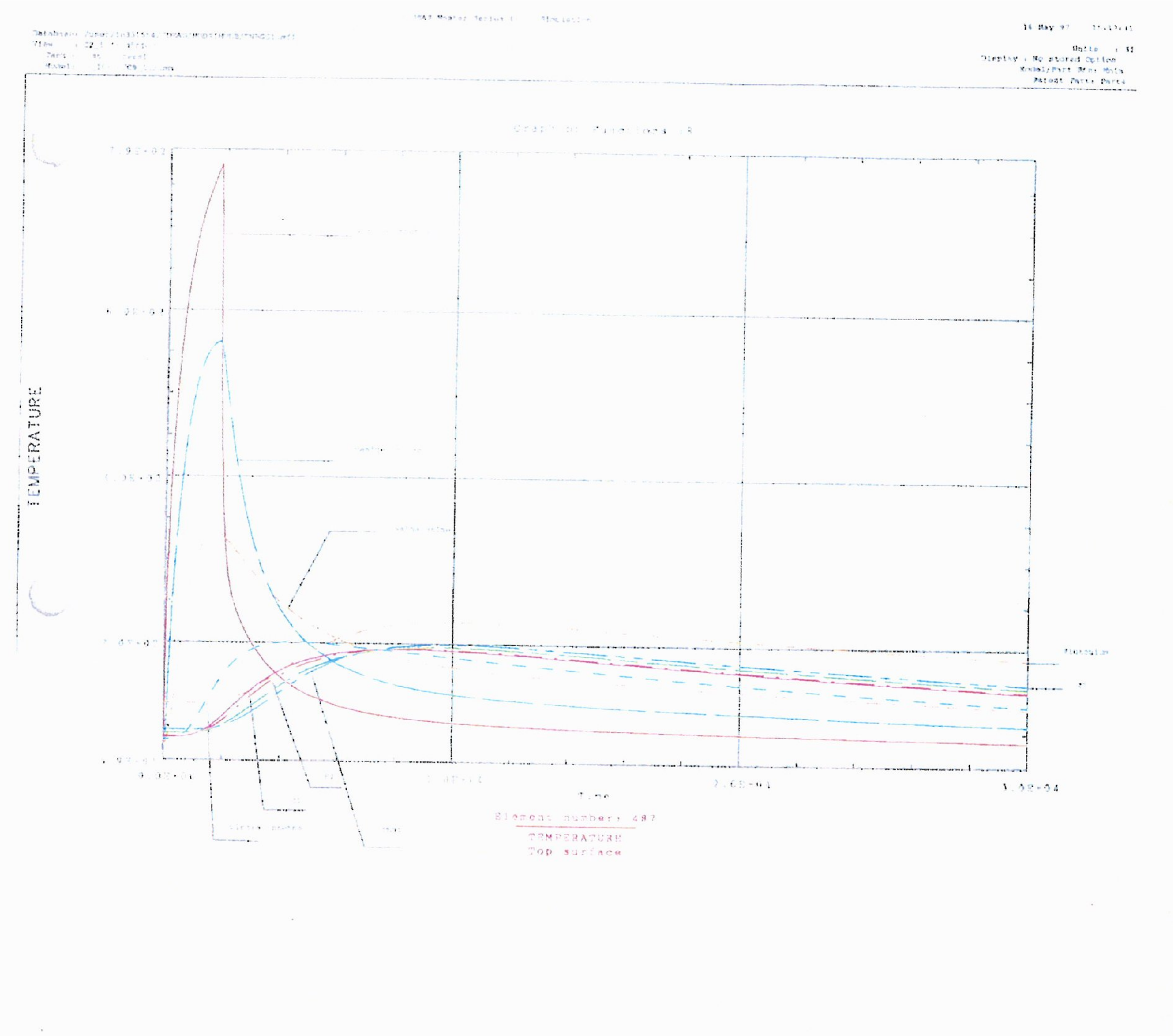

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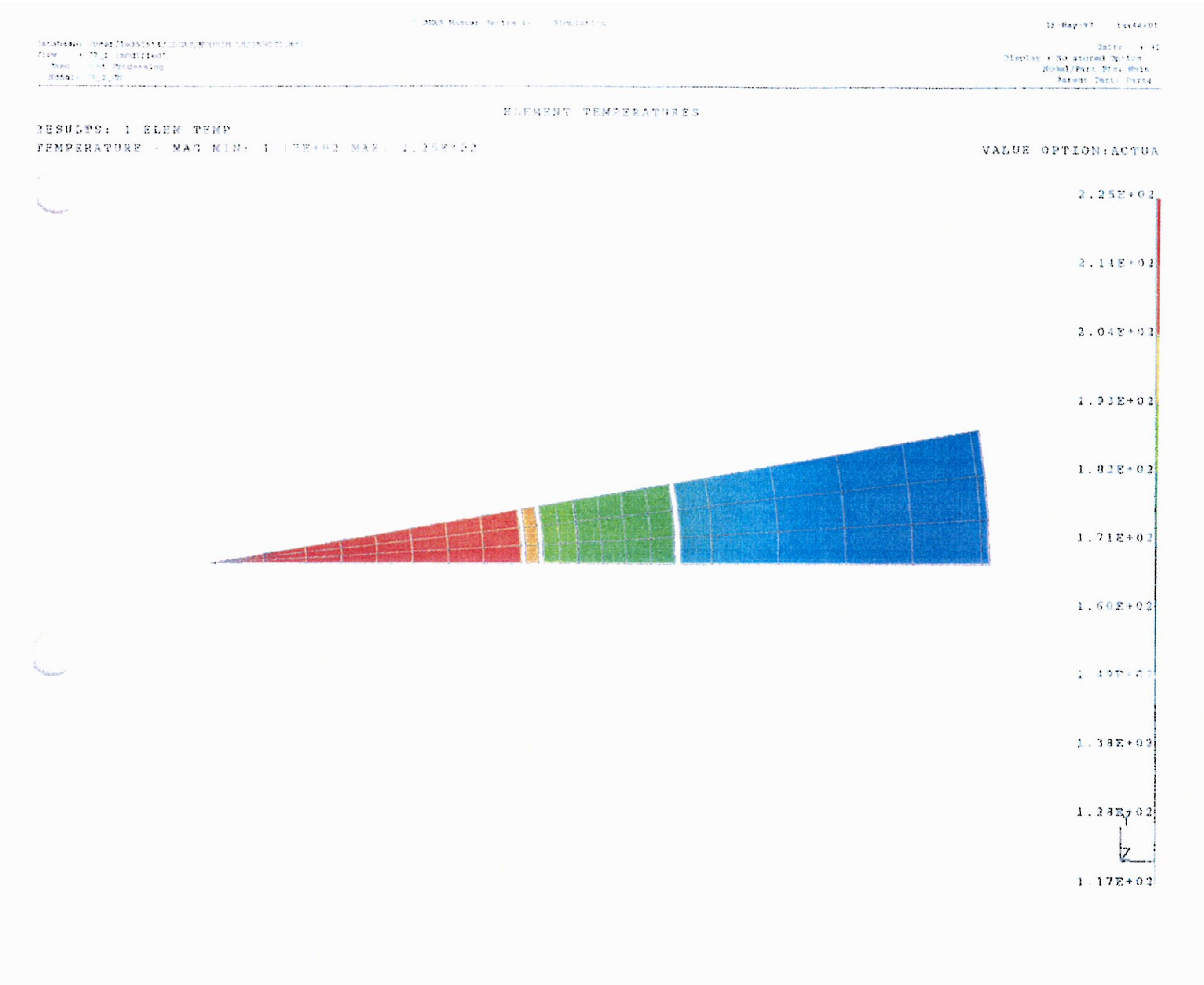

FIGURE 66:
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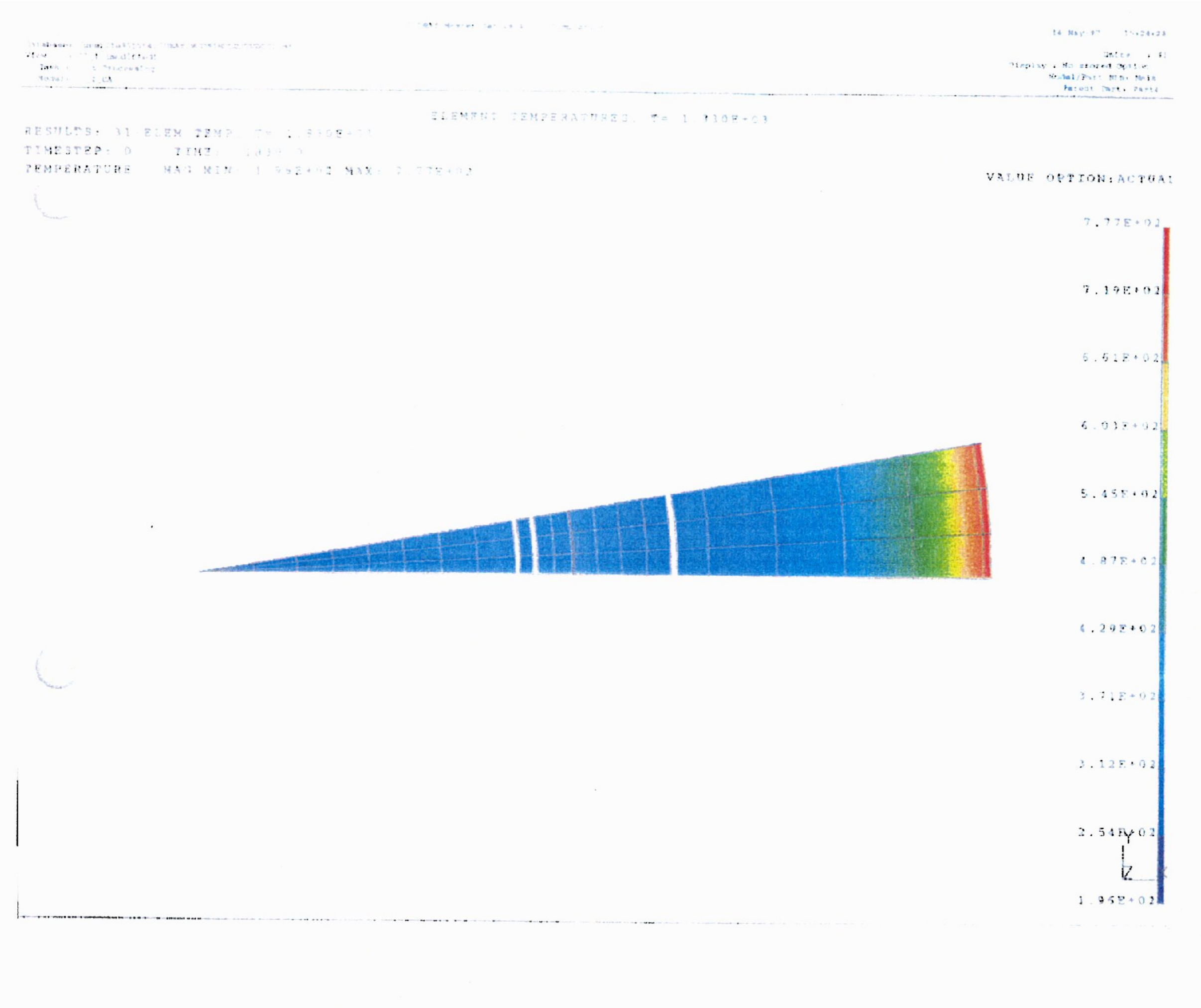

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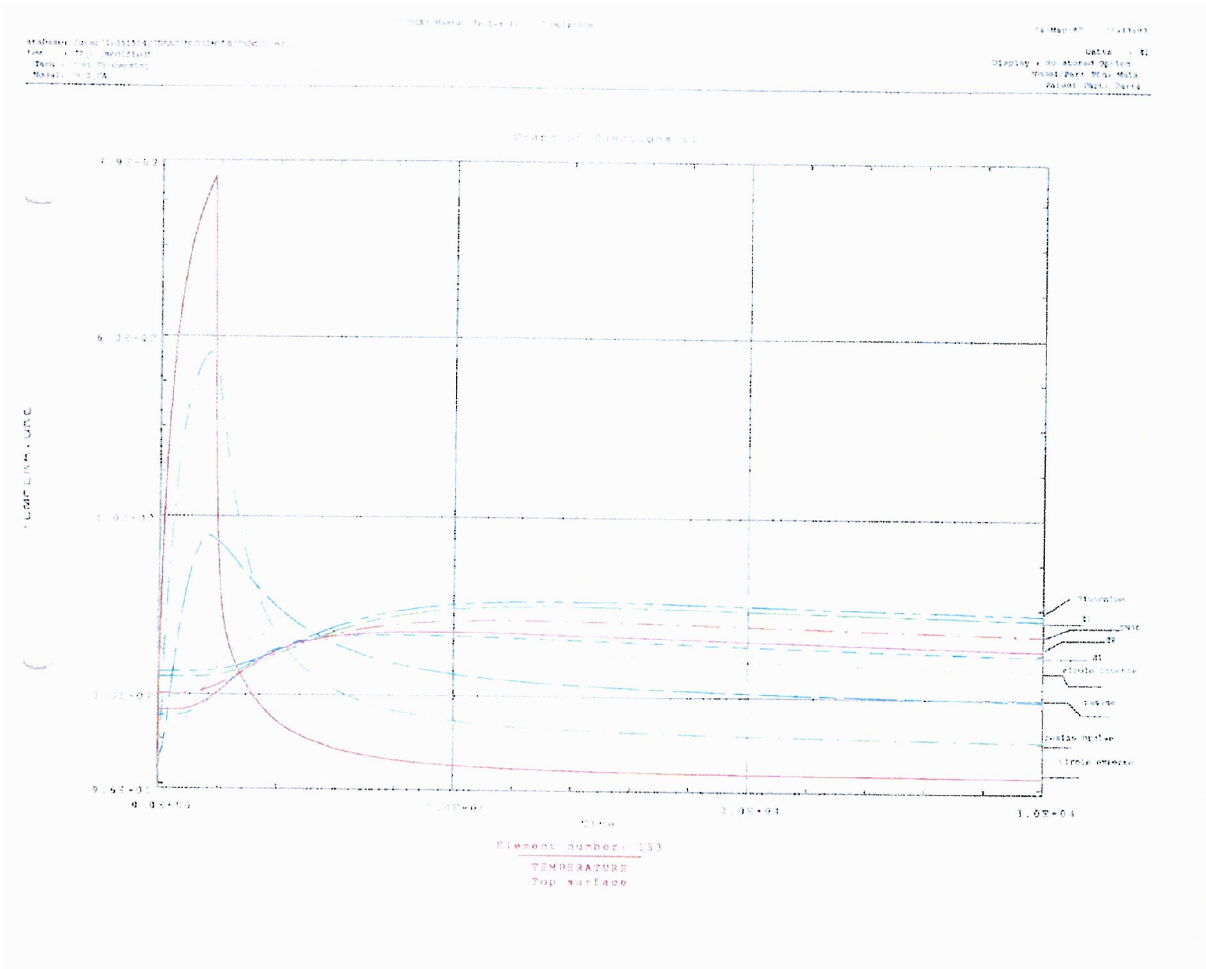

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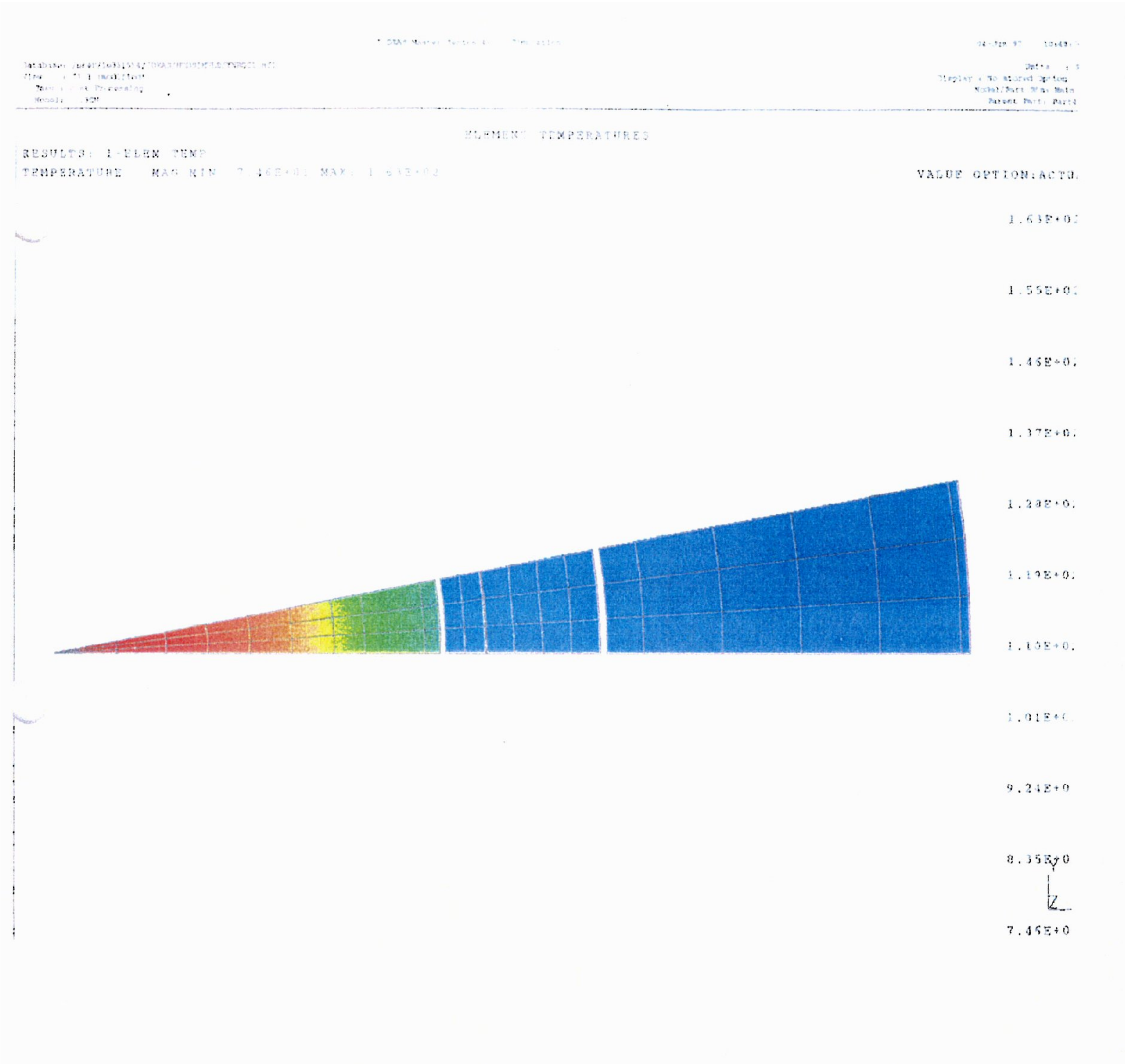

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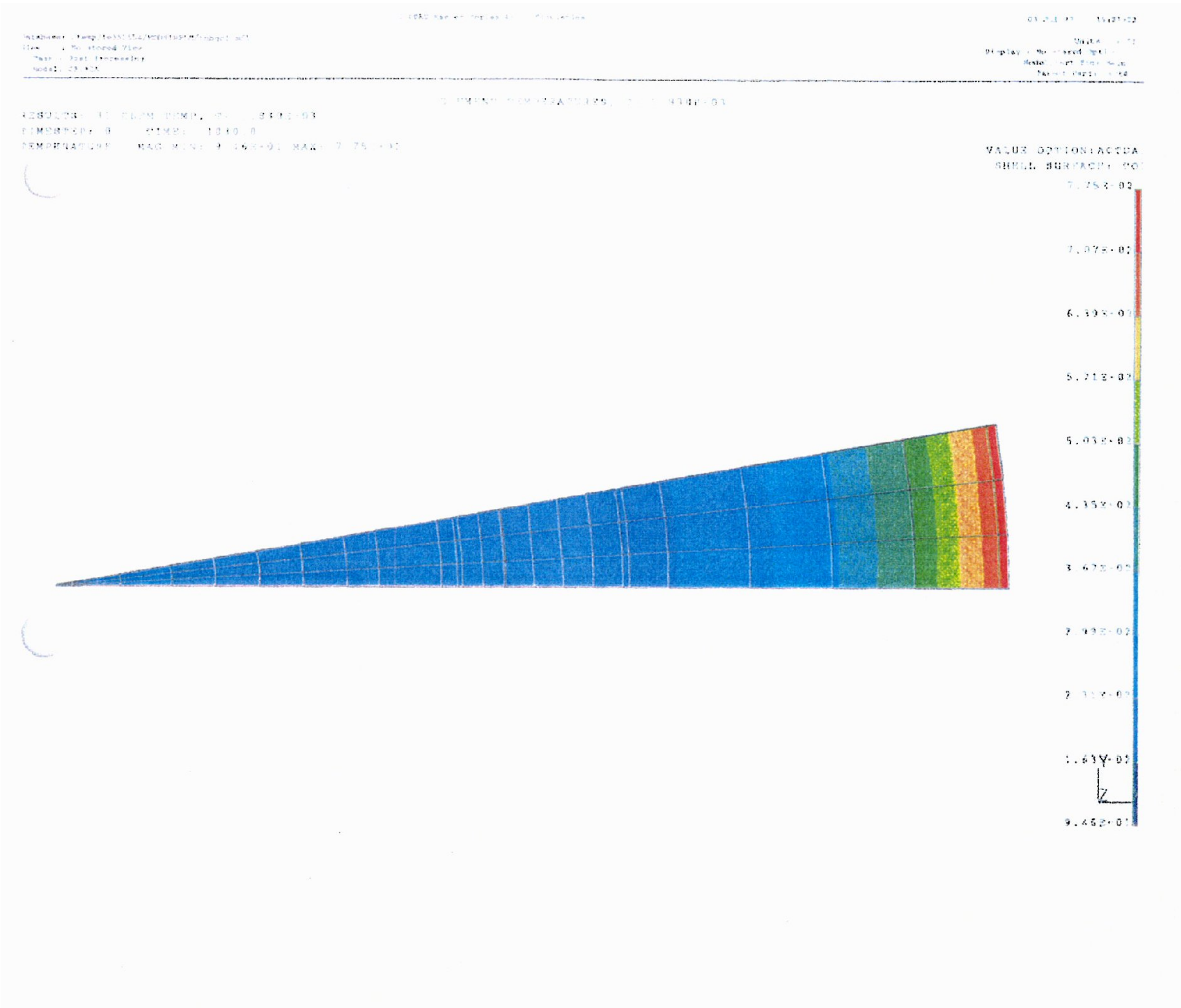

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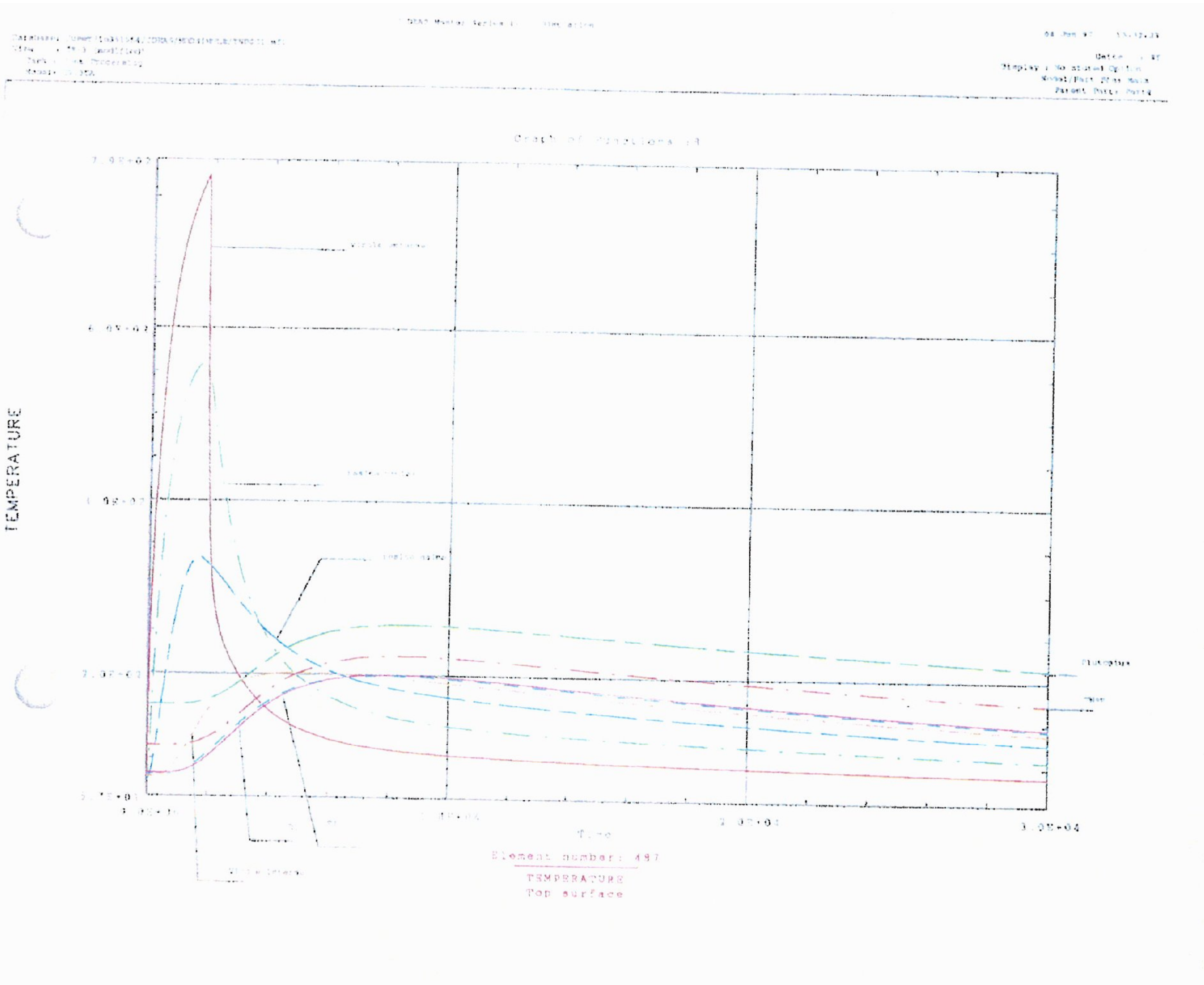

CEA CADARACHE

DESIGN NOTE

THERMAL ANALYSIS OF TN-BGC 1 PACKAGE

Summary: The purpose of this thermal study is to determine the temperature field in the TN BGC 1 packaging in normal and accident conditions of transport.

Key words: Thermal, TN BGC 1, Transport, Normal and accident conditions, Casing.

B.P.E.
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SMT 03/07/06

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SUMMARY

This study aims to define the temperature distribution within the package composed of the TN BGC 1 packaging under different possible installation configurations and contents. These configurations are defined according to the installations that are possible for this package (packing, contents, baskets with or without a cover, spacers, blocks, etc.).

The aim of this service is to prove the resistance:
- of the package model consisting of the TN-BGC1 packaging loaded with its different contents in general,
- of the containment seals in particular,

in accident conditions of transport after the fire test.

Therefore, the objectives are as follows:

OBJECTIVE 1: Thermal calculations **in isolated packages in accident conditions of transport** to determine the temperatures of the different components of the package.

OBJECTIVE 2: Thermal calculations **in the casing in accident conditions of transport** to determine the temperatures of the different components of the package.

This study is conducted with the I-DEAS/TMG finite differences calculation code <2> which simulates thermal phenomena. The digital models implemented are:
- axisymetrical for calculations of isolated packages,
- three-dimensional for calculations of packages in casing.

The calculations demonstrated that the temperatures reached by the different components of the packaging are acceptable and do not undermine their properties. In particular, the temperature of the seals remains lower than their maximum operating temperature and the extrusion temperature.

0 OBJECT

This study aims to define the temperature distribution within the package composed of the TN BGC 1 packaging under different possible configurations and contents. These configurations are defined according to the installations that are possible for this package (packing, contents, baskets with or without a cover, spacers, blocks, etc.).

The aim of this service is to prove the resistance:
- of the package model consisting of the TN-BGC1 packaging loaded with its different contents in general,
- of the containment seals in particular,

in accident conditions of transport after the fire test.

This study is conducted with the I-DEAS/TMG finite differences calculation code <2> which simulates thermal phenomena. The digital model implemented is axisymetrical (calculations in package only) and three-dimensional (calculations in casing).

1 REFERENCE DOCUMENTS

<1> IAEA Safety Standards Series — Regulations for the Safe Transport of Radioactive Material — revised 1996 edition (ST-1 revised).

<2> Software for the calculation of finite elements: I-DEAS Master Series V10 developed by EDS combined with the thermal analysis module TMG

<3> Heat transfer, J. TAINE and J.P. PETIT Edition DUNOD, 1995.

<4> Certification and approval for shipment of a package model DGSNR/SD1/0440/2004 dated 28/07/04

<5> TN BGC1 packaging safety dossier— Chap 3 Appendix 0 — Description of internal installations.

<6> Transnuclear Plan ref 9990-65, 9990-117, 9990-118

<7> Note DEMA— 172C3W01 Ind. F dated 30/06/03 "Thermal analysis of the TN-BGC 1 packaging".

<8> Heat transmission — WH Mc Adams — Chapter VII.

2 CALCULATION CODE

The model is made using I-DEAS <2> software. The thermal calculations are made according to the finite differences method with the TMG module interfacing with I-DEAS.

3 – NOMENCLATURE

The main parameters used in the study are as follows:

a : Absorptivity

C_p: Specific heat (J/kg.K)

E: Sunshine (W/m^2)

F_{gij};: Grey aspect ratio of surface i on surface j

h: Thermal exchange coefficient ($W/m^2.K$)

H: Height (m)

L: Length (m)

P: Thermal power released (W or kW)

r: Radius (m)

S: Surface area (m^2)

T: Temperature (°C or K)

V: Volume (m^3)

ε: Emissivity

λ: Thermal conductivity (W/m.K)

ρ: Density (kg/ m^3)

σ: Stefan Boltzmann constant ($5,674.\ 10^{-8}$ $W/m^2.K^4$)

ΔT: Temperature difference (°C or K)

4 TYPE OF CALCULATIONS

The different transport conditions studied are as follows:

Calculations in normal conditions of transport (NCT):

- The package is placed in an environment of 38°C,
- The solar flux is imposed on the outer surfaces of the packaging according to normal conditions of transport defined in regulations <1>,
- The package is transported vertically,
- Thermal exchanges via conduction, radiation and convection are considered, particularly:
  - convectional and radiative exchanges between the outer surface of the packaging and the ambient air,
  - the conductive and radiative exchanges are taken into account in all the gaps and air zones of the packaging.

– **Calculations in accident conditions of transport (HAC):**

- The package is placed in an environment of 800°C for half an hour, according to the fire conditions defined in regulations <1>, then the rest of the time in an environment of 38°C in statutory sunshine <1>,
- The package is transported horizontally,
- The initial temperatures of the package, before the application of fire conditions, are those determined in normal conditions of transport,
- Thermal exchanges via conduction, radiation and convection are considered:
- The calculation model is the same as that used for normal conditions of transport,

– **Calculations in accident conditions of transport in casing:**

- The casing carries 12 or 24 packagings in a vertical position,
- The outer temperature is 38°C,
- The solar flux is imposed on the outer surfaces of the casing according to normal conditions of transport defined in regulations <1>,
- Thermal exchanges via conduction, radiation and convection are considered:
- The exchange surfaces are considered as straight, the corrugations (corrugated iron) are not taken into account for convectional and radiative exchanges,
- However, the solar flux imposed on the walls of the casing takes into account the real exchange surfaces.

5 METHODOLOGY

The methodology used to conduct calculations in the casing is as follows:

- <u>Calculations in casing</u>

  The casing carries the packagings in a vertical position. Only the outer surfaces of the shell and the wooden covers are modelled. The distances between each packaging, considered as the smallest possible ones (this also applies to distances between the packaging and the inner wall of the casing), are taken in relation to the dimensions of the cage.
  In a detrimental manner, the thermal load is applied onto the outer shell of the packaging.

- <u>NCT axisymmetric 2D calculations</u>

  The maximum temperature of the hottest generator of the packaging outer shell (resulting from the calculation in the casing) is imposed as the threshold conditions for the axisymmetric 2D model to determine the temperature field within the packaging.
  The calculation is carried out in a permanent state.

- <u>HAC axisymmetric 2D calculations</u>
  The initial temperature field comes from the previous calculations.
  The calculation is carried out in a transient state.

The methodology used allows us to carry out axisymmetric calculations based on a three-dimensional calculation in the casing with a simplified modelling of the packaging in the casing (outer shell only). A calculation in the casing followed by two axisymmetric calculations are required to obtain the temperature field of the package in accident conditions of transport in the casing.

6 CALCULATION CONFIGURATIONS

6.1 ISOLATED PACKAGE

Config.	Primary packing	Baskets, Spacers, Covers	Secondary packing	basket, spacer, blocks	Tertiary packing	Outer spacers	Contents	Power	Power to weight	Comments
C1.1	Box x4	covers	AA213 x 4	-	AA226	E1	PuO2 powder	4 x 20 W	20 W/Kg	
C1.2	Box x4	-	AA213 x 4	-	AA226	E1	PuO2 powder	4 x 85 W 340 W	20 W/Kg	
C2.1	Box x4		AA303	block	AA227	E1	PuO2 powder	4 x 85 W 340 W	20 W/Kg	block replaced by air gap
C2.2	Box x5	-	AA236	blocks	AA227	E1	PuO2 powder	5 x 68 W 340 W	20 W/Kg	block replaced by air gap
C3.1	Box x4	-	AA99 x 4	P1 basket	TN90	E1 + E2	PuO2 powder	4 x 85 W 340 W	20 W/Kg	
C3.1bis	Box x4	-	AA99 x 4	Basket P1	TN90	E1 + E2	PuO2 powder	4 x 100 W 400 W	20 W/Kg	
C3.2	Box x4	covers	AA99 x 4	Basket P1	TN90	E1 + E2	PuO2 powder	4 x 20 W	15 W/Kg	
C3.2bis	Box x4	covers	AA99 x 4	Basket P1	TN90	E1 + E2	PuO2 powder	4 x 15 W	15 W/Kg	
C3.3	Box x4	covers	AA99 x 4	Basket P1	TN90	E1 + E2	PuO2 powder	4 x 20 W	20 W/Kg	
C3.3bis	Box x4	covers	AA99 x 4	Basket P1	TN90	E1 + E2	PuO2 powder	4 x 25 W	20 W/Kg	
C4.1	Box x4	-	AA99 x 4	-	AA204	E1+ E10	PuO2 powder	170 W 4 x 42.5 W	20 W/Kg	
C4.2	Box x4	covers	AA99 x 4	-	AA204	E1+ E10	PuO2 powder	4 x 20 W	20 W/Kg	
C4.3	Box x2		AA99 x 2	-	AA203	E1 + E8	PuO2 powder	170 W	20 W/Kg	
C4.4	Box x2	covers	AA99 x 2	-	AA203	E1 + E8	PuO2 powder	2 x 20 W	20 W/Kg	
C4.5	Box x 1		AA99 x 1	-	AA41 x 1	E1+ E11	PuO2 powder	100 W	20 W/Kg	
C4.6	Box x 1	covers	AA99 x 1	-	AA41 x 1	E1+ E11	PuO2 powder	1 x 20 W	20 W/Kg	
C4.7	Box x2	-	AA99 x 2	-	AA41 x 2	E1+ E12 + E13	PuO2 powder	170 W 2 x 85 W	20 W/Kg	
C4.8	Box x2	covers	AA99 x 2	-	AA41 x 2	E1+ E12 + E13	PuO2 powder	2 x 20 W	20 W/Kg	
C4.9	Box x3	-	AA99 x 3	-	AA41 x 3	E1+ E9 + E13	PuO2 powder	170 W 3 x 56.6 W	20 W/Kg	
C4.10	Box x3	covers	AA99 x 3	-	AA41 x 3	E1+ E9 + E13	PuO2 powder	3 x 20 W	20 W/Kg	
C5.1	AA97 x2	P2 basket	TN 90	-	-	E3	UO2 powder	2 x 2 W	0.1 W/Kg	complete filling
C7.1	E4 spacer set	-	TN 90	P4 basket	-	E1 + E2	U bar	4 W	-	8 housing units filled, 1 empty
C7.2	E4 spacer set	-	TN 90	P4 basket		E1 + E2	Pu bar	340 W	-	8 housing units filled, 1 empty
C8	E5 spacer set	-	TN 90	-	-	E1 + E2	Zebra Pu plates	150 W 6 x 25 W	-	each level completely filled
C9	E7	-	TN 90	-	-	E1 + E2	uraniferous material	16 W	0.11 W/Kg	power surrounded by stainless steel casing
C10.1	R1 rack	-	TN 90	-	-	E1 + E2	MOX pencil	340 W	340/20 i.e. 17 W/Kg	Pencils packed down at head end
C10.2	R1 rack	-	TN 90	-	-	E1 + E2	MOX pencil	340 W	Height 1 m	60 pencils evenly spread out
C10.3	R1 rack	-	TN 90	-	-	E1 + E2	MOX pencil	340 W	Height 1 m	10 pencils evenly spread out

6.2 PACKAGE IN CASING

Config.	Power per packaging	Power in casing	distribution	Configuration of package
CA1	4 x 20 W	12 x 80 W	12 packages at bottom of casing	config C4.2
CA2	100 W	12 x 100 W	12 packages at bottom of casing	config C4.5
CA3	4x 50W	12 x 200 W	12 packages at bottom of casing	config C3.1 (at 200 W)
CA4	4 x 20 W	24 x 80 W	24 packages at bottom of casing	config C4.2
CA5	**100** W	24 x 100 W	24 packages at bottom of casing	config C4.5
CA6	340 W	7 x 340 W	7 packages at bottom of casing	config C2.1

7 MODELLING

7.1 HYPOTHESES

The calculation model is performed in accordance with the plans provided by the CEA ref. <4>, <5> and <6>, with 1-DEAS software ref. <2>.

The main modelling hypotheses are as follows:

- Modelling of the TN-BGC packaging is axisymmetric on a vertical axis, and three-dimensional for the casing
- The vertical position in normal conditions of transport and horizontal in accident conditions of transport is a detrimental hypothesis while it reflects the reality of the transportation (loaded packaging secured vertically),
- The heat sources are modelled via cylindrical volumes,
- The dimensions of the packaging chosen for the modelling are as follows (ref <6>):

– The radius of the cavity is 181 mm,

– The thickness of the resin is 49.5 mm,
– The thickness of the internal and external shells is 6 mm and 1.5 mm respectively,
– The length of the packaging (with cover) is taken as 1,794 mm (covers in contact with the body),
– The effective height of the packaging is 1,475 mm.
.

- The dimensions of the casing are as follows:

	Outside	Inside	Thickness of walls
Length (m)	6.13	5.91	0.11
Width (m)	2.50	2.28	
Height (m)	2.26	2.04	

NOTE: The exchange surfaces are considered as straight, the corrugations are not taken into account for convectional and radiative exchanges. However, the solar flux imposed on the walls of the casing takes into account the real exchange surfaces.

- The different axial and radial clearances are considered when "cold" (the thermal expansion of the materials is not considered),
- The aluminium cage and cut sheets are not taken into account,
- The axial and radial clearances between the plug and the packaging are zero (perfect thermal contact),
- The internal packing, blocks, baskets, spacers and power zones are positioned towards the top of the packaging (plug side) in order to maximise heat transfer on the seals of the plug,
- The gap modelled between the covers and the packaging is zero (perfect thermal contact),
- The deformation hypotheses taken to model the packaging in accident conditions of transport (from note in ref <7>) are as follows

During the fire phase (30 minutes)

- The damper cover is reduced by 42 mm along the longitudinal axis (compression of balsa is supposed to be about 60%). This compaction corresponds to an axial drop on the damper cover. The physical properties of the balsa and poplar of this cover are modified: the density and thermal conductivity are multiplied by 2.5.
- The damper cover is reduced by 33 mm along the radius simulating the drop of the generator. The physical properties of the balsa and poplar of this cover are modified: the density and conductivity are multiplied by 2.5.
- Part of the outer shell of the main section is pushed in simulating the impact of a punch. The thermal flows of the fire are applied on all the inner surfaces of this deformation,
- The "damper" part of the packaging is reduced by 39 mm along the longitudinal axis. This compaction corresponds to an axial drop on the bottom of the main section. The physical properties of the balsa and poplar are modified: the density and conductivity are multiplied by 2.5.

- During the cooling phase (after 30 minutes),
- A return to an initial more insulating geometry is simulated by dividing the initial thermal conductivity of the balsa and poplar by 2.5.

In a detrimental way, the calculation models of the packages in normal conditions of transport are identical to those in accident conditions of transport (taking into account the deformations caused by the impact of the punch).

7.2 MESHING

For isolated packaging calculations, the modelling is of an axisymmetric type, the elements are of a quadrilateral / linear and casing / linear type.
For calculations in casing, the modelling is three-dimensional; the elements are of a hexahedron / linear and quadrilateral/ casing / linear type.

7.3 MATERIALS

Material: Stainless steel 304 L (Z2CN18-10).
Package components: Main section of packaging, inner containers, basket, boxes.

Operating temperatures (°C)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg^3)	Emissivity	Solar absorptivity
20°C	14.7	454.3	7 9 3 0	0.5 for outer surfaces: 0.5 before fire 0.9 during and after fire	0.3 before fire 0.9 after fire
100°C	15.8	492			
200°C	17.2	525.2			
300°C	18.6	541.7			
400°C	20	553.1			
500°C	21.1	560.2			
600°C	22.2	566.7			
800°C	24.1	587.8			

Material: Aluminium (AG3 and AU4G).
Package components: El spacer, E10 block.

Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m3)	Emissivity	Solarabsorptivity
134	950	2790	0.5	-

Materials: Environment equivalent to neutron absorbing resin/air.
Package components: Resin layer of packaging.

