PROGRAMME: RENEWAL OF STOCK OF CEA PACKAGES

TITLE: SAFETY ANALYSIS REPORT - TN-BGC1 TYPE PACKAGE

CHAPTER 6 - APPENDIX 6 THERMAL ANALYSIS OF FUEL RODS (CONTENT No. 8) IN TN-BGC1 PACKAGE

Summary:
This appendix studies the thermal behaviour of mixed oxide fuel rods contained in a TN-BGC1 package.

Sign.			
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LIST OF MODIFICATIONS

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A	07/08/03	First issue	

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1. INTRODUCTION

The aim of this chapter is to study the thermal behaviour of mixed oxide fuel rods contained in a TN-BGC1 package.

The study is carried out for normal and accident conditions of transport.

2. METHODOLOGY

Design calculations are carried out for an equivalent square network using the "ROD" [1] method, exclusively based on radiation exchanges, from a maximum temperature, of the TN 90 shell and the inner shell of the package respectively.

For content comprising mixed oxide fuel rods, design is based on the assumption of several numbers of fuel rods, with different linear powers. The total thermal power of the content is less than 340 W. The active rod length adopted is equal to 1000 mm.

The internal arrangement corresponds to that achieving maximum rod temperatures.

Note: the AA 204 container is identical to AA 203 and AA 41 containers except for cavity length. Design output is also therefore valid for these two containers.

3. RESULTS

3.1 Normal conditions of transport

The internal fittings of the AA 204 are assumed, providing an envelope for the TN 90.

Emissivity levels (AA 204 rods and shell) correspond to 0.26 and 0.55 respectively.

The temperature of the AA 204 is equal to 247°C in normal conditions of transport (see chapter 6, appendix 3).

In this case, table 1 shows that the maximum temperature is reached for the maximum number of rods (taken as 100 on a conservative basis), and does not exceed 360.5°C.

If we now assume that the rack itself comprises a bundle of thin sleeving tubes in which the rods are inserted, the temperature calculated above will correspond to the sleeving tube temperature and the rod temperature will then be given (radiation exchange only between the rod and the tube) by:

$$T_{crayon} = (T_{étui}^{4} + 1{,}18.10^{8} \times \phi)^{1/4}$$

where ϕ is the flux leaving the rod (W/m²).

(crayon = rod; étui = sleeving tube)

The results are shown in table 1. It appears that maximum rod temperatures are less than 420°C.

Note 1: With 100 rods, mean rod (or sleeving tube) temperature represents 316°C. With sleeving tubes, mean rod temperature represents 331°C.

The temperature of the gases in the tertiary container cavity is estimated at:

$$t_{gaz} = \frac{247+316}{2} = 281{,}5°C.$$

Note 2: The temperature of the gases in the package cavity is estimated at 189°C (corresponding to the C4 container - see chapter 7).

3.2 Accident conditions of transport

The internal arrangement considered corresponds to that achieving maximum rod temperatures. This is TN 90.

Emissivity levels (TN 90 rods and shell) correspond to 0.26 (see chapter6, appendix 3).

The temperature of the tertiary container shell is equal to 265°C in accident conditions of transport (see chapter 6, appendix 3).

In this case, table 2 summarises the results obtained and shows that the maximum temperature is reached for the maximum number of rods (taken as 100 on a conservative basis), and does not exceed 375°C.

If we now assume that the rack itself comprises a bundle of thin sleeving tubes in which the rods are inserted, the temperature calculated above will correspond to the sleeving tube temperature and the rod temperature will then be given (radiation exchange only between the rod and the tube) by:

$$T_{crayon} = (T_{étui}^4 + 1{,}18.10^8 \times \varnothing)^{1/4}$$

where Ø is the flux leaving the rod (W/m^2).

(crayon = rod; étui = sleeving tube)

The results are shown in table 2. It appears that maximum rod temperatures are less than 427°C.

<u>Note</u>: With 100 rods, mean rod (or sleeving tube) temperature represents 333°C. With sleeving tubes, mean rod temperature represents 347°C.

The temperature of the gases in the cavity is estimated at:

$$t_{gaz} = \frac{265+333}{2} = 299°C$$

4. CONCLUSIONS

Check that the maximum temperature reached by the fuel rod cladding remains acceptable.

In normal conditions of transport, the maximum rod temperature reaches 415°C in the worst case scenario.

In accident conditions of transport, the maximum rod temperature reaches 427°C in the worst case scenario.

5. REFERENCES

[1] Rod method according to R. SAUMON: a Computer Code (CDC 1604 A or IBM 7090) for Calculating the Cost of Shipping Spent Reactor Fuels as a Function of Burn-up, Specific Power, Cooling Time, Fuel Composition and Other Variables, ORNU 3648 (1964).

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TABLE 1

TEMPERATURES REACHED BY THE MIXED OXIDE FUEL RODS IN NORMAL CONDITIONS OF TRANSPORT

Number of rods	3x3 = 9	7 x 7 = 49	10x10 = 100*
Array pitch (mm)	42	14	10*
Wall temperature (°C)	247	247	247
Linear power (W/m)	37.8	6.9	3.4
Rod (or sleeving tube) diameter in mm	10	10	10
Temperature of the hottest rod (or sleeving tube) in °C,	263	317	360.5
Temperature of the hottest rod (with sleeving tubes) in °C,	415	346	373

*: This type of square network cannot be included in internal fittings without modification. 100 rods can however be fitted and this calculation gives a good evaluation of the temperatures reached.

TABLE 2

TEMPERATURES REACHED BY THE MIXED OXIDE FUEL RODS IN ACCIDENT CONDITIONS OF TRANSPORT

Number of rods	3x3 = 9	7 x 7 = 49	10x10 = 100*
Array pitch (mm)	42	14	10*
Wall temperature (°C)	265	265	265
Linear power (W/m)	37.8	6.9	3.4
Rod (or sleeving tube) diameter in mm	10	10	10
Temperature of the hottest rod (or sleeving tube) in °C,	287	332	374.5
Temperature of the hottest rod (with sleeving tubes) in °C,	427	359.5	386

*: This type of square network cannot be included in internal fittings without modification. 100 rods can however be fitted and this calculation gives a good evaluation of the temperatures reached.

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CEA CADARACHE

DESIGN REPORT

THERMAL ANALYSIS OF TN-BGC 1 PACKAGE

Modelling of an explosion in the internal fittings

Summary: The purpose of this thermal study is to determine the temperature span in the TN BGC package if an explosion occurs inside the TN90.

Keywords: Thermal, TN BGC 1, Transport, Normal conditions, Explosion.

B.P.E.
Name Date Sign.

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0 SUMMARY

This service consists of the thermal study of the TN BGC 1 package if an explosion occurs inside of the TN 90. The initial temperature span in based on the calculations carried out for normal conditions of transport.

More specifically, this study aims to assess joint temperatures over time.

The design configuration is as follows:

- Simulation of an explosion in the package with an energy defined over a given period,
- Design case no. 1 is adopted (based on [6]) for this study,
- The explosion area is located in the active power area.
- The initial temperature span is based on the calculations carried out for normal conditions of transport.
- Calculations are carried out based on transient conditions.

Limit conditions (normal conditions of transport) and the design model are based on design report ref. [1].

These calculations were carried out using the finite difference method I-DEAS/TMG <2> to simulate thermal phenomena.

The following assumptions were taken into consideration for the different design cases:

Design calculation Cases	Explosion energy (KJ)	Position of the explosion	Duration of the explosion (s)	Type of configuration	Internal power per package (W)
Case 1:	1000	The explosion area is located at the centre of the active area	30	- Internal fittings resting on the head - 1 power area in the upper part of the frame - Power density: 15 W/Kg	250
Case 2	1200	The explosion area is located in the upper part of the active area (head side)	30	- Internal fittings resting on the head -1 power area in the upper part of the frame - Power density: 15 W/Kg	250
Case 3	1200	The explosion area is located in the upper part of the active area (head side)	15	- Internal fittings resting on the head - 1 power area in the upper part of the frame - Power density: 15 W/Kg	250

1 PURPOSE

This service consists of the thermal study of the TN BGC 1 package if an explosion occurs inside of the TN 90. The initial temperature span in based on the calculations carried out for normal conditions of transport.

More specifically, this study aims to assess joint temperatures over time.

This study was carried out using the finite difference method I-DEAS/TMG <2> to simulate thermal phenomena. The digital model used is axisymmetric.

2 REFERENCE DOCUMENTS

<1>IAEA Safety standards collection – Regulations for the safe transport of radioactive materials – 1996 Edition amended (ST-1 amended)
<2>Finite element calculation software: I-DEAS Master Series V10 developed by EDS associated with TMG Thermal Analysis Module
<3>SOM design report with the reference 472891C030118 Iss. B of 26/01/04.

3 DESIGN METHOD

The model will be produced using the I-DEAS software <2>. The thermal design will be carried out based on the finite difference method using the TMG module interfaced with I-DEAS.

4 PARTS LIST

The main parameters of the study are as follows:

H: Height (m)

L: Length (m)

P: Dissipated thermal power (W or kW)

r : Radius (m)

S: Surface area (m^2)

T: Temperature (°C or K)

V: Volume [m^3]

5 TYPE OF DESIGN

Configuration no. 1 of design report ref. [3] is adopted for this study.

6 METHODOLOGY

The initial temperature span is taken from the calculations carried out for normal conditions of transport (ref.: [3]). During transient design, for a precise power area, significant energy is introduced to model the explosion.

7 MODELLING ASSUMPTIONS

7.1 GEOMETRY

All modelling assumptions are taken from [1].
The explosion area will be modelled using a cylindrical volume with the following characteristics:

- height of 279 mm,
- diameter of 67 mm.

7.2 MESHING

Axisymmetric modelling will be used for the TN BGC 1 package and elements will be linear quadrilateral and linear shell type.

Meshing figures are shown in appendices 1 to 3.

7.3 MATERIALS

The characteristics of the materials are taken from [1].

8 LIMIT CONDITIONS

Calculations are carried out based on transients in normal conditions of transport.
The initial temperature span is based on the calculations carried out for normal conditions of transport (ref.: [3]).

8.1 NORMAL CONDITIONS OF TRANSPORT

The normal conditions of transport used are taken from [1].

8.2 EXPLOSIONS CONDITIONS

A power is applied to a cylindrical segment of the active area in order to simulate the explosion phase, as follows:

Case no. 1 and 2:

t = 0 s	P = 0 W
t = 1 s to t = 31 s	P = Pe W
t = 32 s	P = 0 W
t = CO	P = OW

Case No. 3:

t = 0 s	P = 0 W
t = 1 s to t = 16 s	P = Pe W
t = 17 s	P = 0 W
t = ∞	P = 0 W

Where: Pe: The power corresponding to the heat dissipated by the explosion.

Hence:
- for design case no. 1: Pe = 33.3 KW, i.e. dissipated heat of 1000 KJ,
- for design case no. 2: Pe = 40 KW, i.e. dissipated heat of 1200 KJ,
- for design case no. 2: Pe = 80 KW, i.e. dissipated heat of 1200 KJ,

9 RESULTS

The following tables summarise all of the results obtained according to the different design cases.

9.1 1ST DESIGN CASE

Figures showing isotherms and variation graphs are provided in appendix 1.

CALCULATIONS FOR AN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Temperature (°C)**	**Time (s)**
External shell	**153**	**10 000**
Internal shell	**154**	**10 000**
Head joints	**156**	**10 000**
Container	**347**	**1 900**
Container joints	**181**	**6 500**
PuO2 powder	**1686**	**31**

9.2 2ND DESIGN CASE

Figures showing isotherms and variation graphs are provided in appendix 2.

CALCULATIONS FOR AN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Temperature (°C)**	**Time (s)**
External shell	156	10 000
Internal shell	157	10 000
Head joints	159	10 000
Container	362	1 900
Container joints	199	3 000
PuO2 powder	1925	31

9.3 3RD DESIGN CASE

Figures showing isotherms and variation graphs are provided in appendix 3.

CALCULATIONS FOR AN ISOLATED PACKAGE Maximum temperatures		
TN/BGC 1 PACKAGE	**Temperature (°C)**	**Time (s)**
External shell	156	10 000
Internal shell	157	10 000
Head joints	159	10 000
Container	359	1900
Container joints	199	2 950
PuO2 powder	1878	16

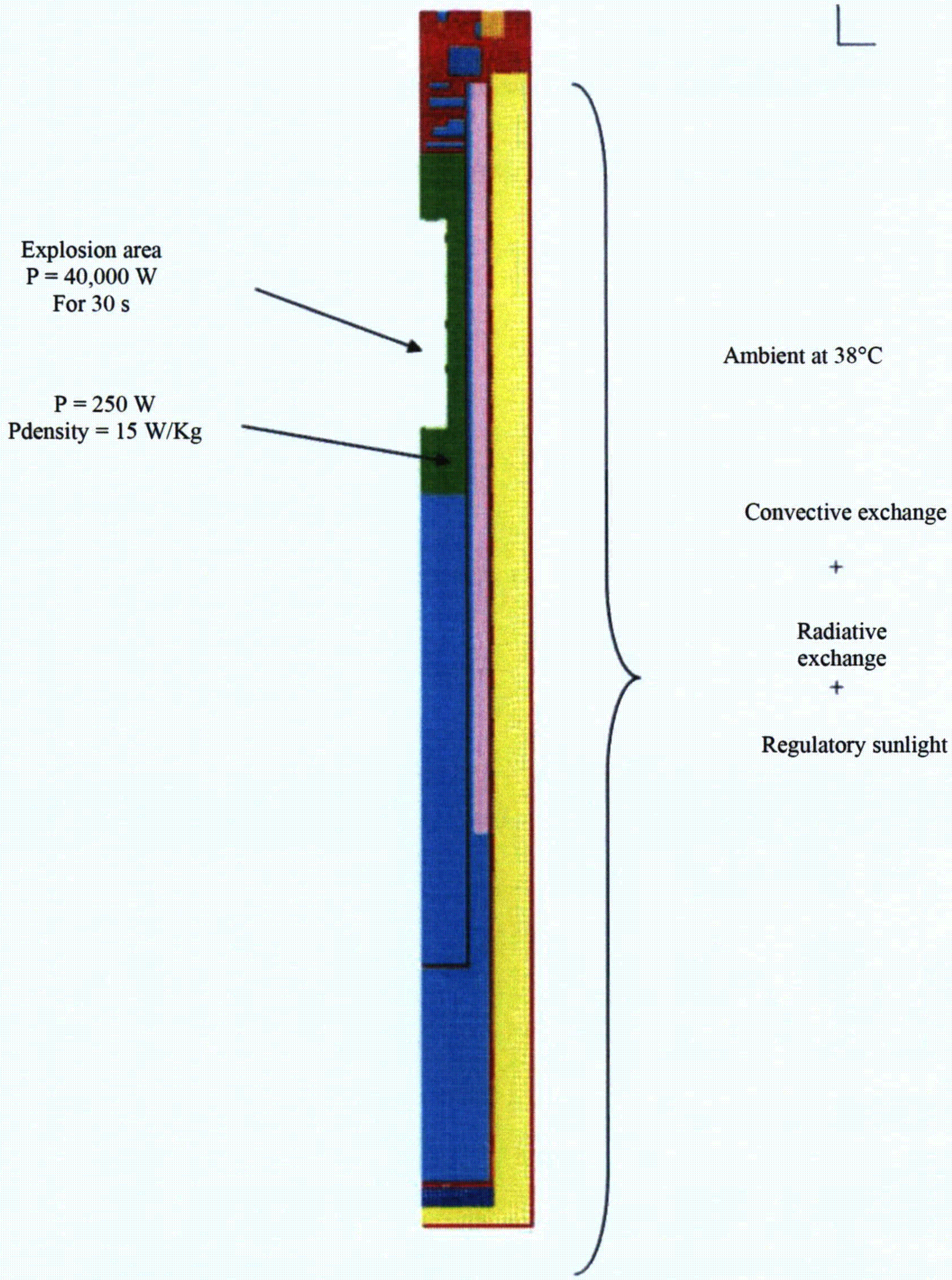
10 CONCLUSION

Following this study, it appears that, for the different configurations simulating an explosion phase in the internal fittings, the maximum operating temperature of the different components of the TN BGC 1 package is not exceeded. In particular, the maximum temperatures reached by the different package joints are:

- 159°C for head joints,
- 199°C for internal fitting joints.