Operating temperatures (°C)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m3)	Emissivity	Solar absorptivity
20°C	0.66	1173	1600	-	-
50°C	0.66	1257			
100°C	0.66	1397			
150°C	0.66	1536			
200°C	0.47	1533			
250°C	0.28	1515			
300°C	0.09*	1415			
400°C	0.09*	764			
500°C	0.09*	615			
600°C	0.09*	543			

Area of neutron absorbing resin damaged after fire.

Material: Plastic.
Package components: Plug disk, AA97 bottle, covers, E3 rings.

Plastic	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)
HDPE	0.46	1881	950
LDPE	0.334	2299	920
PVC-C	0.166	1000	1380
PUR	0.2	1000	1230
PA 6.6	0.25	1045	1140
PTFE	0.23	1000	2200

NOTE: the emissivity of the covers is taken at 0.8.

Materials: Material equivalent to air/steel
Components: Casing wall.

Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m3)	Emissivity	Solar absorptivity
0.1749			0.7	0.3

Material: Air.
Components: Gas filling package and casing.

Operating temperatures (°C)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)	Emissivity	Solar absorptivity
27□	0.0262	1006	1.177	-	
127°C	0.0337	1014	0.883		
227°C	0.0404	1030	0.705		
327°C	0.0466	1055	0.588		
427°C	0.0523	1075	0.503		
527°C	0.0578	1098	0.441		
627°C	0.0628	1121	0.392		
827°C	0.0723	1161	0.32		
1,027°C□	0.0823	1197	0.271		

Material: Bronze.
Package components: Plug retaining nut.

Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m3)	Emissivity	Solar absorptivity
50.2	370	8800	-	-

Material: Aluminium bronze.
Package components: Locking ring.

Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)	Emissivity	Solar absorptivity
37.6	376	7600		-

Material: Steel 39 CD 4.
Package components: Distribution plate of main section of packaging.

Operating temperatures (°C)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)	Emissivity	Solar absorptivity
20□	32.8	473.2	7850	–	-
100□	32.5	484.9	7820		
200□	32.2	523.6	7785		
300□	31.9	554.7	7750		
400□	31.6	594.7	7780		
500□	31.3	658.6	7690		
600□	31	739.5	7663		
800□	-	-	7610		

Material: Wood.

Package components: damper covers.

Wood species	Operating temperatures (°C)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)
Balsa	20	0.051	1100	150
	270	0.086		
Balsa HAC	20	0.128		375
	270	0.215		
Poplar	20	0.13	450	460
	270	0.22		
Poplar HAC	20	0.325		1150
	270	0.55		

NOTE: In accident conditions of transport, in the damaged zones, the densities and thermal conductivities are multiplied by 2.5 (compressed zones).

Materials: PuO2 (powder), U, Pu, MOX (pencil).
Package components: contents

Contents	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)
PuO2	0.2	250	3500
Pu bar	6.3	130	19840
U bar	24.3	125	18950
MOX	2.1	366	10450

NOTE: The thermal properties of the Zebra Pu plates (config. C8) and the uraniferous materials (config. C9) are taken as identical to those of the Pu bars and U bars respectively.

8 THRESHOLD CONDITIONS

The figures presenting all the threshold conditions on the package and the casing are presented in appendix 1.

8.1 CONDUCTION

The conductive exchanges in the package are calculated according to the thermal conductivities of each material. A meshing of the gas fill (air) allows us to consider the conductive effects of the gaps between the different parts of the package.

8.2 CONVECTION

Calculations in isolated package:

- ✓ In normal conditions of transport:

Generally speaking, we can consider that the laws relating to smooth outer surfaces of the packaging "at an ordinary ambient temperature and under atmospheric pressure" from <8> are as follows:

$h = 1.28\ (\Delta T)^{0.33}$ for vertical flat surfaces,
$h = 1.22\ (\Delta T)^{0.33}$ for horizontal cylindrical surfaces,
$h = 1.51\ (\Delta T)^{0.33}$ for horizontal flat surfaces (upward flow)
$h = 0.96\ (\Delta T)^{0.33}$ for horizontal flat surfaces (downward flow).

- ✓ In accident conditions of transport:

During the fire phase, on the outer surfaces of the package: $h = 10\ W/m^2.K$

Calculations in casing:

The coefficients of convectional exchanges are calculated according to the following correlations

(from <3>): for a vertical plate or cylinder:

$Nnu = 0.59 \times Ra^{1/4}$ if $10^4 < Ra < 10^9$ Mc Adams correlations,
$Nnu = 0.13 \times Ra^{1/3}$ if $10^9 < Ra < 10^{12}$ Mc Adams correlations,

for a horizontal plate heating downwards or cooling upwards:

$Nnu = 0.27 \times Ra^{1/4}$ if $3x10^5 < Ra < 3x10^9$ Mc Adams correlations,
$Nnu = 0.58 \times Ra^{1/5}$ if $10^6 < Ra < 10^{11}$ Fujii and Imura correlations

for a horizontal plate heating upwards or cooling downwards:

$Nnu = 0.54 \times Ra^{1/4}$ if $10^5 < Ra < 10^7$ Fischender and Saunder correlations,
$Nnu = 0.14 \times Ra^{1/3}$ if $10^7 < Ra < 3x10^{10}$ Fischender and Saunder correlations,

The Nusselt and Rayleigh numbers are evaluated with air properties taken at the film temperature. The coefficients of convectional exchanges below are evaluated at these temperature levels after several iterations.

Casing	Side walls	Base	Door	Roof	Floor
Inner walls	$h = 1.4 \times (\Delta T)^{033}$	$h = 1.4 \times (\Delta T)^{033}$	$h = 1.4 \times (\Delta T)^{033}$	$h = 1.5 \times (\Delta T)^{033}$	$h = 1.5 \times (\Delta T)^{033}$
Outer walls	$h = 1.5 \times (\Delta T)^{033}$	$h = 1.5 \times (\Delta T)^{033}$	$h = 1.5 \times (\Delta T)^{033}$	$h = 1.6 \times (\Delta T)^{033}$	-
Packaging	Vertical surfaces	Horizontal surfaces (lower part of cover)		Horizontal surfaces (upper part of cover)	
Cover and outer shell	$h = 1.35 \times (\Delta T)^{033}$	$h = 0.66 \times (\Delta T)^{025}$		$h = 1.35 \times (\Delta T)^{025}$	

8.3 RADIATION

The software automatically calculates radiation exchanges. Beforehand, one simply has to define the radiating surfaces, their direction and their emissivity to calculate the aspect ratio. In the case of gaps modelled inside the shell and for all packaging surfaces facing the ambient air (except the adiabatic surfaces), the net radiation flux exchanged between two surfaces i and j is expressed by (or between a surface and the ambient environment):

$\Phi_{ij} = \sigma x \frac{1}{\left(\frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1\right)} x(T_i^4 - T_j^4)s_{i,}$ in which ε_i and ε_j are the emissivities of the surfaces present

With $Fg_{ij} = \frac{1}{\left(\frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1\right)}$

During the fire phase, the radiation flux results in an emissive flux due to the flames (800°C) with an emissivity coefficient equal to 1 (a detrimental value compared to an emissivity equal to 0.9 (from ref. <2>)).

8.4 AMBIENT TEMPERATURE

The ambient temperature is defined at 38°C in normal conditions of transport in accordance with regulations <1>.

During the whole fire phase (30 minutes), this temperature rises to 800°C:

t = 0 s	T = 38°C
t = 30s	T = 800°C
t = 1830 s	T = 800°C
t = 1860 s	T = 38°C
t = ∞	T = 38°C

8.5 THERMAL POWER

The internal power will be applied on the elements with density and positioned in the upper part of the internal installation (plug side) in order to maximise the temperature of the plug seals.
The maximum residual power and type of contents are given in section 6.
For in casing calculations, the thermal load is imposed on the outer shell of the packaging.

8.6 SUNSHINE

The statutory conditions of sunshine <1> are 800 W/m^2 for horizontal surfaces, 400 W/m^2 for curved surfaces, 200 W/m^2 on flat vertical surfaces, and are applied continuously 24 hours a day before and after the fire scenario.

The density of the solar flux received by a surface is expressed:

φ: = a x E.

The densities of solar flux received by the surfaces before the fire are:

φ_0 = 0.30 x 200 = 60 W/m^2, on vertical stainless steel surfaces,
φ_0 = 0.30 x 400 = 120 W/m^2, on cylindrical stainless steel surfaces,

$\varphi_0 = 0.30 \times 800 = 240$ W/m^2, on horizontal stainless steel surfaces.

The densities of solar flux received by the surfaces after the fire are:

$\varphi_1 = 0.90 \times 200 = 180$ W/m^2, on vertical stainless steel surfaces,
$\varphi_1 = 0.90 \times 400 = 360$ W/m^2, on cylindrical stainless steel surfaces,
$\varphi_1 = 0.90 \times 800 = 720$ W/m^2, on horizontal stainless steel surfaces.

In accident conditions of transport, the density of flux applied on the outer surfaces of the model change over time and take the following values successively:

A $t = 0$ s	$\varphi = \varphi_0$
A $t = 30$ s	$\varphi = 0$ (start of fire)
A $t = 1830$ s	$\varphi = 0$ (end of fire)
A $t = 1860$ s	$\varphi = \varphi_1$
A $t = \infty$	$\varphi = \varphi_1$

9 RESULTS

The following tables sum up all the results obtained according to the different calculation cases. As it is difficult to estimate the exact position of the seals of the inner installation using plans <6>, their temperature is considered equivalent to that of the top of the container cover.

9.1 CONFIGURATION C1.1

The figures presenting isotherms and variation charts are presented in appendix 2.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time** (s)
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**171**	**4500**
Locking ring	**134**	**8000**
Packaging seals	**135**	**7500**
Inner side of packaging cover	**134**	**8500**
Gas in packaging cavity	**169**	**4500**
Packaging base	**171**	**4500**
AA226 container shell	**129**	**12000**
Spacer	**122**	**17000**
AA226 container cover	**129**	**12000**
AA213 shell	**135**	**17000**
AA213 cover	**135**	**17000**
Gas in container cavity	**201**	**17000**
Boxes	**148**	**17000**
Contents	**242**	**19000**

9.2 CONFIGURATION C1.2

The figures presenting isotherms and variation charts are presented in appendix 3.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**742**	**1830**
Inner shell of packaging	**187**	**4500**
Locking ring	**156**	**8000**
Packaging seals	**156**	**7500**
Inner side of packaging cover	**158**	**12000**
Gas in packaging cavity	**186**	**4500**
Packaging base	**187**	**4500**
AA226 container shell	**189**	**11000**
Spacer	**172**	**8500**
AA226 container cover	**165**	**14000**
AA213 shell	**216**	**12000**
AA213 cover	**210**	**15000**
Gas in container cavity	**284**	**14000**
Boxes	**282**	**14000**
Contents	**453**	**18000**

9.3 CONFIGURATION C2.1

The figures presenting isotherms and variation charts are presented in appendix 4**.**

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**746**	**1830**
Inner shell of packaging	**177**	**5000**
Locking ring	**163**	**8500**
Packaging seals	**164**	**9500**
Inner side of packaging cover	**170**	**11000**
Gas in packaging cavity	**188**	**10000**
Packaging base	**176**	**4500**
Spacer	**181**	**9000**
AA227 container shell	**195**	**10000**
AA227 container cover	**184**	**13000**
Gas in container cavity	**339**	**16000**
AA303 shell	**242**	**15000**
Boxes	**303**	**15000**
Contents	**518**	**18000**

9.4 CONFIGURATION C2.2

The figures presenting isotherms and variation charts are presented in appendix 5.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**742**	**1830**
Inner shell of packaging	**153**	**9500**
Locking ring	**150**	**8000**
Packaging seals	**150**	**8000**
Inner side of packaging cover	**151**	**10000**
Gas in packaging cavity	**153**	**9500**
Packaging base	**142**	**5500**
Spacer	**152**	**7500**
AA227 container shell	**154**	**9500**
AA227 container cover	**154**	**9500**
Gas in container cavity	**155**	**9500**
AA236 shell	**155**	**10000**
AA236 cover	**155**	**10000**
Boxes	**155**	**10000**
Contents	**357**	**13000**

9.5 CONFIGURATION C3.1

The figures presenting isotherms and variation charts are presented in appendix 6.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**743**	**1830**
Inner shell of packaging	**179**	**5000**
Locking ring	**165**	**8500**
Packaging seals	**165**	**9500**
Inner side of packaging cover	**171**	**9500**
Gas in packaging cavity	**196**	**9500**
Packaging base	**179**	**5000**
Spacer	**187**	**9000**
TN90 container shell	**205**	**10000**
TN90 container cover	**188**	**11000**
Gas in container cavity	**341**	**13000**
AA99	**282**	**12000**
Boxes	**336**	**13000**
Contents	**522**	**16000**

9.6 CONFIGURATION C3. 1 BIS

The figures presenting isotherms and variation charts are presented in appendix 6.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**744**	**1830**
Inner shell of packaging	**186**	**5000**
Locking ring	**170**	**8500**
Packaging seals	**171**	**9500**
Inner side of packaging cover	**178**	**9500**
Gas in packaging cavity	**208**	**9500**
Packaging base	**180**	**5000**
Spacer	**199**	**8500**
TN90 container shell	**218**	**9500**
TN90 container cover	**197**	**11000**
Gas in container cavity	**373**	**13000**
AA99	**301**	**12000**
Boxes	**350**	**12000**
Contents	**540**	**15000**

9.7 CONFIGURATION C3.2

The figures presenting isotherms and variation charts are presented in appendix 7.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time** (s)
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**174**	**4500**
Locking ring	**136**	**8500**
Packaging seals	**137**	**8500**
Inner side of packaging cover	**137**	**9000**
Gas in packaging cavity	**172**	**5000**
Packaging base	**174**	**4500**
Spacer	**136**	**11000**
TN90 container shell	**152**	**7500**
TN90 container cover	**139**	**11000**
Gas in container cavity	**227**	**15000**
AA99	**186**	**14000**
Boxes and cover	**195**	**14000**
Contents	**282**	**16000**

9.8 CONFIGURATION C3.2 BIS

The figures presenting isotherms and variation charts are presented in appendix 7.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time** (s)
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**173**	**4500**
Locking ring	**134**	**8500**
Packaging seals	**134**	**8500**
Inner side of packaging cover	**134**	**9000**
Gas in packaging cavity	**172**	**5000**
Packaging base	**173**	**4500**
Spacer	**132**	**11000**
TN90 container shell	**151**	**7500**
TN90 container cover	**135**	**12000**
Gas in container cavity	**209**	**15000**
AA99	**173**	**14000**
Contents	**245**	**16000**
Boxes and cover	**176**	**14000**

9.9 CONFIGURATION C3.3

The figures presenting isotherms and variation charts are presented in appendix 8.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**174**	**4500**
Locking ring	**137**	**8500**
Packaging seals	**137**	**8500**
Inner side of packaging cover	**137**	**9000**
Gas in packaging cavity	**172**	**5000**
Packaging base	**174**	**4500**
Spacer	**136**	**11000**
TN90 container shell	**152**	**7500**
TN90 container cover	**140**	**11000**
Gas in container cavity	**237**	**15000**
AA99	**192**	**14000**
Boxes and cover	**196**	**14000**
Contents	**286**	**15000**

9.10 CONFIGURATION C3.3 BIS

The figures presenting isotherms and variation charts are presented in appendix 8.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**174**	**4500**
Locking ring	**139**	**8500**
Packaging seals	**139**	**8500**
Inner side of packaging cover	**140**	**9000**
Gas in packaging cavity	**172**	**5000**
Packaging base	**174**	**4500**
Spacer	**140**	**10000**
TN90 container shell	**153**	**7500**
TN90 container cover	**145**	**11000**
Gas in container cavity	**252**	**15000**
AA99	**204**	**14000**
Boxes and cover	**213**	**14000**
Contents	**322**	**15000**

9.11 CONFIGURATION C4.1

The figures presenting isotherms and variation charts are presented in appendix 9.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**168**	**4500**
Locking ring	**154**	**9000**
Packaging seals	**154**	**9500**
Inner side of packaging cover	159	**10000**
Gas in packaging cavity	**188**	**10000**
Packaging base	**168**	**4500**
AA204 container shell	**195**	**11000**
Spacer	**158**	**9000**
AA204 container cover	**180**	**11000**
AA99	**250**	**13000**
Gas in container cavity	**302**	**14000**
Boxes	**284**	**14000**
Contents	**435**	**16000**

9.12 CONFIGURATION C4.2

The figures presenting isotherms and variation charts are presented in appendix 10.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**166**	**4500**
Locking ring	**139**	**9000**
Packaging seals	**139**	**9000**
Inner side of packaging cover	**142**	**10000**
Gas in packaging cavity	**164**	**4500**
Packaging base	**166**	**4500**
AA204 container shell	**157**	**12000**
Spacer	**141**	**9500**
AA204 container cover	**155**	**11000**
Gas in container cavity	**246**	**15000**
AA99	**204**	**14000**
Boxes and cover	**207**	**14000**
Contents	**295**	**15000**

9.13 CONFIGURATION C4.3

The figures presenting isotherms and variation charts are presented in appendix 11.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	786	1830
Resin	739	1830
Inner shell of packaging	168	4500
Locking ring	160	9000
Packaging seals	161	9500
Inner side of packaging cover	167	10000
Gas in packaging cavity	211	11000
Packaging base	168	4500
AA203 container shell	223	11000
Spacer	165	9000
AA203 container cover	194	11000
Gas in container cavity	344	14000
AA99	289	14000
Boxes	336	14000
Contents	521	17000

9.14 CONFIGURATION C4.4

The figures presenting isotherms and variation charts are presented in appendix 12.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time** (s)
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**165**	**4500**
Locking ring	**134**	**9000**
Packaging seals	**134**	**9000**
Inner side of packaging cover	**136**	**10000**
Gas in packaging cavity	**163**	**4500**
Packaging base	**165**	**4500**
AA203 container shell	**149**	**12000**
Spacer	**135**	**9500**
AA203 container cover	**149**	**12000**
Gas in container cavity	**234**	**15000**
AA99	**194**	**15000**
Boxes and cover	**196**	**150000**
Contents	**285**	**16000**

9.15 CONFIGURATION C4.5

The figures presenting isotherms and variation charts are presented in appendix 13.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**166**	**4500**
Locking ring	**150**	**9000**
Packaging seals	**151**	**10000**
Inner side of packaging cover	**158**	**10000**
Gas in packaging cavity	**190**	**11000**
Packaging base	**166**	**4500**
AA41 container shell	**203**	**11000**
Spacer	**153**	**9500**
AA41 container cover	**199**	**11000**
Gas in container cavity	**358**	**14000**
AA99	**267**	**13000**
Boxes	**346**	**13000**
Contents	**640**	**16000**

9.16 CONFIGURATION C4.6

The figures presenting isotherms and variation charts are presented in appendix 14.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**785**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**164**	**4500**
Locking ring	**130**	**9000**
Packaging seals	**130**	**9000**
Inner side of packaging cover	**132**	**10000**
Gas in packaging cavity	**161**	**4500**
Packaging base	**164**	**4500**
AA41 container shell	**143**	**12000**
Spacer	**130**	**9500**
AA41 container cover	**143**	**12000**
AA99	**146**	**13000**
Gas in container cavity	**217**	**14000**
Boxes and cover	**171**	**13000**
Contents	**256**	**14000**

9.17 CONFIGURATTION C4.7

The figures presenting isotherms and variation charts are presented in appendix 15.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	**798**	**1830**
Outer shell	786	1830
Resin	**739**	**1830**
Inner shell of packaging	**165**	**7000**
Locking ring	158	9000
Packaging seals	**159**	**9500**
Inner side of packaging cover	164	10000
Gas in packaging cavity	**198**	**11000**
Packaging base	**137**	**6500**
AA41 container shell	**208**	**12000**
Spacer	**162**	**9500**
AA41 container cover	**204**	**13000**
AA99	**262**	13000
Gas in container cavity	**322**	**15000**
Boxes	**318**	**14000**
Contents	**501**	**17000**

9.18 CONFIGURATION C4.8

The figures presenting isotherms and variation charts are presented in appendix 16.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	785	1830
Resin	739	1830
Inner shell of packaging	145	6000
Locking ring	133	9000
Packaging seals	134	9000
Inner side of packaging cover	135	10000
Gas in packaging cavity	220	14000
Packaging base	129	6500
AA41 container shell	147	14000
Spacer	134	9500
AA41 container cover	147	14000
AA99	150	13000
Gas in container cavity	142	5000
Boxes and cover	175	13000
Contents	260	14000

9.19 CONFIGURATION C4.9

The figures presenting isotherms and variation charts are presented in appendix 17.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	786	1830
Resin	739	1830
Inner shell of packaging	172	4500
Locking ring	154	9000
Packaging seals	155	9500
Inner side of packaging cover	160	9500
Gas in packaging cavity	183	12000
Packaging base	172	4500
AA41 container shell	194	13000
Spacer	158	9000
AA41 container cover	194	13000
AA99	229	14000
Gas in container cavity	296	15000
Boxes	283	15000
Contents	449	17000

9.20 CONFIGURATION C4.10

The figures presenting isotherms and variation charts are presented in appendix 18.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	785	1830
Resin	739	1830
Inner shell of packaging	170	4500
Locking ring	136	9000
Packaging seals	136	8500
Inner side of packaging cover	138	10000
Gas in packaging cavity	169	4500
Packaging base	170	4500
AA41 container shell	151	14000
Spacer	145	7000
AA41 container cover	151	14000
AA99	153	14000
Gas in container cavity	222	14000
Boxes and cover	178	15000
Contents	263	16000

9.21 CONFIGURATION C5.1

The figures presenting isotherms and variation charts are presented in appendix 19.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**797**	**1830**
Resin	**739**	**1830**
Inner shell of packaging	**172**	**4500**
Locking ring	**129**	**9000**
Packaging seals	**129**	**9000**
Inner side of packaging cover	**131**	**9500**
Gas in packaging cavity	**171**	**4500**
Packaging base	**172**	**4500**
Spacer	**142**	**5500**
TN90 container shell	**145**	**7500**
TN90 container cover	**135**	**8000**
Gas in container cavity	**144**	**7500**
Contents	**131**	**10000**
AA97 bottles	**132**	**10000**

9.22 CONFIGURATION C7.1

The figures presenting isotherms and variation charts are presented in appendix 20.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	785	1830
Resin	739	1830
Inner shell of packaging	171	4500
Locking ring	125	8000
Packaging seals	125	8000
Inner side of packaging cover	124	8500
Gas in packaging cavity	170	4500
Packaging base	171	4500
Spacer	108	10000
TN90 container shell	126	7000
TN90 container cover	118	10000
Gas in container cavity	125	7000
Contents	105	16000

9.23 CONFIGURATION C7.2

The figures presenting isotherms and variation charts are presented in appendix 21.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**742**	**1830**
Inner shell of packaging	**186**	**5000**
Locking ring	**167**	**8500**
Packaging seals	**167**	**8500**
Inner side of packaging cover	**172**	**9500**
Gas in packaging cavity	**185**	**5000**
Packaging base	**186**	**5000**
Spacer	**207**	**16000**
TN90 container shell	**193**	**14000**
TN90 container cover	**193**	**14000**
Gas in container cavity	**201**	**16000**
Contents	**216**	**16000**

9.24 CONFIGURATION C8

The figures presenting isotherms and variation charts are presented in appendix 22.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**740**	**1830**
Inner shell of packaging	**184**	**5000**
Locking ring	**142**	**8500**
Packaging seals	**142**	**8500**
Inner side of packaging cover	**143**	**8500**
Gas in packaging cavity	**182**	**7000**
Packaging base	**184**	**5000**
Spacer	**194**	**16000**
TN90 container shell	**183**	**7000**
TN90 container cover	**145**	**10000**
Gas in container cavity	**243**	**11000**
Boxes	**249**	**12000**
Contents	**252**	**12000**

9.25 CONFIGURATION C9

The figures presenting isotherms and variation charts are presented in appendix 23.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	785	1830
Resin	739	1830
Inner shell of packaging	173	4500
Locking ring	128	8500
Packaging seals	129	8500
Inner side of packaging cover	128	9000
Gas in packaging cavity	172	4500
Packaging base	173	4500
Spacer	120	9000
TN90 container shell	138	7500
TN90 container cover	126	10000
Gas in container cavity	137	7500
E7 shell	120	12000
Contents	120	13000

9.26 CONFIGURATION C10.1

The figures presenting isotherms and variation charts are presented in appendix 24.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**743**	**1830**
Inner shell of packaging	**226**	**12000**
Locking ring	**188**	**8500**
Packaging seals	**189**	**9500**
Inner side of packaging cover	**217**	**11000**
Gas in packaging cavity	**268**	**13000**
Packaging base	**176**	**4500**
Spacer	**228**	**12000**
TN90 container shell	**312**	**15000**
TN90 container cover	**247**	**13000**
Gas in container cavity	**335**	**16000**
Contents	**376**	**17000**

9.27 CONFIGURATION C10.2

The figures presenting isotherms and variation charts are presented in appendix 25.

CALCULATIONS IN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**787**	**1830**
Resin	**743**	**1830**
Inner shell of packaging	**183**	**4500**
Locking ring	**167**	**8500**
Packaging seals	**167**	**8000**
Inner side of packaging cover	**177**	**10000**
Gas in packaging cavity	**195**	**14000**
Packaging base	**179**	**4500**
Spacer	**185**	**11000**
TN90 container shell	**208**	**17000**
TN90 container cover	**185**	**12000**
Gas in container cavity	**206**	**16000**
Contents	**221**	**20000**

9.28 CONFIGURATION C10.3

The figures presenting isotherms and variation charts are presented in appendix 26.

CALCULATIONS IN ISOLATED PACKAGE **Maximum temperatures**		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**797**	**1830**
Resin	**743**	**1830**
Inner shell of packaging	**188**	**11000**
Locking ring	**170**	**8500**
Packaging seals	**171**	**8000**
Inner side of packaging cover	**182**	**11000**
Gas in packaging cavity	**205**	**12000**
Packaging base	**179**	**4500**
Spacer	**193**	**12000**
TN90 container shell	**218**	**13000**
TN90 container cover	**193**	**12000**
Gas in container cavity	**220**	**13000**
Contents	**220**	**13000**

9.29 CONFIGURATION CA1 (12X80W)

Isolated package configuration C4.2 was chosen for this calculation in the casing. The figures presenting isotherms and variation charts are presented in appendix 27.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	**798**	**1830**
Outer shell	**786**	**1830**
Resin	**741**	**1830**
Inner shell of packaging	**176**	**4500**
Locking ring	**150**	**8500**
Packaging seals	**150**	**8000**
Inner side of packaging cover	**152**	**10000**
Gas in packaging cavity	**174**	**4500**
Packaging base	**176**	**4500**
AA204 container shell	**166**	**11000**
Spacer	**152**	**9000**
AA204 container cover	**165**	**11000**
Gas in container cavity	**252**	**14000**
AA99	**212**	**13000**
Boxes	**214**	**13000**
Contents	**302**	**14000**
CASING	**Normal conditions of transport Maximum temperatures**	
	Temperature (°C)	
Side wall	**69**	
Roof	**70**	
Door	**65**	
Base	**70**	
Floor	**74**	
Package	**81**	
Air	**70**	

9.30 CONFIGURATION CA2 (12X100W)

Isolated package configuration C4.5bis was chosen for this calculation in the casing. The figures presenting isotherms and variation charts are presented in appendix 28.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	786	1830
Resin	742	1830
Inner shell of packaging	179	4500
Locking ring	164	8500
Packaging seals	165	9000
Inner side of packaging cover	171	9500
Gas in packaging cavity	201	10000
Packaging base	179	4500
AA41 container shell	214	11000
Spacer	167	9000
AA41 container cover	211	10000
Gas in container cavity	364	13000
AA99	276	12000
Boxes	354	12000
Contents	647	15000
CASING	Normal conditions of transport Maximum temperatures	
	Temperature (°C)	
Side wall	74	
Roof	74	
Door	68	
Base	75	
Floor	79	
Package	88	
Air	74	

9.31 CONFIGURATION CA3 (12X200W)

Isolated package configuration C3.1 at 4 x 50 W per package was chosen for this calculation in casing. The figures presenting isotherms and variation charts are presented in appendix 29.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	798	1830
Outer shell	788	1830
Resin	747	1830
Inner shell of packaging	201	5000
Locking ring	182	7500
Packaging seals	182	7000
Inner side of packaging cover	184	8500
Gas in packaging cavity	200	5000
Packaging base	201	5000
Spacer	187	9000
TN90 container shell	199	10000
TN90 container cover	192	10000
Gas in container cavity	313	11000
AA99	260	10000
Boxes	302	11000
Contents	464	13000
CASING	**Normal conditions of transport Maximum temperatures**	
	Temperature (°C)	
Side wall	95	
Roof	92	
Door	85	
Base	97	
Floor	103	
Package	117	
Air	95	

9.32 CONFIGURATION CA4 (24 x 80 w)

Isolated package configuration C4.2 was chosen for this calculation in the casing. The figures presenting isotherms and variation charts are presented in appendix 30.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	798	1830
Outer shell	787	1830
Resin	743	1830
Inner shell of packaging	184	4500
Locking ring	162	8000
Packaging seals	162	7500
Inner side of packaging cover	163	9500
Gas in packaging cavity	182	4500
Packaging base	184	4500
Spacer	162	8500
AA204 container shell	175	10000
AA204 container cover	175	10000
Gas in container cavity	258	13000
AA99	219	12000
Boxes	222	12000
Contents	309	13000
CASING	**Normal conditions of transport Maximum temperatures**	
	Temperature (°C)	
Side wall	76	
Roof	80	
Door	72	
Base	75	
Floor	90	
Package	97	
Air	86	

9.33 CONFIGURATION CA5 (24 x 100W)

Isolated package configuration C4.5.bis was chosen for this calculation in the casing. The figures presenting isotherms and variation charts are presented in appendix 31.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	Accident conditions of transport	
	Temperature (°C)	Time (s)
Outer surface	798	1830
Outer shell	787	1830
Resin	744	1830
Inner shell of packaging	188	4500
Locking ring	177	8000
Packaging seals	178	8500
Inner side of packaging cover	184	9000
Gas in packaging cavity	212	9500
Packaging base	188	4500
Spacer	179	8500
AA41 container shell	226	10000
AA41 container cover	222	10000
Gas in container cavity	369	12000
AA99	284	11000
Boxes	360	12000
Contents	654	14000
CASING	Normal conditions of transport Maximum temperatures	
	Temperature (°C)	
Side wall	82	
Roof	85	
Door	78	
Base	81	
Floor	98	
Package	106	
Air	94	

9.34 CONFIGURATION CA6 (7 x 340W)

Isolated package configuration C2.1 was chosen for this calculation in the casing. The figures presenting isotherms and variation charts are presented in appendix 32.

CALCULATIONS IN CASING Maximum temperatures		
TN/BGC 1 PACKAGE	**Accident conditions of transport**	
	Temperature (°C)	**Time (s)**
Outer surface	798	1830
Outer shell	788	1830
Resin	752	1830
Inner shell of packaging	205	5000
Locking ring	195	7000
Packaging seals	196	8000
Inner side of packaging cover	200	10000
Gas in packaging cavity	216	8500
Packaging base	204	4500
Spacer	210	7500
AA227 container shell	223	9000
AA227 container cover	213	11000
Gas in container cavity	355	12000
AA303 shell	265	12000
Boxes	322	12000
Contents	536	15000
CASING	**Normal conditions of transport Maximum temperatures**	
	Temperature (°C)	
Side wall	95	
Roof	92	
Door	84	
Base	101	
Floor	104	
Package	127	
Air	94	

9.35 CONCLUSION

Summary table of results:

Packing components	**C1.1**	**C1.2**	**C2.1**	**C2.2**	**C3.1**	**C3.2**	**C3.3**	**C4.1**	**C4.2**	**C4.3**	**C4.4**	**C4.5**
Total dissipated power (W)	80	340	340	340	340	80	80	170	80	170	40	100
Type of contents	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder
Packaging												
Outer surface	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**
Outer shell	**786**	**786**	**787**	**787**	**787**	**785**	**785**	**786**	**785**	**786**	**785**	**785**
Resin	**739**	**742**	**746**	**742**	**743**	**739**	**739**	**739**	**739**	**739**	**739**	**739**
Inner shell	**171**	**187**	**177**	**153**	**179**	**174**	**174**	**168**	**166**	**168**	**165**	**166**
Locking ring	**134**	**156**	**163**	**150**	**165**	**136**	**137**	**154**	**139**	**160**	**134**	**150**
Packaging seals	**135**	**156**	**164**	**150**	**165**	**137**	**137**	**154**	**139**	**161**	**134**	**151**
Inner side of cover	**134**	**158**	**170**	**151**	**171**	**.137**	**137**	**159**	**142**	**167**	**136**	**158**
Gas in packaging cavity	**169**	**186**	**188**	**153**	**196**	**172**	**172**	**188**	**164**	**211**	**163**	**190**
Packaging base	**171**	**187**	**176**	**142**	**179**	**174**	**174**	**168**	**166**	**168**	**165**	**166**
Internal installations and contents												
Tertiary container shell	**129**	**189**	**195**	**154**	**205**	**152**	**152**	**195**	**157**	**223**	**149**	**203**
Spacer	**122**	**172**	**181**	**152**	**187**	**136**	**136**	**158**	**141**	**165**	**135**	**153**
Tertiary container cover	**129**	**165**	**184**	**154**	**188**	**139**	**140**	**180**	**155**	**194**	**149**	**199**
Secondary container shell	**135**	**216**	**242**	**155**	**282**	**186**	**192**	**250**	**204**	**289**	**194**	**267**
Secondary container cover	**135**	**210**	**242**	**155**	**282**	**186**	**192**	**250**	**204**	**289**	**194**	**267**
Gas in container cavity	**201**	**284**	**339**	**155**	**341**	**227**	**237**	**302**	**246**	**344**	**234**	**358**
Boxes and cover*	**148**	**282**	**303**	**155**	**336**	**195**	**196**	**284**	**207**	**336**	**196**	**346**
Contents	**242**	**453**	**518**	**357**	**522**	**282**	**286**	**435**	**295**	**521**	**285**	**640**

*configurations with a cover are as follows: C3.2, C3.3, C4.2, C4.4

Summary table of results (cont.):

Packing components	C4.6	C4.7	C4.8	C4.9	C4.10	C5.1	C7.1	C7.2	C8	C9	C10.1	C10.2	C10.3
Total dissipated power (W)	20	170	40	170	60	4	4	340	150	16	340	340	340
Type of contents	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	U bar	Pu bar	Zebra Pu plates	Uraniferous matter	MOX pencil	MOX pencil	MOX pencil
Packaging													
Outer surface	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**	**798**
Outer shell	**785**	**786**	**785**	**786**	**785**	**797**	**785**	**786**	**786**	**785**	**787**	**787**	**797**
Resin	**739**	**739**	**739**	**739**	**739**	**739**	**739**	**742**	**740**	**739**	**743**	**743**	**743**
Inner shell	**164**	**165**	**145**	**172**	**170**	**172**	**171**	**186**	**184**	**173**	**226**	**183**	**188**
Locking ring	**130**	**158**	**133**	**154**	**136**	**129**	**125**	**167**	**142**	**128**	**188**	**167**	**170**
Packaging seals	**130**	**159**	**134**	**155**	**136**	**129**	**125**	**167**	**142**	**129**	**189**	**167**	**171**
Inner side of cover	**132**	**164**	**135**	**160**	**138**	**131**	**124**	**172**	**143**	**128**	**217**	**177**	**182**
Gas in packaging cavity	**161**	**198**	**220**	**183**	**169**	**171**	**170**	**185**	**182**	**172**	**268**	**195**	**205**
Packaging base	**164**	**137**	**129**	**172**	**170**	**172**	**171**	**186**	**184**	**173**	**176**	**179**	**179**
Internal installations and contents													
Tertiary container shell	**143**	**208**	**147**	**194**	**151**	-	-	-	-	-	-	-	-
Spacer	**130**	**162**	**134**	**158**	**145**	**142**	**108**	**207**	**194**	**120**	**228**	**185**	**193**
Tertiary container cover	**143**	**204**	**147**	**194**	**151**	-	-	-	-	-	-	-	-
Secondary container shell	**146**	**262**	**150**	**229**	**153**	**145**	**126**	**193**	**183**	**138**	**312**	**208**	**218**
Secondary container cover	**146**	**262**	**150**	**229**	**153**	**135**	**118**	**193**	**145**	**126**	**247**	**185**	**193**
Gas in container cavity	**217**	**322**	**142**	**296**	**222**	**144**	**125**	**201**	**243**	**137**	**335**	**206**	**220**
Boxes and cover*	**171**	**318**	**175**	**283**	**178**	**132** (AA97)	-		**249**	**120** (E7 shell)	-	-	-
Contents	**256**	**501**	**260**	**449**	**263**	**131**	**105**	**216**	**252**	**120**	**376**	**221**	**220**

*configurations with a cover are as follows: C4.6, C4.8, C4.10

Summary table of results (cont. and end)

Packing components	C3.1 bis	C3.2 bis	C3.3 bis	CA1	CA2	CA3	CA4	CA5	CA6
Total dissipated power (W)	400	60	100	12 x 80W (C4.2)	12 x 100 W (C4.5)	12 x 200 W (C3.1 to 4 x 50 W/pack.)	24 x 80W (C4.2)	24 x100 W (C4.5)	7 x340 W (C2.1)
Type of contents	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder	PuO_2 powder
Packaging									
Outer surface	798	798	798	798	798	798	798	798	798
Outer shell	787	785	786	786	786	788	787	787	788
Resin	744	739	739	741	742	747	743	744	752
Inner shell	186	173	174	176	179	201	184	188	205
Locking ring	170	134	139	150	164	182	162	177	195
Packaging seals	171	134	139	150	165	182	162	178	196
Inner side of cover	178	134	140	152	171	184	163	184	200
Gas in packaging cavity	208	172	172	174	201	200	182	212	216
Packaging base	180	173	174	176	179	201	184	188	204
Internal installations and contents									
Tertiary container shell	218	151	153	166	214	199	175	226	223
Spacer	199	132	140	152	167	187	162	179	210
Tertiary container cover	197	135	145	165	211	192	175	222	213
Secondary container shell	301	173	204	212	276	260	219	284	265
Secondary container cover	301	173	204	212	276	260	219	284	265
Gas in container cavity	373	209	252	252	364	313	258	369	355
Boxes and cover*	350	176	213	214	354	302	222	360	322
Contents	540	245	322	302	647	464	309	654	536

*configurations with a cover are as follows: C3.2 bis, C3.3 bis, CA1, CA4

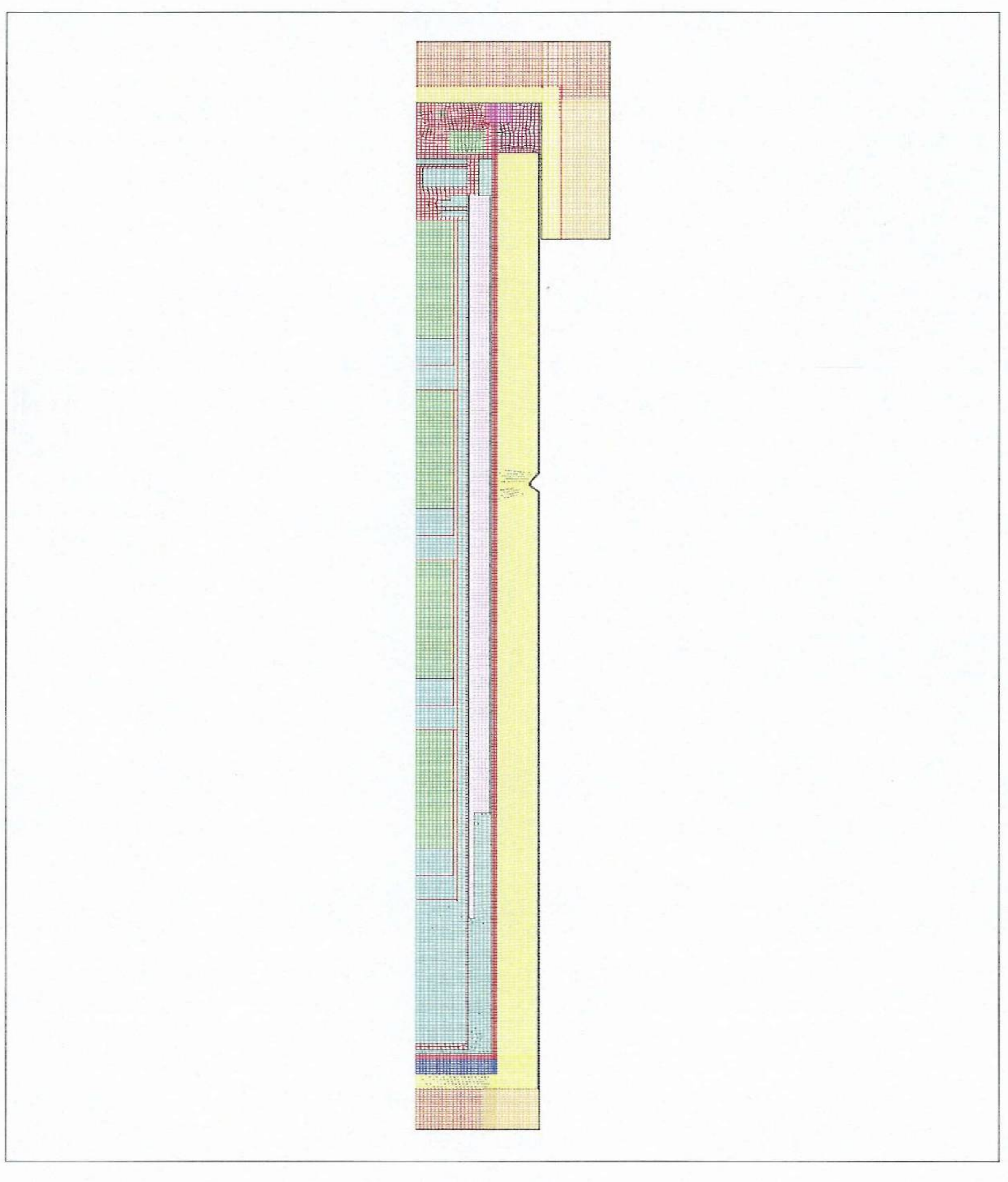
This study demonstrated that the temperatures reached by the different components of the packaging are acceptable and do not undermine their properties. In particular, the temperature of the seals remains lower than their maximum operating temperature and the extrusion temperature.
When covers are used, the temperatures reached demonstrate that we cannot rule out the risk of thermolysis in accident conditions of transport.
With regard to the temperatures reached by the gas fill, either in the packaging cavity or in the internal installation, the values calculated are of the same order of magnitude as those defined in previous studies (and even lower in most cases) and do not call into question studies in which this temperature is an input data (H2 discharge, maintaining leak-tightness at high temperatures, releasing). Finally, the temperatures reached by the various contents will not damage the contents (in particular the maximum temperature reached by the Zebra plate cladding or the Mox pencils remains acceptable)

APPENDIX 1

PRESENTATION OF MODEL

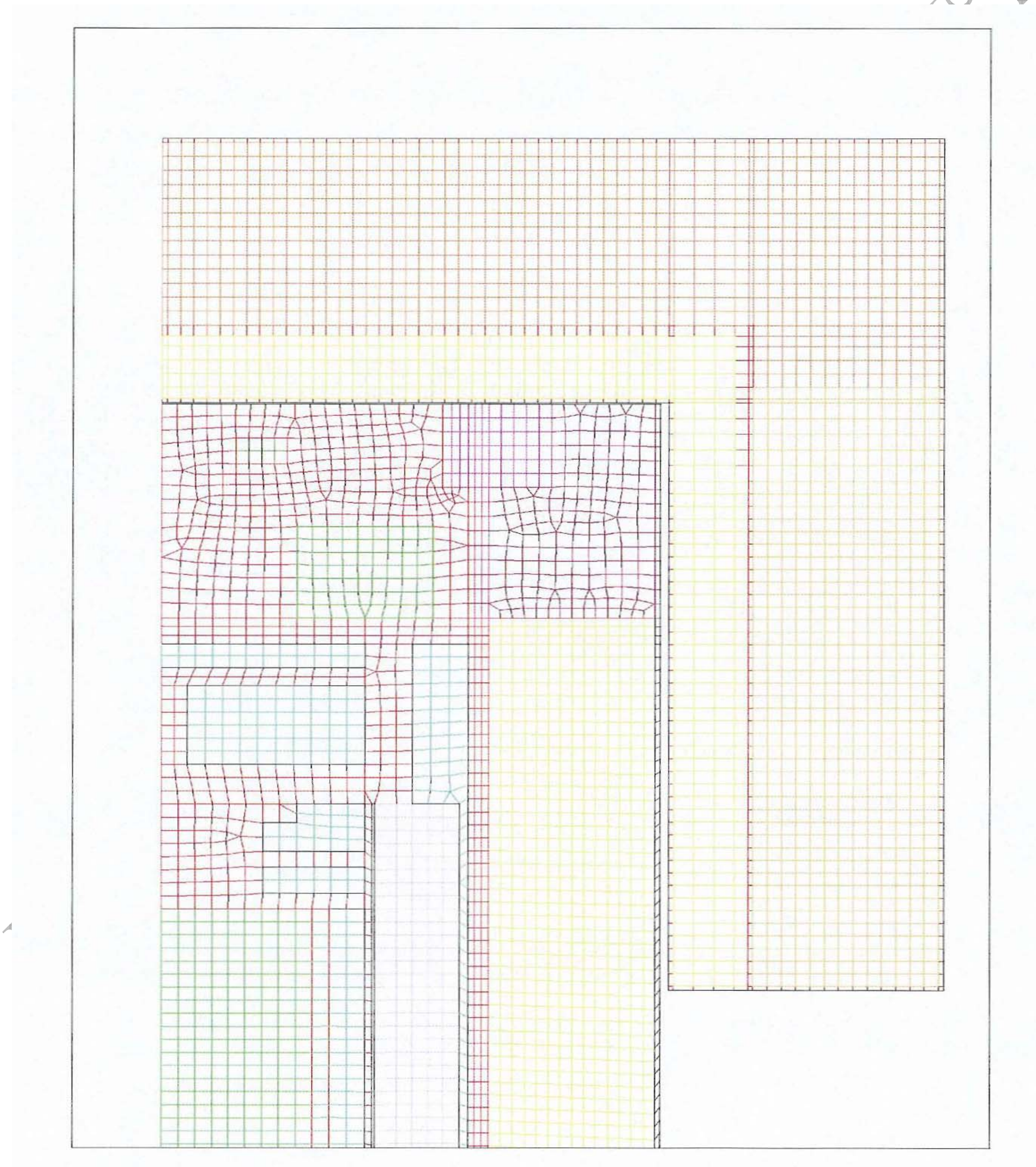
APPENDIX 1

MESHING OF PACKAGE
PACKAGE



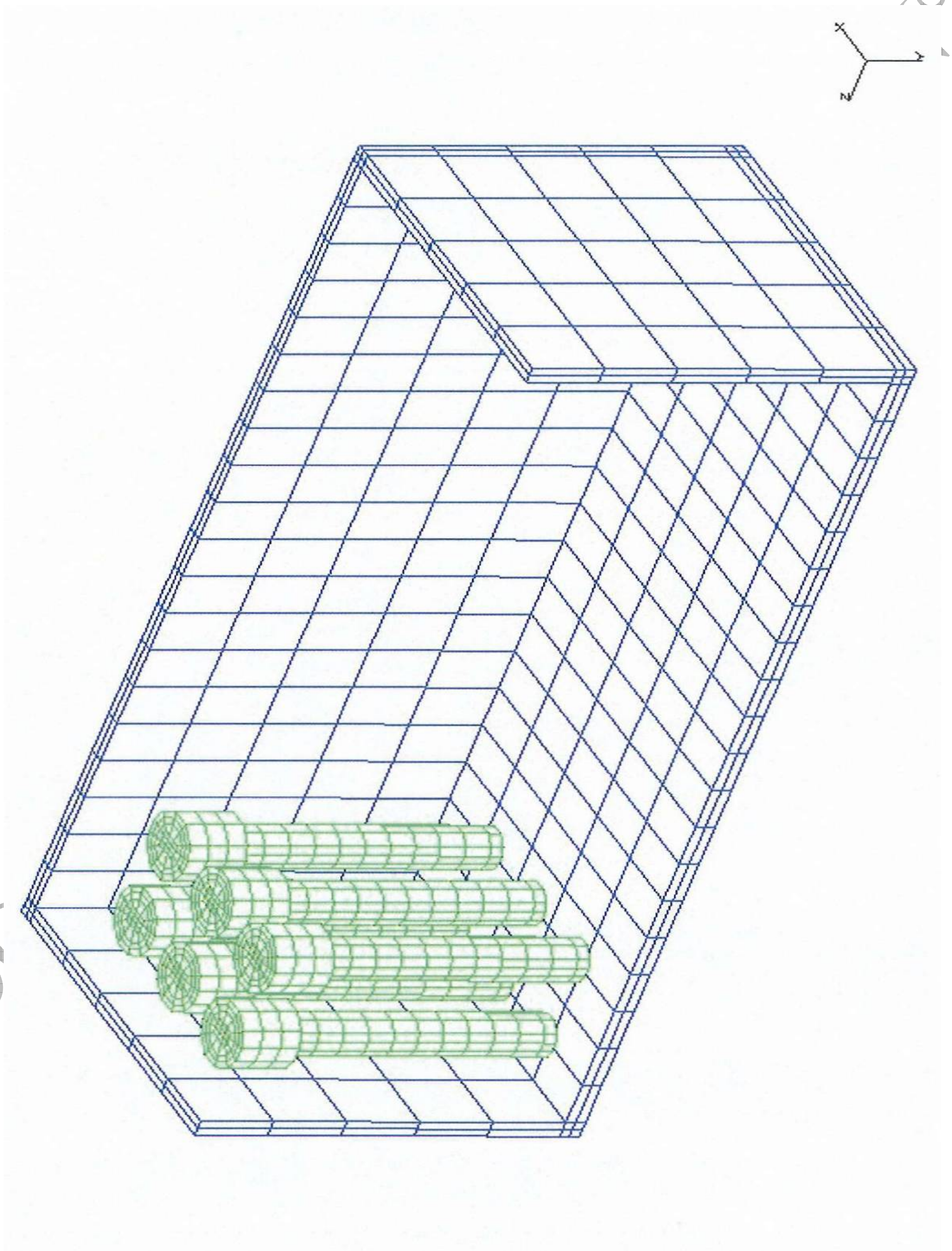
APPENDIX 1

MESHING OF PACKAGE
PACKAGE (UPPER PART)



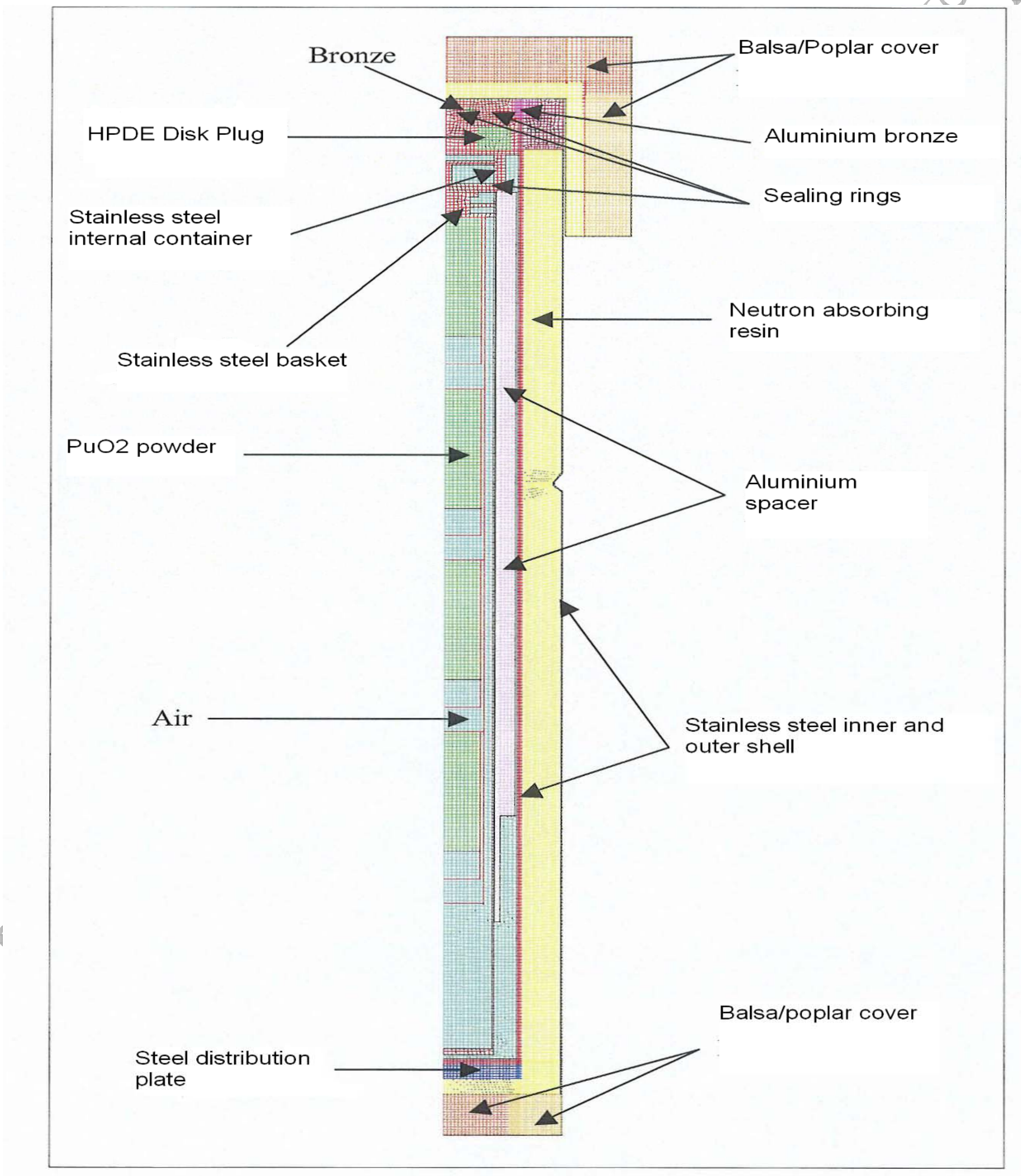
APPENDIX 1

MESHING OF CASING



APPENDIX 1

PACKAGE MATERIALS



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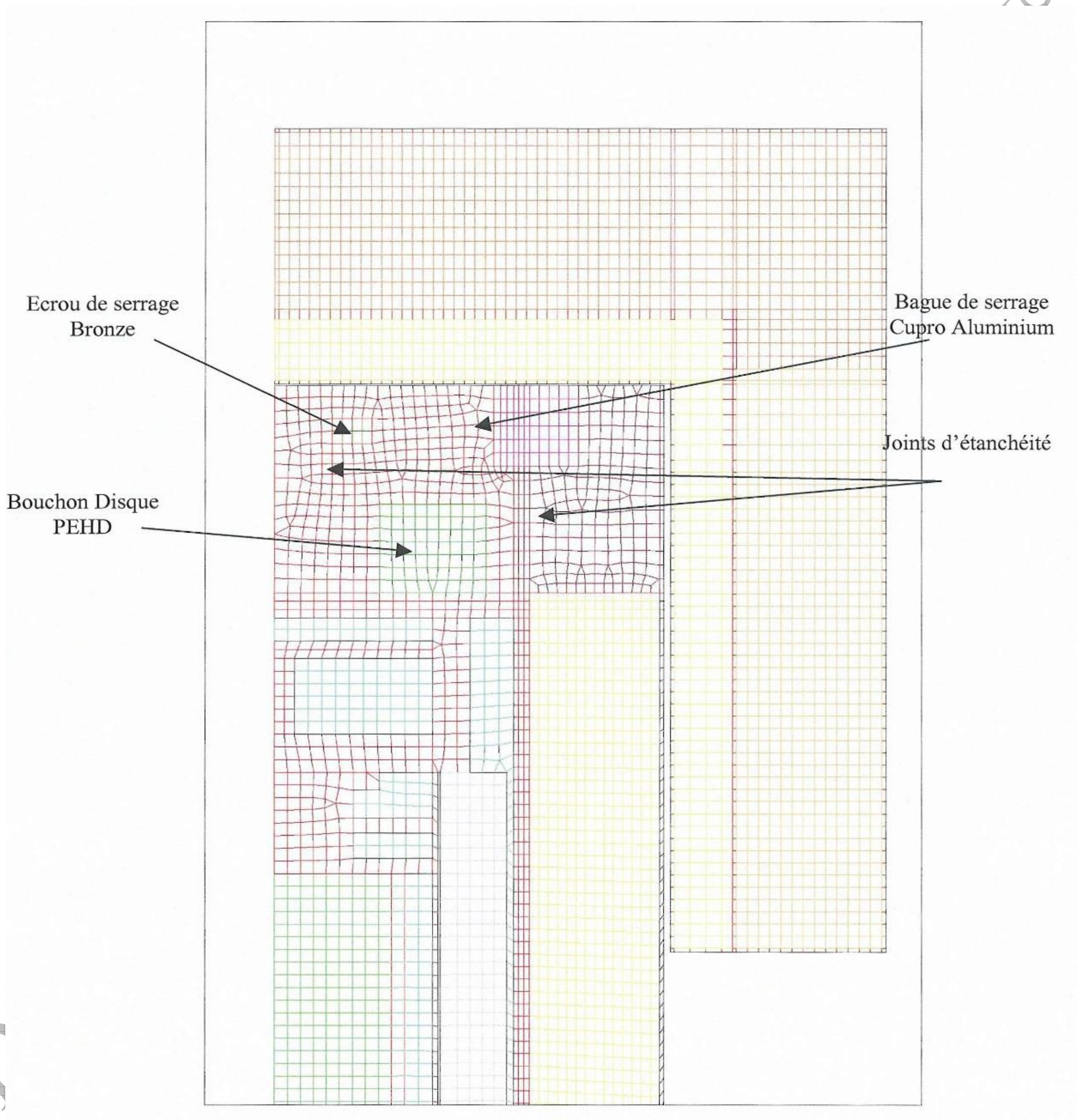
APPENDIX 1

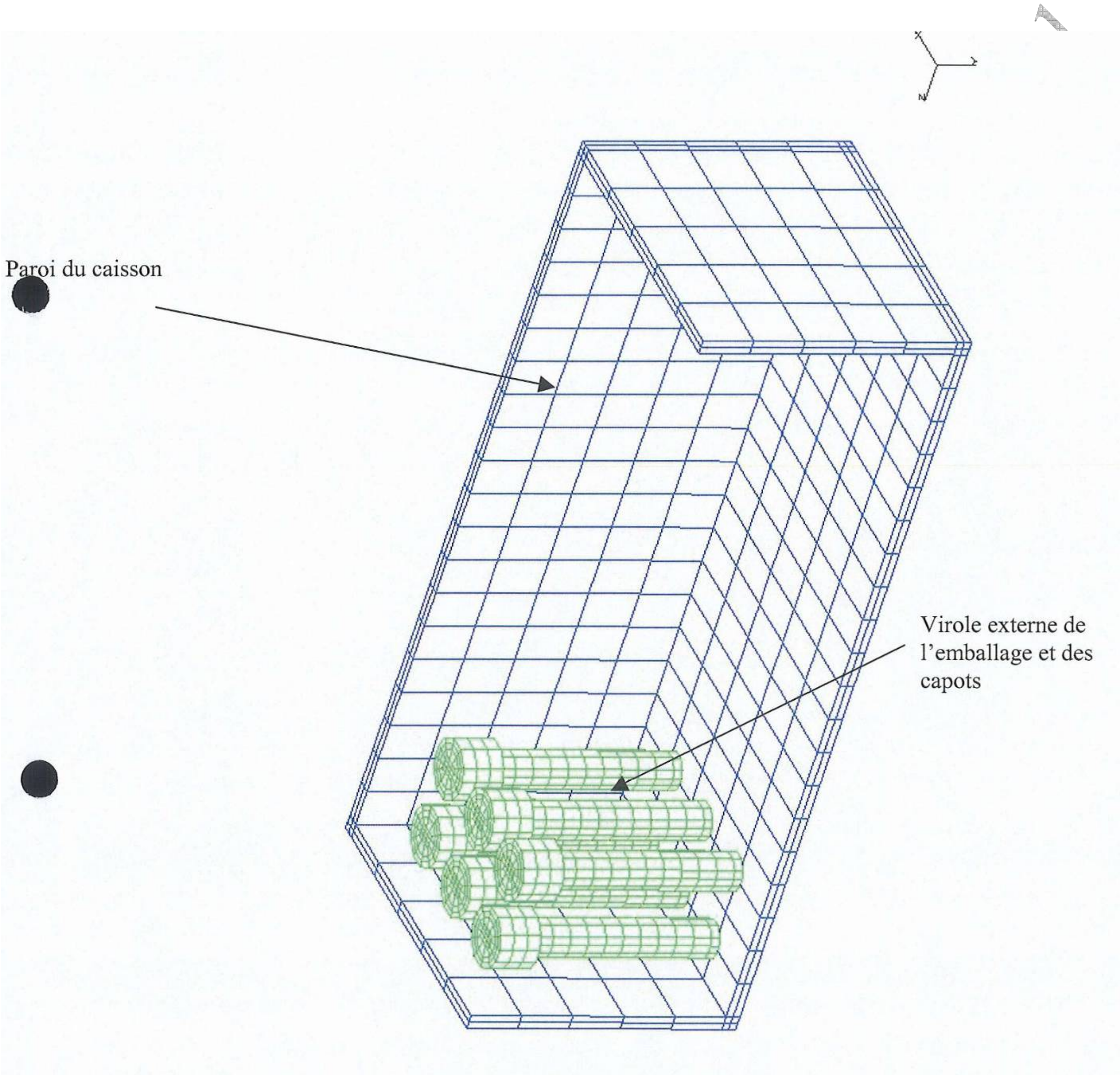
PACKAGE MATERIALS
PACKAGE (UPPER PART)



Ecrou de serrage Bronze	Bronze retaining nut
Bouchon Disque PEHD	HDPE Disk Plug
Bague de serrage Cupro Aluminium	Aluminium bronze locking ring
Joints d'étanchéité	Sealing rings

APPENDIX 1

DESCRIPTION OF CASING



Paroi du caisson	Wall of casing
Virole externe de l'emballage et des capots	Outer shell of packaging and covers

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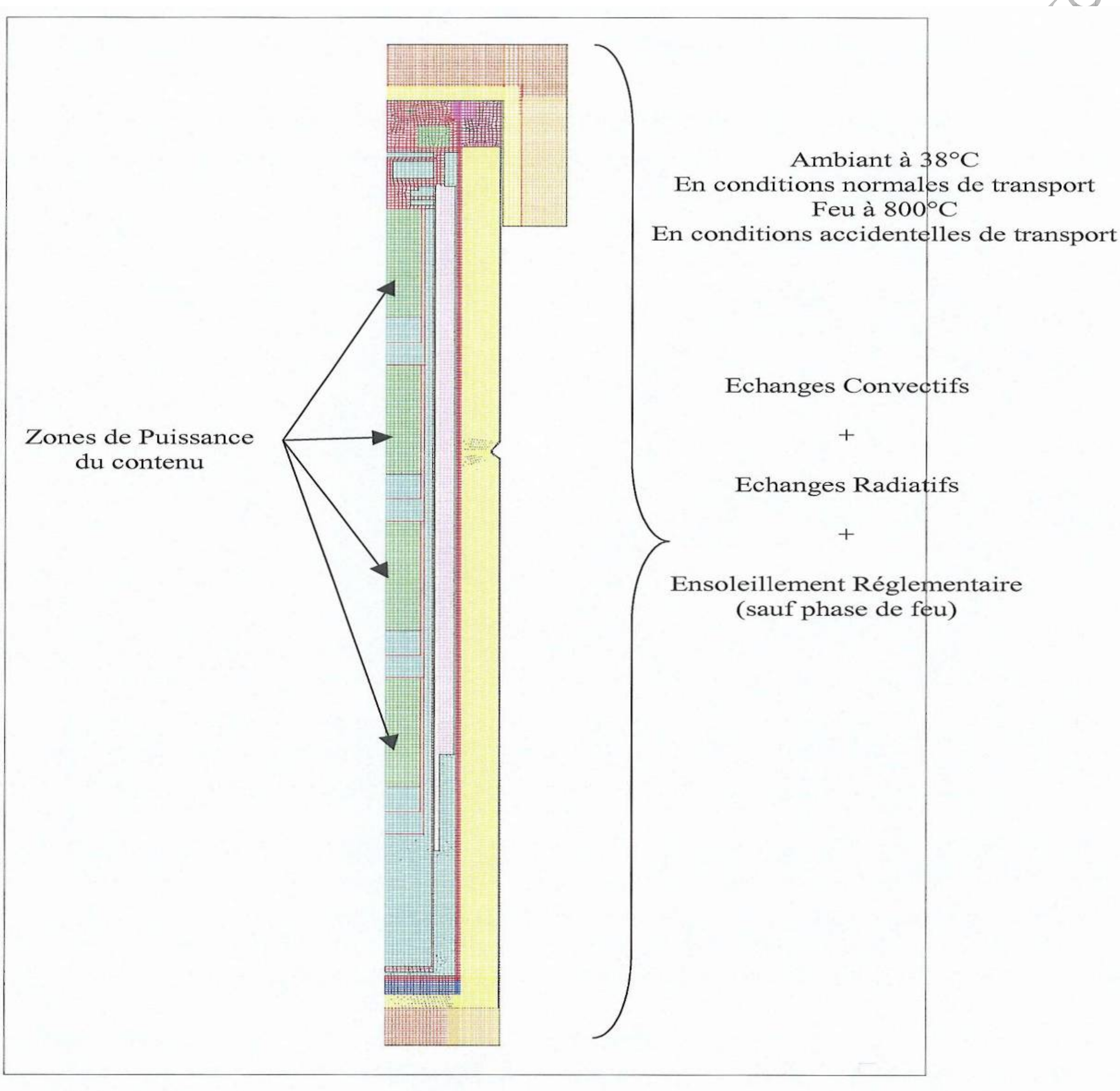
APPENDIX 1

THRESHOLD CONDITIONS
PACKAGE



Zones du puissance du contenu	Power zones of contents
Ambient à 38°C En conditions normales de transport	Ambient at 38°C In normal conditions of transport
Feu à 800°C En conditions accidentales de transport	Fire at 800°C In accident conditions of transport
Echanges convectifs	Convectional exchanges
Echanges radiatifs	Radiation exchanges
Ensoleillement réglémentaire (sauf phase defeu)	Statutory sunshine (except during fire phase)

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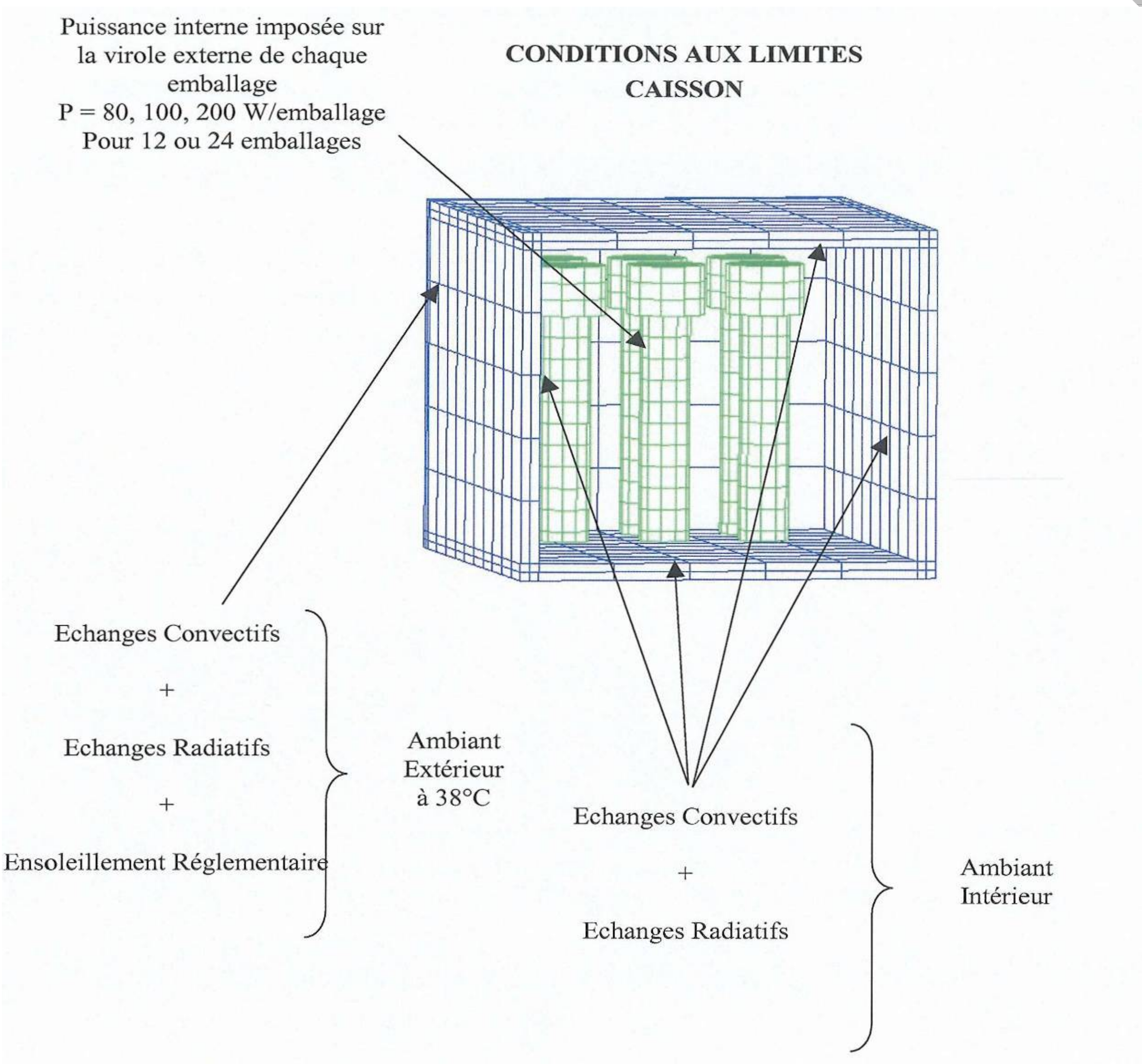
APPENDIX 1

THRESHOLD CONDITIONS
CASING



Puissance interne impose sur la virole externe de chaque emballage P = 80, 100, 200 W/emballage Pour 12 ou 24 emballage	Internal power imposed on the outer shell of each packaging P = 80, 100, 200 W per packaging For 12 or 24 packagings
Echanges convectifs	Convectional exchanges
Echanges radiatifs	Radiation exchanges
Ensoleillement réglémentaire	Statutory sunshine
Ambient extèrieur à 38°C	Outside ambient environment at 38°C
Echanges convectifs	Convectional exchanges
Echanges radiatifs	Radiation exchanges
Ambient intérieur	Inside ambient environment

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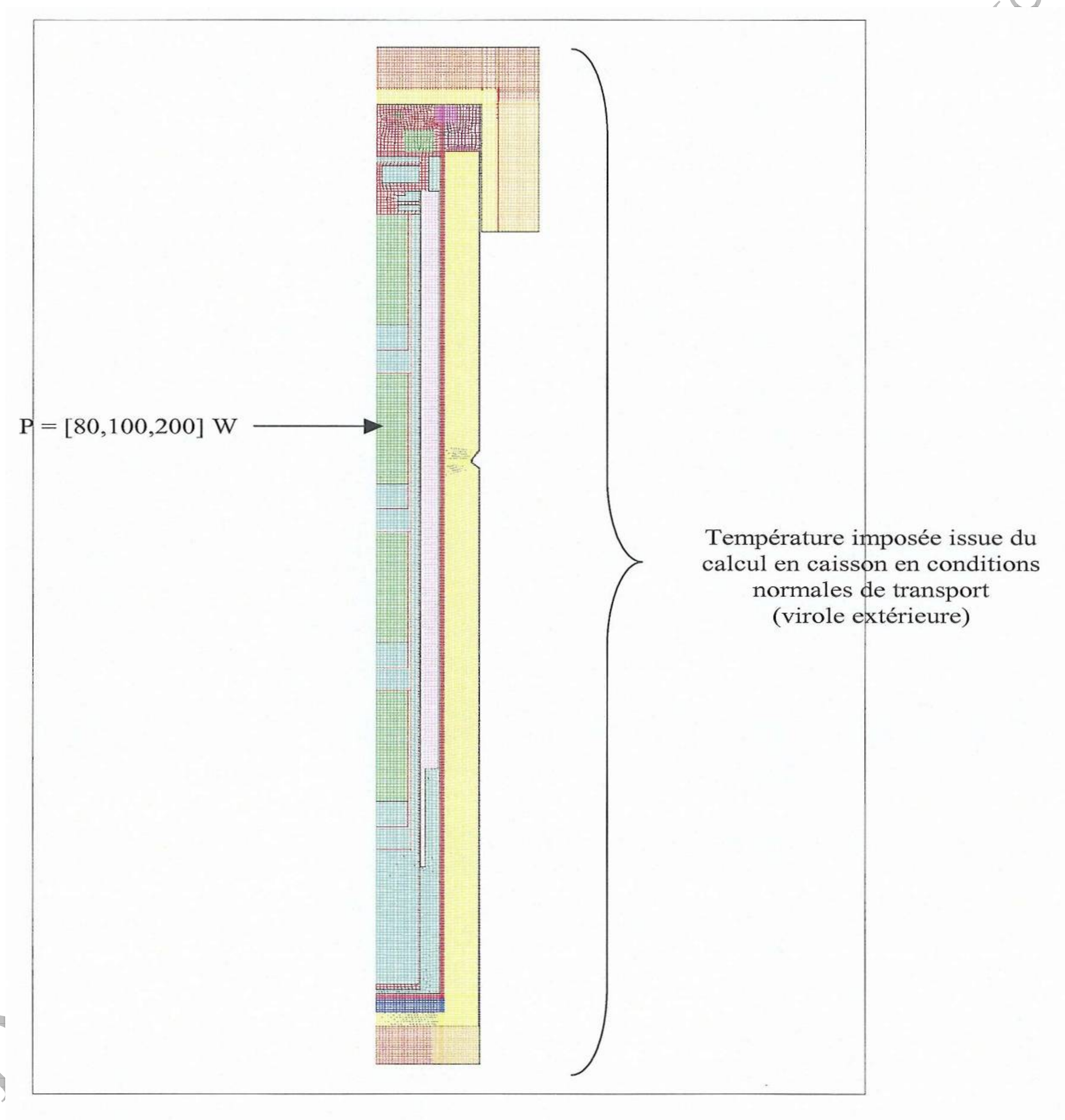
APPENDIX 1

THRESHOLD CONDITIONS

PACKAGE IN CASING



P = [80, 100, 200] W	P = [80, 100, 200] W
Température imposée issue du calcul en caisson en conditions normales de transport (virole extèrieure)	Temperature imposed as a result of the in-casing calculation in normal conditions of transport (outer shell)

APPENDIX 2
CONFIGURATION C1.1

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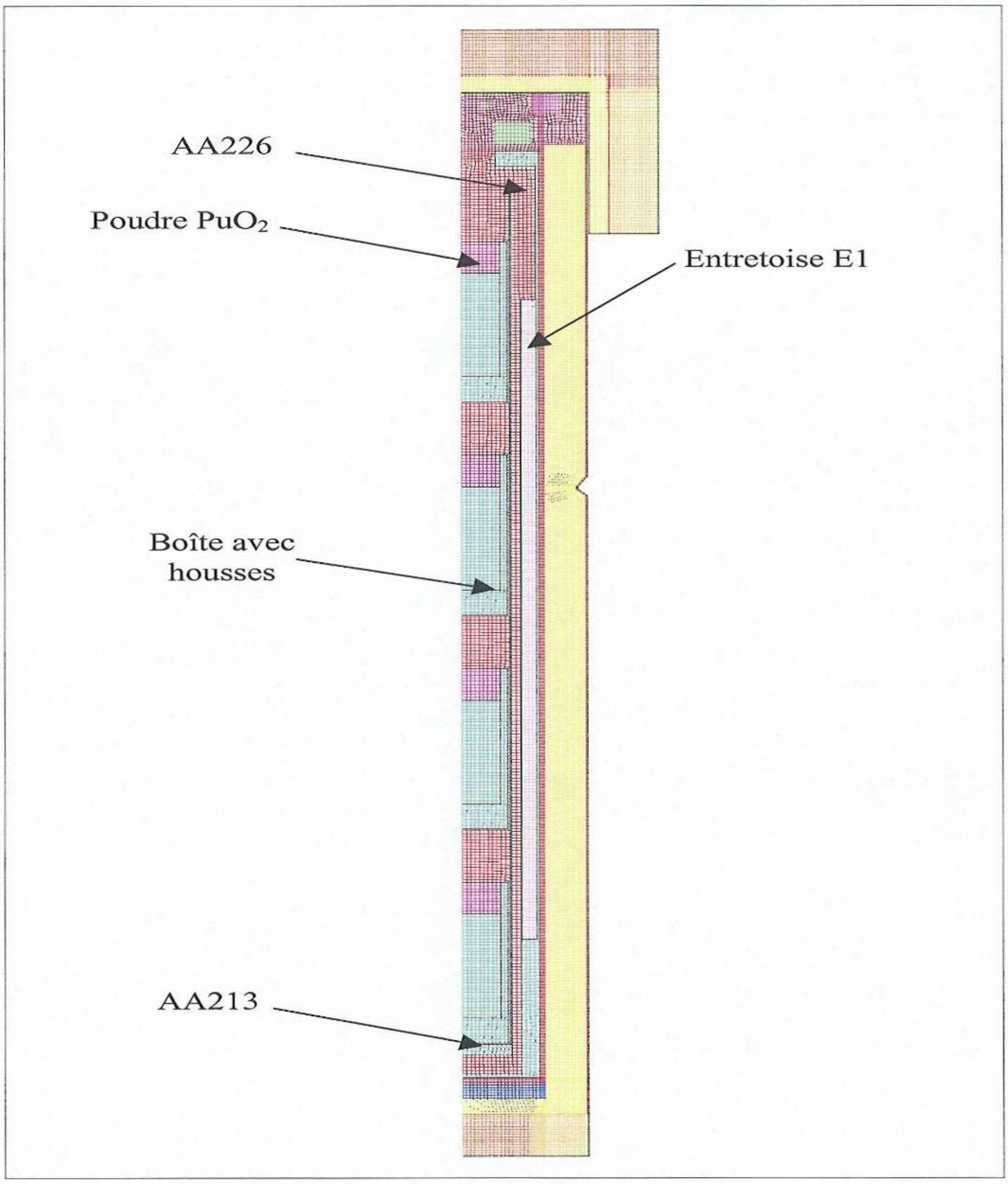
APPENDIX 2

CONFIGURATION C1.1
PRESENTATION OF MODEL

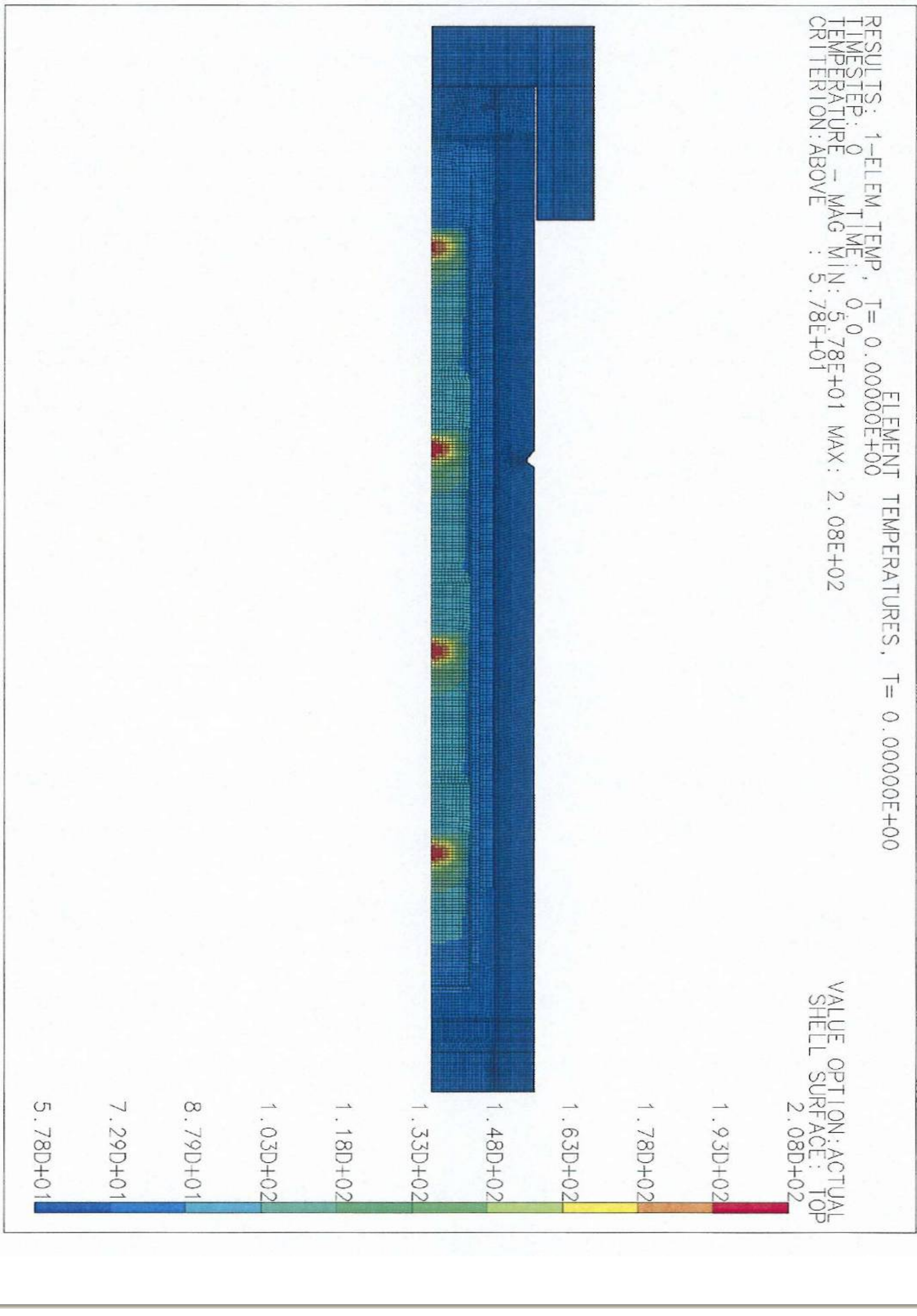


AA226	AA226
Poudre Pu02	PuO_2 powder
Boîte avec housses	Box with covers
AA213	AA213
Entretoise E1	E1 spacer