APPENDIX 1

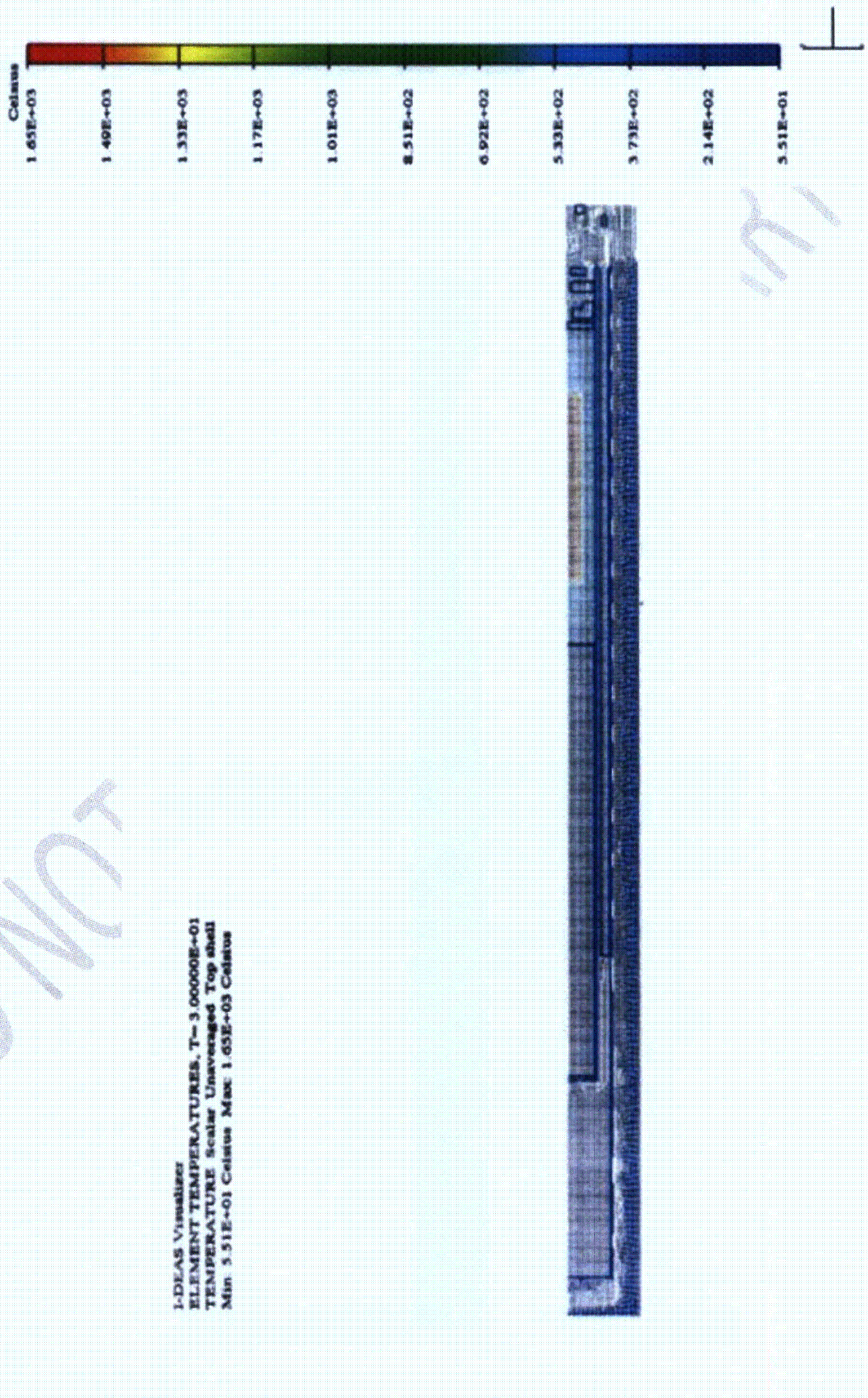
LIMIT CONDITIONS FOR THE PACKAGE



APPENDIX 1

PACKAGE ISOTHERMS

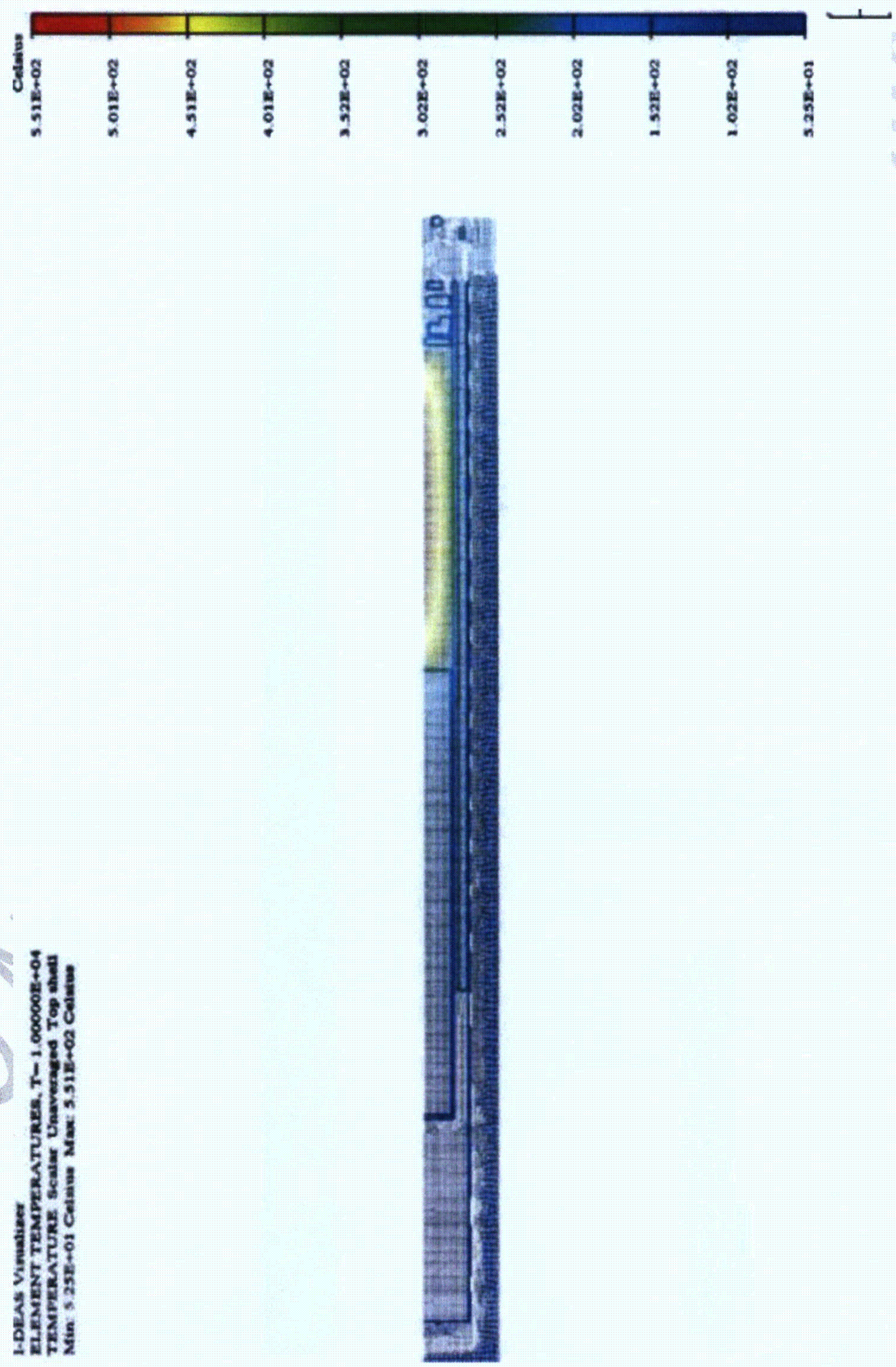
T = 30 s



APPENDIX 1

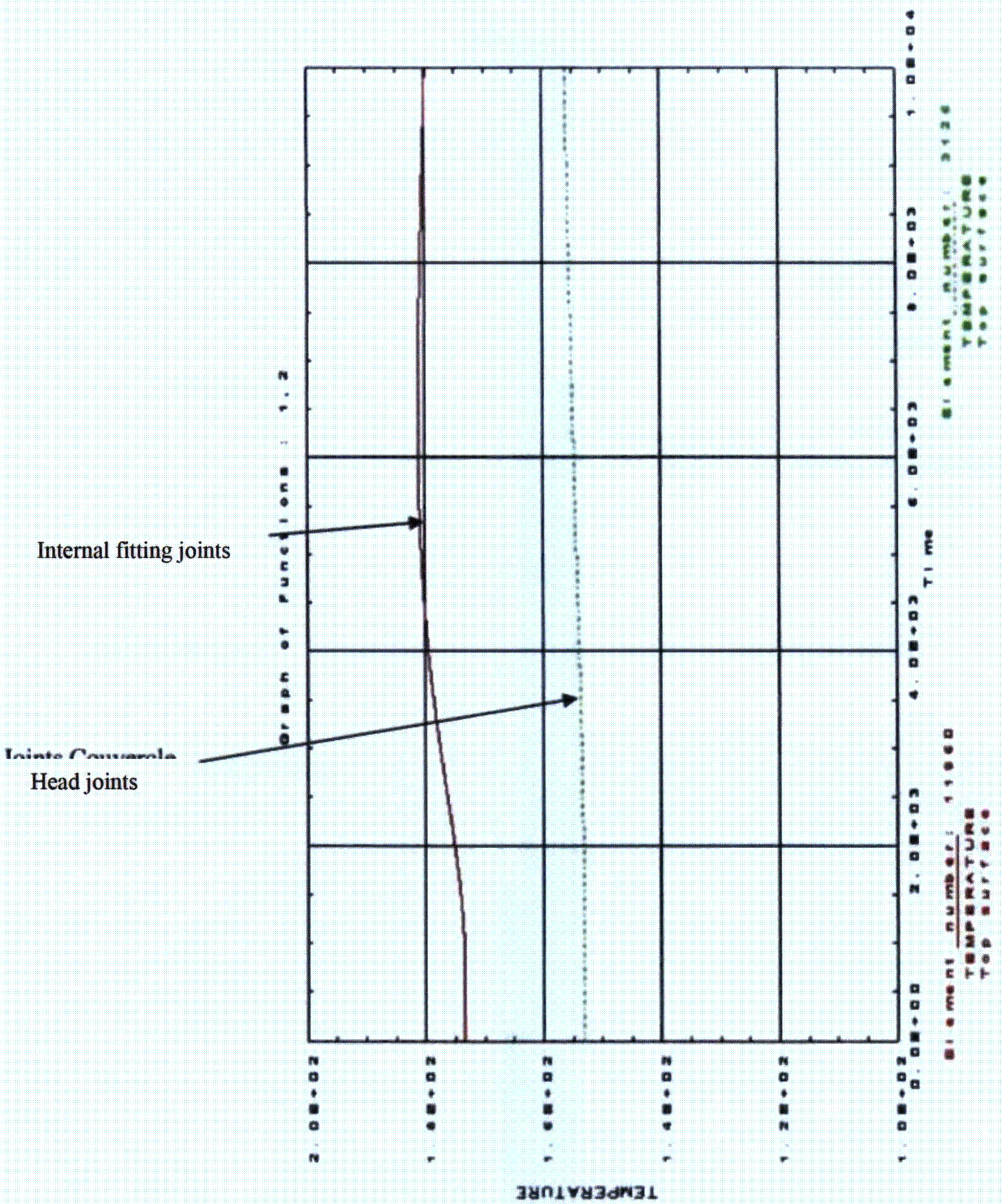
PACKAGE ISOTHERMS

t = 10,000 s



APPENDIX 1

GRAPH OF VARIATION IN JOINT TEMPERATURES



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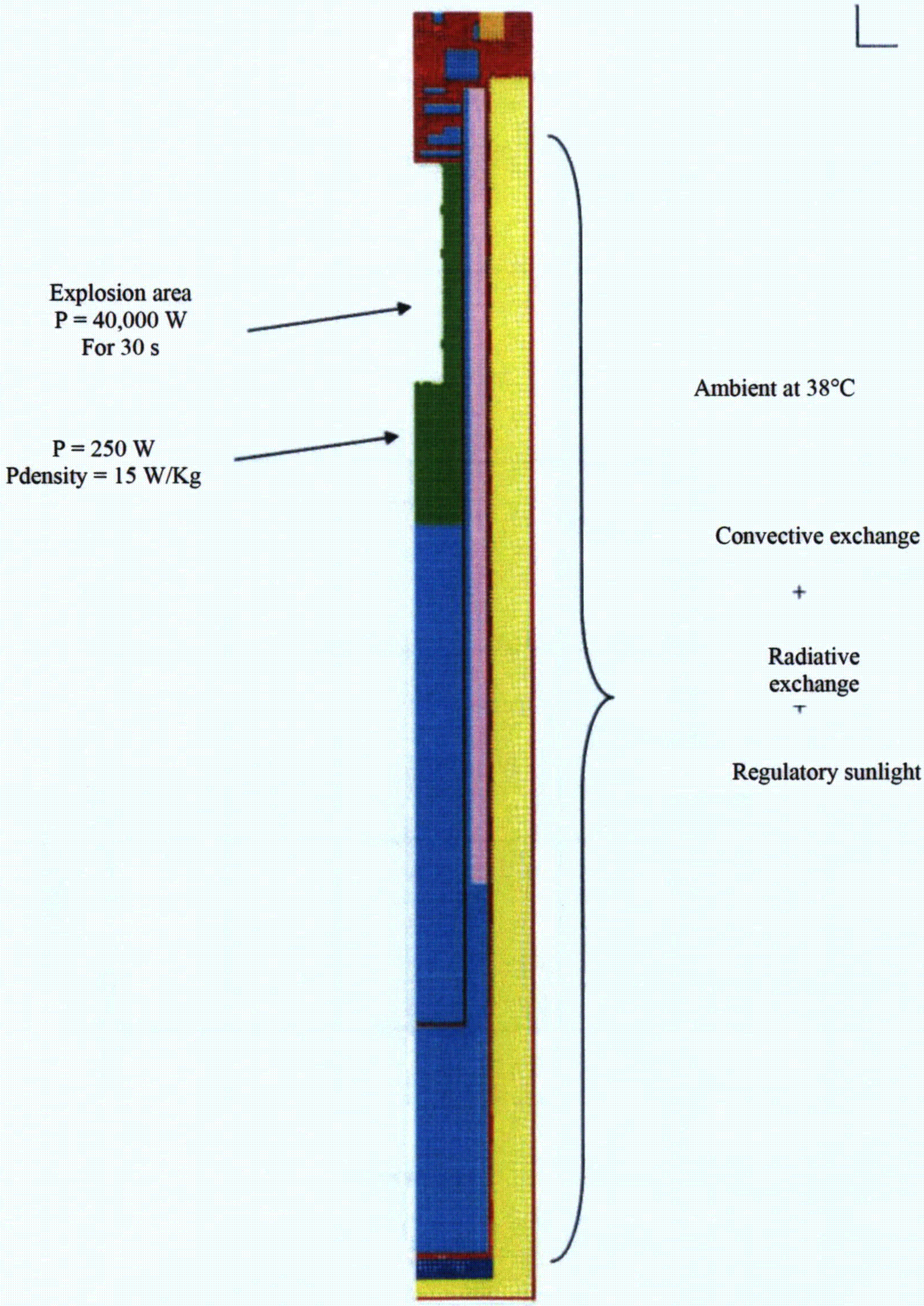
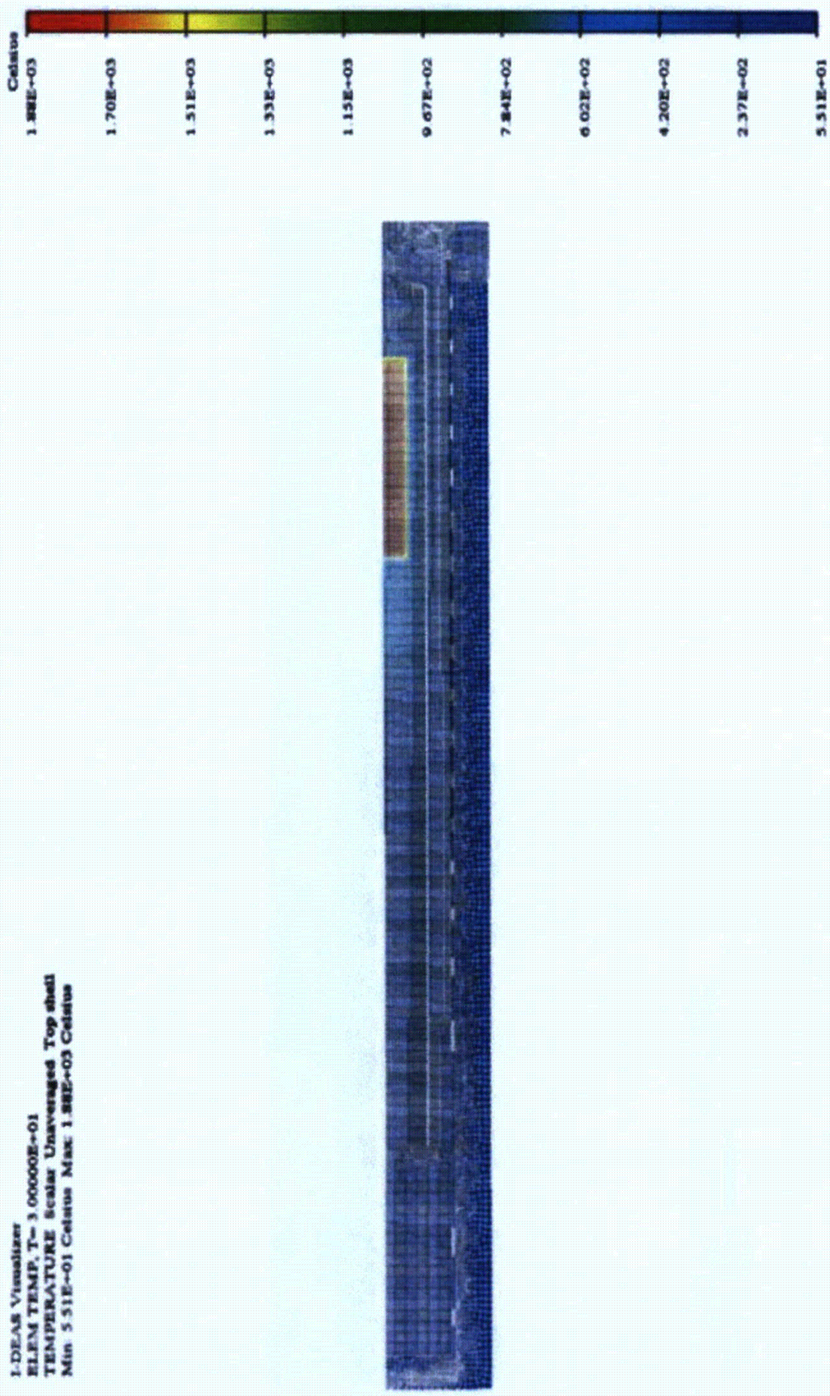
LIMIT CONDITIONS