APPENDIX 2

CONFIGURATION C1.1

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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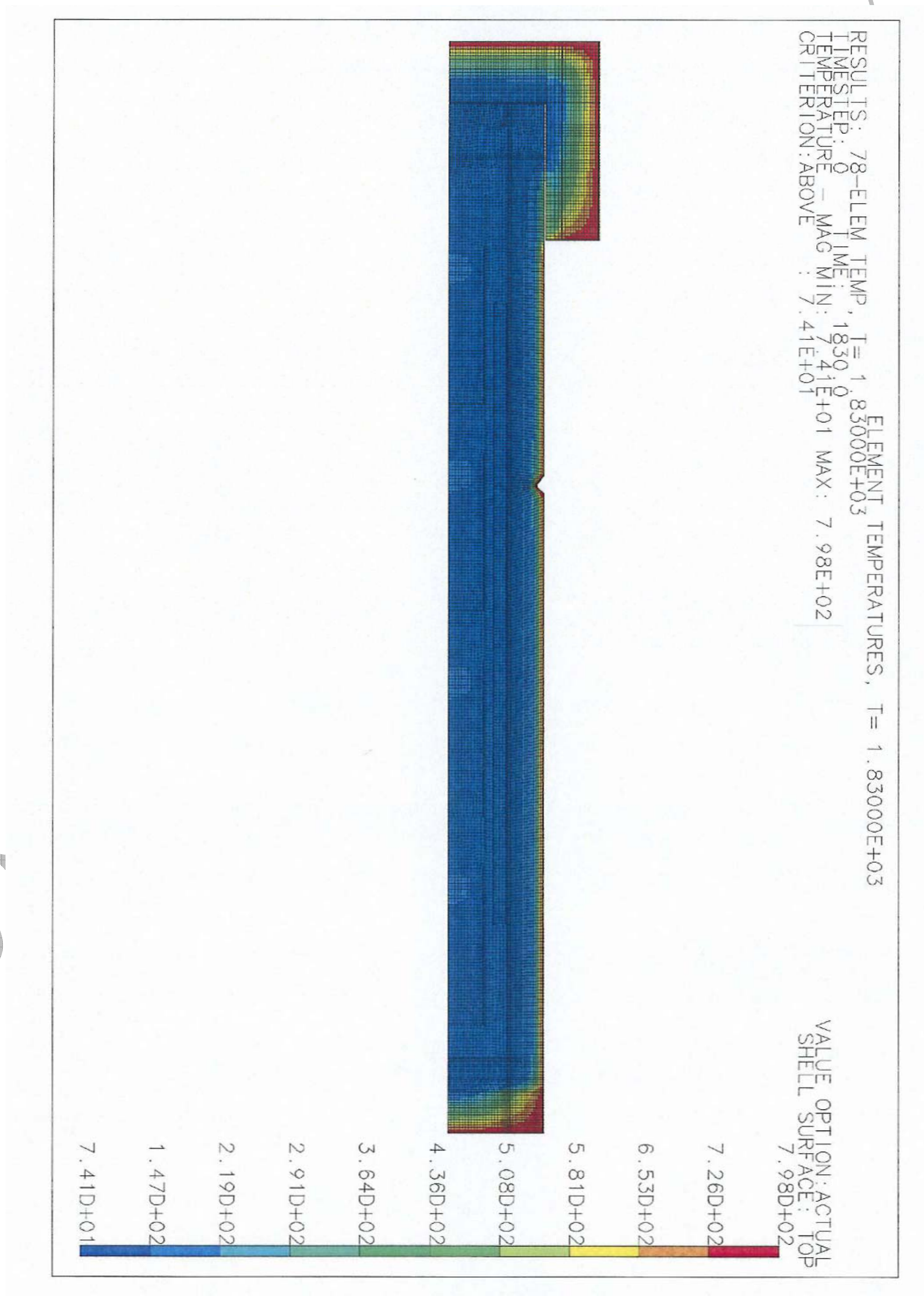
APPENDIX 2

CONFIGURATION C1.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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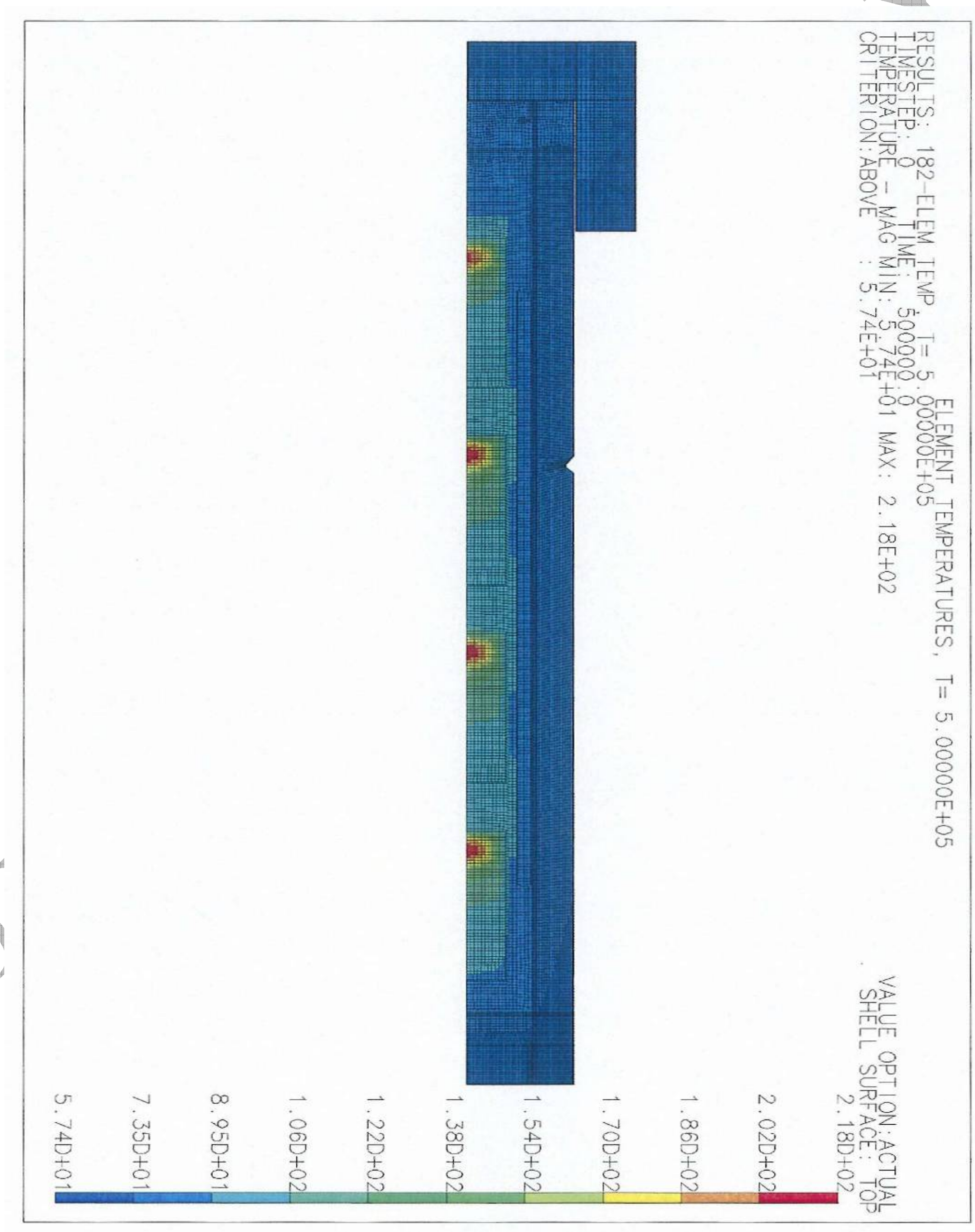
APPENDIX 2

CONFIGURATION C1.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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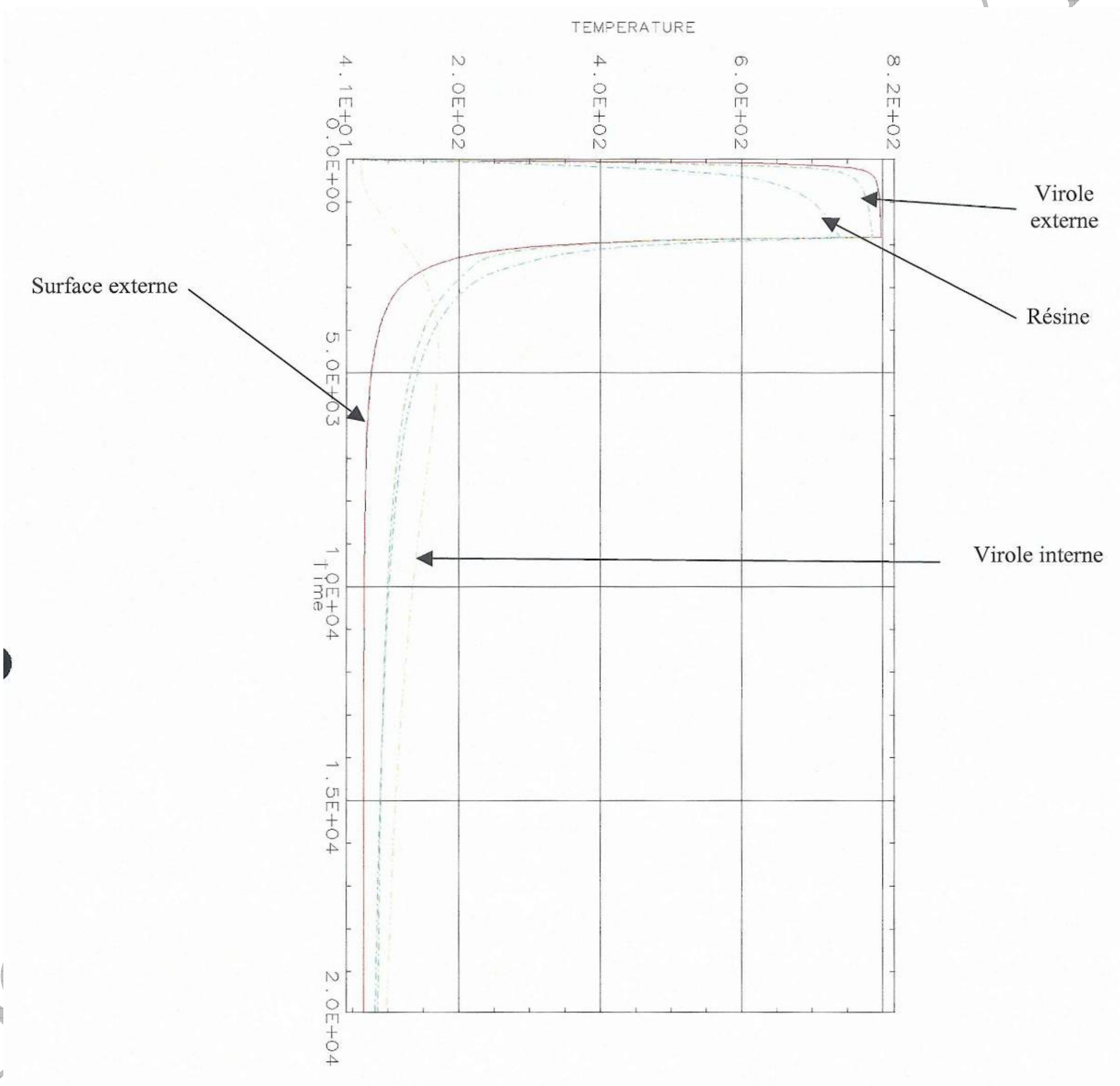
APPENDIX 2

CONFIGURATION C1.1

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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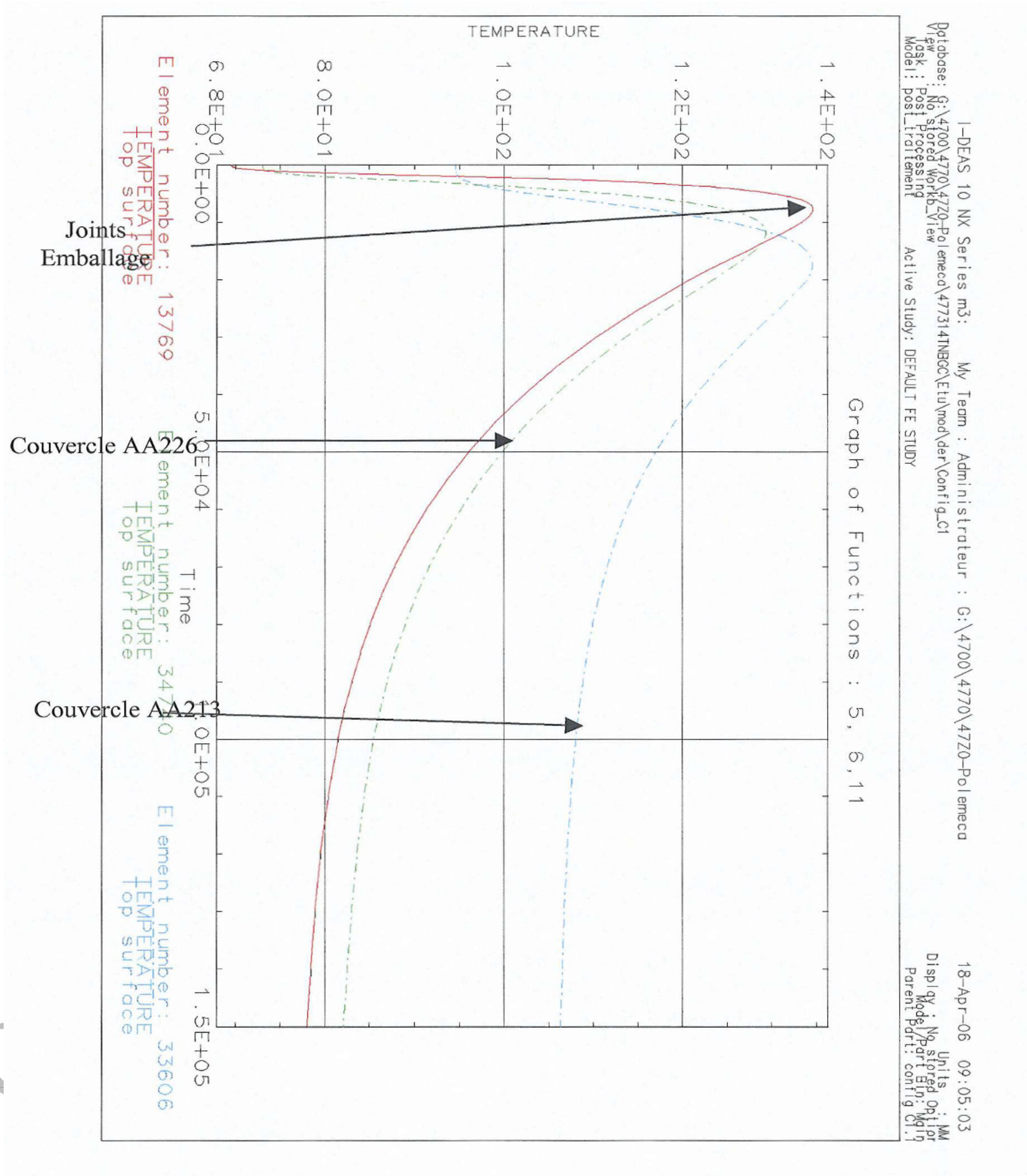
APPENDIX 2

CONFIGURATION C1.1

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle AA226	AA226 cover
Couvercle AA213	AA213 cover

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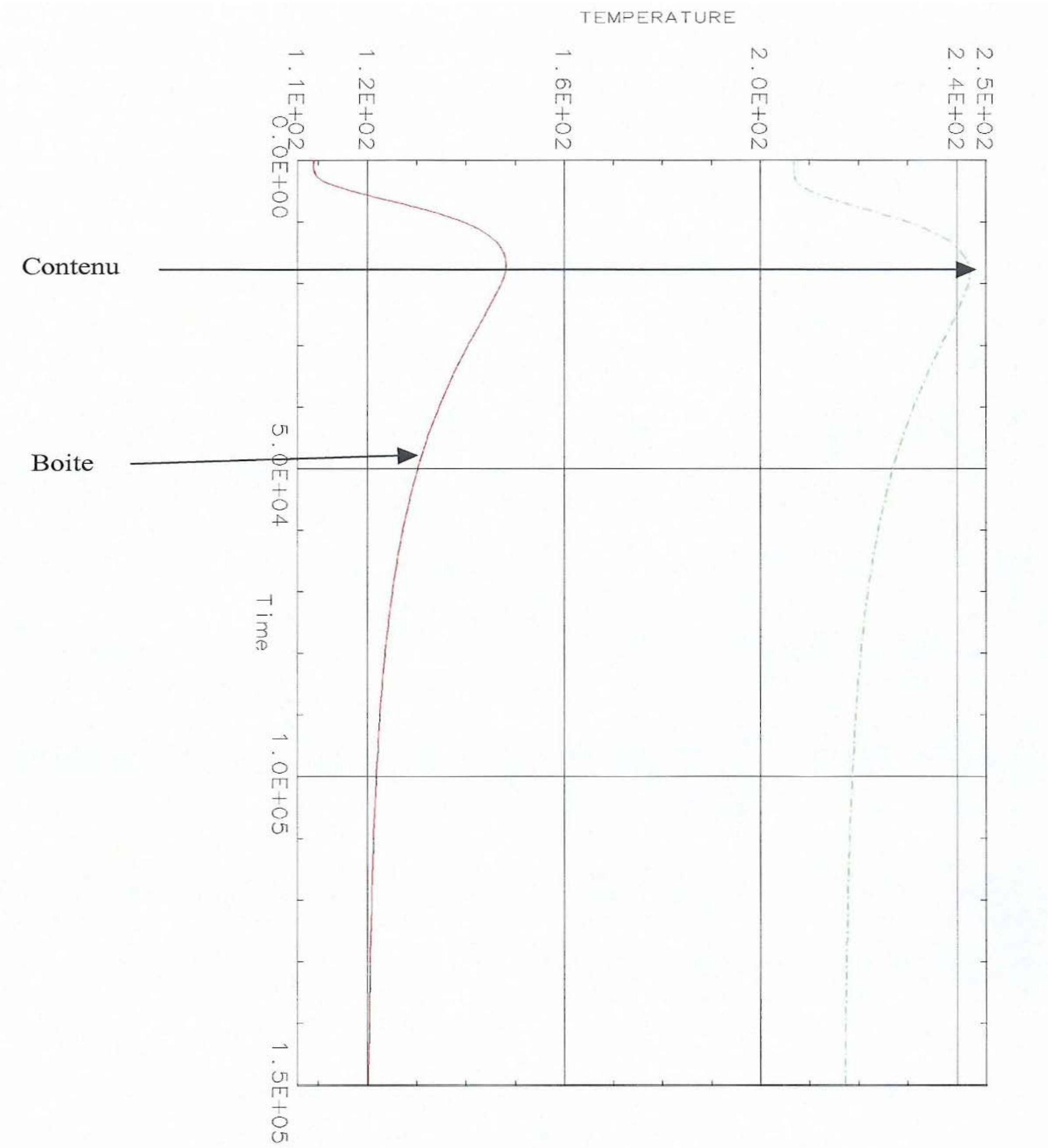
APPENDIX 2

CONFIGURATION C1.1

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



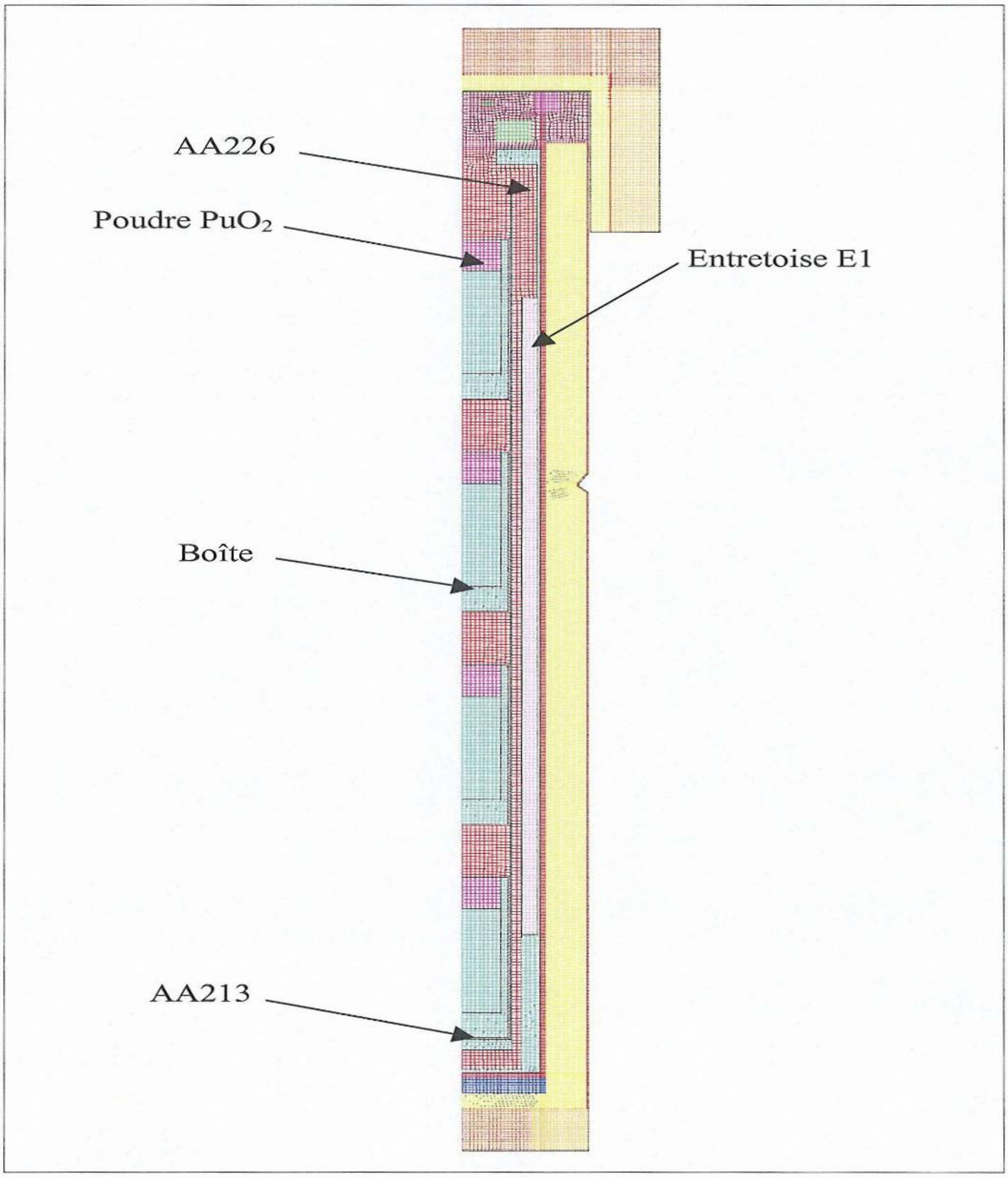
Contenu	Contents
Boite	Box

APPENDIX 3
CONFIGURATION C1.2

APPENDIX 3

CONFIGURATION C1.2

PRESENTATION OF MODEL

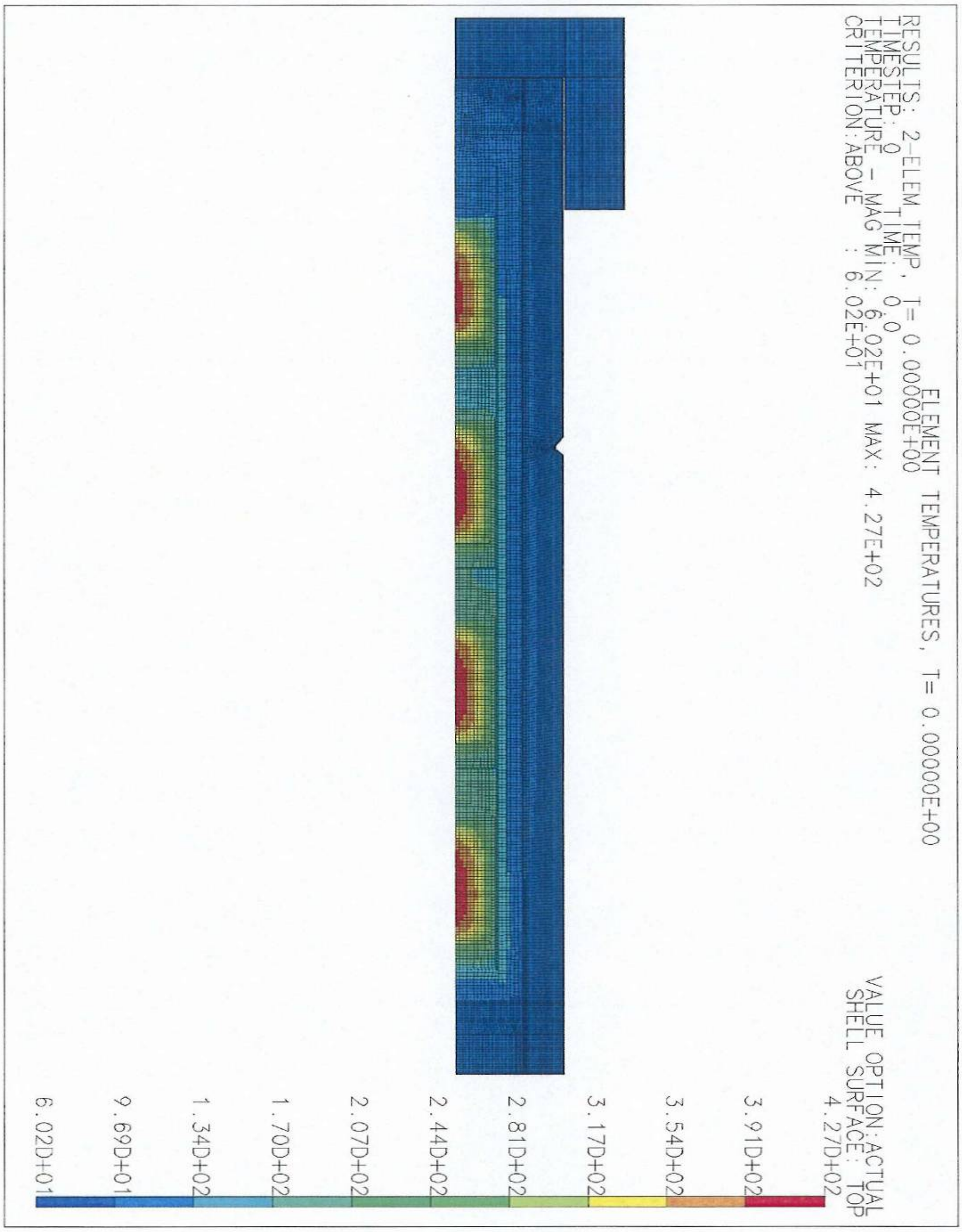


AA226	AA226
Poudre Pu02	PuO_2 powder
Boîte	Box
AA213	AA213
Entretoise E1	E1 spacer

APPENDIX 3

CONFIGURATION C1.2

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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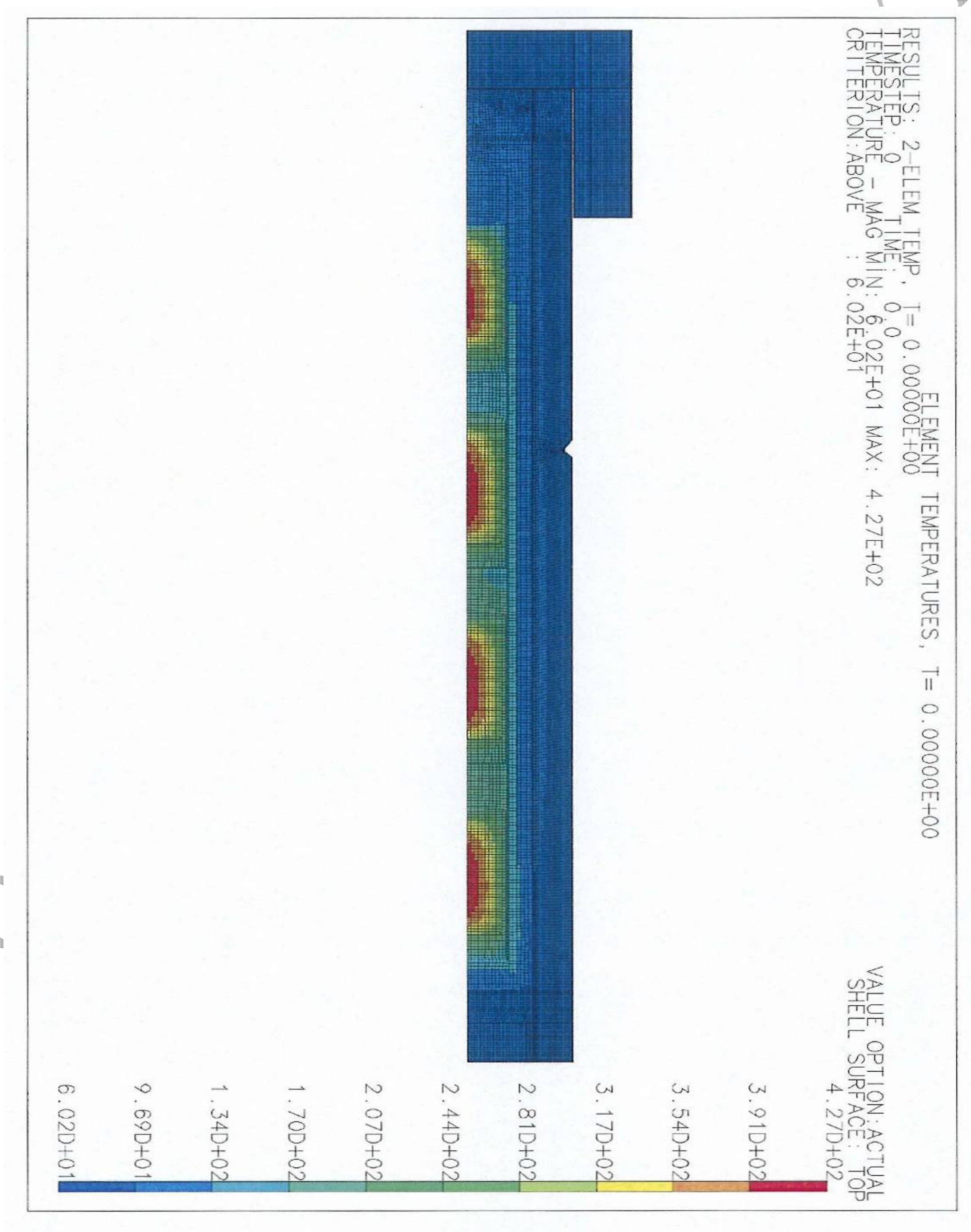
APPENDIX 3

CONFIGURATION C1.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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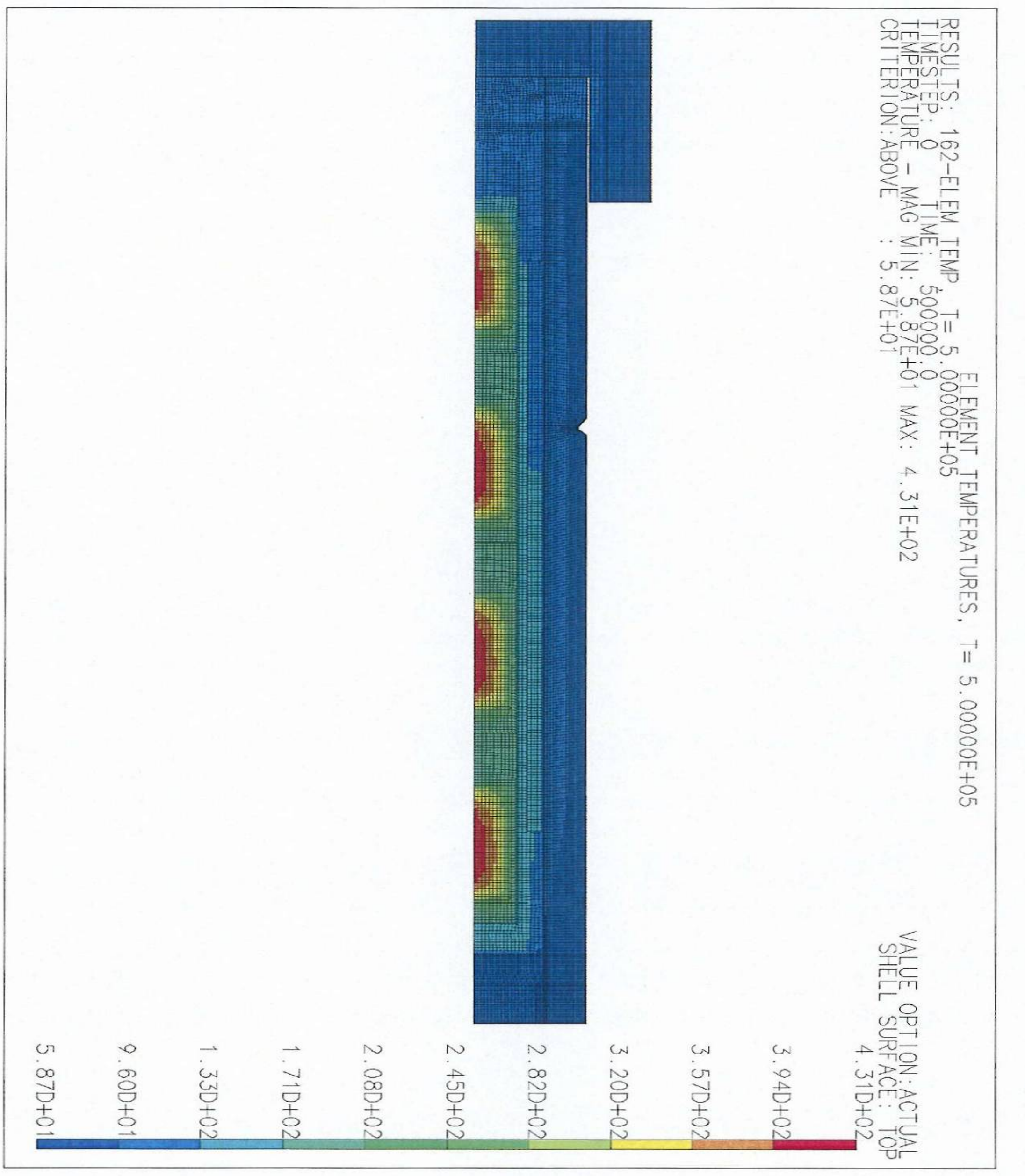
APPENDIX 3

CONFIGURATION C1.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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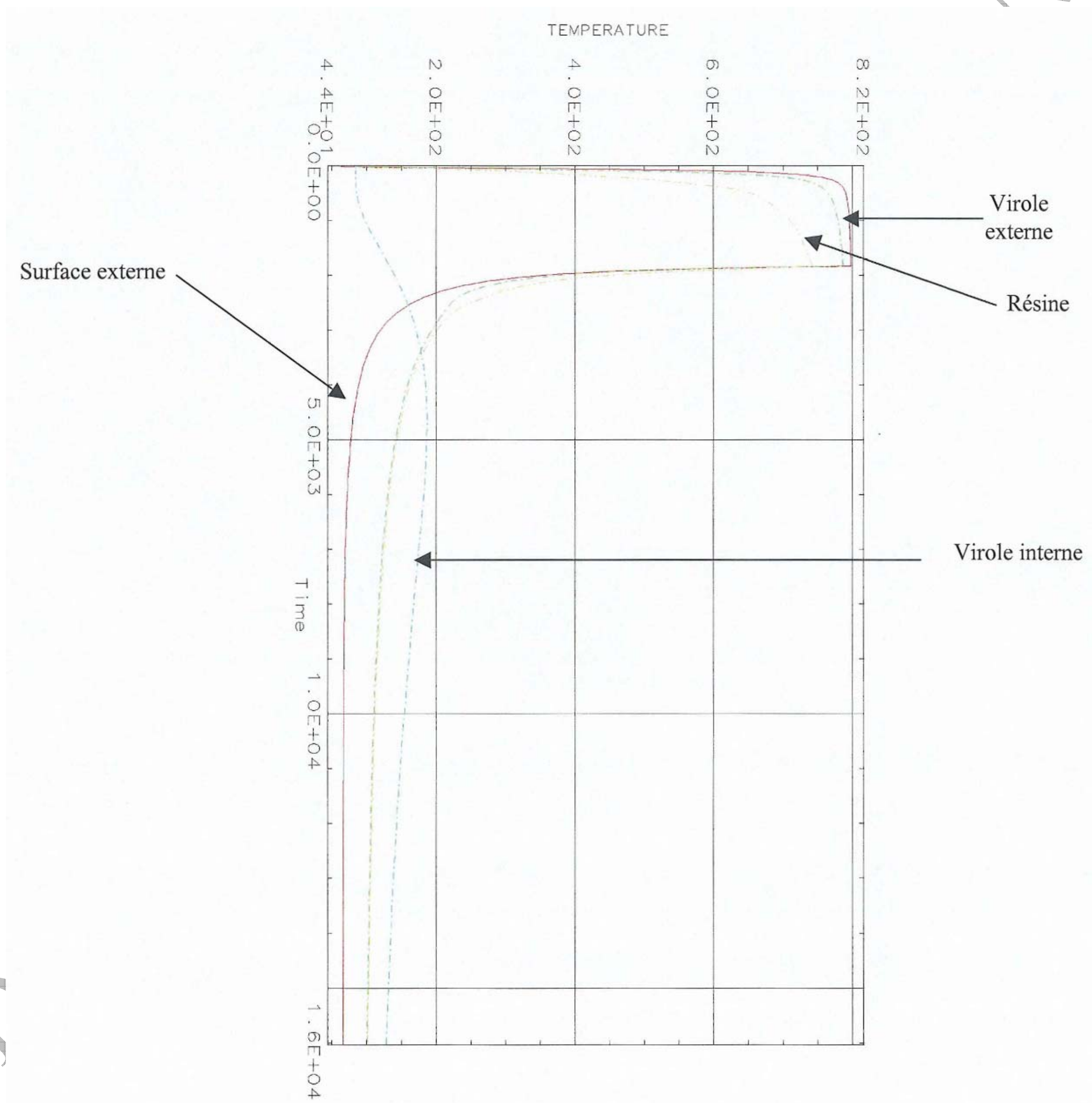
APPENDIX 3

CONFIGURATION C1.2

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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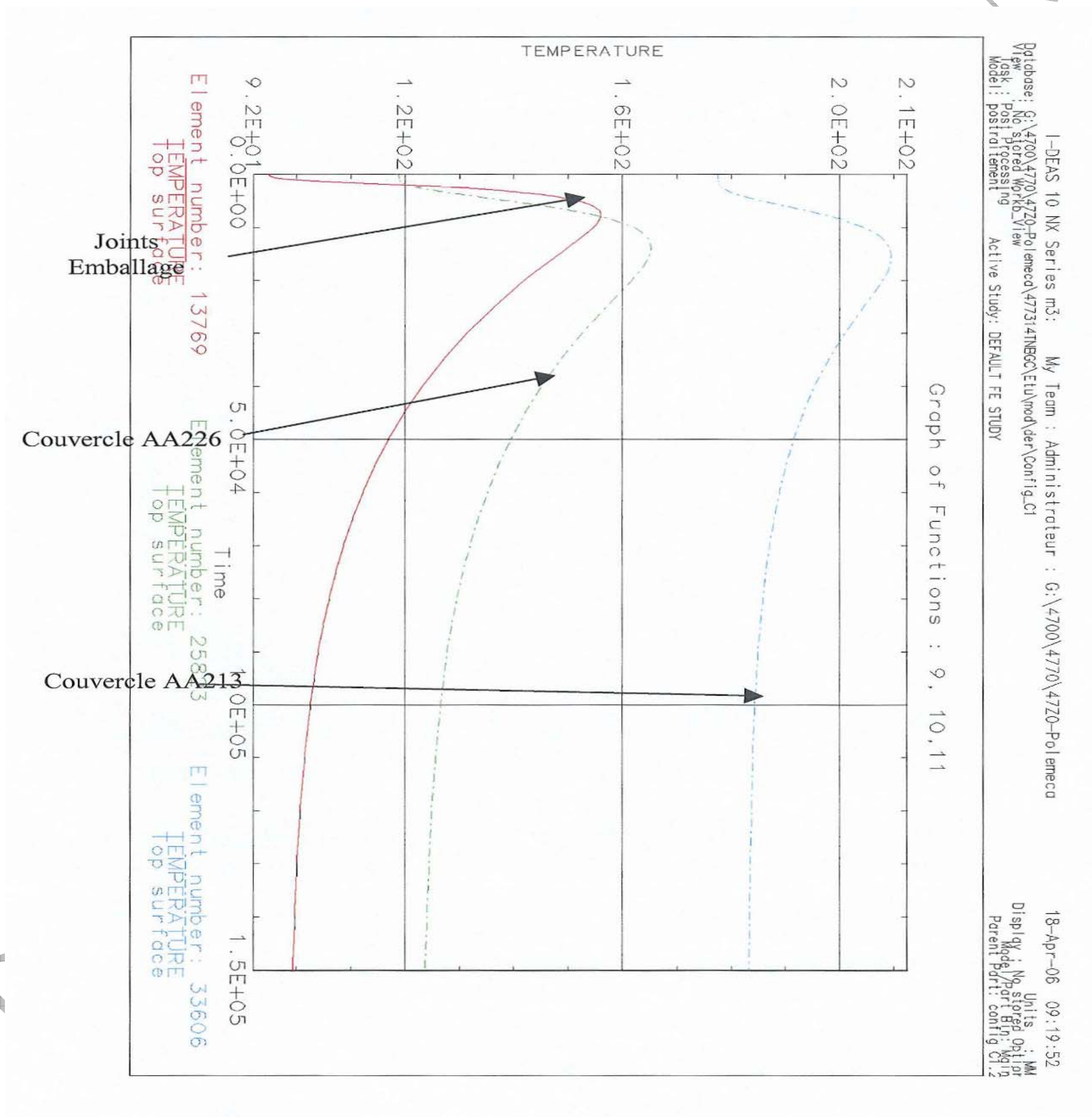
APPENDIX 3

CONFIGURATION C1.2

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle AA226	AA226 cover
Couvercle AA213	AA213 cover

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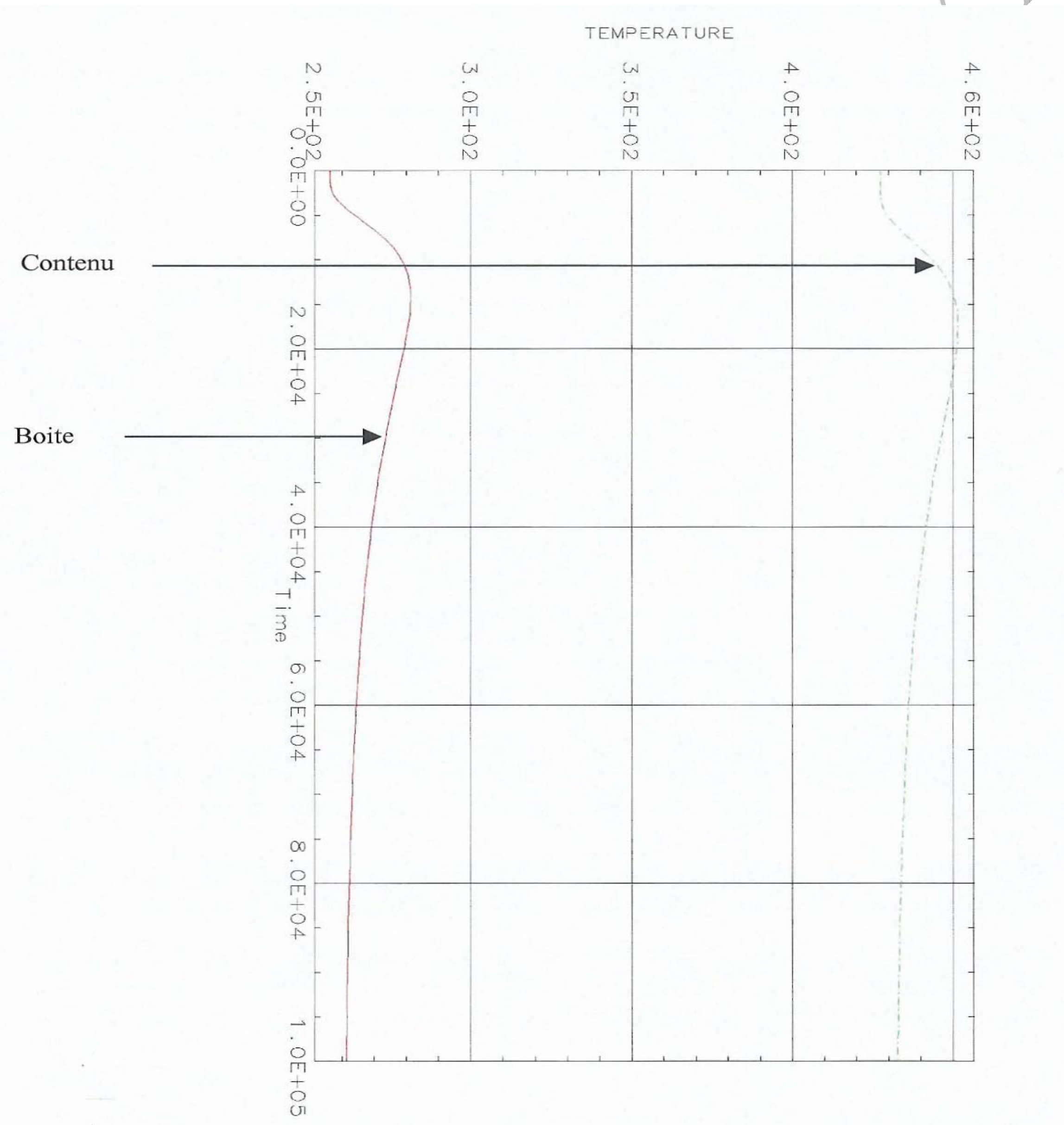
APPENDIX 3

CONFIGURATION C1.2

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boite	Box

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CONFIGURATION C2.1

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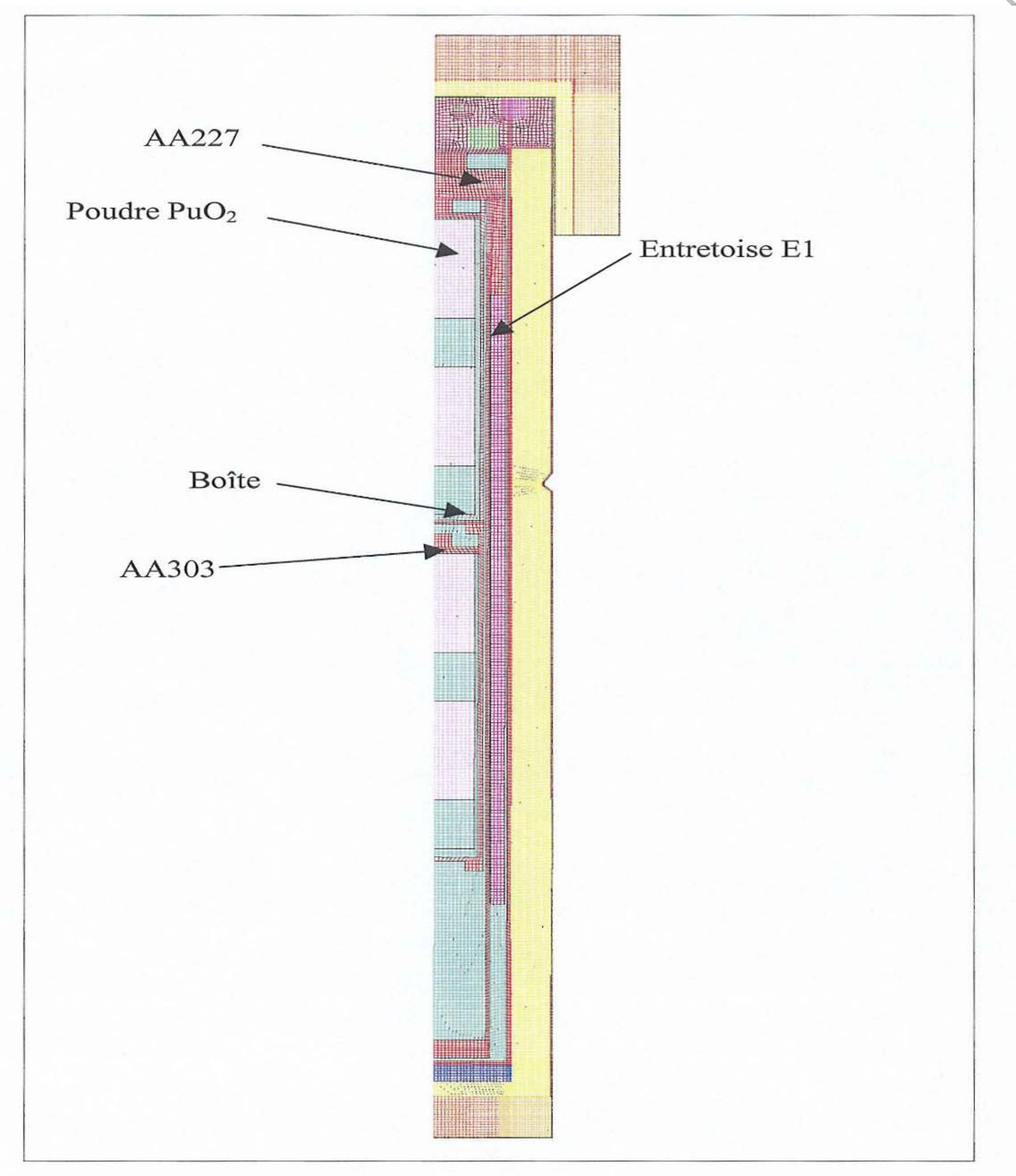
APPENDIX 4

CONFIGURATION C2.1
PRESENTATION OF MODEL



AA227	AA227
Poudre Pu02	PuO_2 powder
Boîte	Box
AA303	AA303
Entretoise E1	E1 spacer

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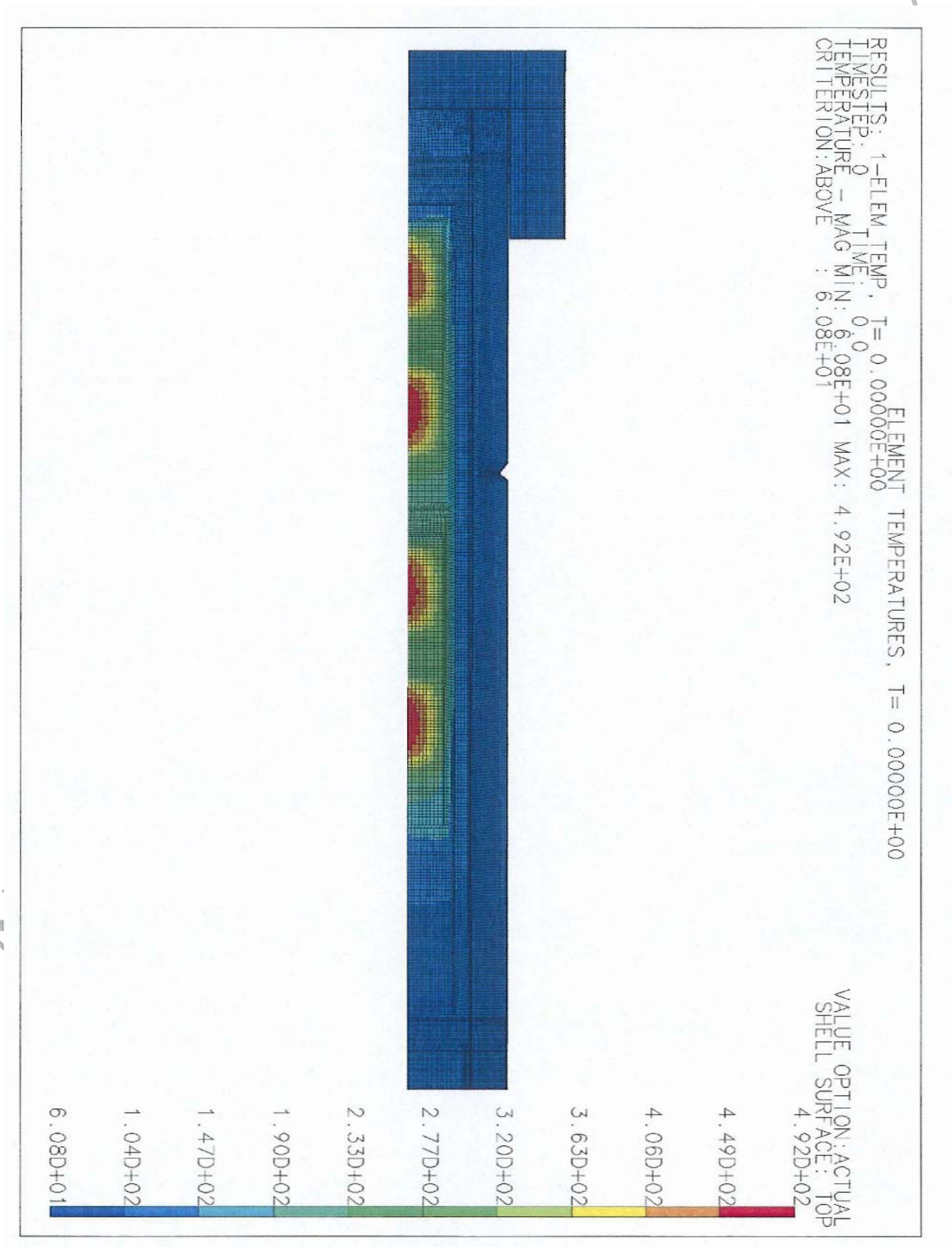
APPENDIX 4

CONFIGURATION C2.1

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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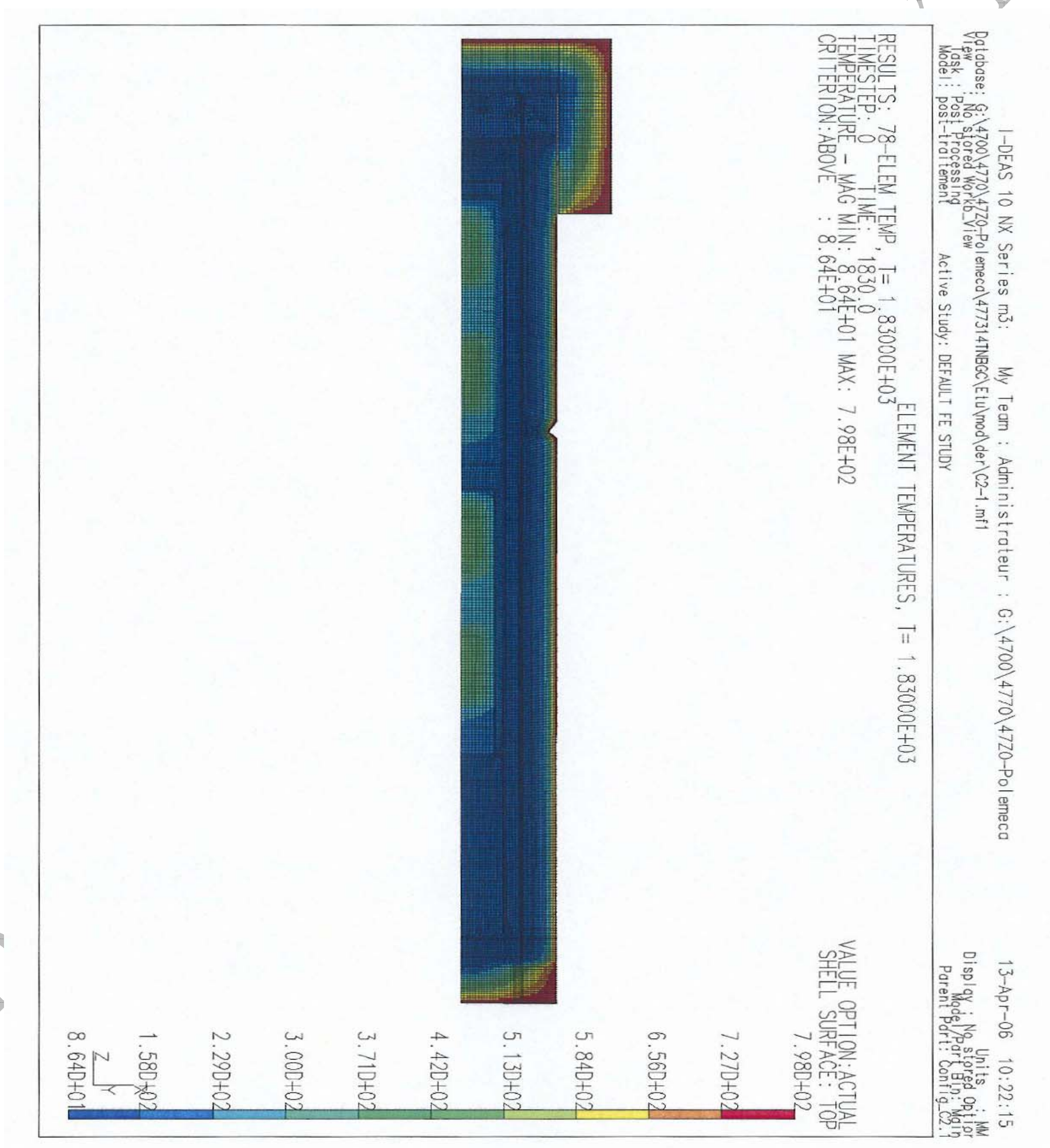
APPENDIX 4

CONFIGURATION C2.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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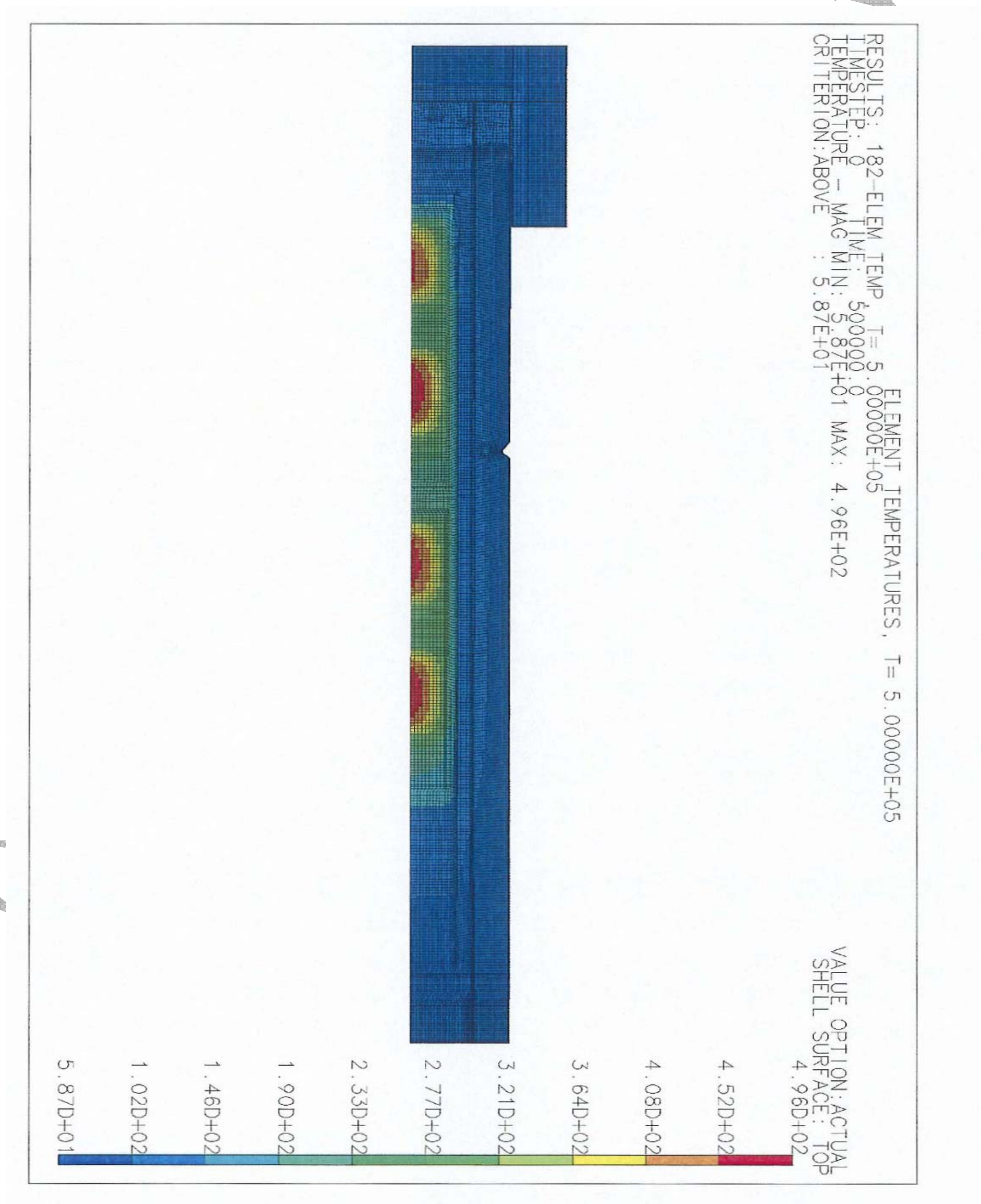
APPENDIX 4

CONFIGURATION C2.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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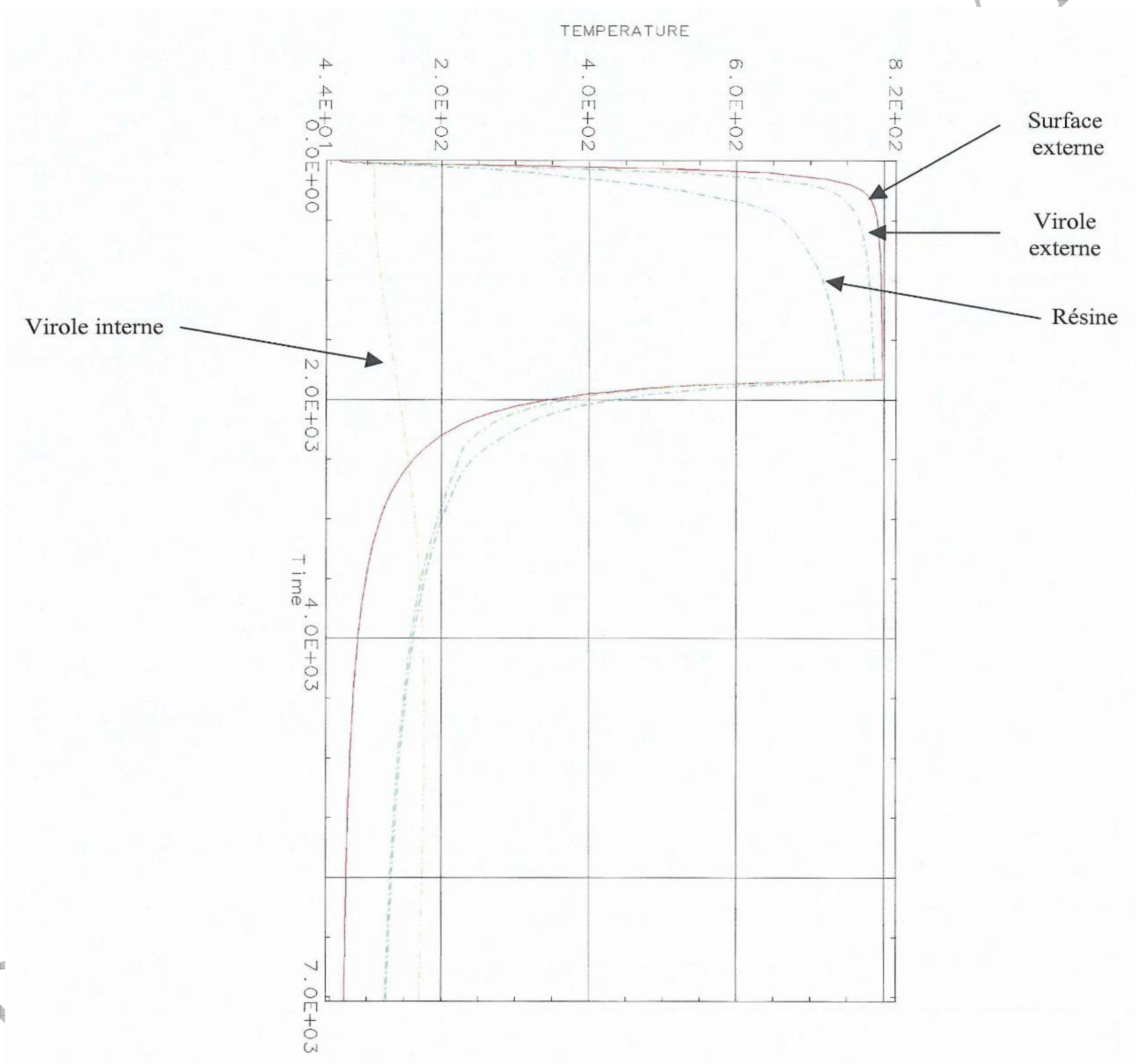
CONFIGURATION C2.1

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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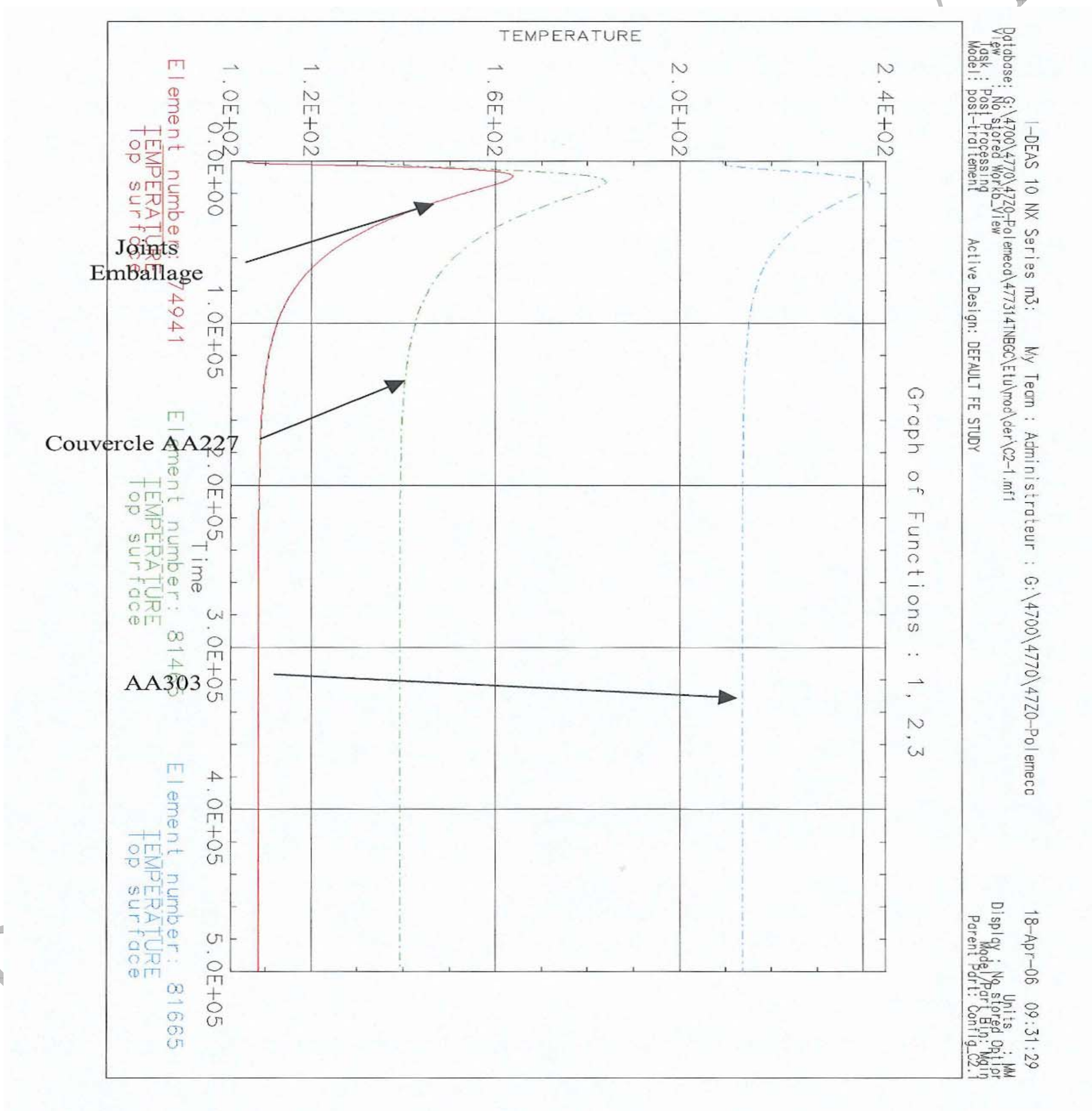
APPENDIX 4

CONFIGURATION C2.1

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle AA227	AA227 cover
AA303	AA303

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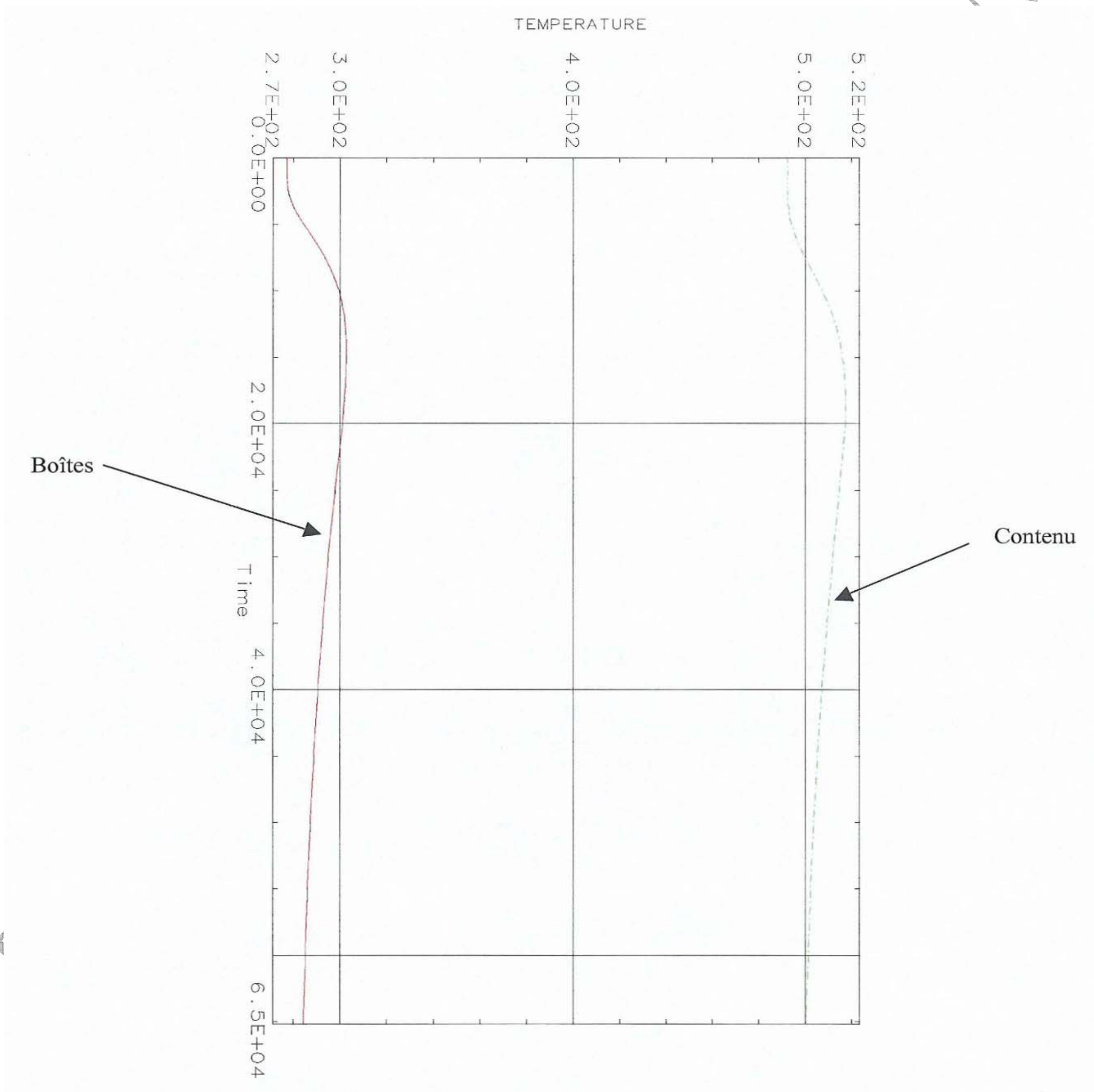
APPENDIX 4

CONFIGURATION C2.1

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boites	Boxes

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CONFIGURATION C2.2

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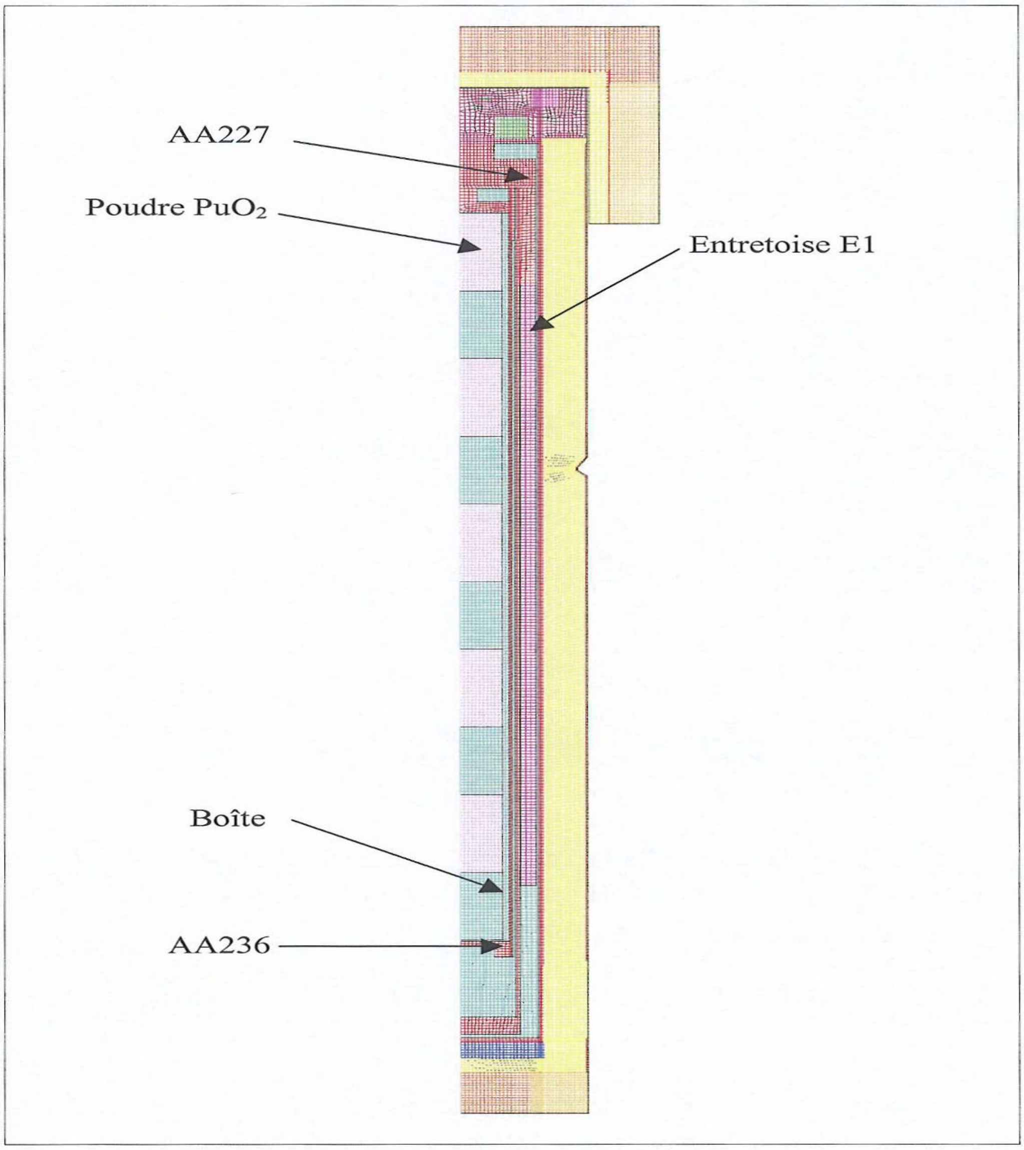
APPENDIX 5

CONFIGURATION C2.2
PRESENTATION OF MODEL

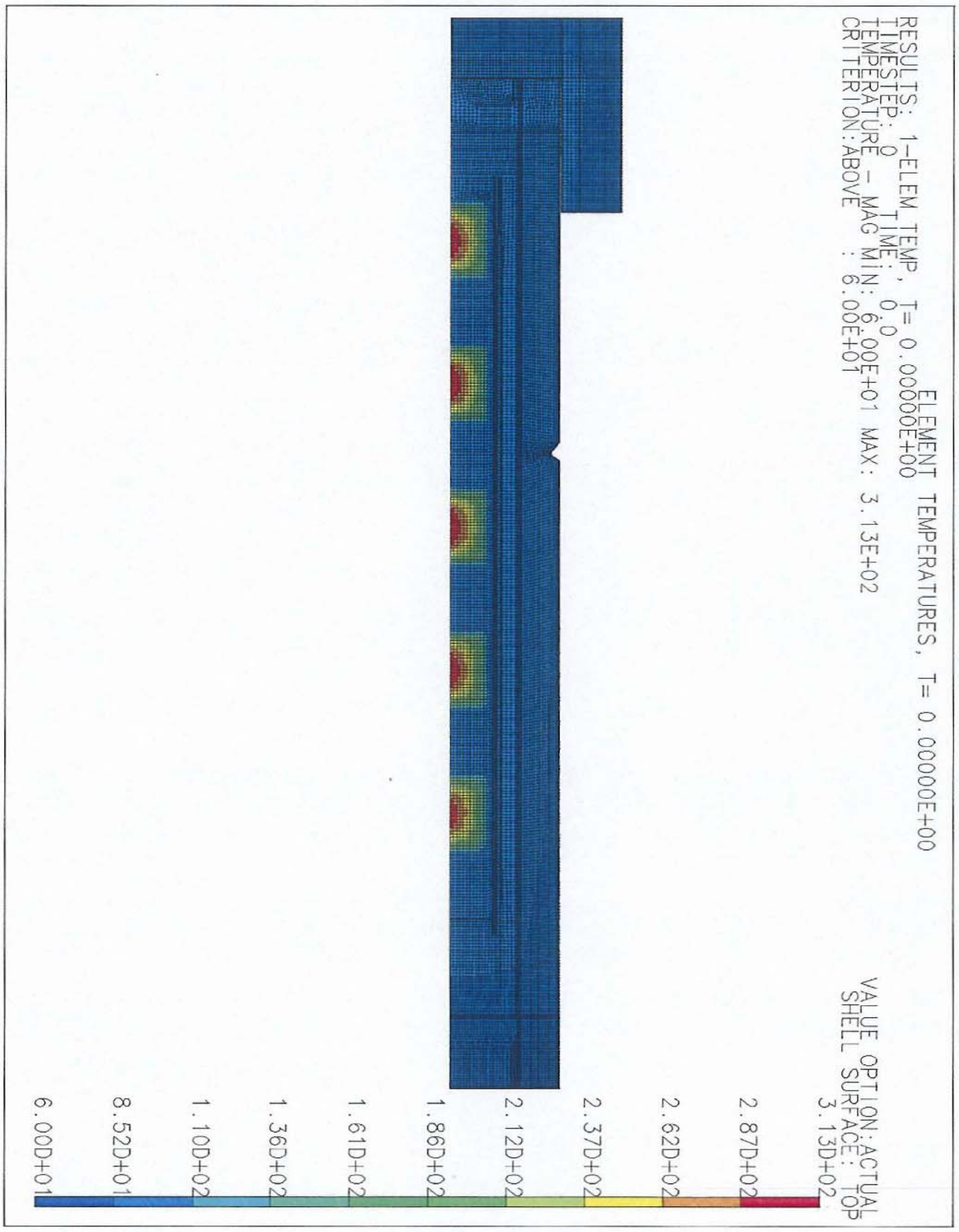


AA227	AA227
Poudre Pu02	PuO_2 powder
Boîte	Box
AA236	AA236
Entretoise E1	E1 spacer

APPENDIX 5

CONFIGURATION C2.2

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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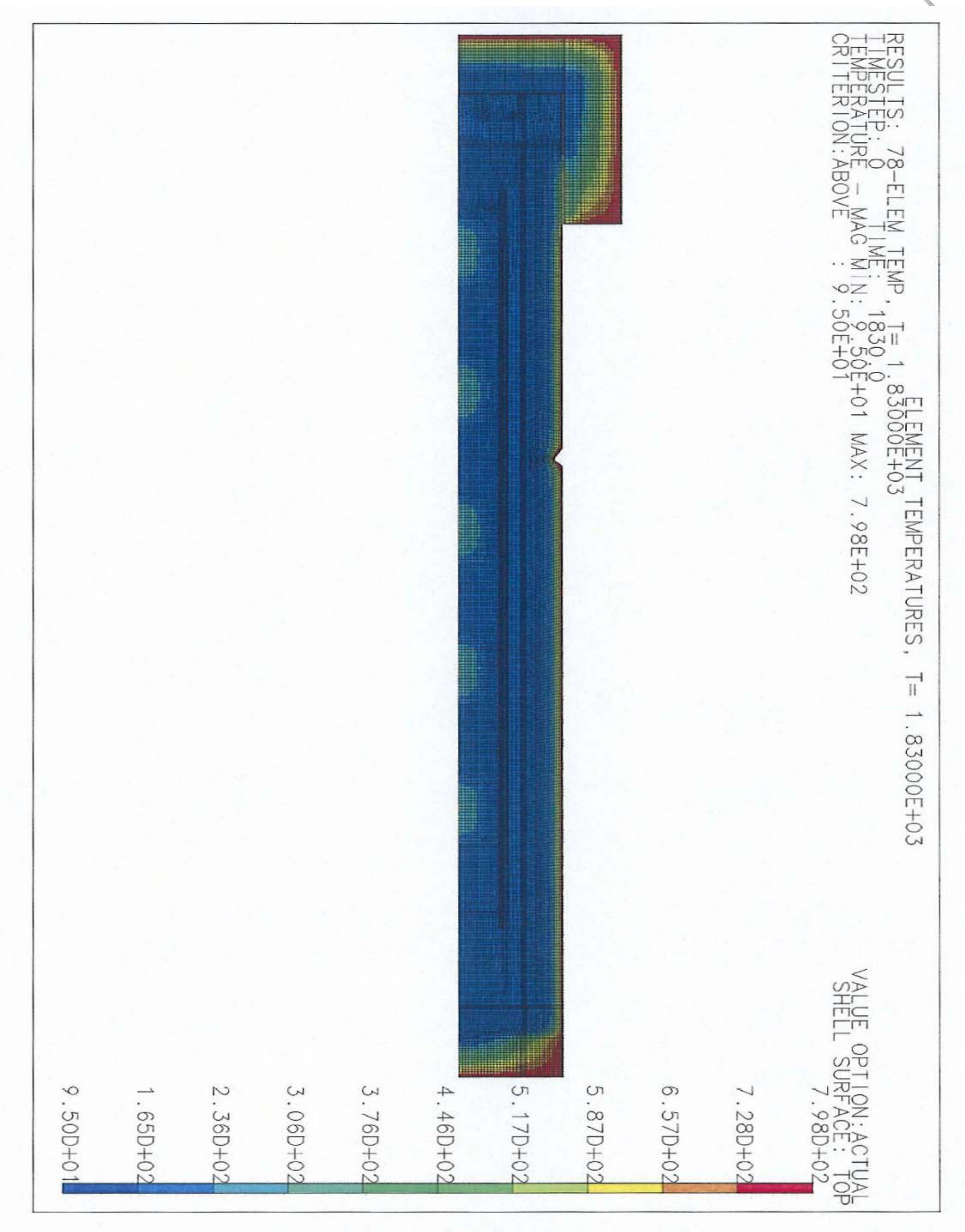
APPENDIX 5