APPENDIX 2

PACKAGE ISOTHERMS

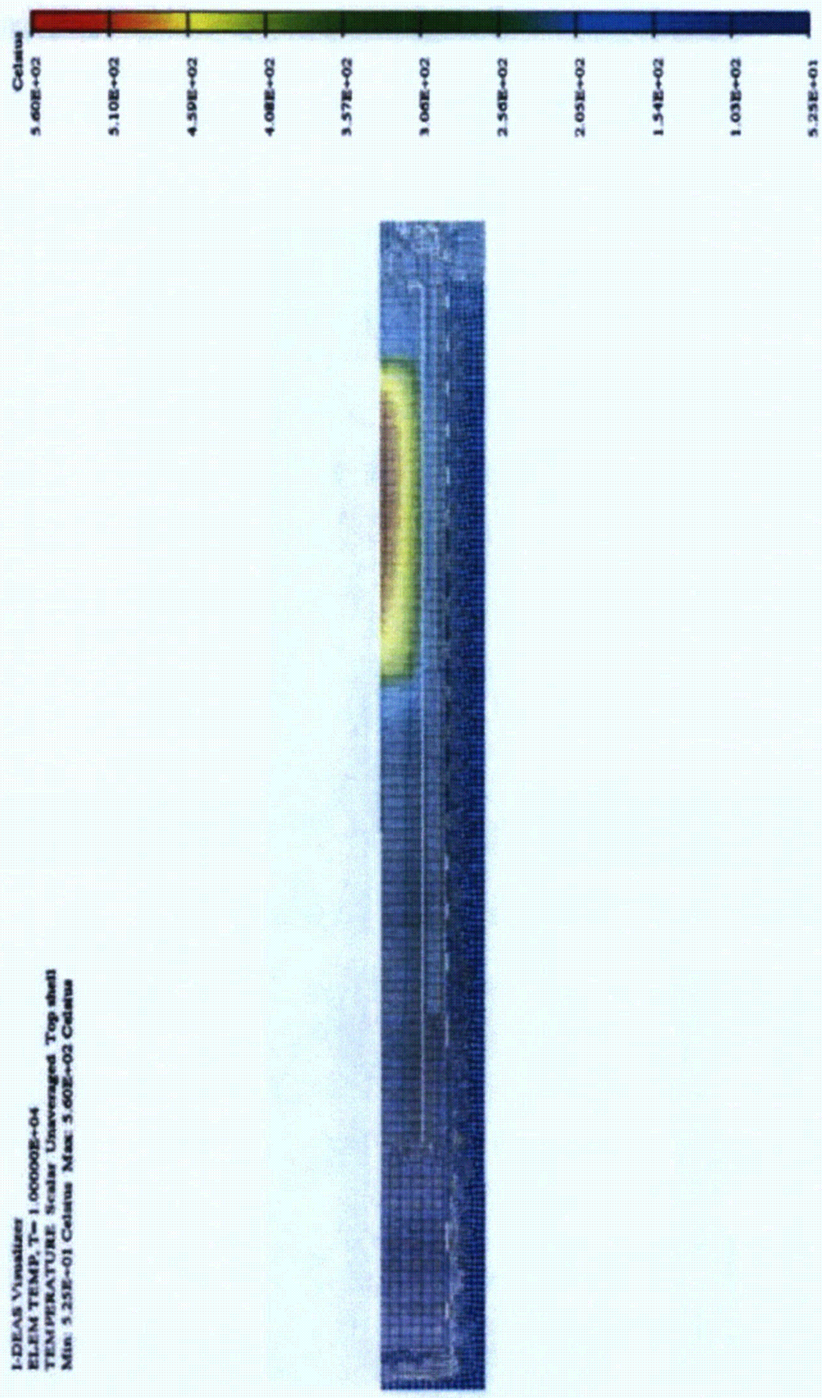
t = 30 s



APPENDIX 2

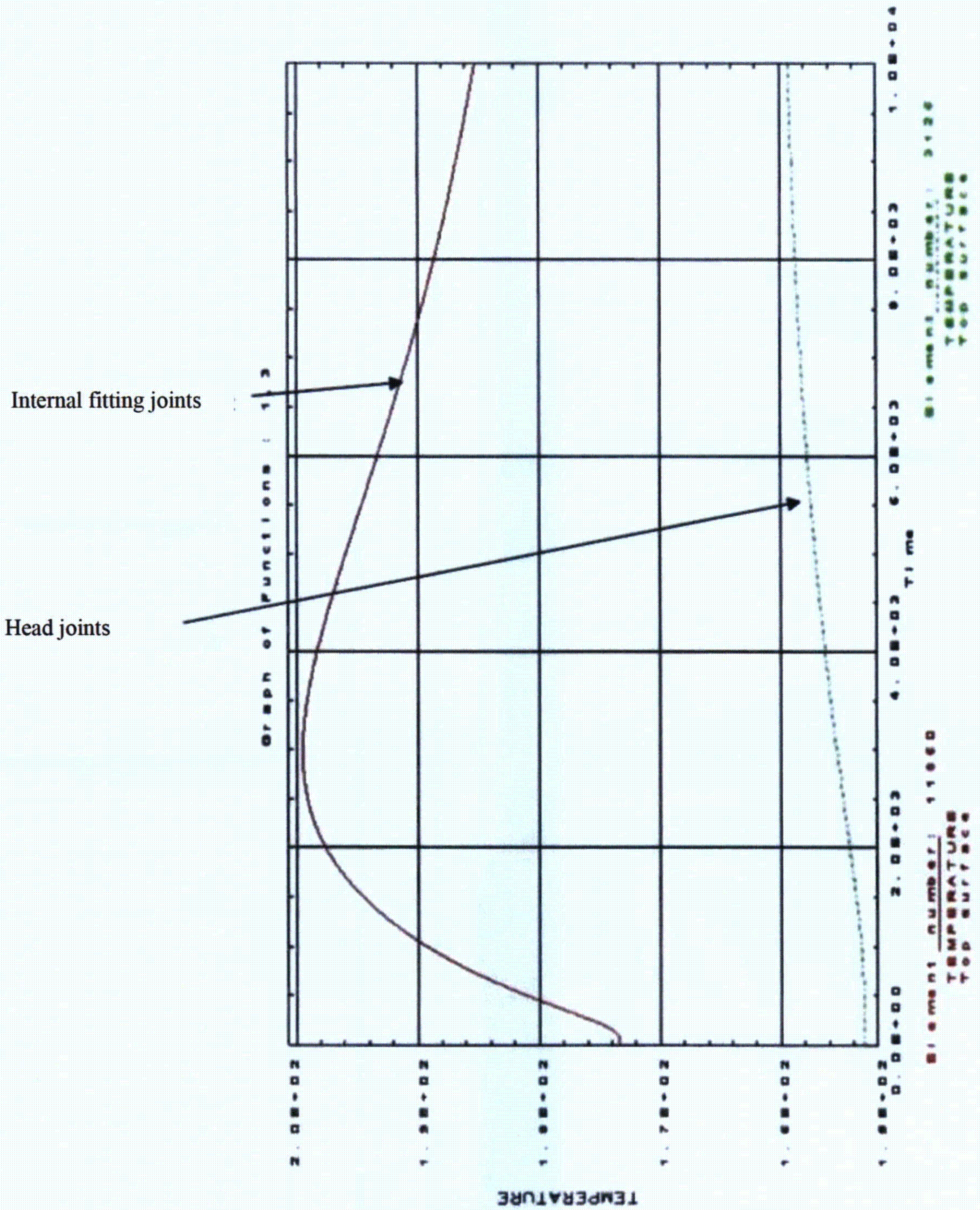
PACKAGE ISOTHERMS

t = 10,000 s



APPENDIX 2

GRAPH OF VARIATION IN JOINT TEMPERATURES



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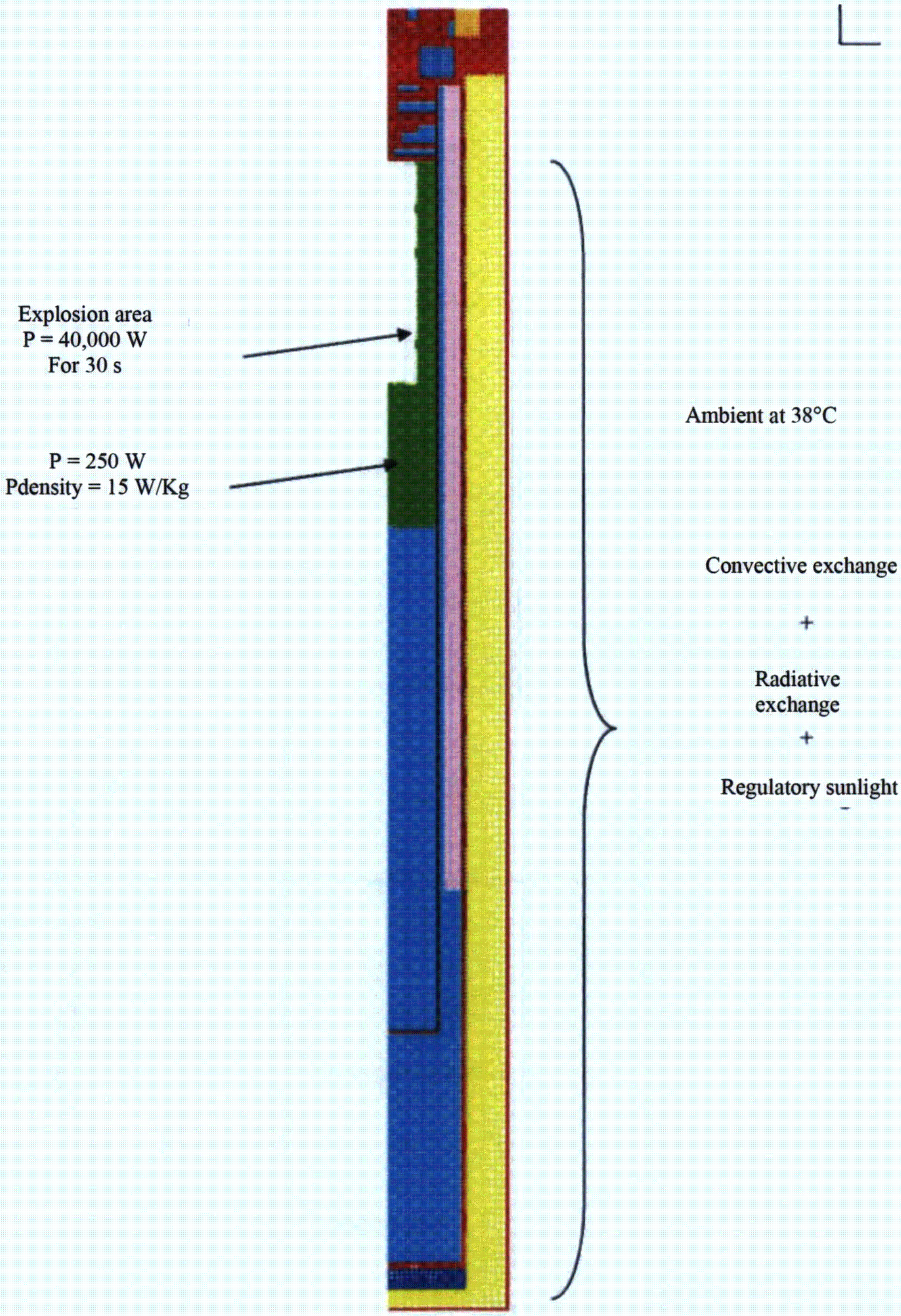
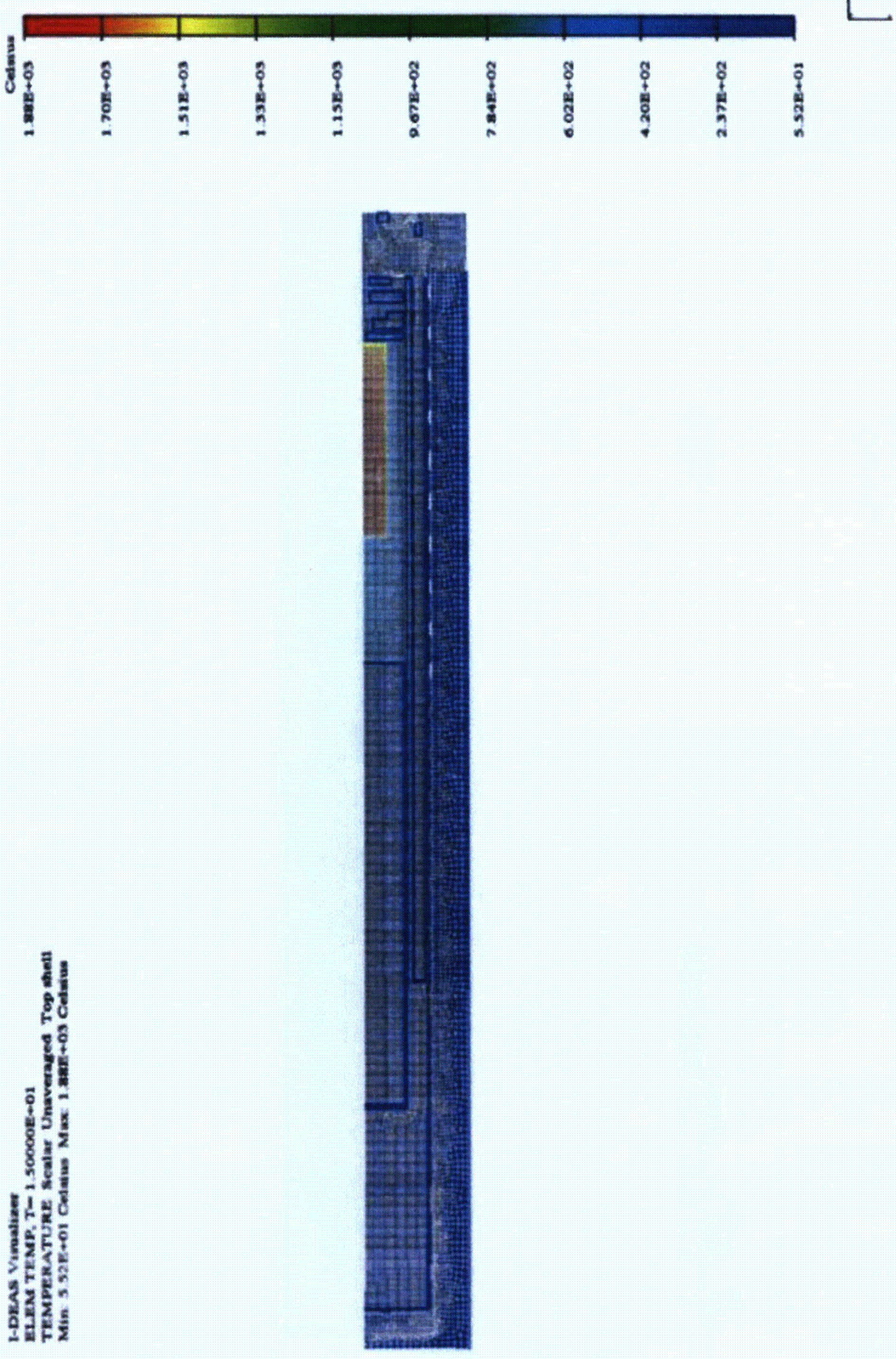
LIMIT CONDITIONS