CONFIGURATION C2.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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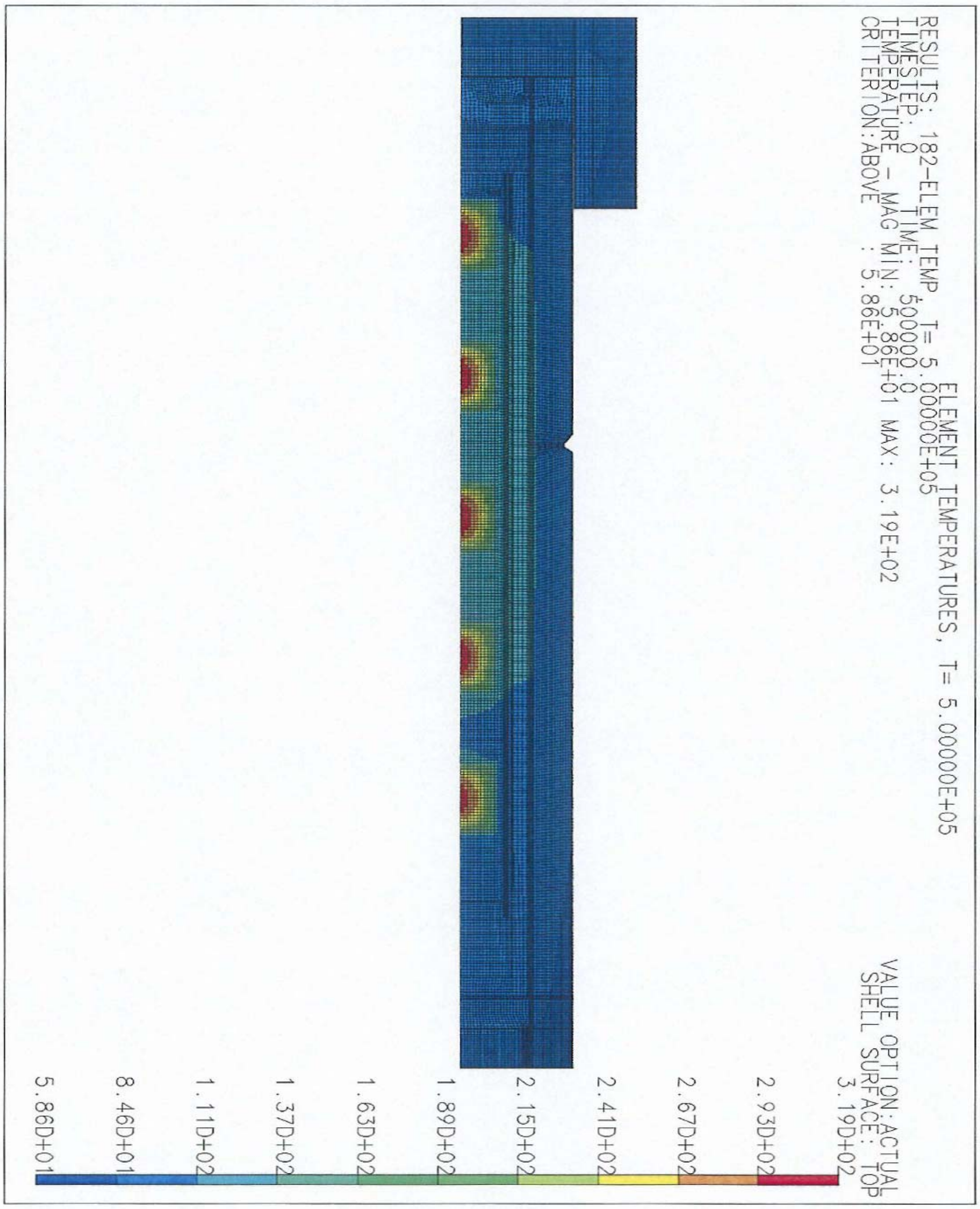
CONFIGURATION C2.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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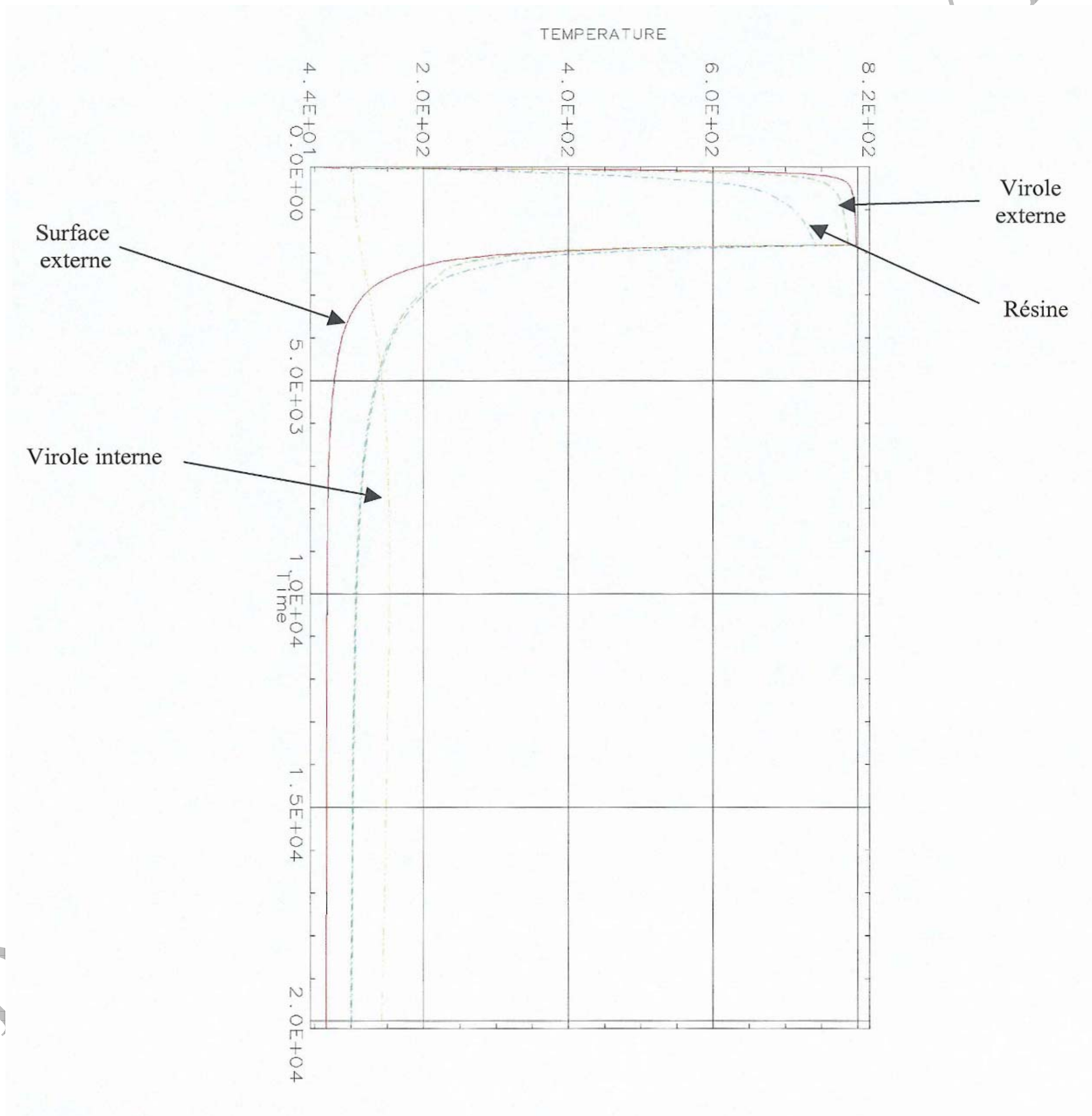
APPENDIX 5

CONFIGURATION C2.2

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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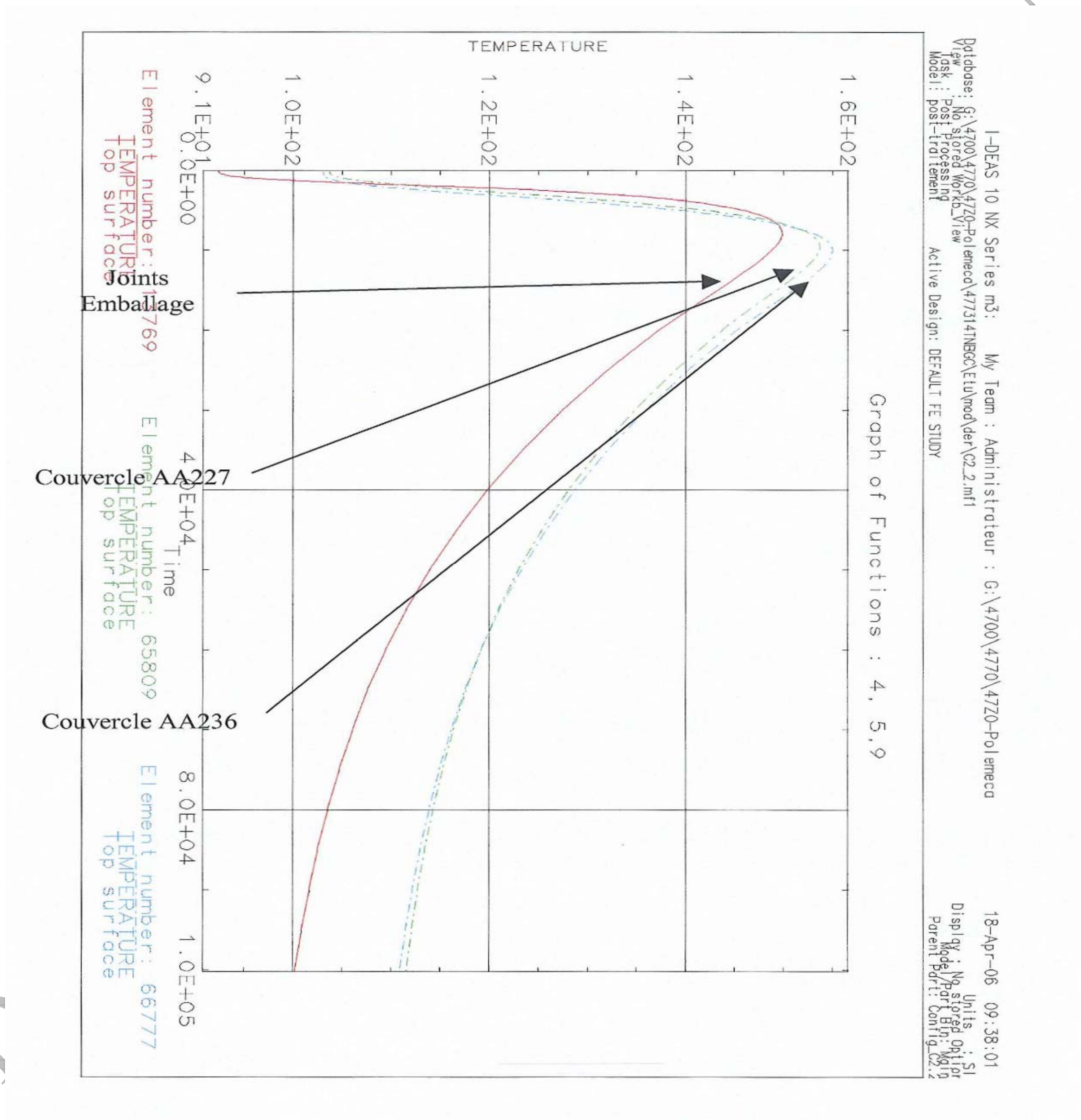
APPENDIX 5

CONFIGURATION C2.2

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle AA227	AA227 cover
Couvercle AA236	AA236 cover

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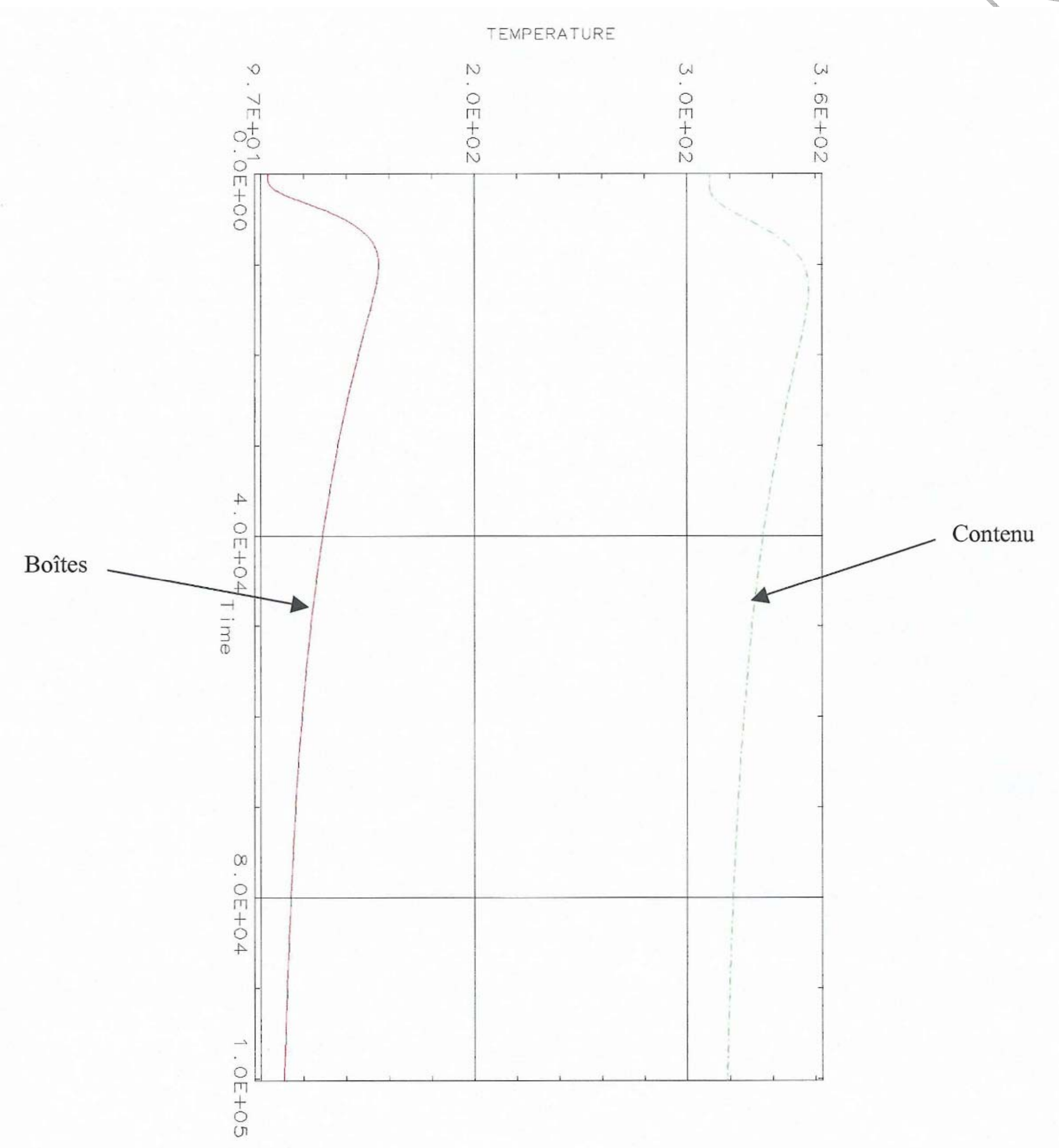
APPENDIX 5

CONFIGURATION C2.2

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boites	Boxes

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CONFIGURATIONS C3.1 and C3.1 bis

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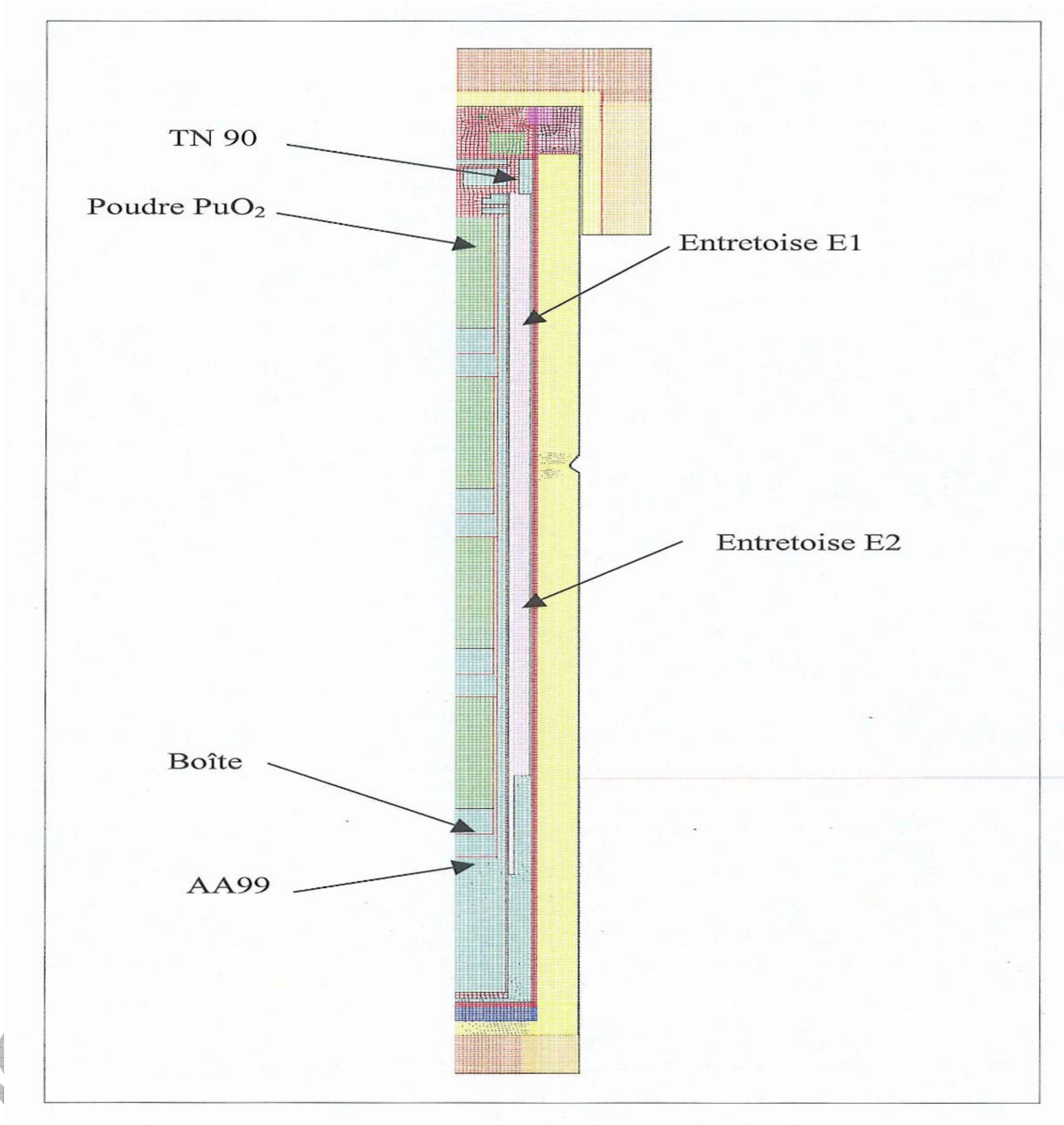
APPENDIX 6

CONFIGURATION C3.1

PRESENTATION OF MODEL

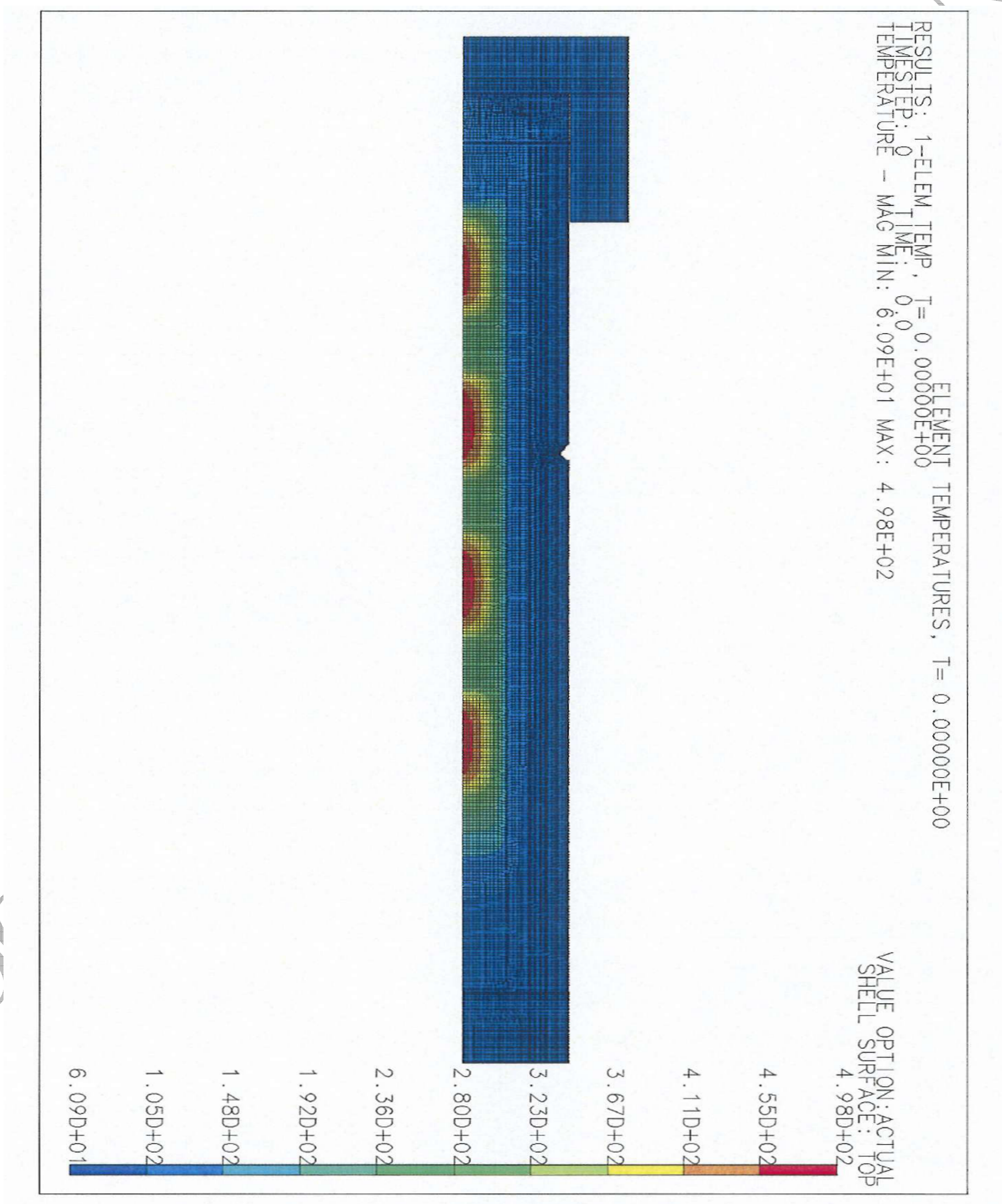


TN 90	TN 90
Poudre Pu02	PuO_2 powder
Boîte	Box
AA99	AA99
Entretoise E1	E1 spacer
Entretoise E2	E2 spacer

APPENDIX 6

CONFIGURATION C3.1

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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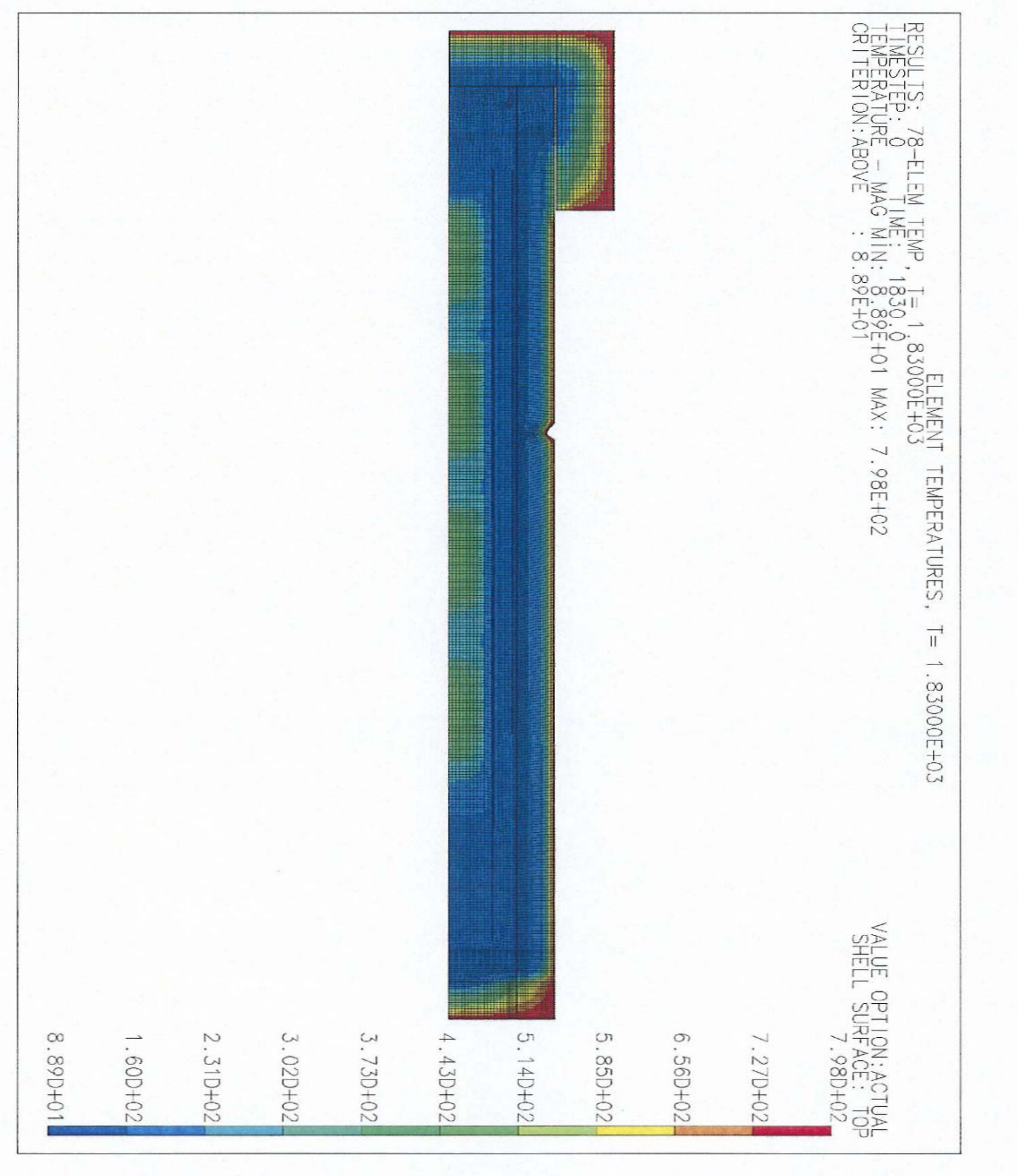
APPENDIX 6

CONFIGURATION C3.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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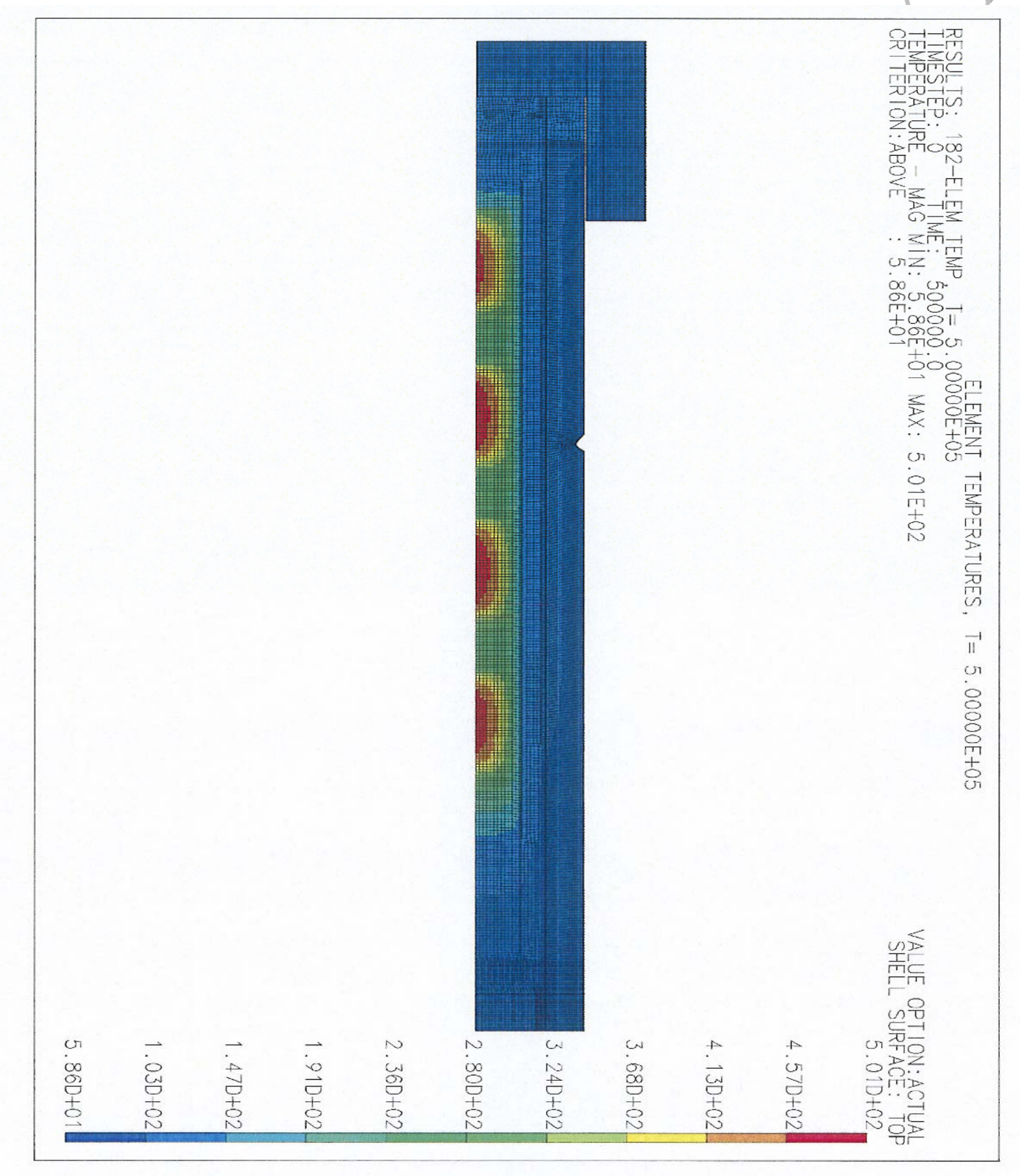
APPENDIX 6

CONFIGURATION C3.1

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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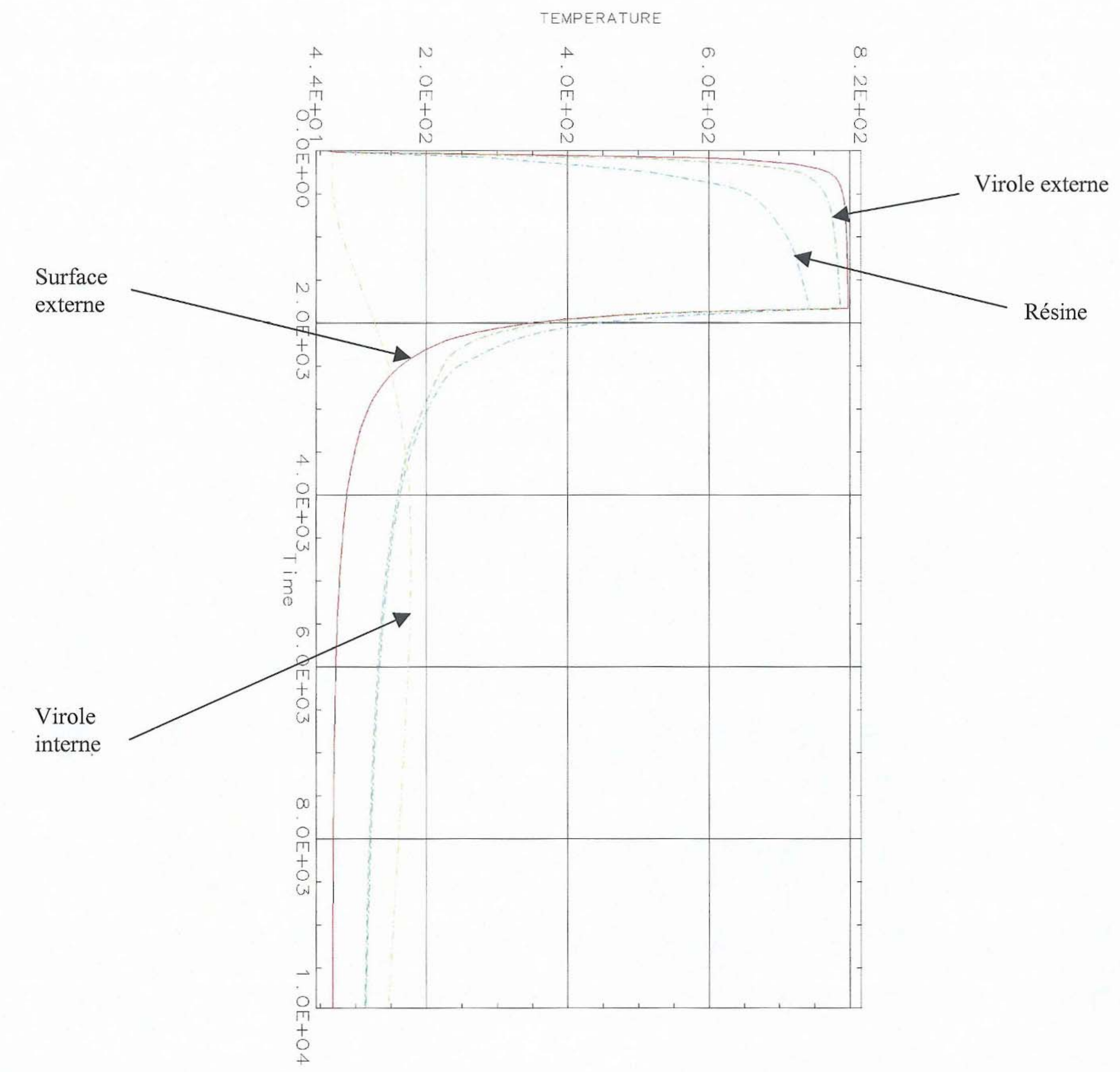
CONFIGURATION C3.1

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT

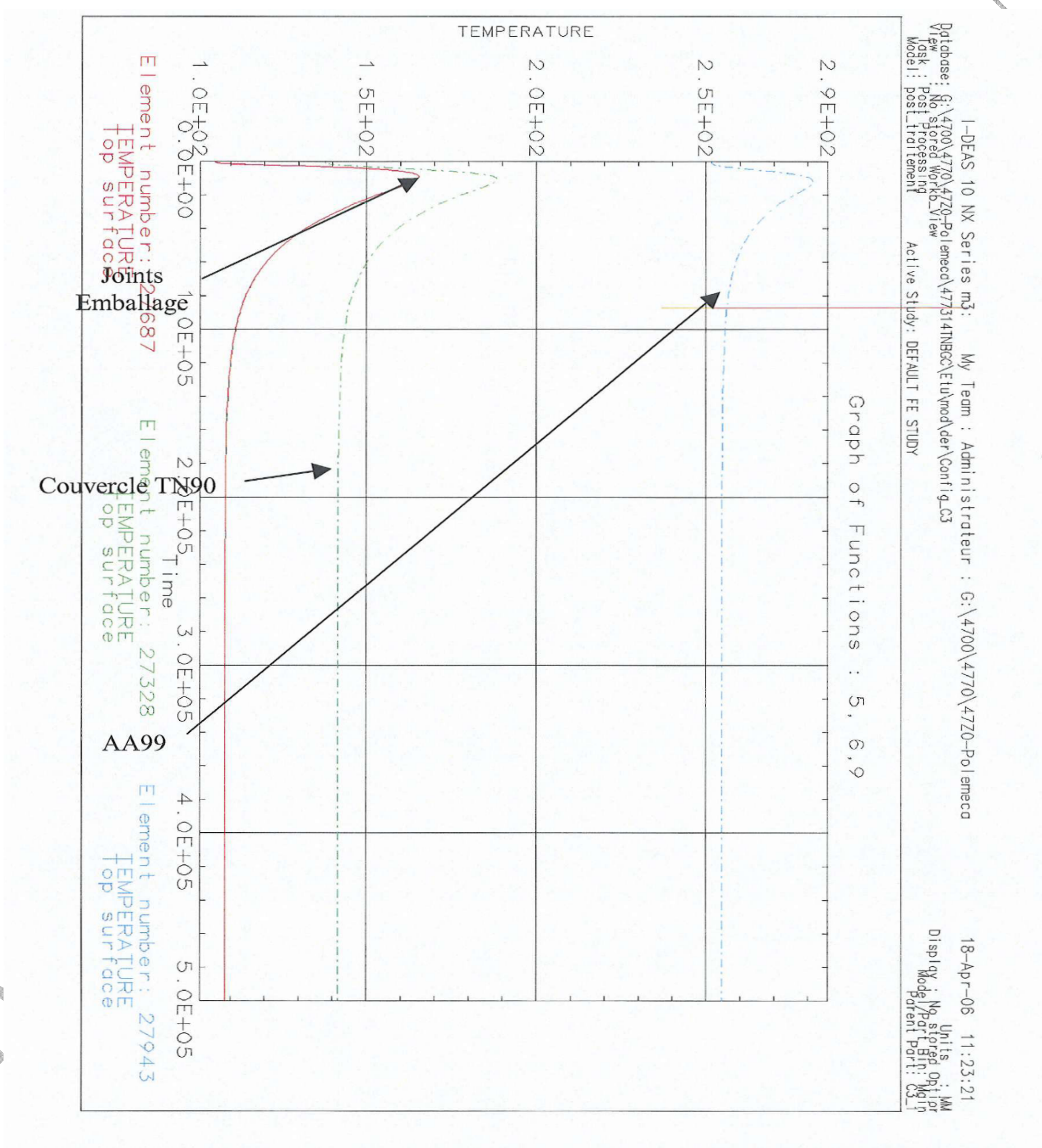


Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

APPENDIX 6

CONFIGURATION C3.1

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT

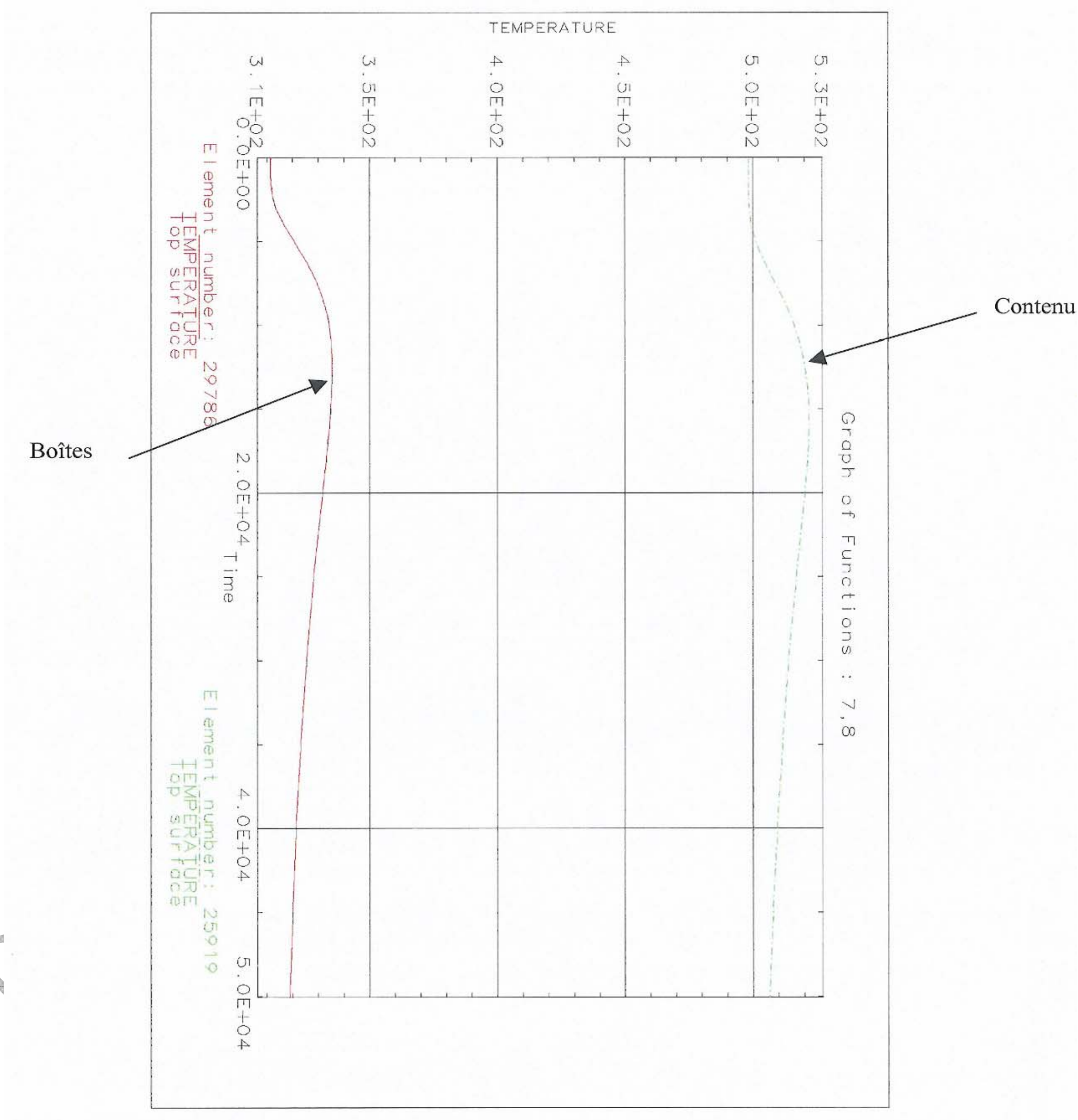


Joints Emballage	Packaging seals
Couvercle TN90	TN90 cover
AA99	AA99

APPENDIX 6

CONFIGURATION C3.1

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boites	Boxes

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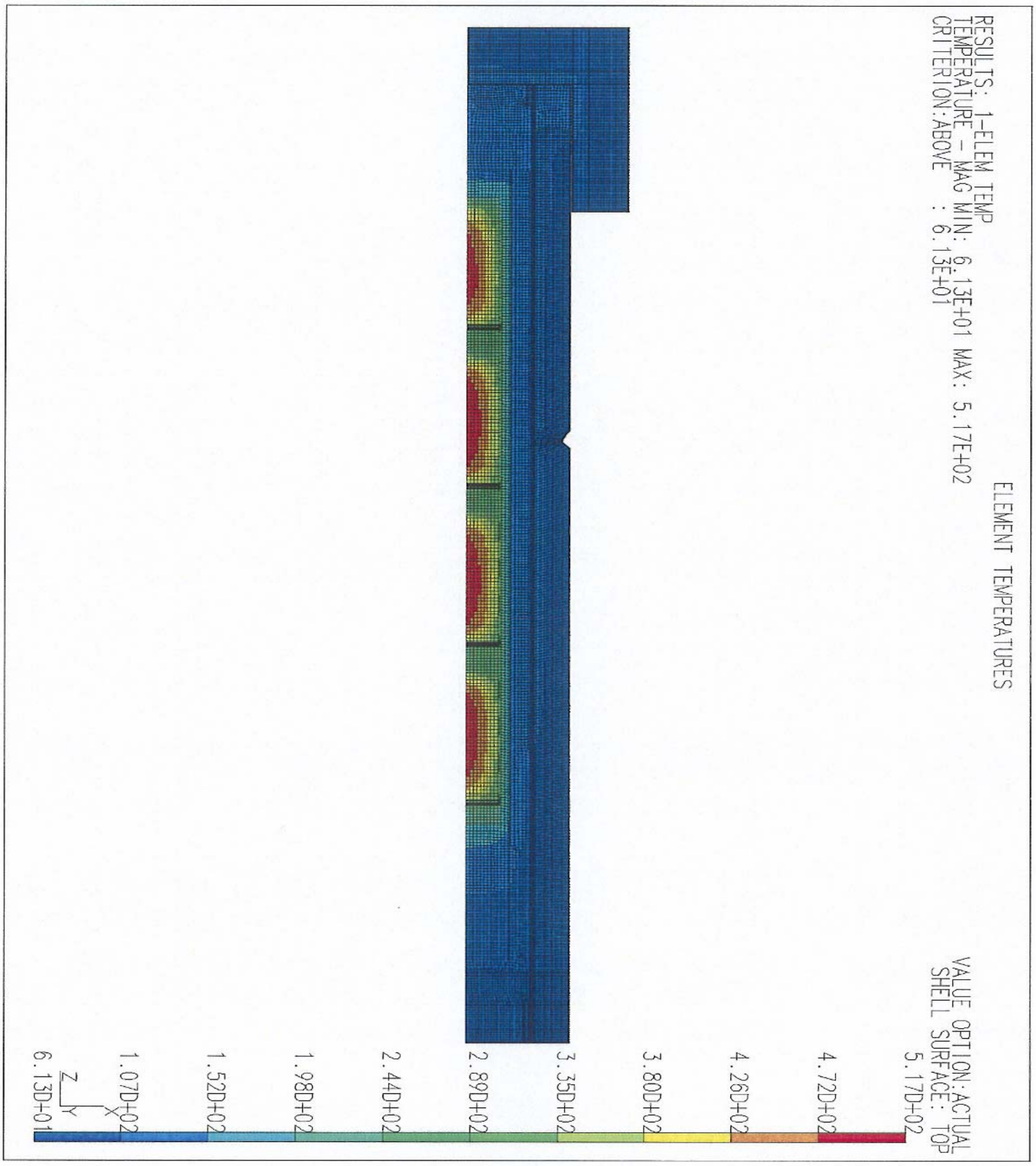
CONFIGURATION C3.1 bis