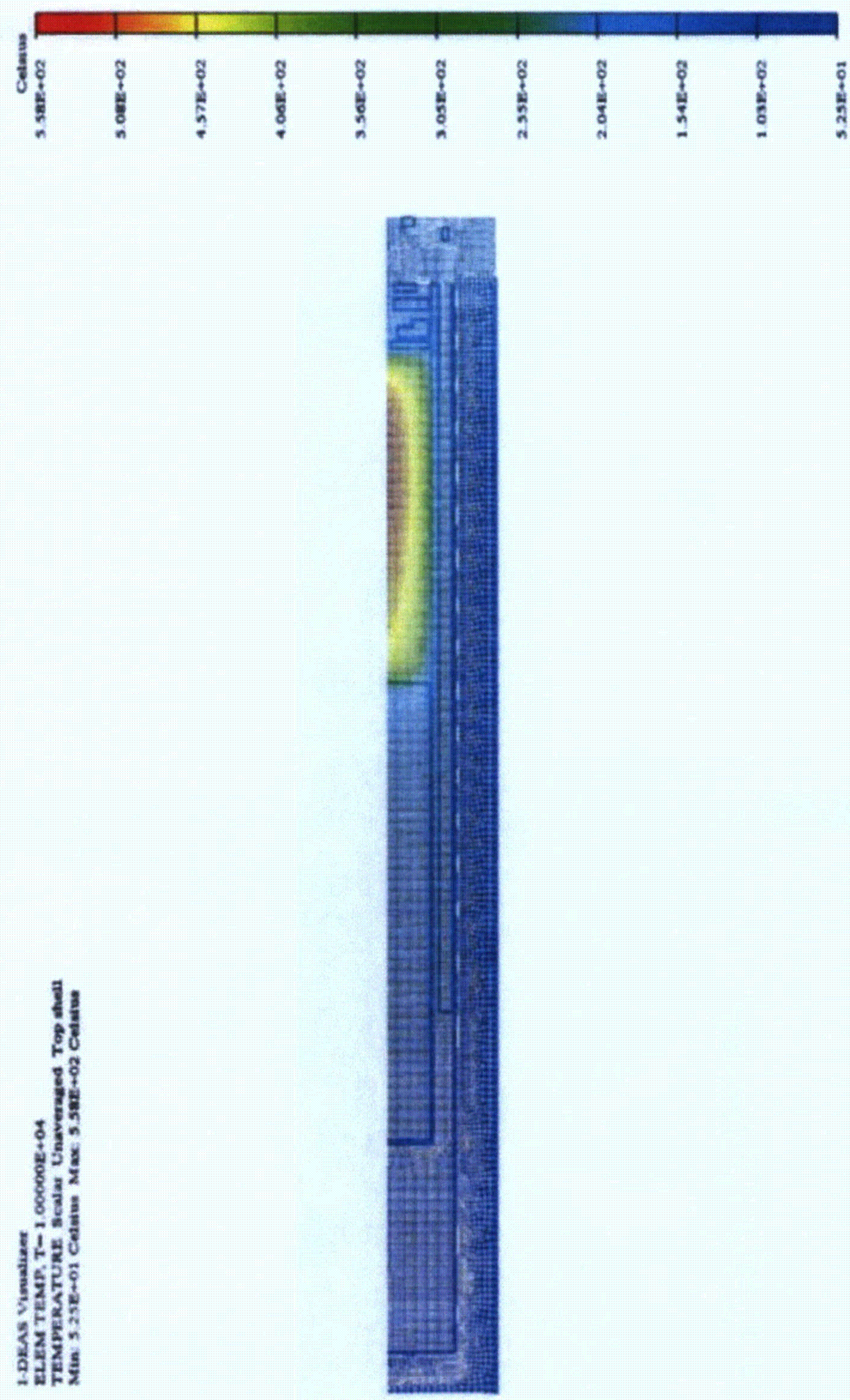
APPENDIX 3

PACKAGE ISOTHERMS T = 15 s



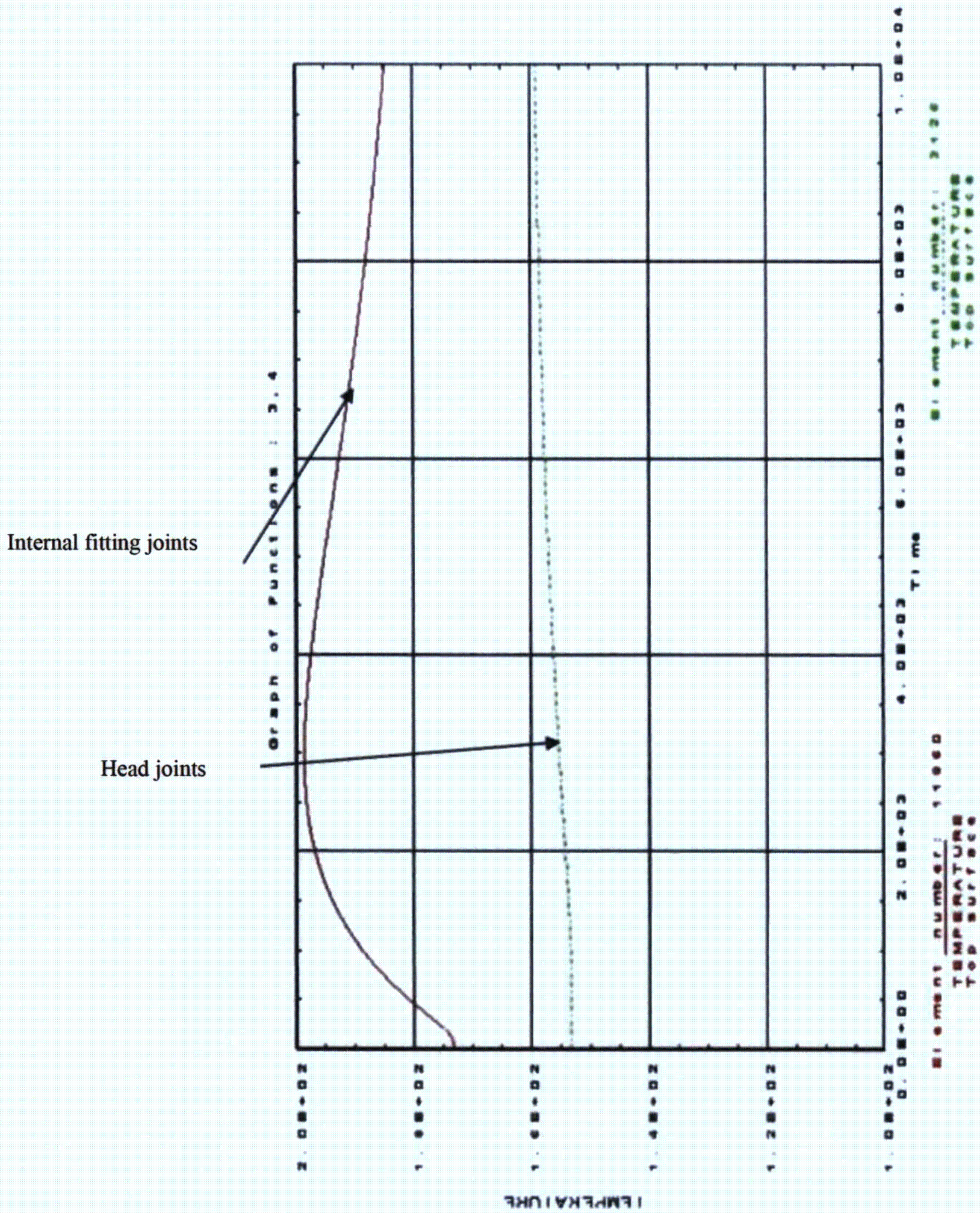
APPENDIX 3

PACKAGE ISOTHERMS T = 10,000 s



APPENDIX 3

GRAPH OF VARIATION IN JOINT TEMPERATURES



CEA

Thermal design report for the TN-BGC1 package loaded with 238Pu sources

Changes table

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Guntzburger		Azais

Summary

This report includes details of the results of the thermal testing of the TN-BGC1 package in normal conditions of transport (CNT) and accident conditions of transport (CAT) based on IAEA regulations (ref.[1]). The TN-BGC1 package is used to transport plutonium. The radioactive substance is packaged in an AA99 type container, itself placed inside an AA41-type container. Three AA41 containers are stacked inside the cavity. Two loading scenarios are studied: the quantity of plutonium in the containers will be adapted to give a power of either 13 W or 34 W.

The general purpose of this study is to determine the temperatures reached by the different package components and particularly to check:

- compliance with criteria on:
  - package joints with a threshold temperature of 250°C,
  - AA41 container joints with a threshold temperature of 300°C,
- that:
  - the temperature of the gases used to fill the cavity remains below 268°C,
  - the temperature of the gas used to fill the AA41 container remains below 335°C.

When calculating NCT, the package is in the vertical position, exposed to sunlight on a permanent basis in ambient air at 38 °C. ACT calculations, initialised with temperatures obtained in NCT, are carried out in two phases:

- this first is a fire phase and has a duration of 30 minutes. The package is entirely surrounded by a flame front at 800°C which exchanges thermal flows with all surfaces,
- the second is a cooling phase in an environment at 38°C with permanent sunlight, and the package in a horizontal position, considered as a worst-case scenario.

When the loading of each container is 13 W, maximum temperatures are as follows:

- 142.7°C for package joints,
- 144.2°C for AA41 container joints,
- 143.8°C for package filling gases,
- 147.8°C for AA41 container filling gases.

When the loading of each container is 34 W, maximum temperatures are as follows:

- 196.9°C for package joints,
- 205.1°C for AA41 container joints,
- 204.2°C for package filling gases,
- 205.1°C for AA41 container filling gases.

To conclude, the temperatures reached by the different parts of the TN-BGC 1 package and the AA41 containers are acceptable for the materials used. The temperature limits inherent to regulations are not exceeded.

Furthermore, the results obtained demonstrate that temperature criteria for joints are satisfied and that the temperatures of the gases filling the cavity and the AA41 container do not exceed 268°C and 335°C respectively. Therefore, the conclusions of the thermal study carried out for folder 160 EMBAL PFM DET 08000157 A of 26/02/08 and the inherent safety analyses (particularly containment) continue to apply.

References

[1] Regulations for the safe transport of radioactive material - Réf. TS-R-1 - Safety Requirements - IAEA 2009

[2] Advisory material for the IAEA regulations for the safe transport of radioactive material - Ref. TS-G-1.1 - Safety guide - IAEA 2009

[3] "Emballage TN-BGCI-Plan de concept-Ensemble" (TN-BGC1 package - Design plan - Overview) 9990-65C - Transnuclear

[4] "Emballage TN-BGCI-Bouchon assemblé" (TN-BGC 1 package - Assembled plug): 9990-117B - Transnuclear

[5] Chapter 2_160 EMBAL PFM DET 08000160, CEA/DEN/DPIE/SET

[6] Drawing file BGC PLA 275 - Drawings 01 - 06, ICm south

[7] Drawings AA99, AA41, Shim E1, Shim E9 and Shim E13 - study input document th 238Pu

[8] "Analyse thermique du colis TB-BGC1" (Thermal analysis of the TN-BGC1 package) - Ref. 177652C070223 - SOM

[9] Heat and mass transfer - H.D. BAEHR & W. STEFAN - Ed. SPRINGER 1999

[10] Heat transmission – WH Mc Adams, Chapter VII

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1 Introduction

This report includes details of the results of the thermal testing of the TN-BGC1 package in normal conditions of transport (CNT) and accident conditions of transport (CAT) based on IAEA regulations (ref.[1]).

The TN-BGC 1 package model consists of:

- a casing for three AA41 stacked containers each housing a AA99-type container (AA99 hereafter) housing the radioactive substance (plutonium). The casing consists of a shell and a base, surrounded by a resin-based mixture ensuring neutron-absorbing and thermal protection, and with a wood shock absorber under the base,
- a cavity closing system mainly comprising a plug, a bronze clamp ring and a bayonet ring,
- a dampening cover protecting the package in case it falls on the plug-side.

The general purpose of this study is to determine the temperatures reached by the different package components and particularly to check:

- compliance with criteria on:
  - package joints with a threshold temperature of 250°C,
  - AA41 container joints with a threshold temperature of 300°C,
- that:
  - the temperature of the gases used to fill the cavity remains below 268°C,
  - the temperature of the gas used to fill the AA41 container remains below 365°C.

2 Numerical model

2.1 Meshing

The package has rotational symmetry, enabling the use of an axisymmetric 2D model. This model exclusively consists of 4-node quadrangular elements (linear interpolation). The model includes 13 555 elements for 13 425 nodes. The mesh is shown in Figure 3, where axis Y is adopted as the axis of rotation.

2.2 Thermal characteristics of the materials used

All of the thermal characteristics of the materials used are taken from ref. |8].

For carbon steel and air, it was necessary to take into consideration variation in parameters λ, p and Cp depending on temperature. Conversions were necessary due to the formal nature of the allocation of design software properties: only conductivity λ and specific heat Cp are entered as a function of temperature, with Cp corrected to ensure that the product p x Cp at a given temperature is equal to the product po x $Cp_{corrected}$ where p_0 is the reference density independent to temperature variation, taken as 20 °C, and $Cp_{corrected}$ the value used in the calculation.

2.2.1 Stainless steel

Stainless steel components are:

- the external and internal shell of the package and plug casing,
- the shell and cover of AA99 and AA41,

	Temperature (°C)	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m^3)	ε	solar α
304L stainless steel	20	14,7	454.3	7930	0.5 before fire 0.9 during and after fire	0.3 before fire 0.9 after fire
	100	15,8	492			
	200	17,2	525.2			
	300	18,6	541.7			
	400	20	553.1			
	600	22,2	566.7			
	800	24,1	587.8			

Table 1: thermal properties of INOX 304L steel

2.2.2 Aluminium

Aluminium components are: shims E1, E9 and E13.

	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m^3)	ε
Aluminium	134	950	2790	0.5

Table 2: thermal properties of aluminium

2.2.3 Bronze

Bronze components are: plug locknuts.

	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m^3)
Bronze	50.2	370	8800

Table 3: thermal properties of bronze

2.2.4 Neutron absorbing resin

A 24 mm layer of resin is present under the head damper, and a layer of 48 mm is placed between the internal shell and the external shell of the package.

	Temperature (°C)	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m³)
Air/neutron-absorbing resin	20	0.66	1173	1600
	50	0.66	1257	
	100	0.66	1397	
	150	0.66	1536	
	200	0.47	1533	
	250	0.28	1515	
	300	0.09*	1415	
	400	0.09*	764	
	500	0.09*	615	
	600	0.09*	543	

* Area of neutron-absorbing resin damaged after the fire

Table 4: thermal properties of the neutron-absorbing resin

2.2.5 HDPE

HDPE components are: polyethylene disc components in the plug.

	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m³)
HDPE	0.46	1881	950

Table 5: thermal properties of HDPE

2.2.6 Steel 39 CD 4

The package distribution plate is in 39 CD 4 steel.

	Temperature (°C)	λ (W/m.K)	ρ (kg/m³)	Cp (J/Kg.K)	ρ (kg/m³)	Cp corrected to ρ cst (J/kg/K)
Steel 39 CD 4	20	32.8	7850	473.2	7850	473.2
	100	32.5	7820	484.9		483
	200	32.2	7785	523.6		519
	300	31.9	7750	554.7		547.6
	400	31.6	7780	594.7		589.4
	500	31.3	7690	658.6		645.2
	600	31	7663	739.5		721.9

Table 6: thermal properties of 39 CD 4 steel

2.2.7 Copper-aluminium

The plug clamp ring is in copper-aluminium.

	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m³)
Copper-aluminium	37.6	376	7600

Table 7: thermal properties of copper-aluminium

2.2.8 Plutonium 238

The content is a layer of plutonium 238.

	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m^3)
^{238}Pu	6.3	130	19840

Table 8: thermal properties of ^{238}Pu

2.2.9 Protection wood

Wood components are fitted in the head damper cover and in the base of the package casing.

Wood	Temperature (°C)	λ (W/m.K)	Cp (J/Kg.K)	ρ (kg/m^3)
Balsa wood	20	0.051	1100	150
	270	0.086		
ACT balsa	20	0.128		375
	270	0.215		
Poplar	20	0.13	450	460
	270	0.22		
Poplar ACT	20	0.325		1150
	270	0.55		

Table 9: thermal properties of the protection wood

2.2.10 Filling gas / Air

The thermal properties of air will be assumed for all the cavities of the package, AA99 and AA41.

	Operating temperature (°C)	Conductivity (W/m.K)	Density ρ (kg/m^3)	Specific heat Cp (KJ/Kg.K)	Density ρ (kg/m^3)	Cp corrected to ρ cst (KJ/kg/K)
Air	20	0.0257	1.188	1.007	1.188	1.007
	50	0.0280	1.067	1.007		0.904
	100	0.0314	0.933	1.012		0.795
	150	0.0348	0.822	1.017		0.704
	200	0.0379	0.736	1.026		0.636
	300	0.0441	0.607	1.046		0.534
	400	0.0500	0.517	1.069		0.465
	500	0.0556	0.450	1.093		0.414
	600	0.0611	0.399	1.116		0.375
	700	0.0665	0.358	1.137		0.343
	800 and beyond	0.0715	0.324	1.155		0.315

Table 10: thermal properties of air

3 Thermal exchange assumptions

3.1 Configuration

It is assumed that all components located in the TN-BGC1 package (Shims, AA41, AA99, plutonium) are displaced towards the head of the package (see Figure 2). This assumption gives the worst case scenario as it promotes the thermal path between the sources (plutonium) and the joints of the AA41 container and the package.

In NCT, the package is in a vertical position, in permanent sunlight, in ambient air at 38°C.

In ACT, the calculation is initialised by the results for NCT and carried out in two phases:

- Fire phase:
  This corresponds to a transient with a duration of 30 minutes. The package is damaged: the wood is assumed to be compressed by 60%:
  - the head damper cover is reduced by 42 mm along the longitudinal axis,
  - the damper cover is reduced by 33 mm for one centre line,
  - the "shock absorbing" part of the base is reduced by 39 mm along the longitudinal axis.

  All of the surfaces of the package are subjected to the same thermal load consisting of radiation and forced convection with flames at 800°C. These conditions are based on IAEA ref.[2]. The thermal properties of balsa and poplar are modified (see table 9).
- Cooling phase:
  Cooling is carried out at an ambient temperature of 38°C with permanent sunlight. According to ref. [8], the horizontal position represents the worst-case scenario. The initial geometry with better insulation can be recovered by dividing the initial thermal conductivity of the balsa and poplar by 2.5 (see Table 9).

3.2 Modelling internal heat exchanges

The following internal exchange conditions are applied in the model on a permanent basis:

- contact between separate volumes,
- thermal exchanges by conduction and radiation in cavities,
- thermal power emitted by the substance transported.

The gas inside the package is assumed to be air.