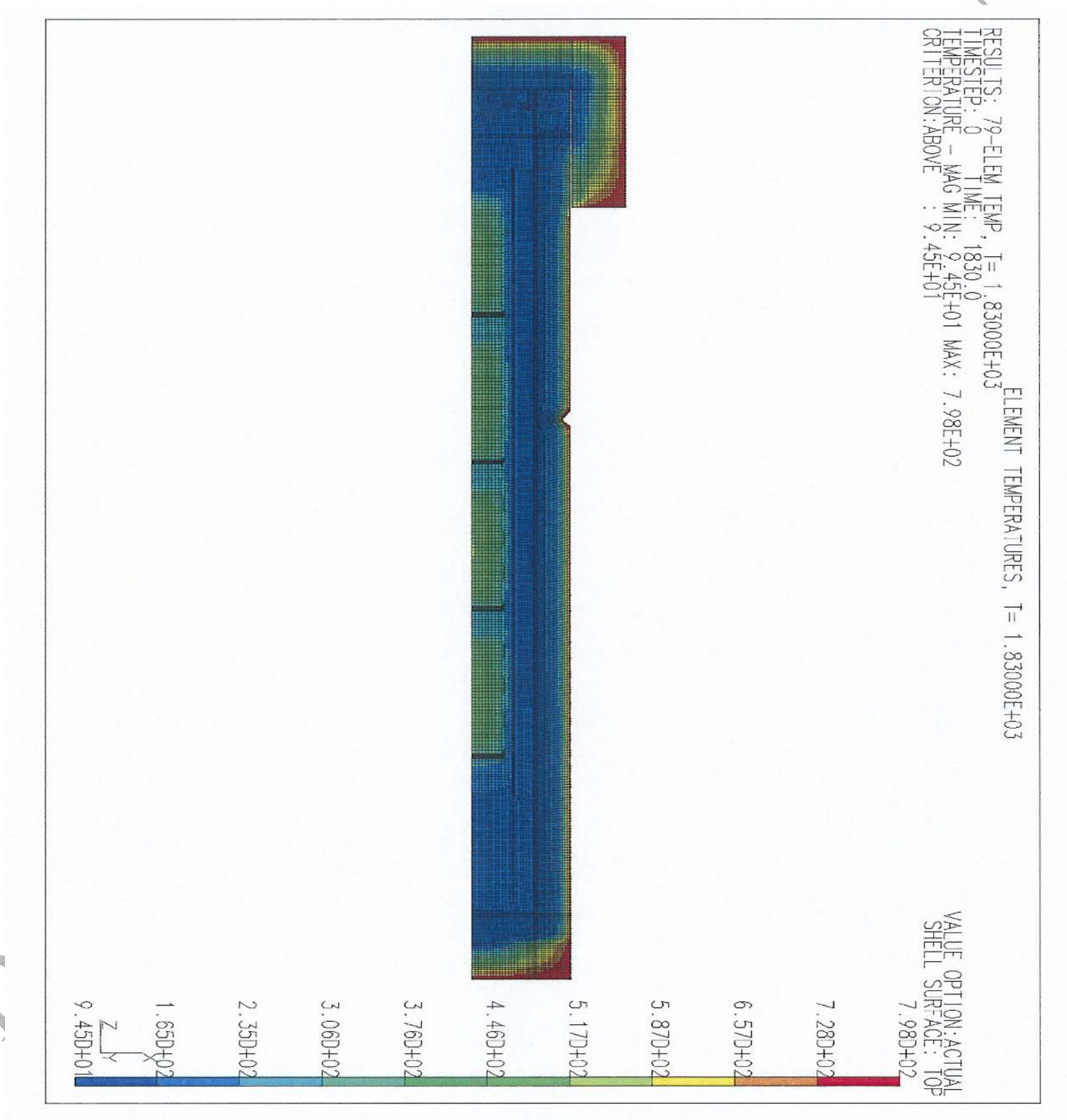
ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



APPENDIX 6

CONFIGURATION C3.1 bis

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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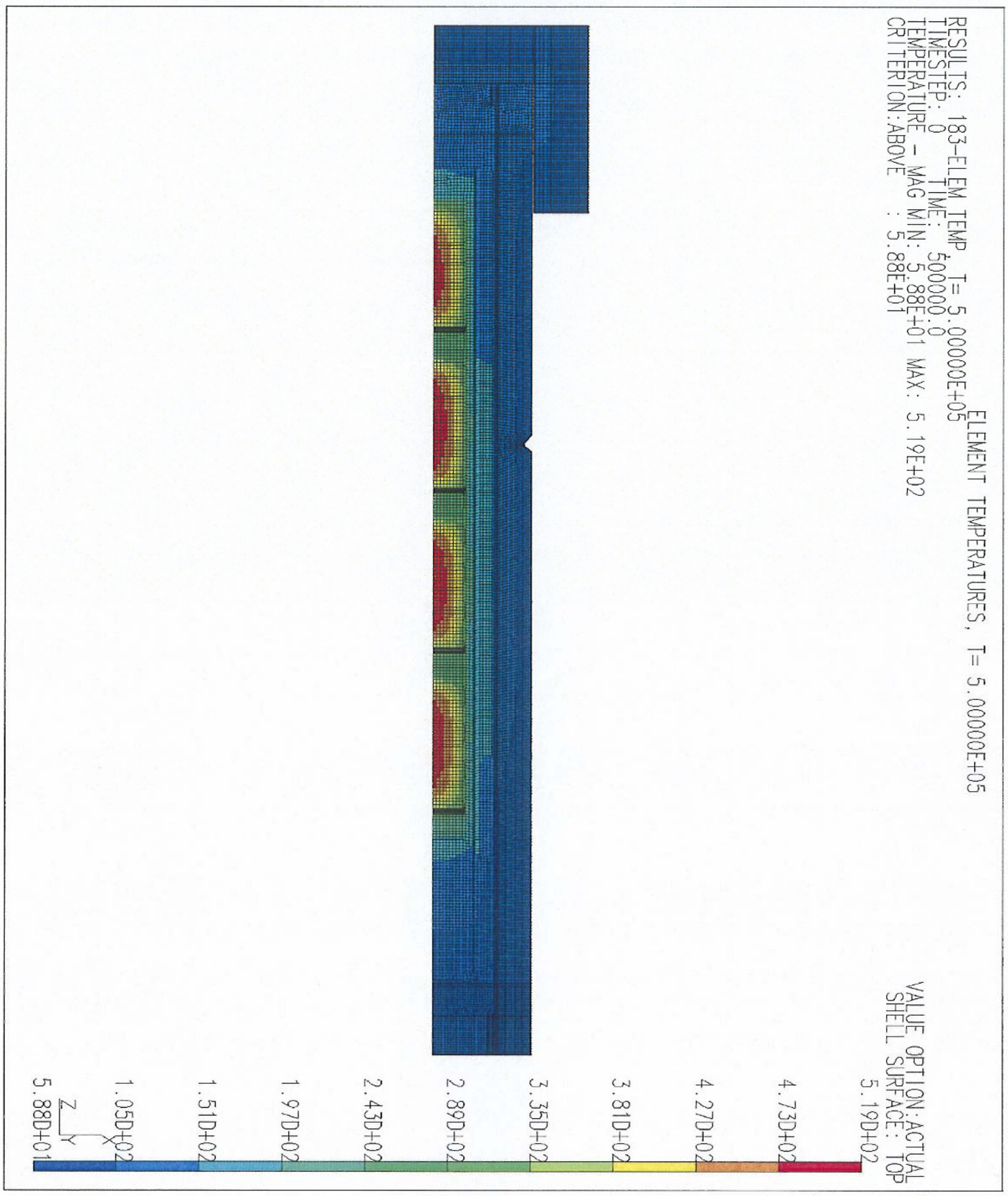
CONFIGURATION C3.1 bis

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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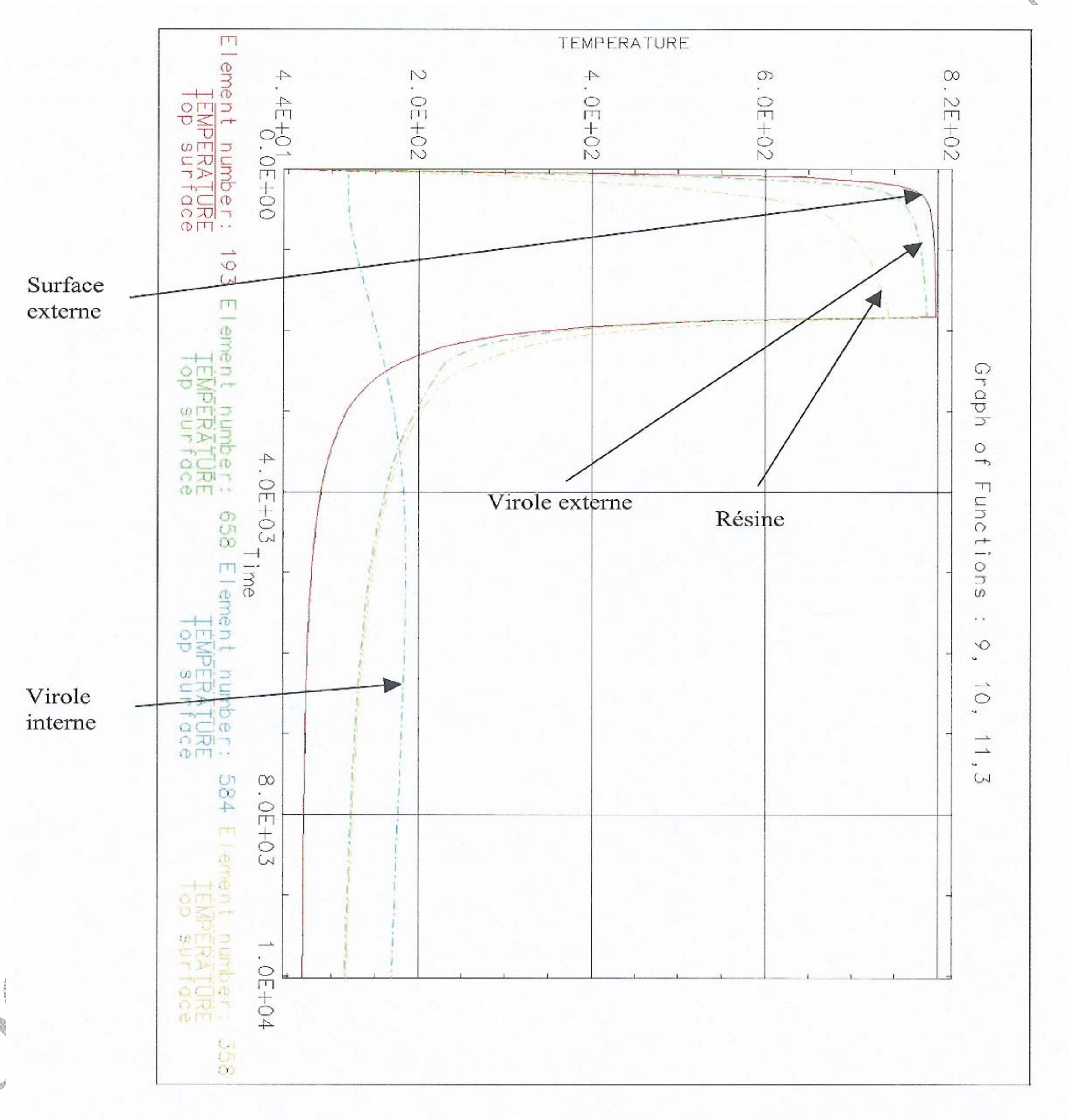
CONFIGURATION C3.1 bis

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT

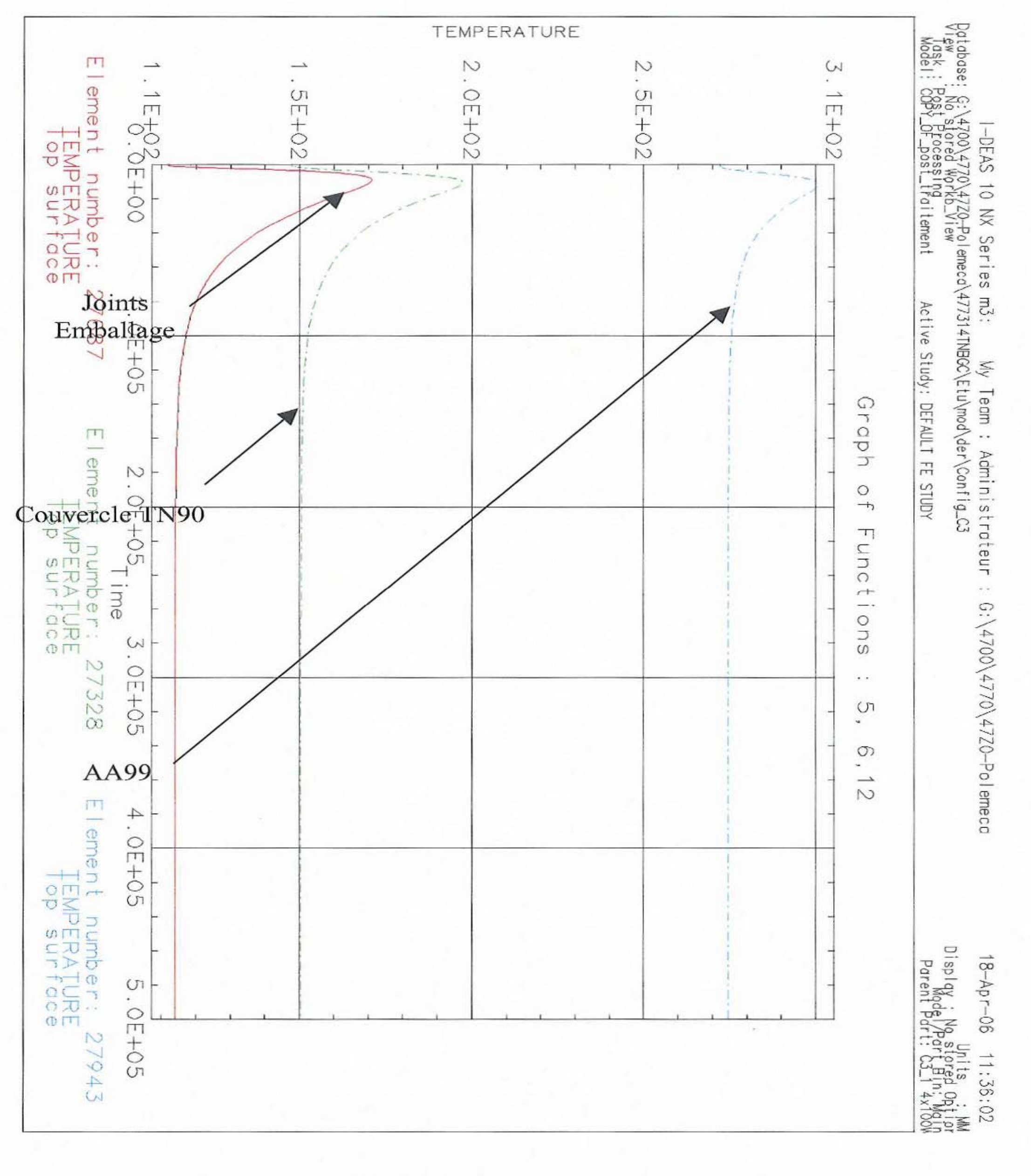


Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

APPENDIX 6

CONFIGURATION C3.1 bis

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle TN90	TN90 cover
AA99	AA99

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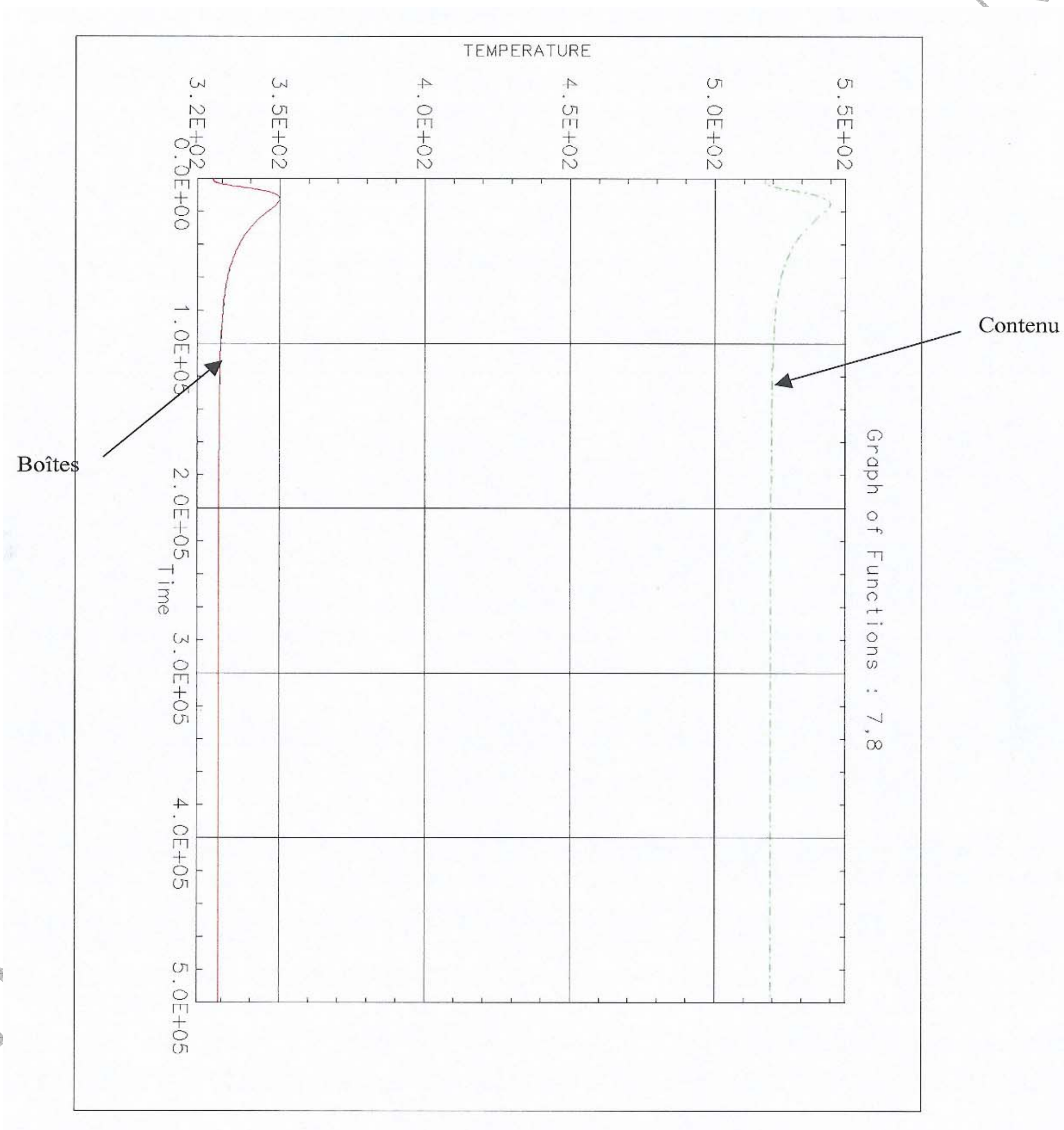
CONFIGURATION C3.1 bis

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boites	Boxes

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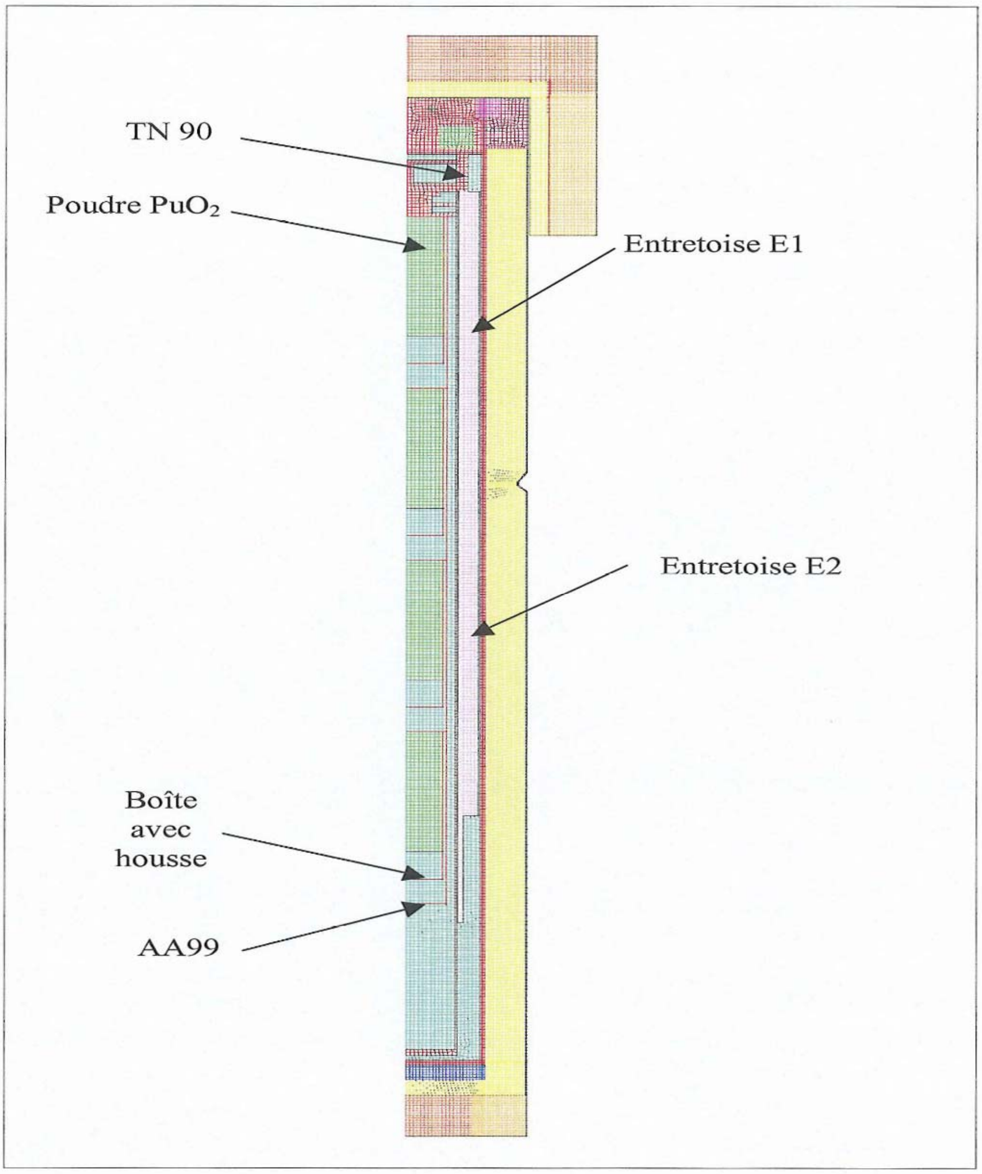
APPENDIX 7

CONFIGURATION C3.2
PRESENTATION OF MODEL

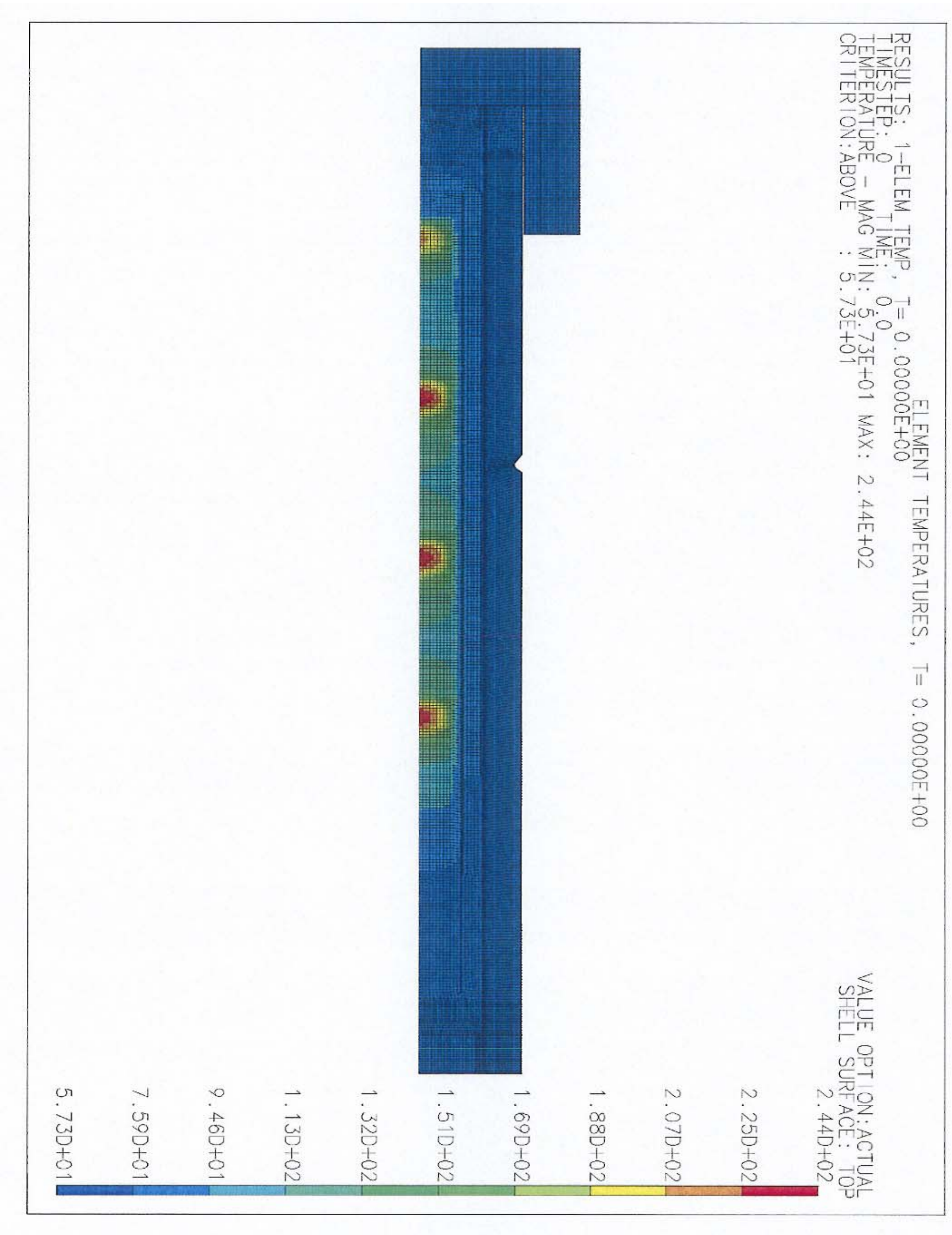


TN 90	TN 90
Poudre Pu02	PuO_2 powder
Boîte avec housse	Box with cover
AA99	AA99
Entretoise E1	E1 spacer
Entretoise E2	E2 spacer

APPENDIX 7

CONFIGURATION C3.2

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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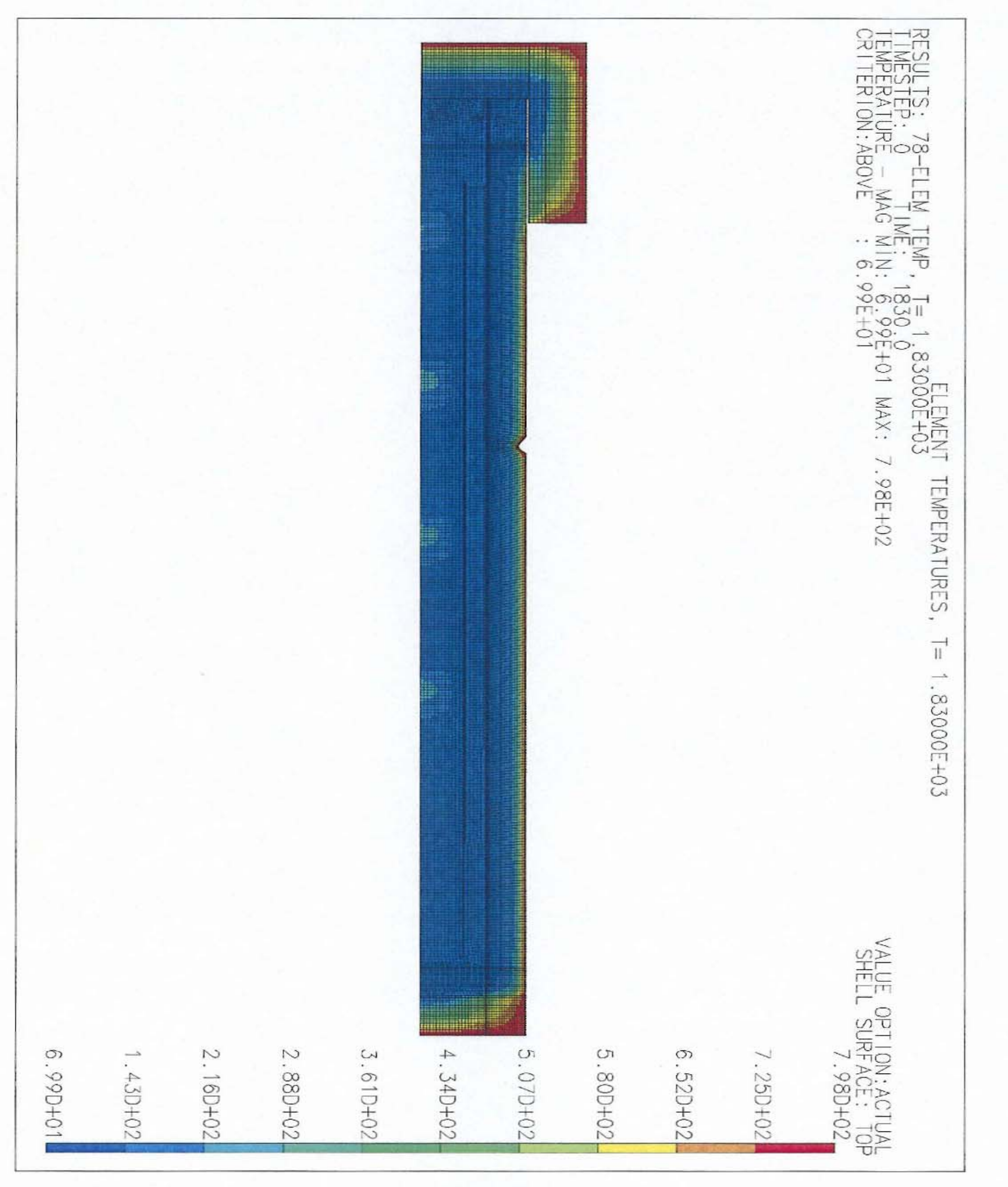
APPENDIX 7

CONFIGURATION C3.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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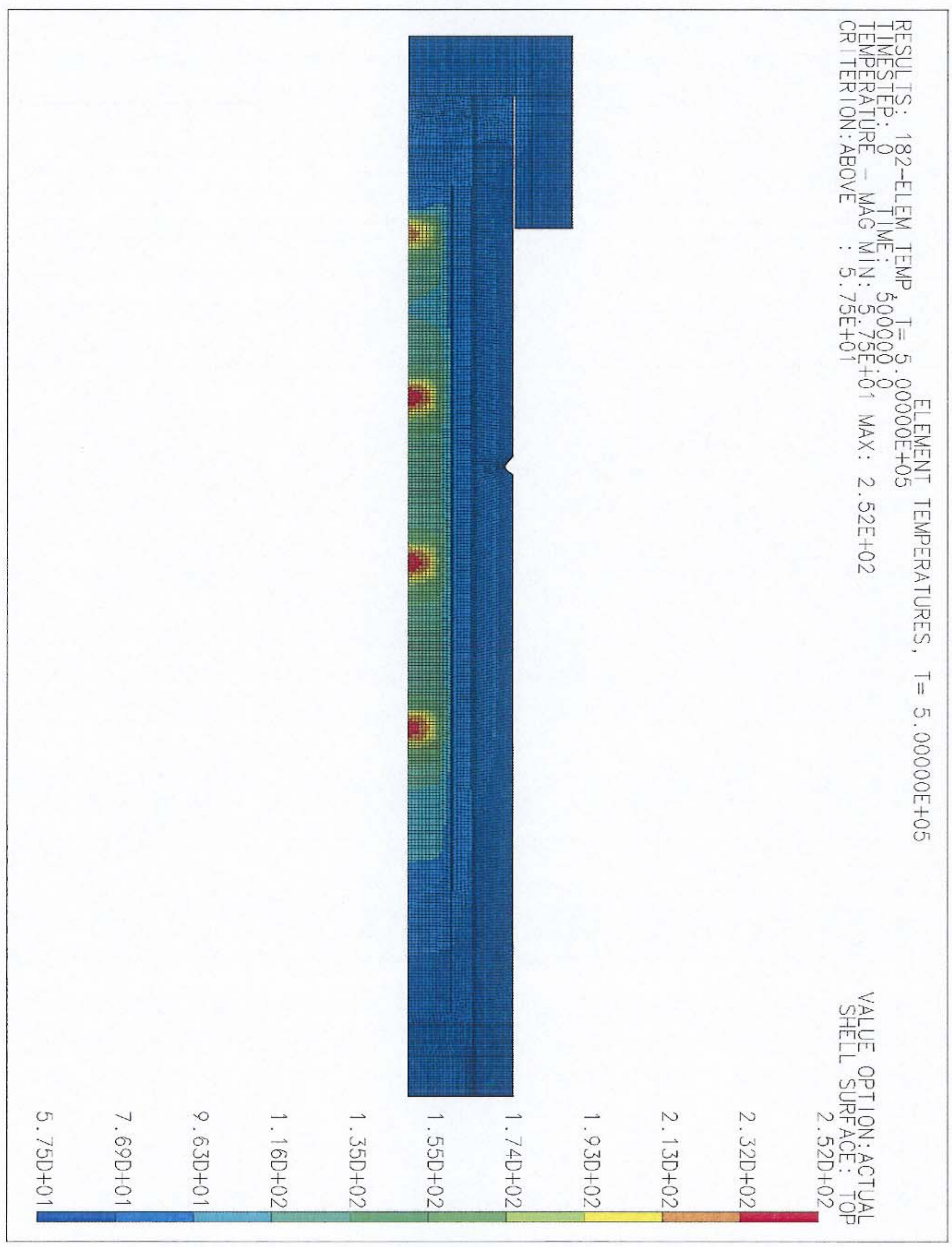
CONFIGURATION C3.2

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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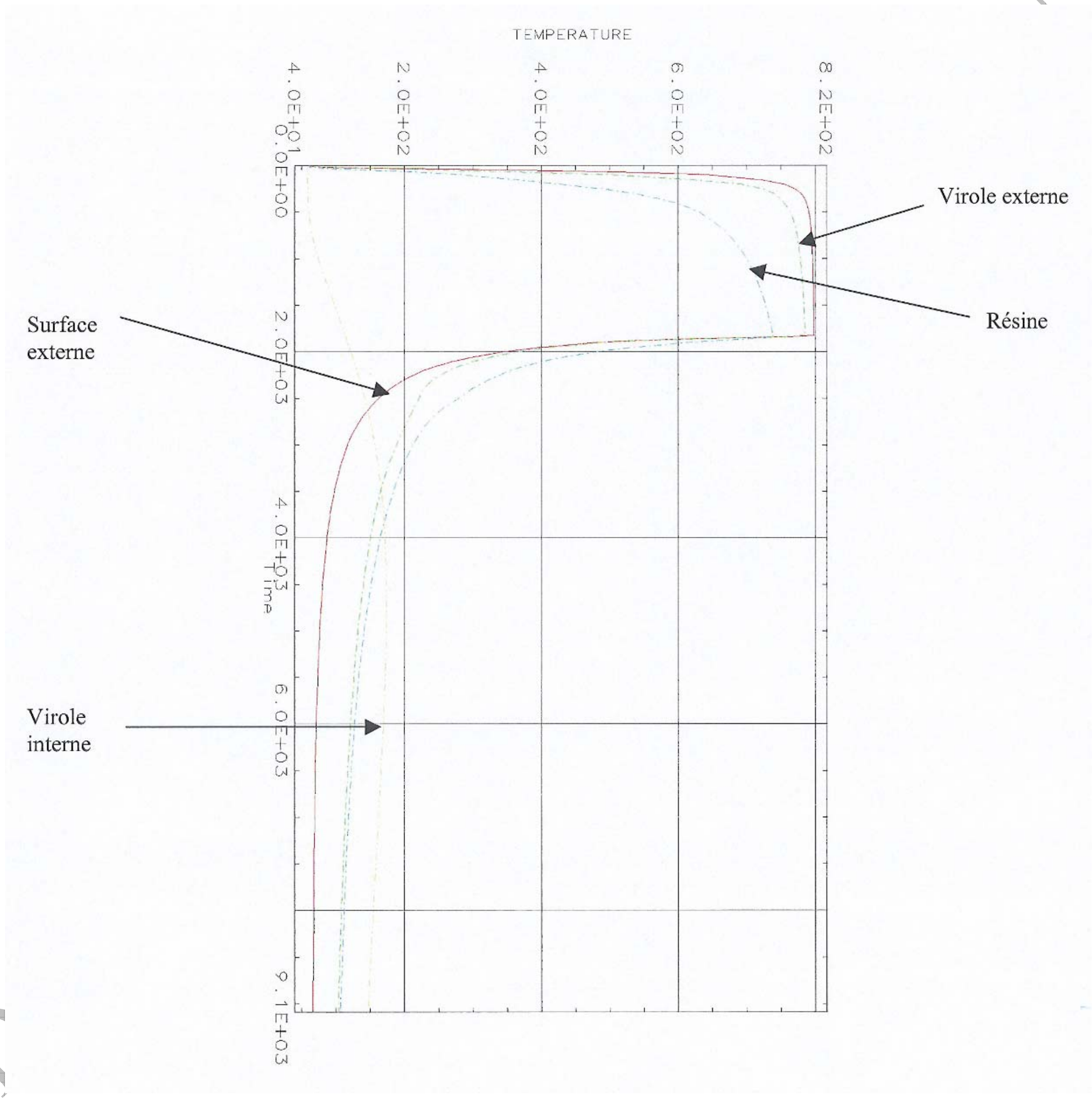
CONFIGURATION C3.2