3.2.1 Contact management:

The following parts are assumed to be in perfect contact, i.e. modelled in common nodes with the rest of the package (see Figure 4):

- CP-01 : Plug / Damper cover internal shell
- CP-02 : Plug / Package flange
- CP-03 : Plug / Package flange
- CP-04 : Plug / AA41 cover
- CP-05 : AA41 cover / Shim E1

- CP-06 : AA41 cover / AA9 cover
- CP-07 : Package internal shell / Shim E1
- CP-08 : Shim E1 / Shim E9
- CP-09 : Shim E13 / AA41 cover
- CP-10 : Damper cover / package external shell
- CP-11 : Shim E1/ Shim E9 (not shown on figure)
- CP-12 : Shim E9/ Package internal shell (not shown on figure)

3.2.2 Processing of exchanges in the cavity

The air is represented as a volume of material with thermal properties and in which heat transfer occurs by conduction and radiation between facing surfaces. For conduction, the properties adopted are taken from table 10. For the mutual radiation of internal surfaces, a Monte Carlo method is used where form factors between each cavity component are calculated automatically by the software.

Several cavities are modelled within the package (see Figure 4):

- CAV-01 : AA99 cavity,
- CAV-02 : AA41 cavity,
- CAV-03 : cavity between the AA41 and shim E13,
- CAV-04 : cavity between the AA41 and shim E1,
- CAV-05 : cavity in the AA41 cover,
- CAV-06 : cavity between shim E9 and the internal shell of the package (not shown on figure).

3.2.3 Thermal power emitted by the plutonium

The quantity of plutonium in the AA99 is adapted to give a power of Pi = 13W or P_2 = 34W. The specific power of the plutonium is equal to 556 W/Kg and the density of the plutonium is equal to 19.84.

The volume flow applied is therefore:

$$\phi_{volume} = 0.011 \text{ W/mm}$$

Power is distributed uniformly in the plutonium volume represented by a cylinder with a diameter equal to that of the AA99 (100 mm) and a height of H_1 = 0.15 mm if power is equal to P_1 and height H_2 = 0.39 mm for power P_2.

3.3 Modelling external heat exchanges

3.3.1 Solar flux

The solar flux is applied to the exposed surfaces according to the conventions described in the IAEA regulations ref. [l] . These values are corrected based on the absorption coefficient a of the surface subjected to the solar flux. The flow actually applied is therefore:

$$F_{app} = Fs \times \alpha$$

In NCT, the absorption coefficient of external surfaces (Stainless steel) is α =0.3.

In ACT, during the fire, the solar flux is not taken into consideration. After the fire, the external surfaces are considered to have been blackened by the flames: α = 0.9.

	Solar flux	Flux applied in NCT with the Package vertical	Flux applied in ACT during the cooling phase with the Package horizontal
Flat horizontal surfaces	F_s = 800 W/m^2	F app = 240 W/m^2	-
Vertical surfaces	F_s = 200 W/m^2	F_{app} = 60 W/m^2	Fapp = 180 W/m^2
Other surfaces	F_s = 400 W/m^2	-	Fapp = 360 W/m^2

Table 11: solar flux values applied in the model

3.3.2 Convection

NCT and during the cooling phase in ACT:

The external surfaces of the package (T_{Pack}) exchange heat with the ambient environment by natural convection (T_{Ext} = 38°C) as follows:

$$\Phi_{Pack\text{->}Ext}(T) = h \times (T_{Pack} - t_{Ext})$$

h is the convection coefficient taken from ref. [10]:

- $h = 1.28\ (\Delta T)^{0.33}$ for flat vertical surfaces,
- $h = 1.22\ (\Delta T)^{0.33}$ for cylindrical surfaces,
- $h = 1.51\ (\Delta T)^{0.33}$ for flat horizontal surfaces facing upwards,
- $h = 0.96\ (\Delta T)^{0.33}$ for flat horizontal surfaces facing downwards,

In ACT during the fire phase:

The external surfaces of the package (T_{Pack}) exchange heat with the flames by forced convection (T_f = 800°C) as follows:

$$\Phi_{f\text{->}Pack}(T) = h \cdot (T_f - t_{Pack})$$

In this case, h = 10 W/m^2·K, according to the recommendations of the IAEA.

3.3.3 Radiation

NCT and during the cooling phase in ACT:

The package radiates to an outside environment considered to be infinite and therefore acting as a black body (α=1). In this case, the surface flow lost from the structure by radiation is expressed by:

$$\varphi_{Pack\text{->}Ext}(T) = \varepsilon_{PACK} \cdot \sigma \cdot (T_{PACK}^4 - T_{EXT}^4)$$

Where ε_{PACK} is the emissivity of the wall of the structure, σ the Stephan - Boltzmann constant, T_{PACK} its temperature, and T_{EXT} that of the environment.

The radiation of the package to the external environment is taken into consideration by using an equivalent convection coefficient based on the linear expression of the radiation flux:

$\varphi_{Pack\text{->}Ext}(T)=h(T)\cdot(T_{Pack}-T_{ext})$ with $h(T)=\varepsilon_{Pack}\cdot\sigma\cdot(T_{Pack}^3+T_{Pack}^2\cdot T_{Ext}+T_{Pack}\cdot T_{Ext}^2+T_{Ext}^3)$

Where:

$\sigma = 5.67\cdot10^{-8}\ W/m^2/K^4$,

T_{ext}=38°C,

ε_{PACK} = 0.3 in NCT and ε_{PACK} = 0.9 in ACT during the cooling phase (stainless steel blackened by the flames).

<u>In ACT during the fire phase:</u>

We consider that the flames have an emissivity of ε_f = 1 (black body) and a temperature T_f= 800°C, they cover the entire surface of the package and absorption of $\alpha_{Pack}=\varepsilon_{Pack}$ = 0.9 is adopted, corresponding to a blackened metal surface. The net flux exchanged is therefore calculated as:

$\Phi_{f\text{->}Pack}(T)=\varepsilon_{eq}\cdot\sigma\cdot(T_f^4 - T_{Pack}^4)$ where $\varepsilon_{eq}=\dfrac{\varepsilon_f\cdot\varepsilon_{Emb}}{1-((1-\varepsilon_f)(1-\varepsilon_{Emb}))}$

Where ε_{eq} = 0.9.

4 Results

4.1 Results in NCT

The values of temperatures for package components for the powers released by the plutonium P_1 and P_2 are shown below. Temperature maps are included in APPENDIX 2.

		T°C (P_1 = 13W)	T°C (P_2 = 34W)
PACKAGING	External shell	77.5	119.2
	Resin	92.2	156.1
	Internal shell	91.3	156.2
	Clamp ring	87.0	153.7
	Package joints	91.3	153.9
	Plug internal surface	92.2	156.2
	Filling gas	95.6	164.6
	Base of the package	78.8	122.7
AA41	AA41 shell	96.1	165.4
	AA41 cover	108.7	194.9
	Filling gas	100.1	174.7
	AA41 joints	96.1	165.4
AA99	AA99 shell	100.2	165.4
	Plutonium	108.8	195.3

Table 12: Temperatures of package components in NCT for P_1 = 13 W and P_2 = 34 W

The temperatures of AA41 and AA99 shown above correspond to those at the point of contact with the plug as their temperatures are higher. In fact, the upper surface of the package receives more solar flux (240 W/m^2) than the side surfaces (60 W/m^2) and the displacement of internal package components against the plug accentuates the heat received.

4.2 Results in ACT

4.2.1 Maximum temperatures reached

The following tables show the maximum temperatures. Temperature maps at point in time t = 1800 s (end of the fire) and t = 18000 s (when the joint temperature is highest) are shown in APPENDIX 2.

		T°C P_1 = 13 W		T°C P_2 = 34 W	
		Tmax (°C)	Point in time	Tmax (°C)	Point in time
PACKAGING	External shell	793.3	0 h 30 min	794.2	0 h 30 min
	Resin	789.9	0 h 30 min	791.2	0 h 30 min
	Internal shell	141.7	2 h 30 min	196.8	2 h 53 min
	Clamp ring	143.0	2 h 10 min	197.1	2 h 40 min
	Package joints	142.7	2 h 20 min	196.9	2 h 47 min
	Plug internal surface	142	2 h 53 min	197.7	3 h 03 min
	Package filling gas	143.8	2 h 43 min	204.2	3 h 00 min
	Base of the package	122.5	1 h 53 min	160.0	1 h 53 min
AA41	AA41 shell	144.2	2 h 47 min	205.0	2 h 57 min
	AA41 cover	155.8	2 h 53 min	232.7	3 h 10 min
	AA41 filling gas	147.8	2 h 53 min	213.7	3 h 03 min
	AA41 joints	144.2	2 h 43 min	205.1	3 h 07 min
AA99	AA99 shell	147.9	2 h 50 min	214.1	3 h 07 min
	Plutonium	156	2 h 57 min	233.1	3 h 10 min

Table 13: Maximum temperatures of package components in ACT for P_1 = 13 W and P_2 = 34 W

Containers AA99 and AA41 reached the highest temperatures and are also those in contact with the plug.

The maximum temperatures of the filling gases for the package and AA41 container remain below their respective threshold temperatures of 268°C and 365°C.

The package joints and joints of the AA41 container retain their containment characteristics, and their temperatures remain far from their maximum operating temperatures (250°C and 300°C respectively).

4.2.2 Positions of the measurement points

Results from various measurement points are provided over time to fill out the above table. They can be used to assess the thermal inertia of the package and to visualise the extreme values which may be reached during the phase.

The figure below shows the positioning of measurement points, with these points located where the part reaches its maximum temperature.

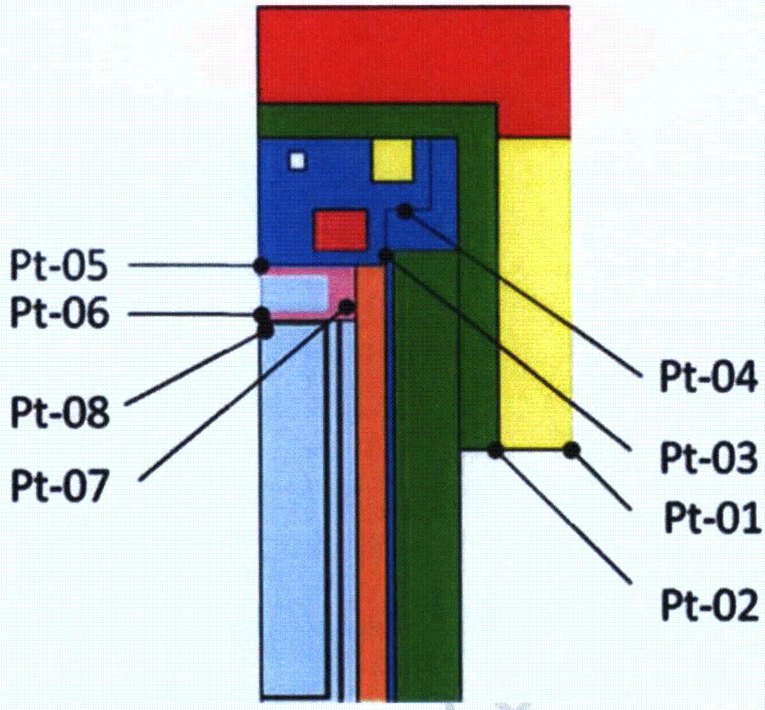

Figure 1: Position of measurement points on the package

- measurement point Pt-01 is located on the outer compartment of the package,
- measurement point Pt-02 is located on the package resin,
- measurement point Pt-03 is located on the inner compartment of the package,
- measurement point Pt-04 is located on the package joints,
- measurement point Pt-05 is located at the contact point between the plug and the cover of AA41,
- measurement point Pt-06 is located at the contact point between the cover of AA41 and the cover of AA99,
- measurement point Pt-07 is located on the AA41 joint,
- measurement point Pt-08 is located on the plutonium.

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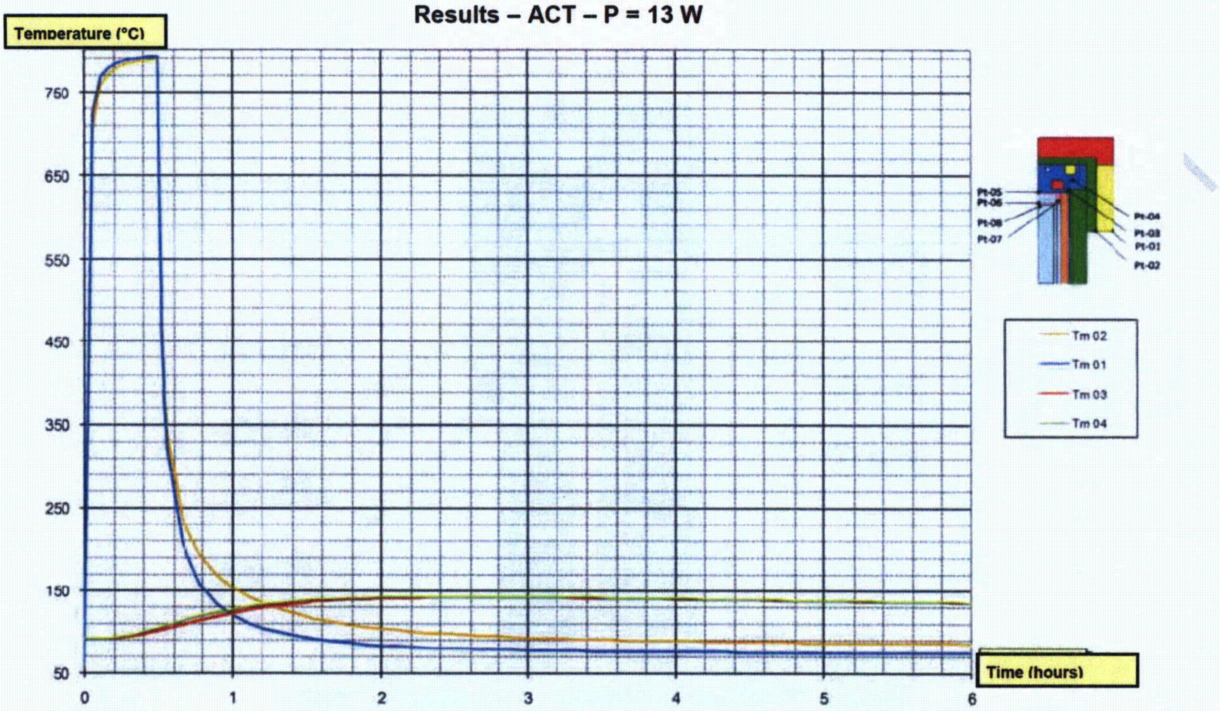
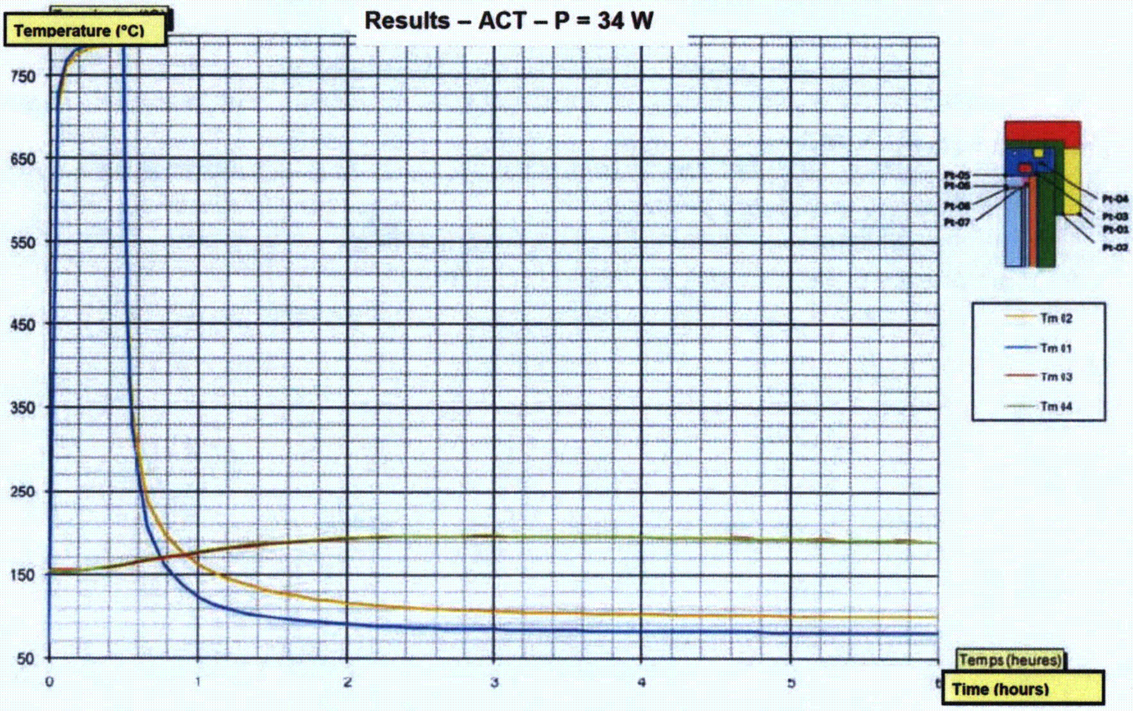
4.2.3 Graphs of results

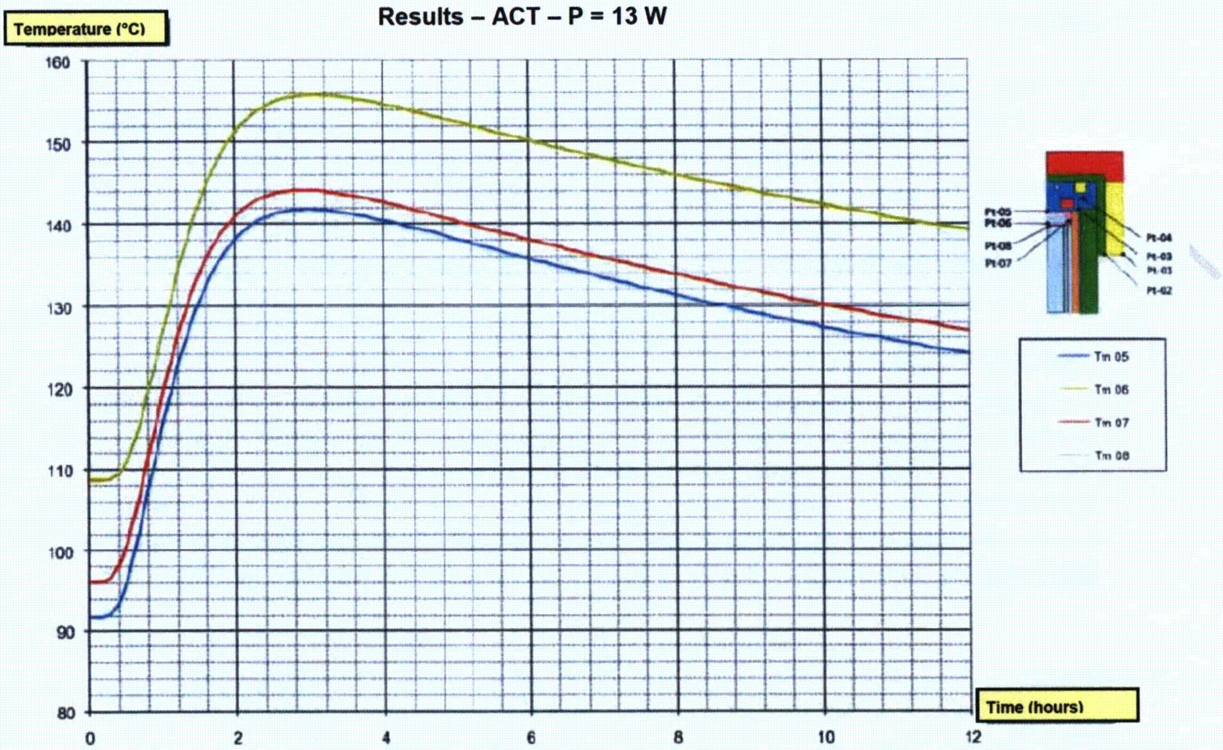


Graph 1: Package temperature – P_1 = 13 W

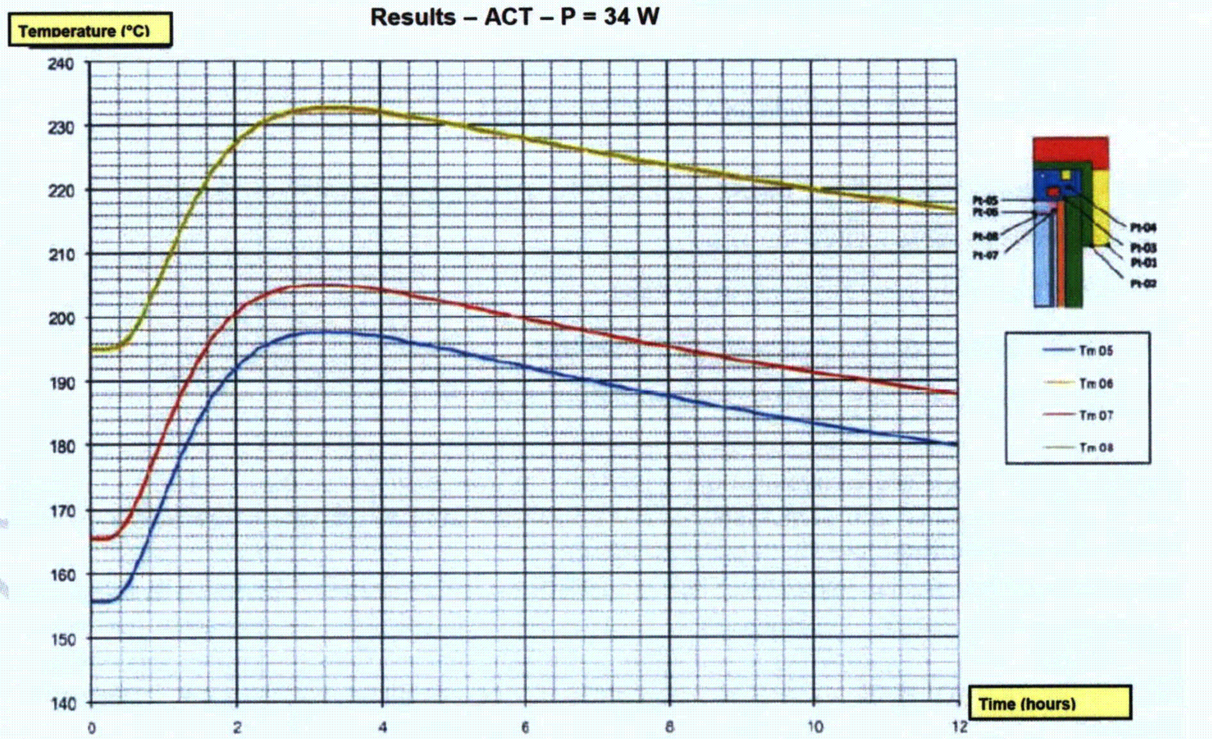


Courbe 2 : Températures de l'emballage - P_2 = 34 W

Graph 2: Package temperature – P_2 = 34 W



Graph 3: Package content temperature – P_1 = 13 W



Graph 4: Package content temperature – P_2 = 34 W

4.2.4 Analysis of the results

Graph 1 and Graph 2:
The protection wood (Pt-01) and above all the resin (Pt-02) provide effective thermal protection. Their temperatures are similar to those of the flames (800°C) while the inner shell (Pt-04) and the package joints (Pt-03) reach maximum temperatures of approximately 140°C when $P = P_1$ and 200°C when $P = P_2$. The maximum values are reached after 150/180 minutes, as the resin used has high thermal inertia ($\rho \cdot Cp = 2$ MJ/m^3/K).

Graph 3 and Graph 4:
The package plug, the cover of AA41, the cover of AA99 and the plutonium are in contact, therefore the thermal gradient between these parts is quite low and remains constant in ACT: approx. 15°C when $P = P_1$ and 35°C when P = P2.
This configuration gives the worst case scenario for joints as it promotes the thermal path between the source (plutonium) and the joints of AA41 and the package. Despite this configuration, the temperature of the joints of AA41 (145°C for P_1 and 205°C for P_2) remains below the threshold of 300°C.

5 Conclusion

When the loading of each container is 13 W, maximum temperatures are as follows:

- 142.7°C for package joints,
- 144.2°C for AA41 container joints,
- 143.8°C for package filling gases,
- 147.8°C for AA41 container filling gases.

When the loading of each container is 34 W, maximum temperatures are as follows:

- 196.9°C for package joints,
- 205.1°C for AA41 container joints,
- 204.2°C for package filling gases,
- 205.1°C for AA41 container filling gases.

To conclude, the temperatures reached by the different parts of the TN-BGC 1 package and the AA41 containers are acceptable for the materials used. The temperature limits inherent to regulations are not exceeded.

Furthermore, the results obtained demonstrate that temperature criteria for joints are satisfied and that the temperatures of the gases filling the cavity and the AA41 container do not exceed 268°C and 335°C respectively. Therefore, the conclusions of the thermal study carried out for folder 160 EMBAL PFM DET 08000157 A of 26/02/08 and the inherent safety analyses (particularly containment) continue to apply.

APPENDIX 1: MODELLING THE TN-BGC1 PACKAGE

Balsa head cap

Bronze locknut

Copper-aluminium

HDPE disk

Poplar head cap

Stainless steel AA41 cover

Plutonium

24 mm resin cap

Stainless steel AA41 shell

Air Package Cavity

Stainless steel AA99

AA99 cavity

Stainless steel package internal shell

Stainless steel package external shell

Aluminium shim E13

Aluminium shim E1

Aluminium shim E9

Cover cavity AA41

48 mm package resin

Air Package Cavity

Carbon steel distribution baffle

Balsa base cap

Poplar base cap

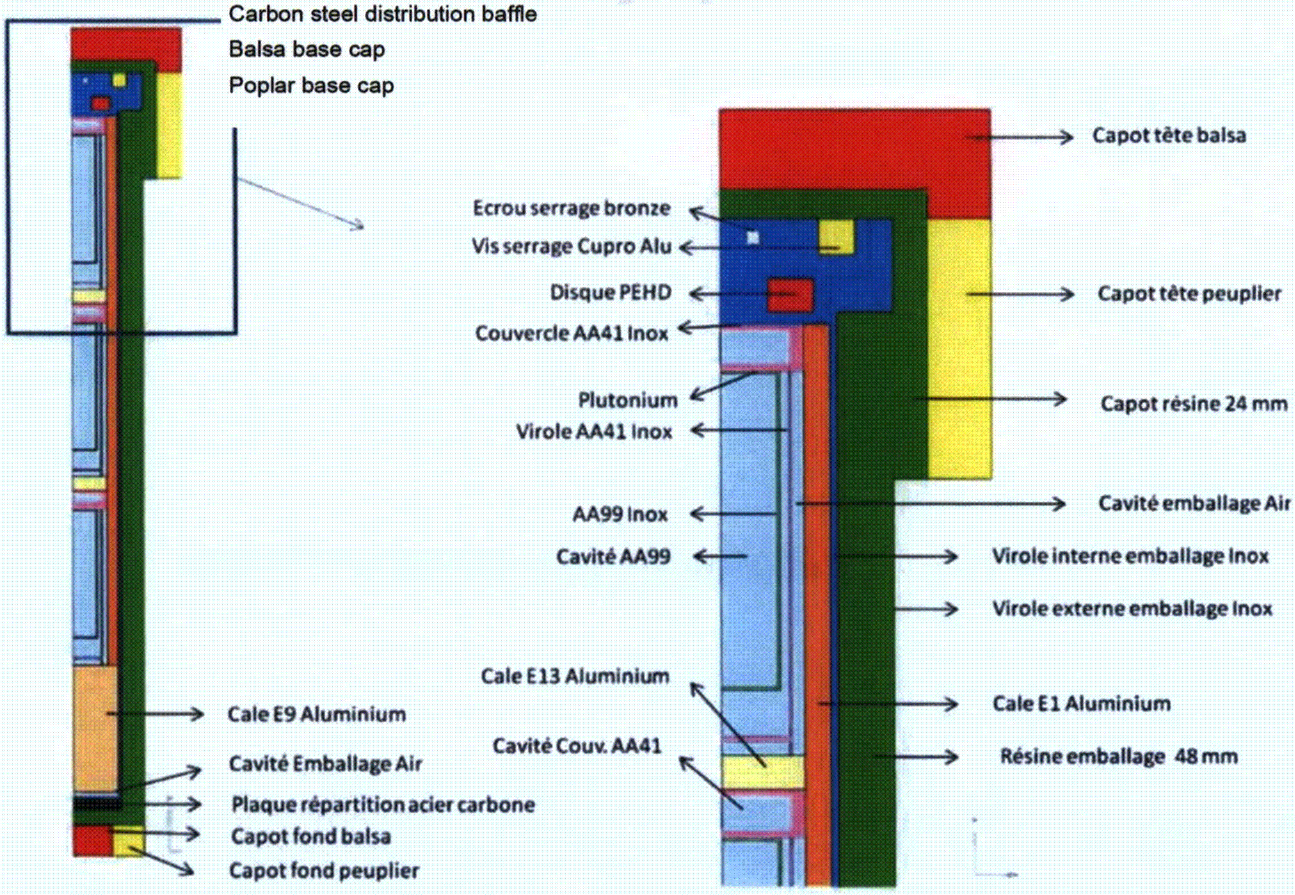


Figure 2: Description of the digital model

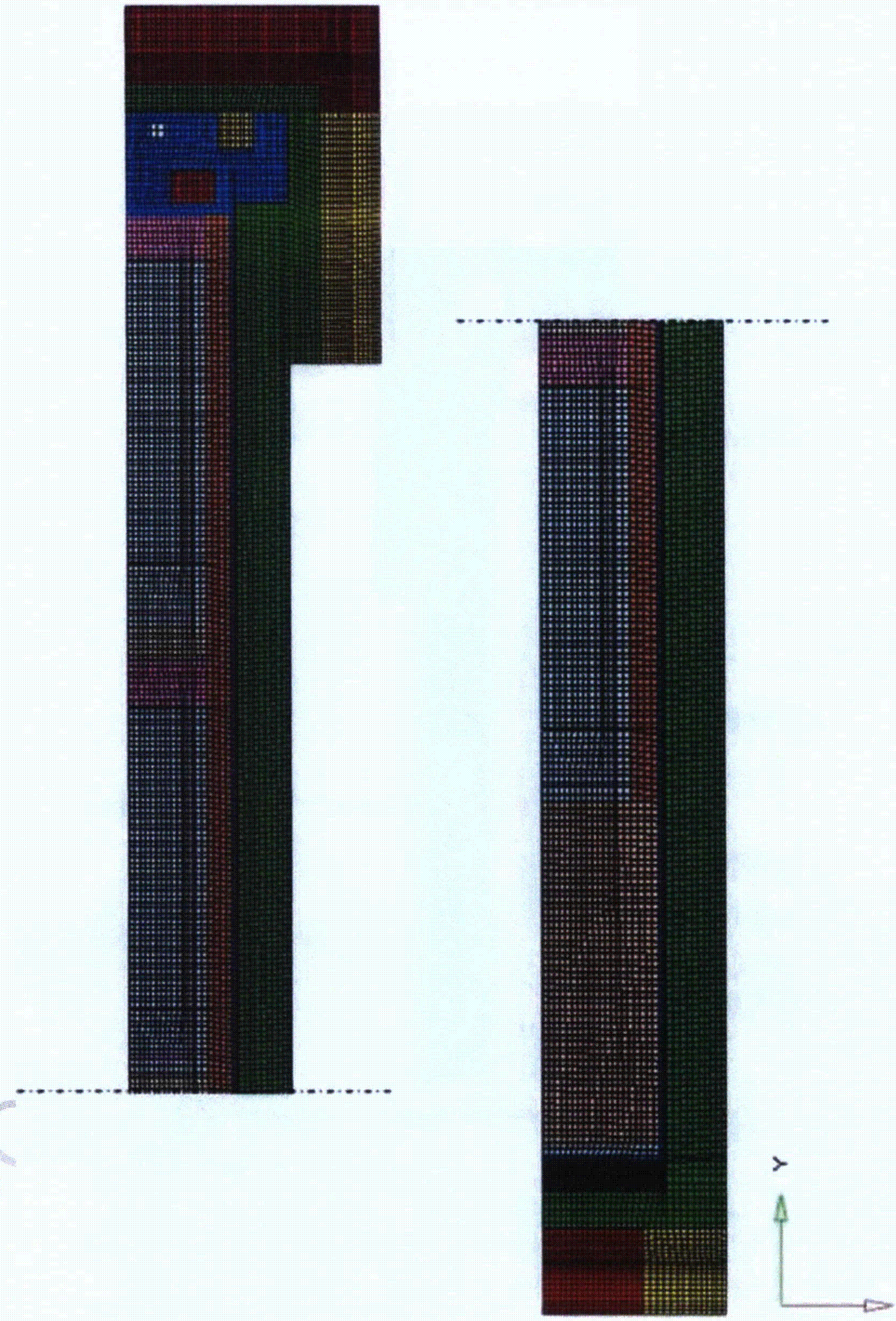


Figure 3: Presentation of meshing

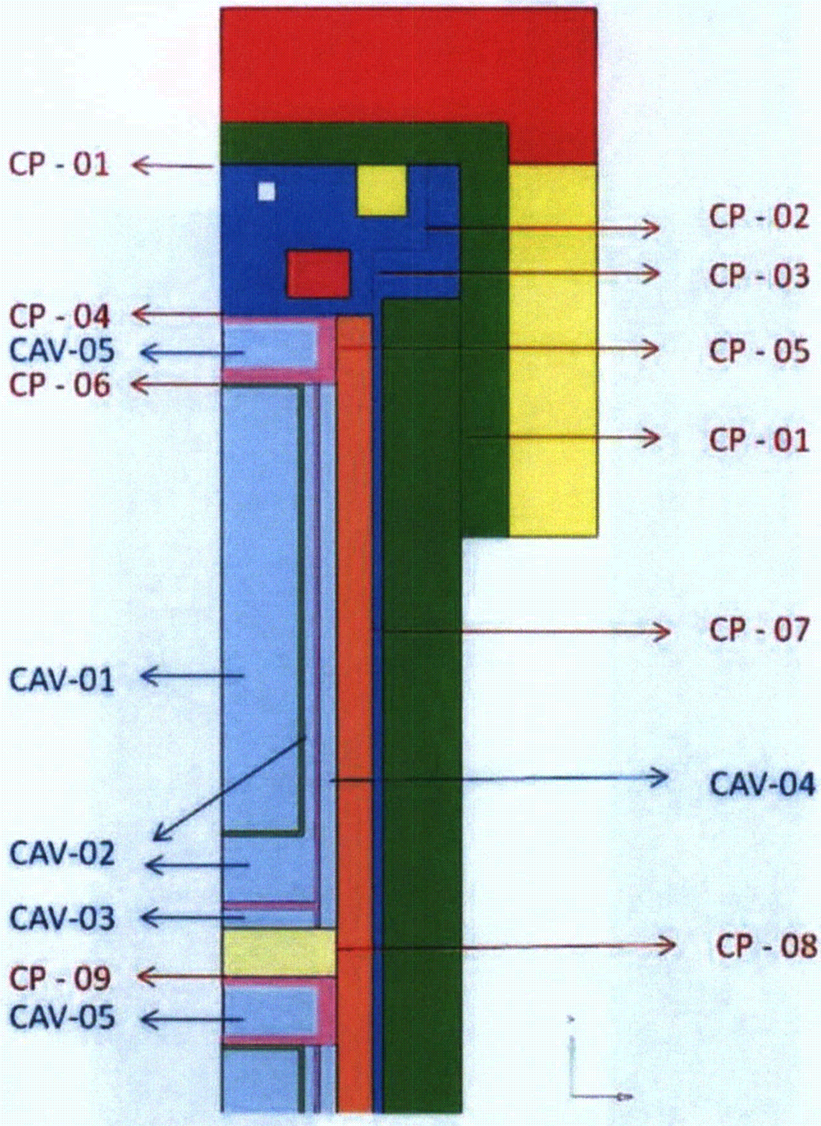


Figure 4: Modelling of contacts and air cavities

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APPENDIX 2: TEMPERATURE FIELDS