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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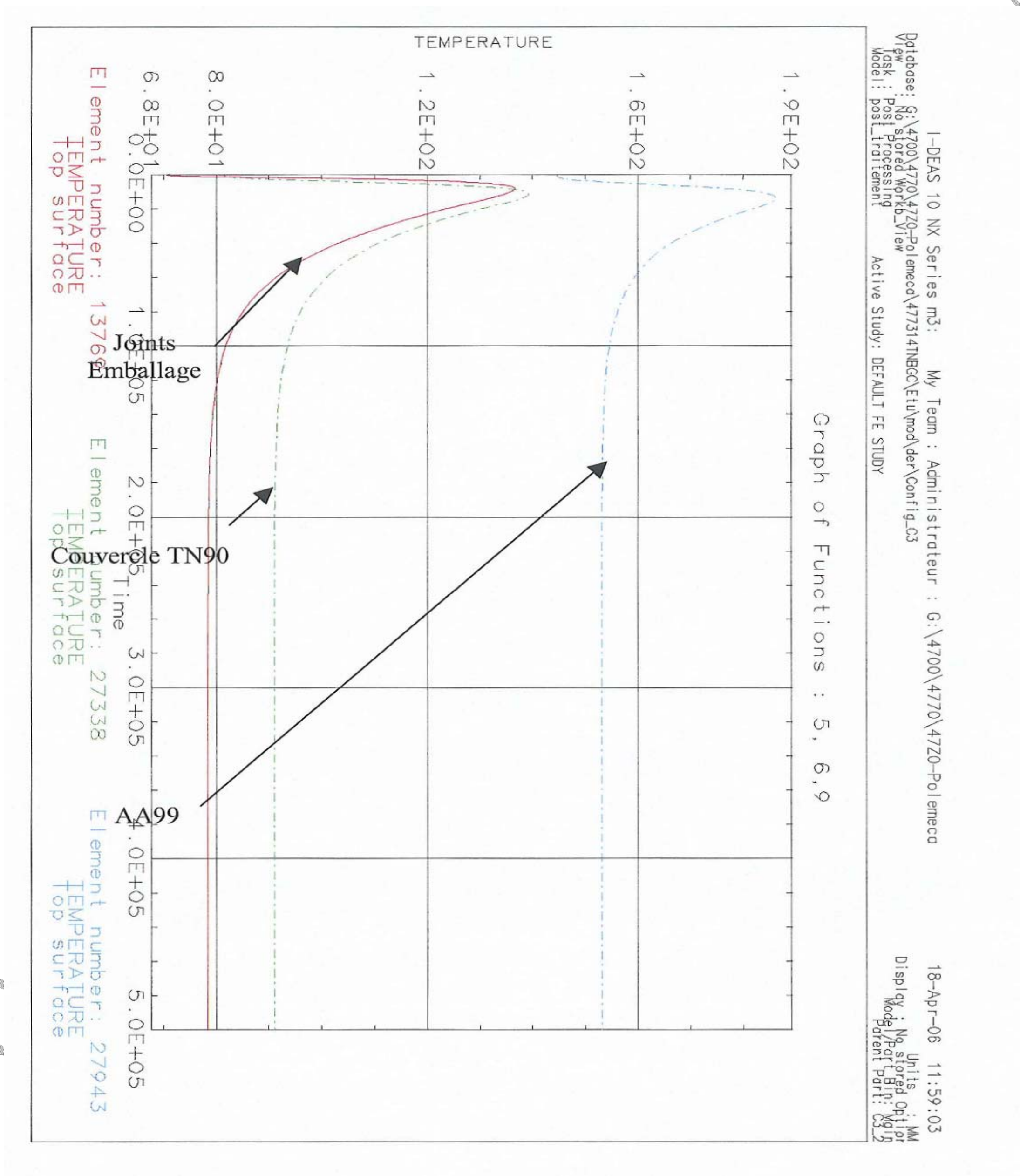
APPENDIX 7

CONFIGURATION C3.2

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT

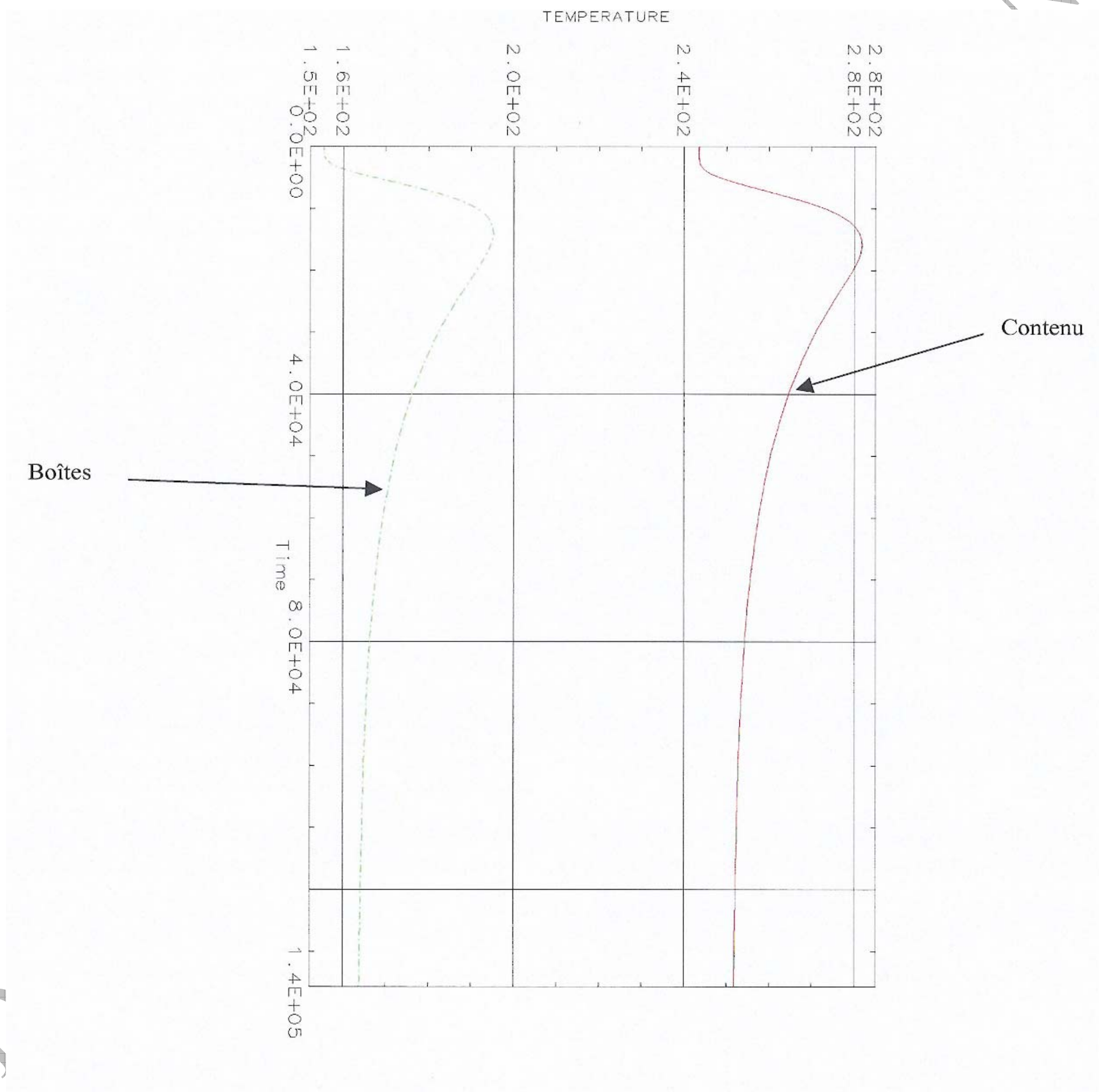


Joints Emballage	Packaging seals
Couvercle TN90	TN90 cover
AA99	AA99

APPENDIX 7

CONFIGURATION C3.2

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT

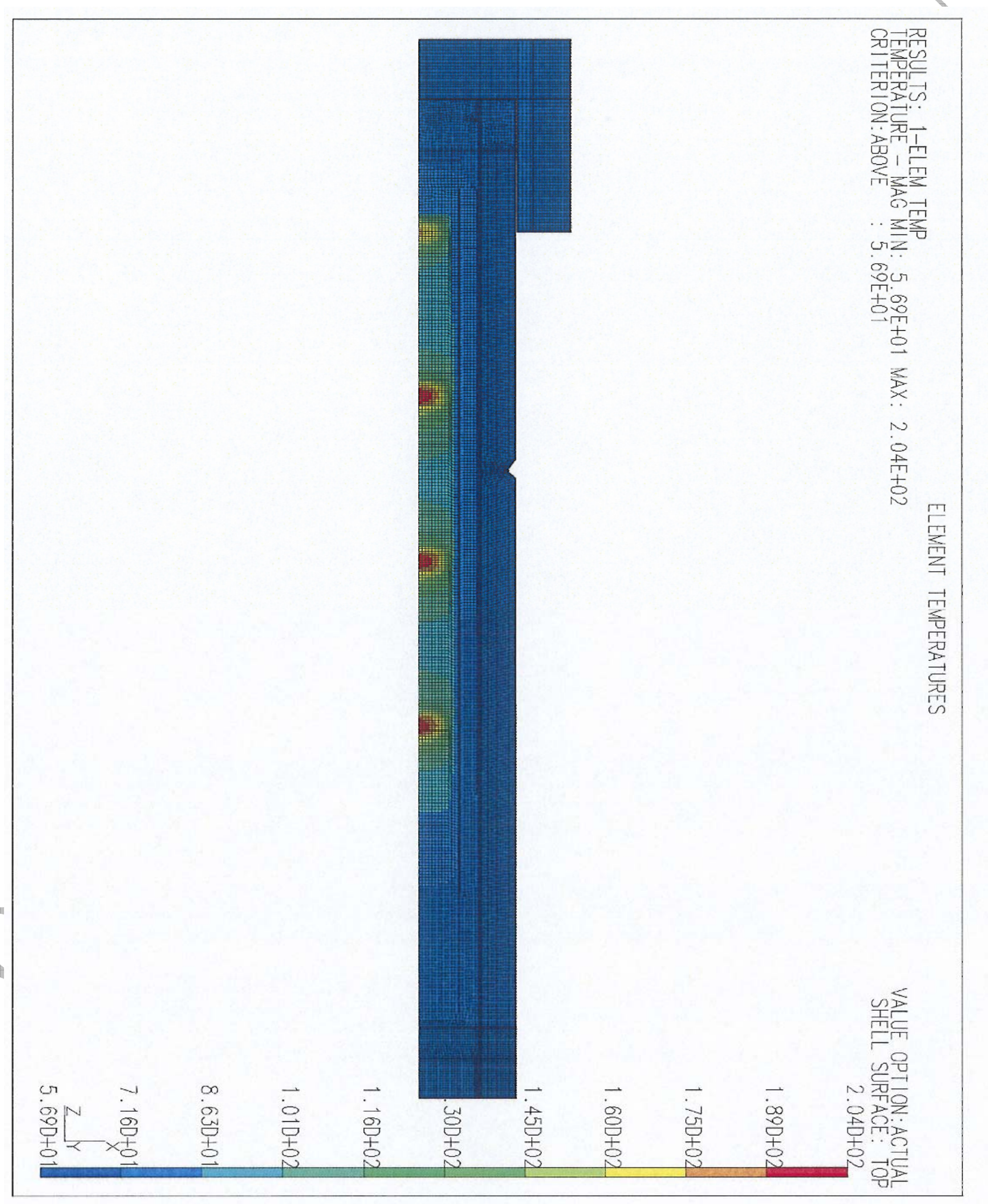


Contenu	Contents
Boites	Boxes

APPENDIX 7

CONFIGURATION C3.2 bis

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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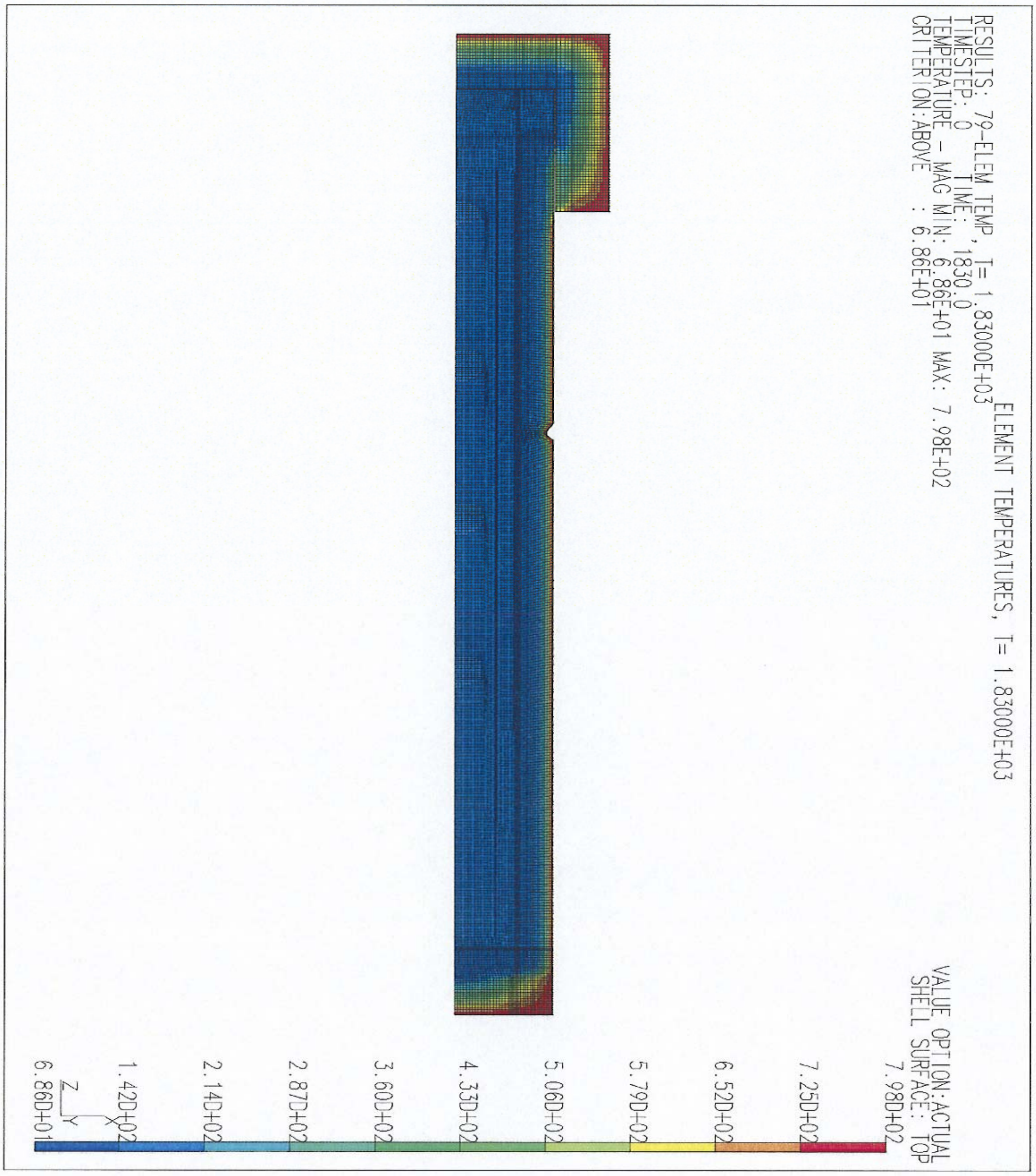
CONFIGURATION C3.2 bis

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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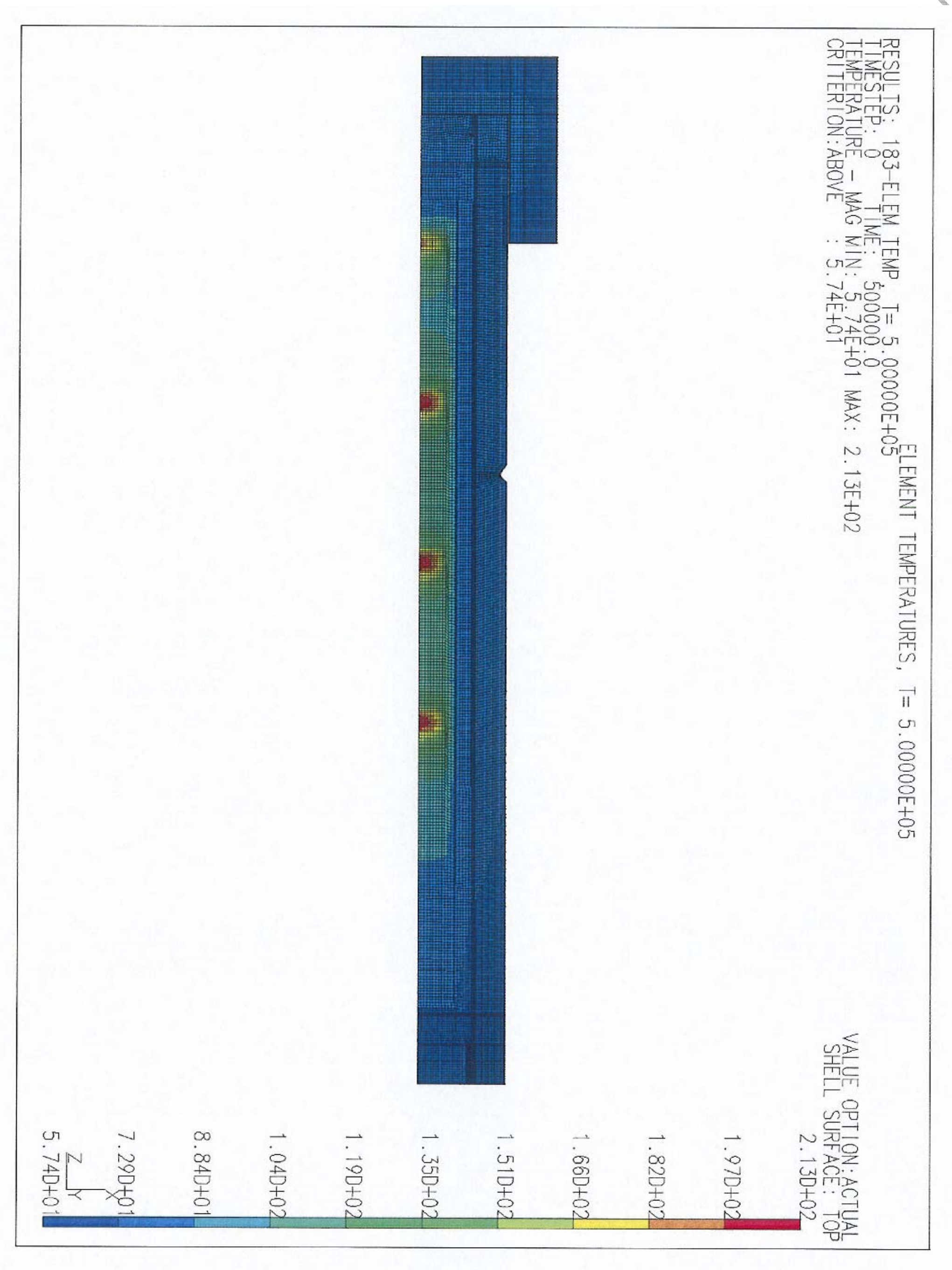
CONFIGURATION C3.2 bis

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s



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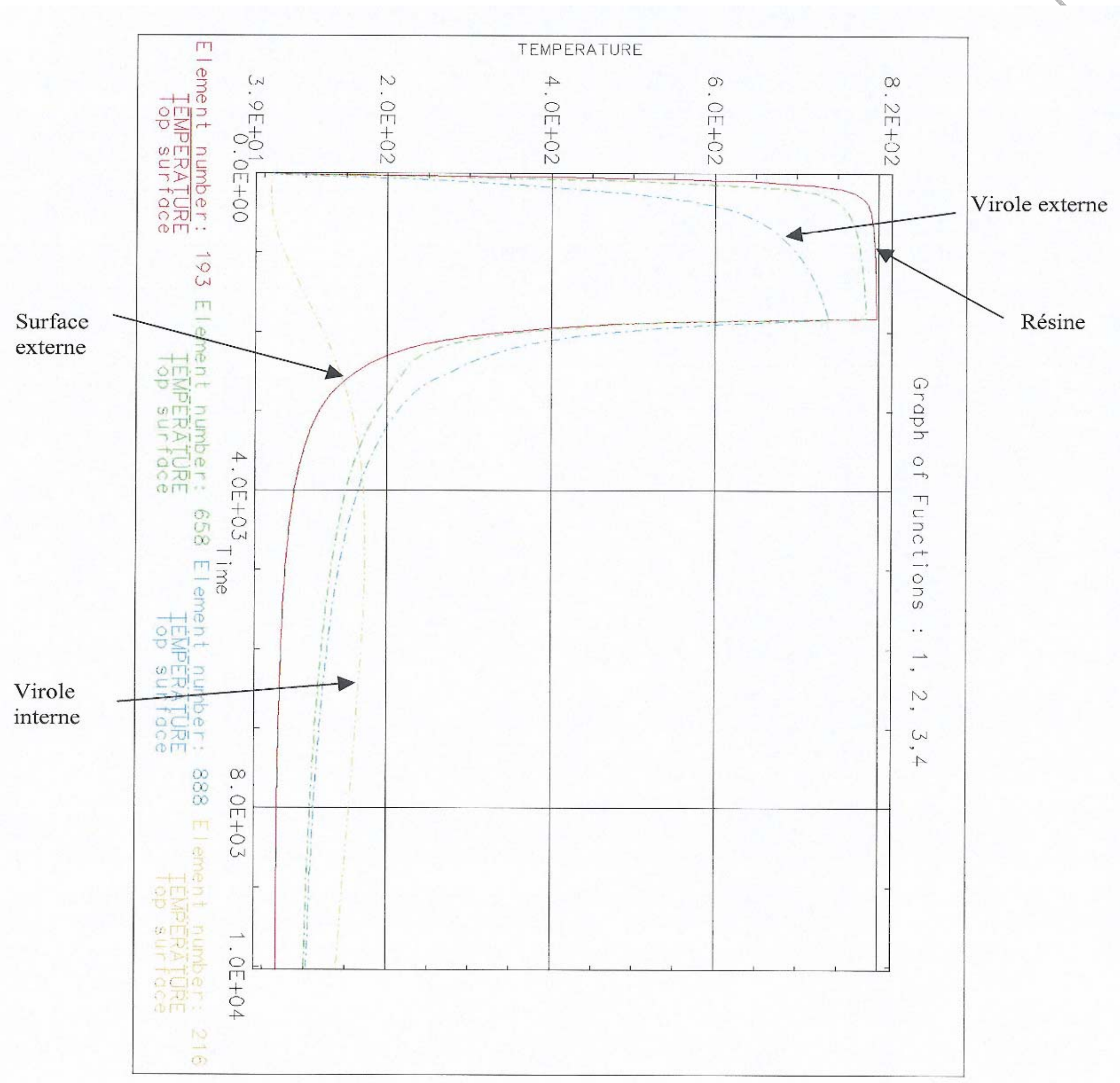
CONFIGURATION C3.2 bis

PACKAGING TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Surface externe	Outer surface
Virole externe	Outer shell
Résine	Resin
Virole interne	Inner shell

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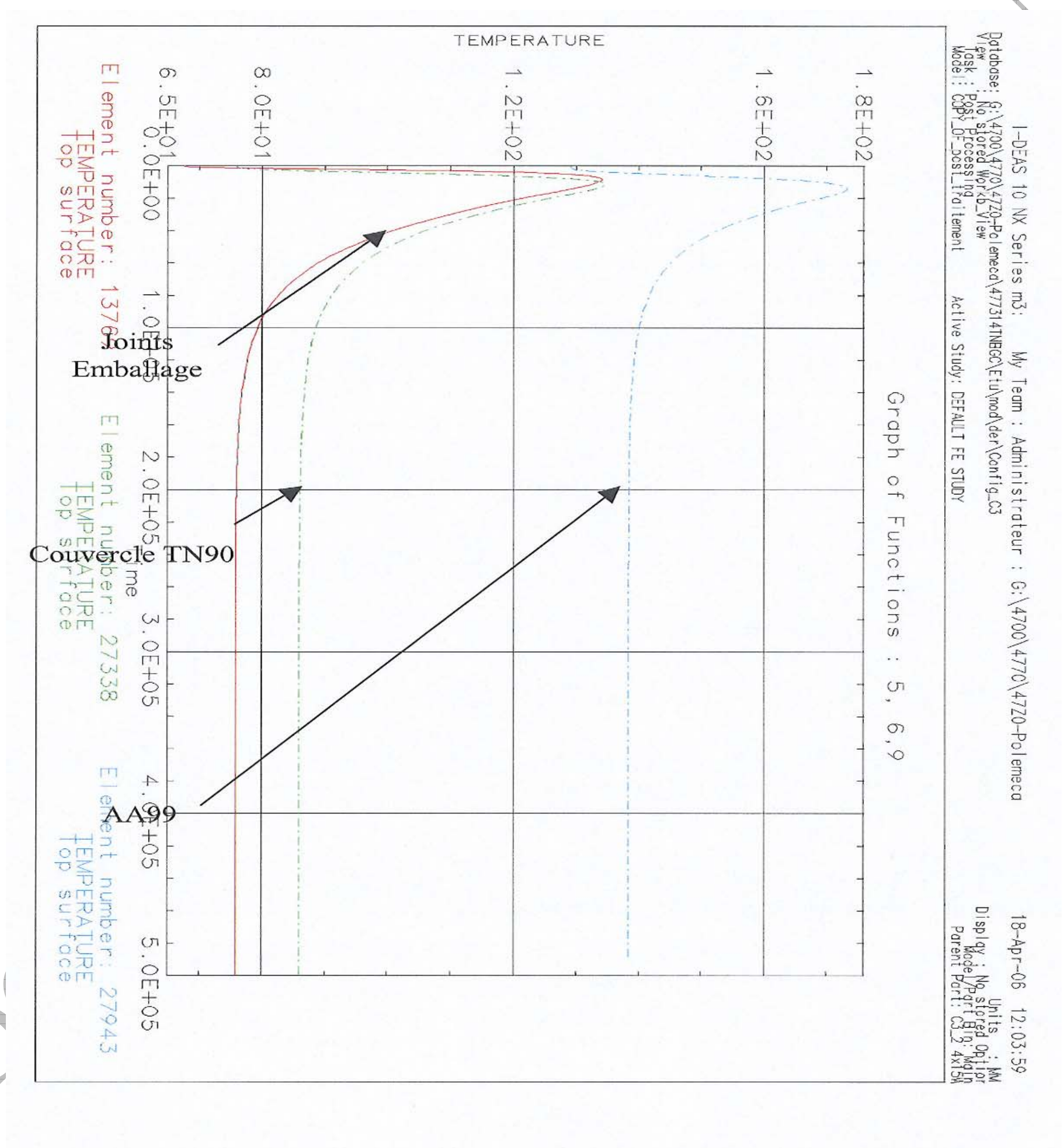
CONFIGURATION C3.2 bis

SEAL TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Joints Emballage	Packaging seals
Couvercle TN90	TN90 cover
AA99	AA99

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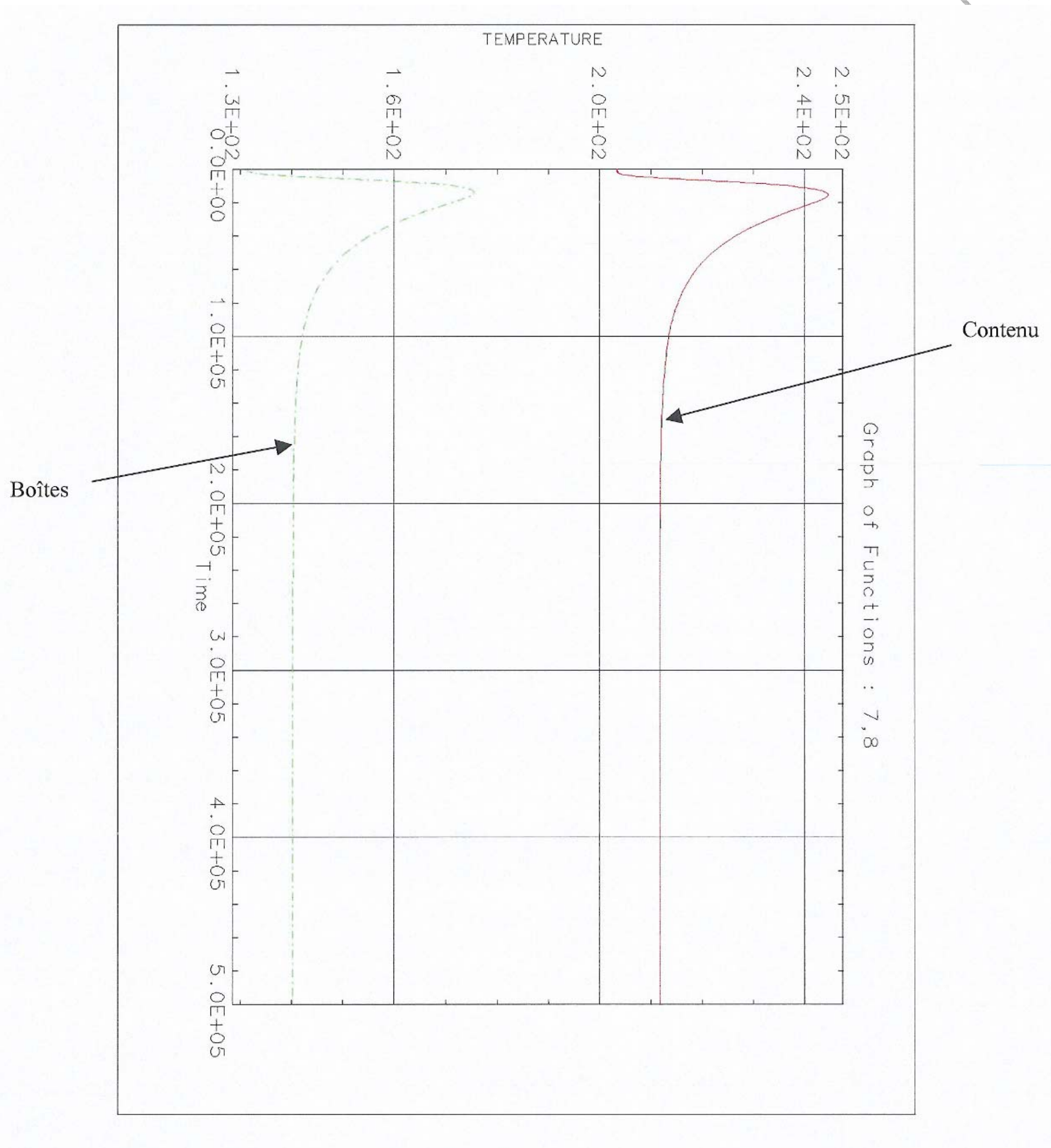
CONFIGURATION C3.2 bis

BOXES AND CONTENTS TEMPERATURE VARIATION CHART
ACCIDENT CONDITIONS OF TRANSPORT



Contenu	Contents
Boites	Boxes

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CONFIGURATIONS C3.3 and C3.3 bis

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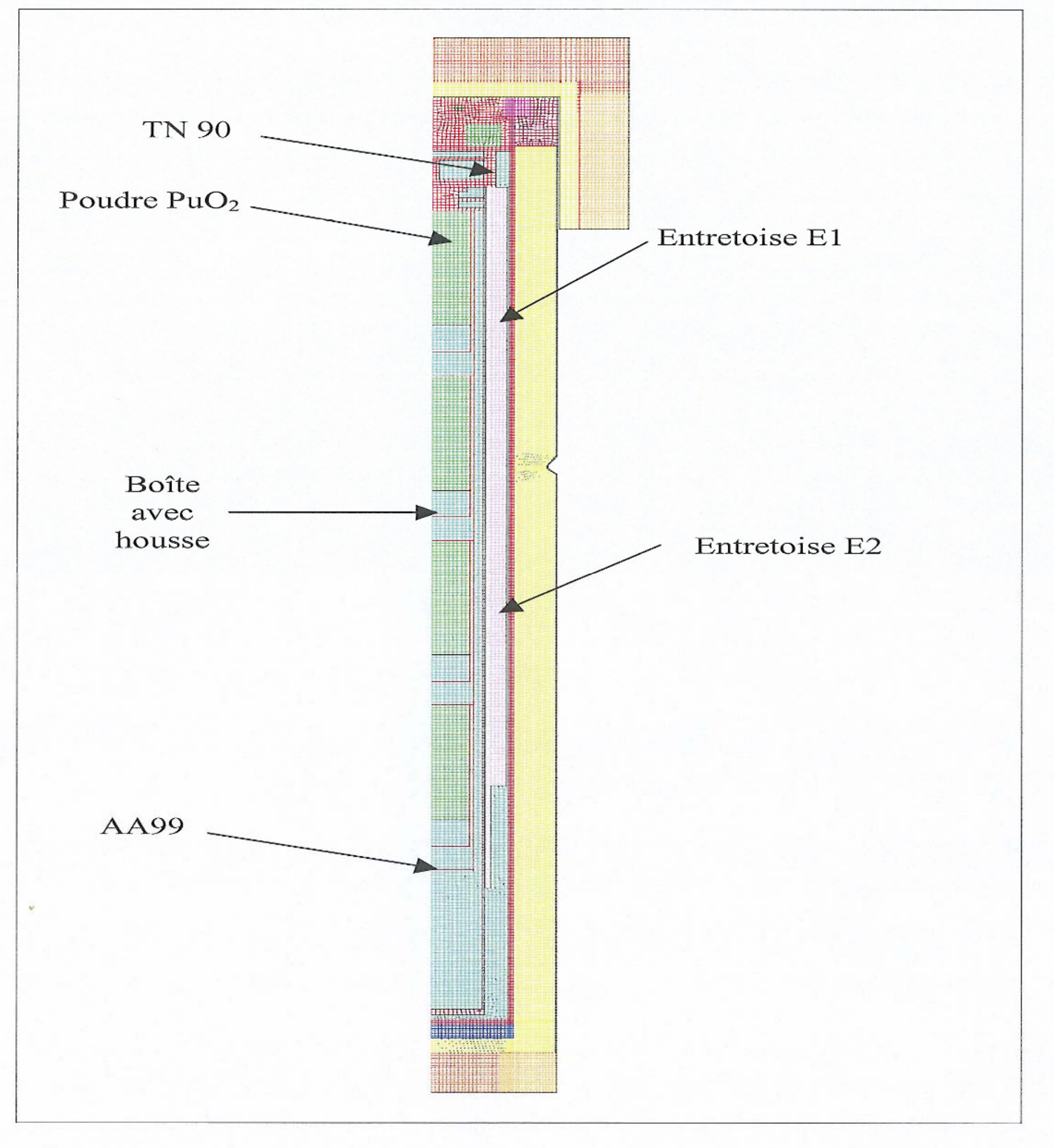
APPENDIX 8

CONFIGURATION C3.3
PRESENTATION OF MODEL

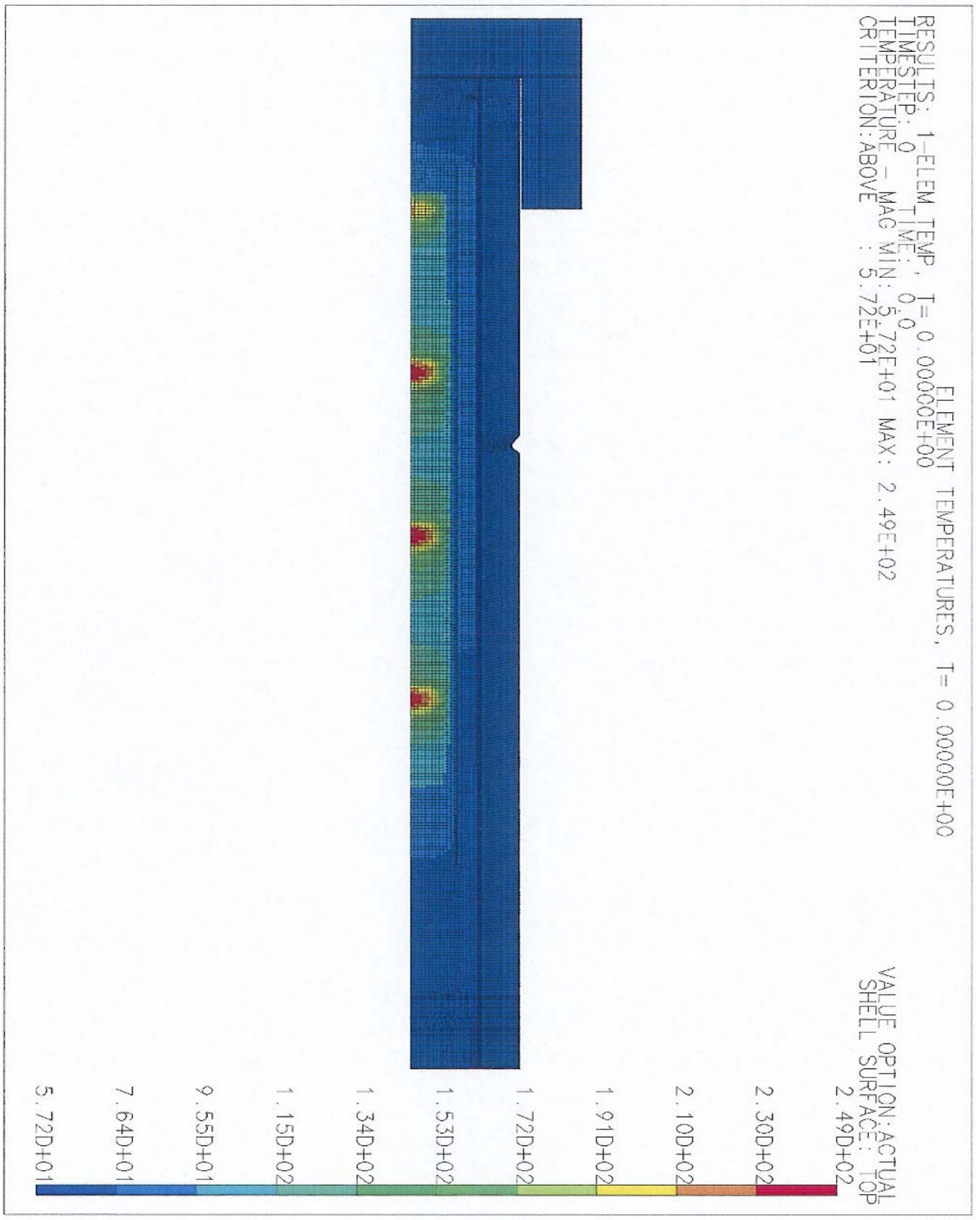


TN 90	TN 90
Poudre Pu02	PuO_2 powder
Boîte avec housse	Box with cover
AA99	AA99
Entretoise E1	E1 spacer
Entretoise E2	E2 spacer

APPENDIX 8

CONFIGURATION C3.3

ISOTHERMS OF ISOLATED PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
Before fire



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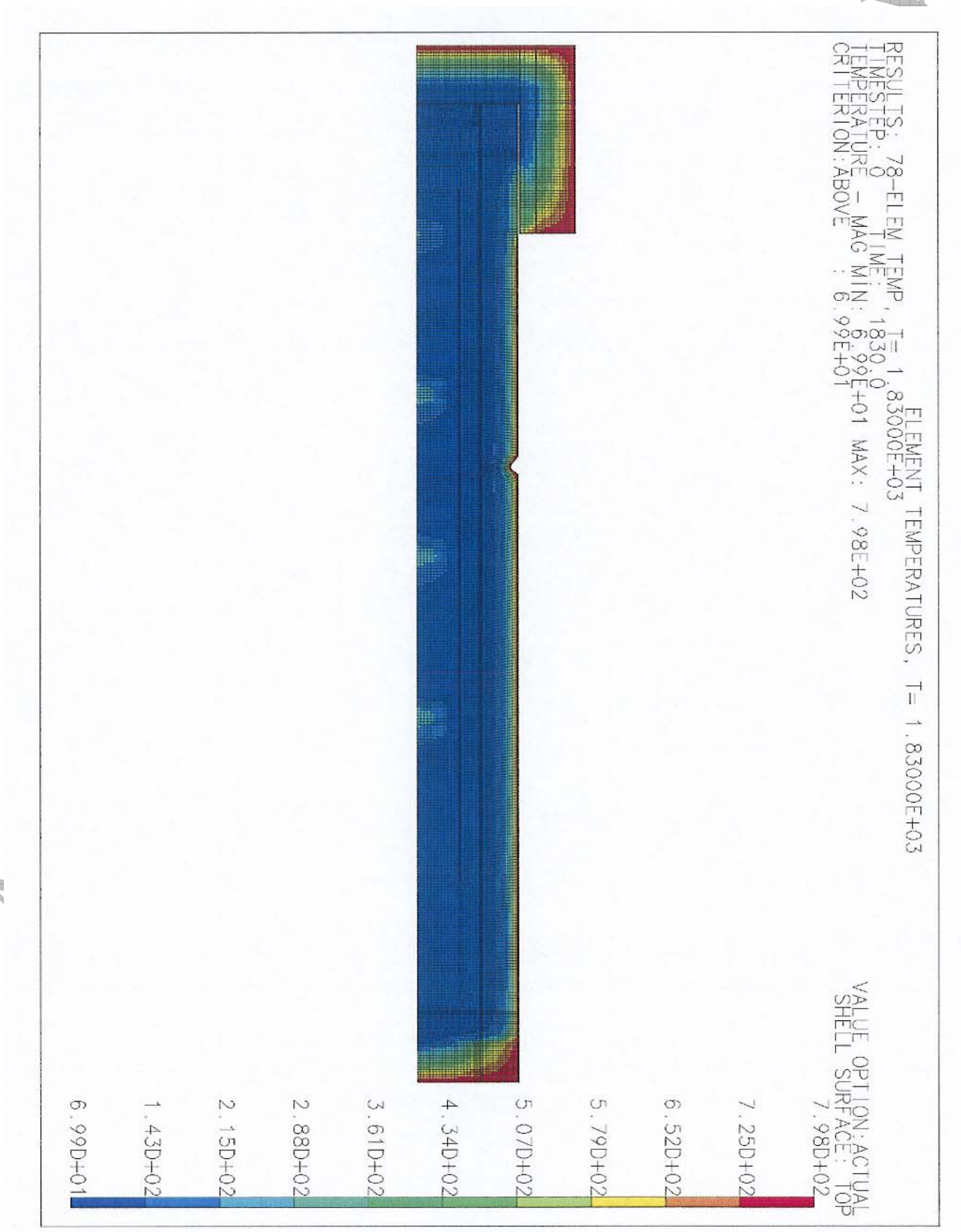
CONFIGURATION C3.3

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 1830 s



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CONFIGURATION C3.3

ISOTHERMS OF PACKAGE
ACCIDENT CONDITIONS OF TRANSPORT
t = 500 000 s