P_1 = 13 W **P_2 = 34 W**

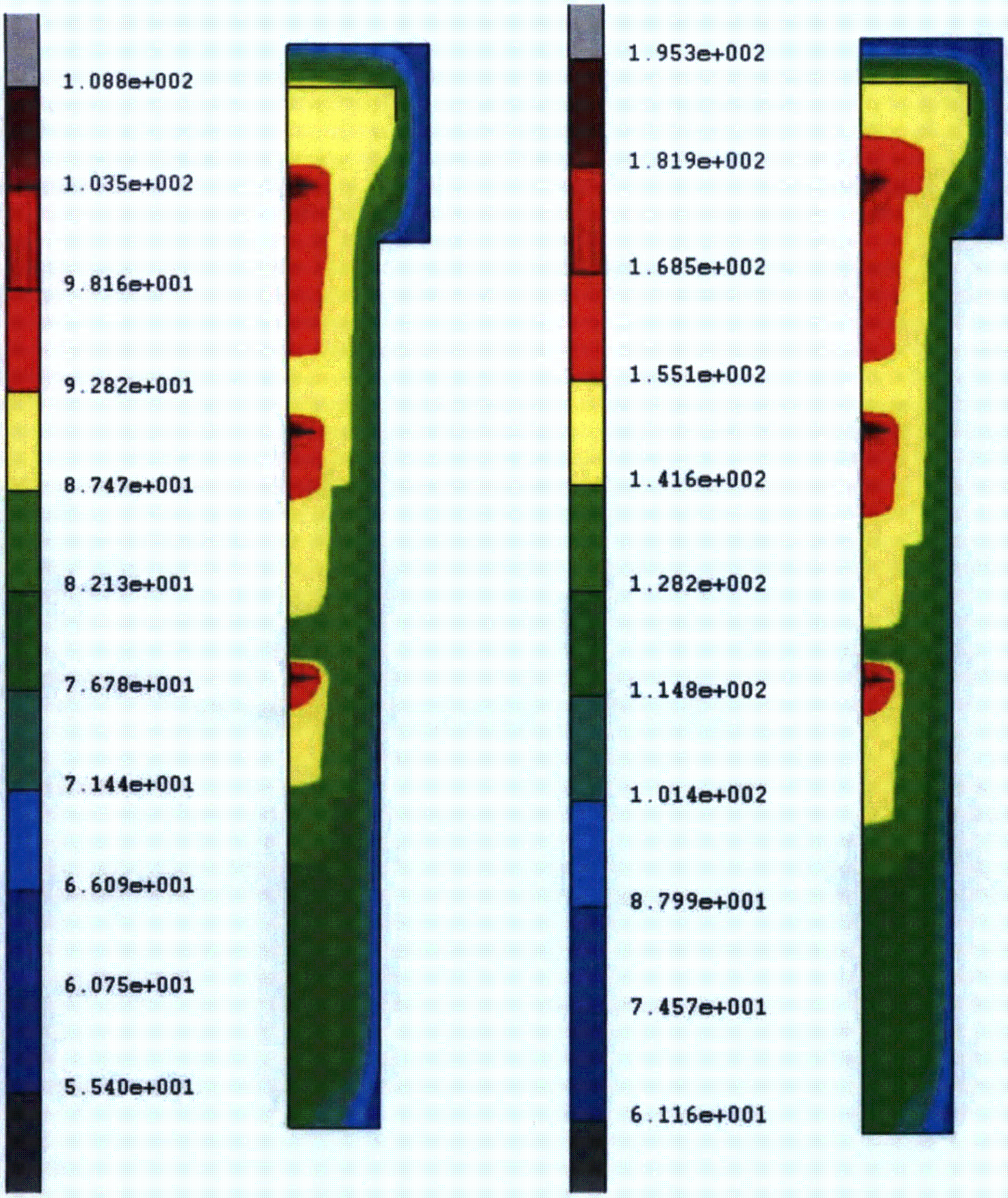


Figure 5: Temperature fields for the package and its content in NCT

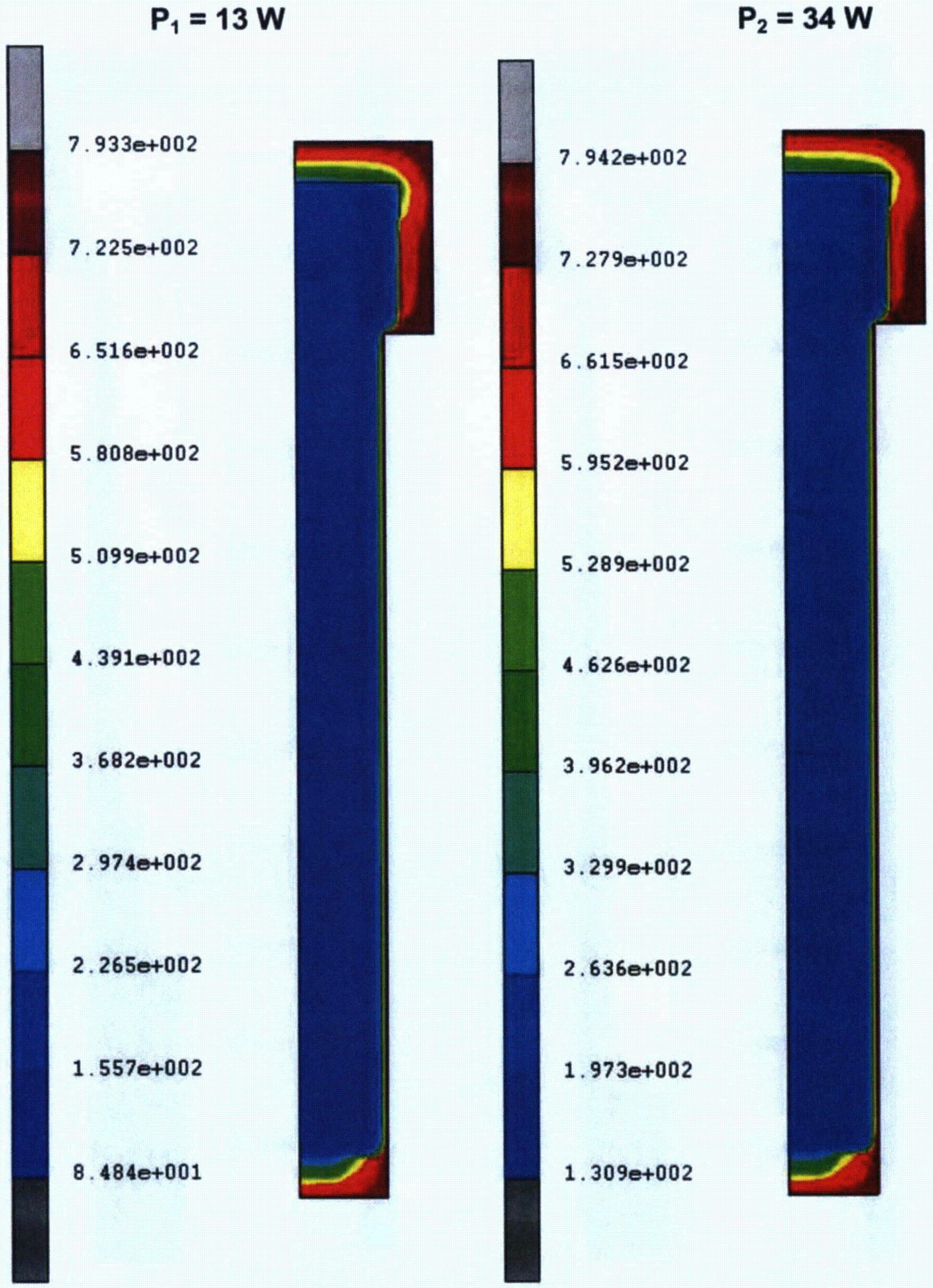


Figure 6: Temperature fields for the package and its content in ACT at t = 1800 s

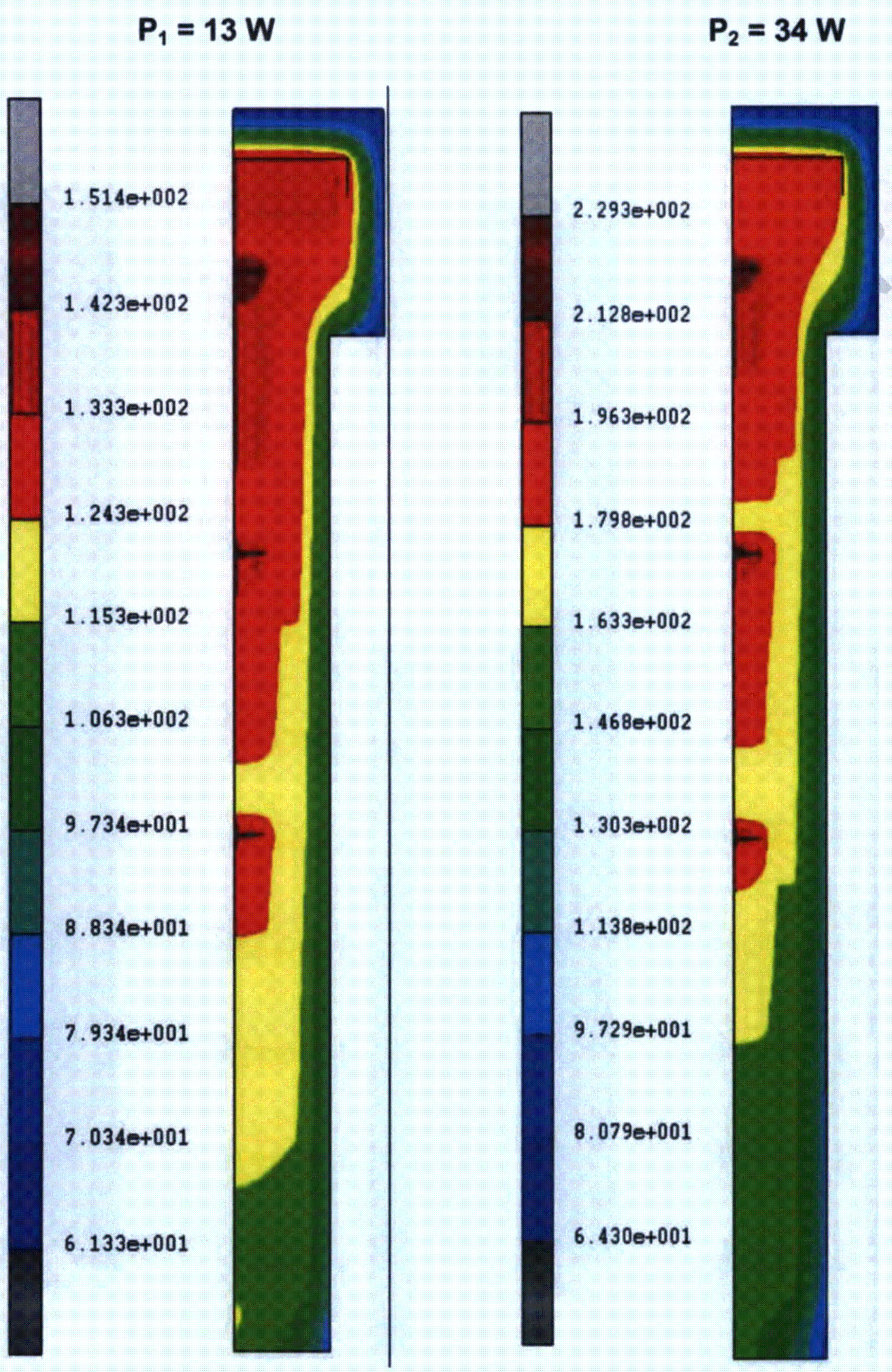


Figure 7: Temperature fields for the package and its content in ACT at t = 18000 s

CEA

Design report on the thermal tests of the TN-BGC 1 package

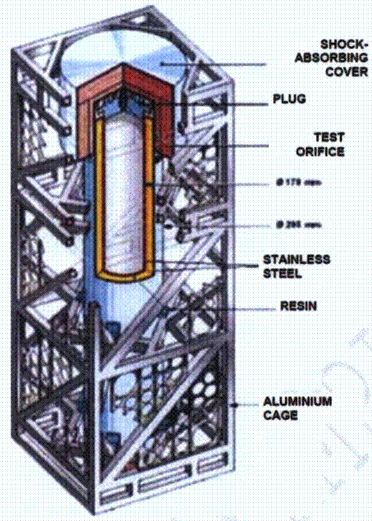
Changes table

Version	History	Pages modified	Date	Revised by	Approved by
A	First issue	All	28/09/12	TLE	ATR

Author: D. MOREL	Checked by: S. THOLANCE	Approved by: R. ARTUR

Summary

This report includes details of the results of modelling based on the finite element method for the regulatory thermal testing of the TN-BGC1 package in routine conditions of transport (RCT), normal conditions of transport (NCT) and accident conditions of transport (ACT), according to IAEA rules (ref.[1]).
The TN-BGC 1 package consists of a grid-type parallelepipedic cage in square section aluminium tubing, and a main cylindrical casing. In addition to this cage, the package casing is protected by a shock-absorbing cover on its head:



<u>Configurations studied:</u>

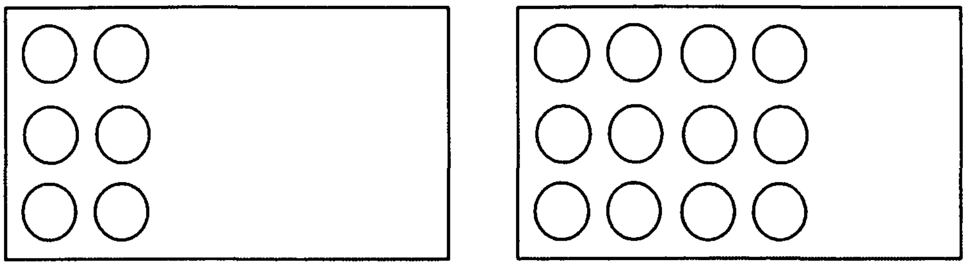
The study involves calculating the temperatures within the TN-BGC 1 package for 11 different loading configurations:

Configuration to be studied	Power per package	Loading composition	Power in the transport caisson
CA1	4x20 W	TN90 + 4 AA99	6x80 W
CA2	2x20 W	2 AA41 + 2 AA99	6x40 W
CA3	80 W	1 AA41 + 1 AA99	6x80 W
CA4	4x40 W	TN90 + 4 AA99	6 x 160 W
CA5	4x40 W	AA204 + 4 AA99	6 x 160 W
CA6	2 x 80 W	AA203 + 2 AA99	6 x 160 W
CA7	2x80 W	2 AA41 + 2 AA99	6 x 160 W
CA8	175 W	TN90+ E5	6 x 175 W
CA9	160 W	TN90 + Equivalent environment h = 1 m	6 x 160 W
CA10	4 W	TN90 + 2 AA97	12x4 W
CA11	4 W	TN90+ E7	12x4 W

EXEMPLARY N°1

Study assumptions in RCT and NCT:

For each of these configurations, studies in RCT and NCT are carried out focusing on the transport of several TN-BGC 1 packages in their transport caisson (6 or 12 packages depending on the configurations). The caisson is similar to a transport container with a layer of isolation on the internal wall.



- RCT:

In RCT, TN-BGC 1 packages are assumed to travel in a vertical position at the bottom of their transport caisson. Consequently:

- Only exchange by radiation from the TN-BGC 1 packages, between the packages and with the walls of the caisson, is taken into consideration (and conduction in the caisson floor). **Natural convection inside the caisson, around the TN-BGC packages, is not shown.**
- Kirchhoff's assumption of a grey body is adopted, with emissivity equal to the absorption coefficient for each of the surfaces inside the caisson. This emissivity is taken as 0.3 for the external walls of TN-BGC packages, and 0.2 for the internal wall of the caisson.
- Outside the caisson, natural convection in outdoor air at a temperature of 38°C and the radiation of the caisson in the external environment are taken into consideration. The emissivity of the external wall of the caisson is taken as 0.9.

- NCT:

The assumed sunlight is combined with the RCT assumptions, intervening in the form of successive 12-hour cycles of sunlight per 24 hours. The period of modelling is taken to represent a stabilised cycle of fluctuations covering at least three 24-hour periods.
Sunlight is taken into consideration in the form of the application of a regulatory flux of solar radiation on the walls of the caisson, representing:

- 800 W/m^2 x the absorption coefficient of the external surface of the top panel of the caisson x the effective surface coefficient,
- 200 W/m^2 x the at auction coefficient of the external surface of the top panel of the caisson x effective surface coefficient,

The absorption coefficient of the external surfaces of the caisson is defined as 0.3.

For these two study series, packages and their content are modelled in 3D in a sufficiently detailed manner, with representation of internal fittings and the gaseous cavities around these fittings, as well as contact areas between parts and the locations of joints.

They are represented in the caisson, with 6 or 12 packages, depending on the configurations studied. Internal powers are applied in the corresponding areas of their internal fittings.

Study assumptions in ACT:

In ACT, the TN-BGC 1 package is studied alone. It is assumed that the transport caisson was damaged during the fall tests prior to the fire phase, and this caisson is no longer considered in the definition of the thermal exchanges characterising the package during the fire and cooling phases.
This situation comprises the following sequences:

- An initial phase for the package in its caisson at 38°C, in NCT, at the end of the period of sunlight, in a stabilised cycle.
- A 30-minute fire phase, during which the package is assumed to be in the middle of the area where the fire starts, represented by:
  - Forced convection with flames at a temperature of 800°C, modelled using Colburn's correlations on the walls of the damaged package,
  - Mutual radiation between the flames at 800°C and the package casing, with an equivalent emissivity coefficient of 0.818, corresponding to a flame emissivity of 0.9 and an emissivity for the package wall of 0.9.
- A package cooling phase, with the package assumed to be horizontal. This phase uses the same thermal exchange conditions taken into consideration in NCT, except:
  - modification of the emissivity of the external surfaces of the TN-BGC package, maintained at 0.9;
  - consideration of the natural convection occurring around the package, as the caisson is assumed to be damaged.

Finally, and specific to ACT, the following two assumptions must be taken into consideration:

- wood densification, due to the compacting of absorbing elements during the fall tests,
- the reduced thickness of the resin along the package casing, from 51 mm in NCT to 48 mm in ACT.

Analysis of the results:

The purpose of this study is to determine the temperatures reached by the different package components and particularly to check compliance with criteria on:

- package joints,
- any covers used,
- gases filling the TN-BGC 1 cavity,
- gases filling the internal containers.

References

[1] Regulations for the safe transport of radioactive material - Ref. TS-R-1 - Safety Requirements - IAEA 2009

[2] Advisory material for the IAEA regulations for the safe transport of radioactive material - Ref. TS-G-1.1 - Safety guide - IAEA 2009

[3] "Emballage TN-BGCI-Plan de concept-Ensemble" (TN-BGC1 package - Design plan - Overview) 9990-65C - Transnuclear

[4] "Emballage TN-BGCI-Bouchon assemblé" (TN-BGC1 package - Assembled plug) 9990-117B - Transnuclear

[5] Chapter 2_160 EMBAL PFM DET 08000160, CEA/DEN/DPIE/SET

[6] Drawing file BGC PLA 275 - Drawings 01 - 06, ICm south

[7] Drawings AA99, AA41, Shim E1, Shim E9 and Shim E13 - study input document th 238Pu

[8] "Analyse thermique du colis TB-BGC1" (Thermal analysis of the TN-BGC1 package) - Ref. 177652C070223 - SOM

[9] Heat and mass transfer - H.D. BAEHR & W. STEFAN - Ed. SPRINGER 1999

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1. Introduction

This report includes details of the results of the thermal testing of the TN-BGC1 package in route conditions of transport (RCT), normal conditions of transport (CNT) and accident conditions of transport (CAT) based on IAEA regulations (ref.[1]). for 11 transport configurations:

Configuration to be studied	Power per package	Loading composition	Power in the transport caisson	Covers present
CA1	4x20 W	TN90 + 4 AA99	6x80 W	yes
CA2	2x20 W	2 AA41 + 2 AA99	6x40 W	yes
CA3	80 W	1 AA41 + 1 AA99	6 x 80 W	no
CA4	4x40 W	TN90 + 4 AA99	6 x 160 W	no
CA5	4x40 W	AA204 + 4 AA99	6 x 160 W	no
CA6	2x80 W	AA203 + 2 AA99	6 x 160 W	no
CA7	2x80 W	2 AA41 + 2 AA99	6 x 160 W	no
CA8	175 W	TN90+ E5	6x175 W	no
CA9	160 W	TN90 + Equivalent environment h = 1 m	6 x 160 W	no
CA10	4 W	TN90 + 2 AA97	12x4 W	Yes (potentially)
CA11	4 W	TN90+ E7	12x4 W	Yes (potentially)

The general purpose of this study is to determine the temperatures reached by the different package components and particularly to check compliance with criteria on:

- the temperature of package joints, which must remain below 250 °C.
- the temperature of polymer covers,
- the temperature of the gases used to fill the package cavity,
- the temperature of the gases used the fill the internal container.

2. Presentation of the package, its internal fittings and the caisson

2.1. Presentation of the TN-BGC 1 package

The TN-BGC 1 package consists of a grid-type parallelepipedic cage in square section aluminium tubing, and a main cylindrical casing. The cage will not be represented in this study, regardless of the model. The casing of the TN-BGC1 package consists of:

- a casing housing one of the internal fittings described in section 4.1.1. in its cavity This casing consists of a shell and a base, surrounded by a resin-based mixture ensuring neutron-absorbing and thermal protection, and with a wood shock absorber under the base,
- a closure system for the casing cavity, mainly consisting of a plug, a bronze clamp ring and a bayonet ring,
- a shock-absorbing cover protecting the package in case it falls on the plug-side.

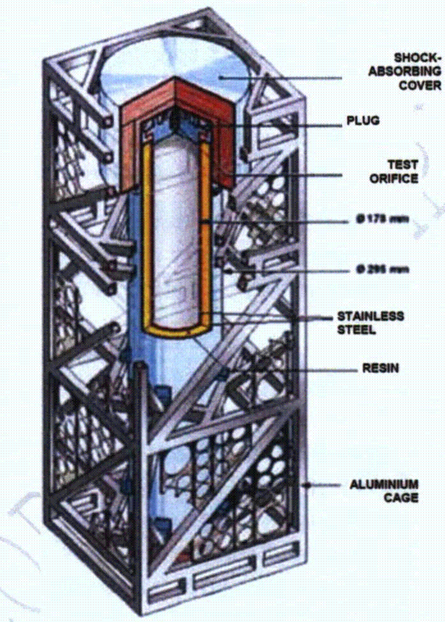


Figure 1: section view of the TN-BGC 1 transport package

2.1.1. Main dimensions

The main dimensions are as follows (see plan ref. [1]):

- overall dimensions of the cage:
  - length: 600 mm,
  - width: 600 mm,
  - height: 1821 mm,

- overall dimensions of the casing with its cover:
  - diameter of main part of the casing: 295 mm,
  - diameter at the level of the cover: 466 mm,
  - height: 1808 mm,
- useful dimensions of the cavity:
  - length: 1475 mm,
  - diameter: 178 mm,

2.1.2. Description of the package casing

The casing cavity is formed from a stainless steel shell with a useful inner diameter of 178 mm, a minimum thickness of 6 mm, and an 8-mm thick base, also in stainless steel, assembled with a circular weld.

A second stainless steel shell with an inner diameter of 295 mm and a thickness of 1.5 mm combines with the first shell to delimit a 51-mm radial space full of charged resin that acts to absorb neutrons and provides active heat insulation.

A 25-mm distribution plate in special steel is attached to the base to provide extra strength in the event of a fall on the package base.

A caisson consisting of a poplar disc in the central section and a balsa ring on the outer part, acts as a shock absorber for the lower part of the casing in case of a fall.

In the upper part, a stainless steel machined flange is welded to the two shells to receive the closure system described below and provide a suitable bearing surface at its seals. This flange includes 4 x 50° impressions to allow for the introduction and axial locking of the bayonet ring in the plug clamp system.

2.1.3. Description of the closing system

The cavity of the casing is closed using a system consisting of 3 main parts: a plug, a clamp ring and a bayonet ring.
The plug is machined from a 92-mm thick stainless steel disc. It has a 20-mm thick shoulder at its edge, supported by the casing flange. A handling knob is fitted on the upper side for gripping by an automatic tool. A polyethylene ring placed inside the plug completes the package's axial neutron shielding.

In the centre of the plug, a hole fitted with a quick-connect coupling allows the package to be depressurised before dispatch and re-pressurised to atmospheric pressure upon arrival before unloading. The plug on the casing and the orifice fitted with the quick-connect coupling are sealed by two o-rings fitted in two concentric trapezoidal grooves machined in the shoulder of the plug, and by a cap on the quick-connect coupling with two o-rings, respectively.

This plug is held in place by a bronze clamp ring screwed into the stainless steel bayonet ring.

The bayonet ring has a height of 26 mm and a width of 12 mm. On the inside, this bayonet ring includes an M 230 x 4 thread over the full height, and, on the outside, four male extrusions of 40° that are 15 mm thick and 6 mm wide that fit in the corresponding marks on the flange on the package casing.

2.1.4. Description of the upper shock-absorbing cover

A shock-absorbing cover is placed over the top of the casing and the closing system. This cover consists of two caissons in stainless steel sheeting, generally 1,5 mm thick, except for the flat intermediate sheet, where thickness increases to 4 mm to ensure the correct transmission and distribution of forces.

The caisson closest to the casing is filled with a resin identical to that surrounding the casing, to 25 mm in the upper part and 23.5 mm in the lateral part, to protect the closure system from heat.

The second caisson contains wood: poplar, with fibres laid out radially in the lateral part (thickness: 55 mm), and balsa in the upper part, with fibres laid out longitudinally on the external ring and transversely in the centre (thickness: 70 mm).

2.2. Presentation of the CB9 transport caisson

Studies in RCT and NCT are carried out focusing on the transport of several TN-BGC 1 packages in their transport caisson (6 or 12 packages depending on the loading configurations). Caisson CB9 is similar to an ISO 20' type transport container with a layer of isolation on the internal wall.

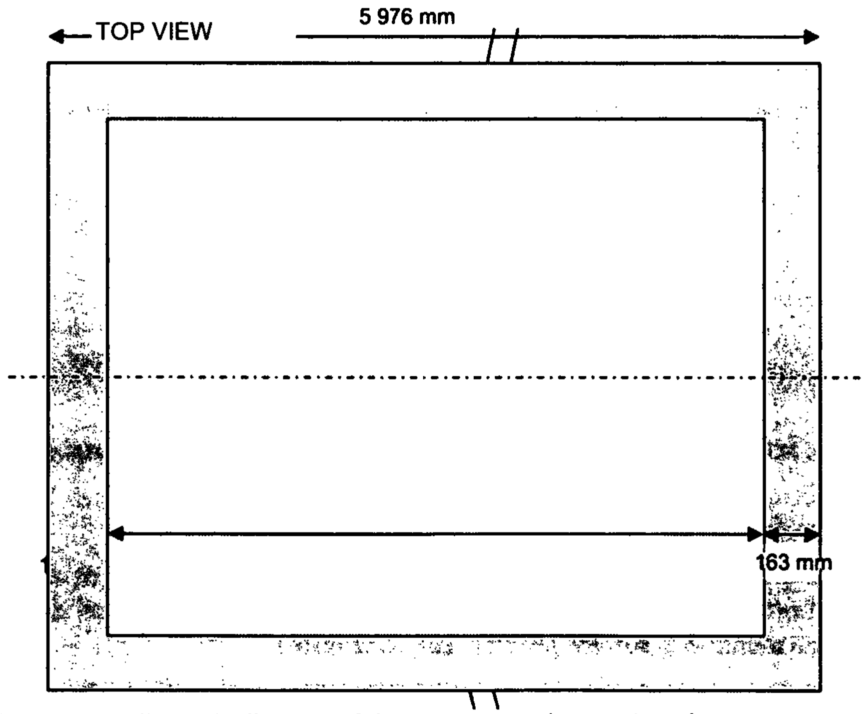


Figure 2: diagram of the transport caisson - top view

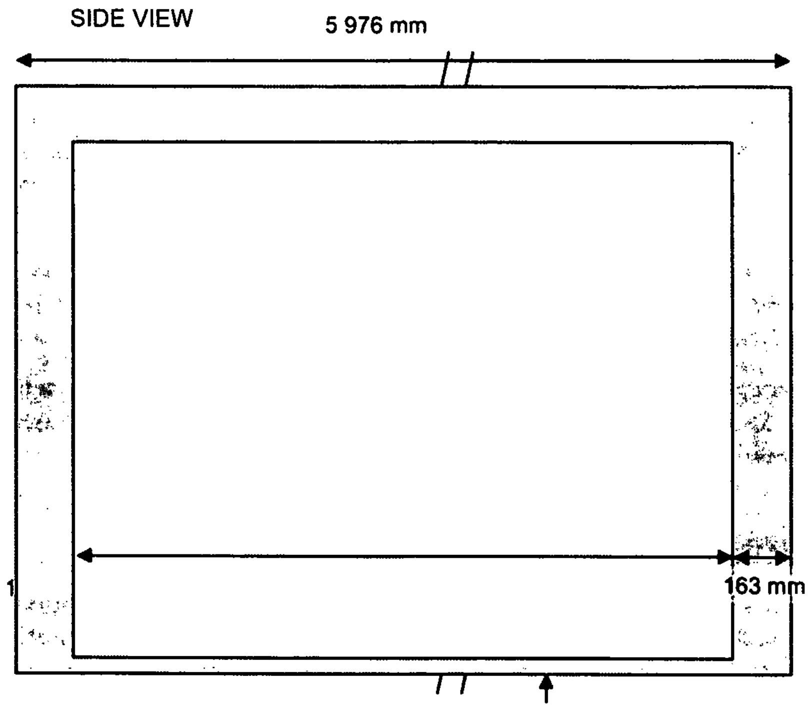


Figure 3: diagram of the transport caisson - side view

Its lateral external wall and its top panel consist of corrugated sheeting with the following envelope measurements for corrugations:

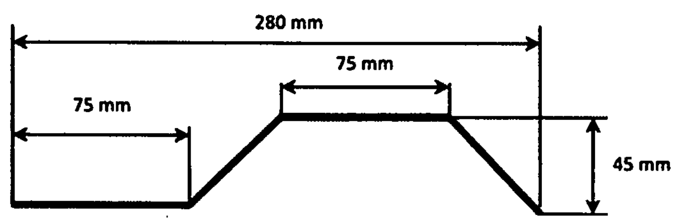


Figure 4: diagram of the profile of the panelling of transport caisson walls

Using corrugated sheeting causes a vane effect by increasing the exchange surfaces between the caisson and the outside environment. The increase in this exchange surface is determined by this geometric profile, which multiplies the general surface area by a rate of:

$$\frac{1}{280}\times\left(2\times 75+2\times\sqrt{\left(\frac{280-(2\times 75)}{2}\right)^2+45^2}\right)=1,10.$$

3. Modelling principles applied

3.1. Thermal characteristics of the materials used

All of the thermal characteristics of the materials used are taken from ref. |8]. For:

- the stainless steel used for the different shells, heads and panelling,
- the resin in the casing and the upper package cover,
- the carbon steel of the anti-punch plate,
- the air contained in the different cavities.

Variation in parameters λ, ρ and Cp based on temperature is taken into consideration.

Conversions were applied due to the formal nature of the allocation of design software properties: only conductivity λ and specific heat Cp are entered as a function of temperature, with Cp corrected to ensure that the product ρ x Cp at a given temperature is equal to the product ρo x $Cp_{corrected}$ where ρ_0 is the reference density independent to temperature variation, taken as 20°C, and $Cp_{corrected}$ the value used in the calculation.

3.1.1. Stainless steel

Stainless steel components are (non-exhaustive list):

- the outer and inner shell of the package and plug casing,
- the shell and head of the AA99 housings, frame P1, and AA41, AA203, AA204 and TN90 sheaths.

	Temperature (°C)	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)	ε	solar α
304L stainless steel	20	14.7	454.3	7930	0.3 before fire□0.9 during and after fire	0.3 before fire□0.9 after fire
	100	15.8	492.0			
	200	17.2	525.2			
	300	18.6	541.7			
	400	20.0	553.1			
	600	22.2	566.7			
	800	24.1	587.8			

Table 1: thermal properties of INOX 304L steel

In the specific case of the emissivity of AA99 containers, the value adopted is 0.7. When the configuration includes covers (CA1, CA2, CA10 and CA11), the emissivity of the walls of the AA99 container is fixed at 0.5 to represent a worst-case scenario (see appendix 1).

3.1.2. Aluminium

Aluminium components are: shims and spacers E1, E2, E5, E7, E8, E10, E11 and E12.

Aluminium	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)	ε
	134	950	2790	0,5

Table 2: thermal properties of aluminium

3.1.3. Bronze

Bronze components are: plug locknuts.

Bronze	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
	50,2	370	8800

Table 3: thermal properties of bronze

3.1.4. Neutron-absorbing resin

A 24 mm layer of resin is present under the head shock-absorbing cover, and a layer of 51 mm (48 mm in ACT) is placed between the inner shell and the outer shell of the package.

	Temperature (°C)	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
Air/neutron-absorbing resin	20	0.66	1173	1600
	50	0.66	1257	
	100	0.66	1397	
	150	0.66	1536	
	200	0.47	1533	
	250	0.28	1515	
	300	0.09*	1415	
	400	0.09*	764	
	500	0.09*	615	
	600	0.09*	543	

Area of neutron-absorbing resin damaged after the fire

Table 4: thermal properties of the neutron-absorbing resin

3.1.5. HDPE

HDPE components are: the polyethylene disc in the TN-BGC 1 plug. To simplify, the joints of the AA41, AA203 and AA204 containers are also assumed to be in HDPE.

HDPE	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
	0.46	1881	950

Table 5: thermal properties of HDPE

3.1.6. Steel 39 CD 4

The anti-punch plate in the lower part of the package is 39 CD 4 steel.

	Temperature (°C)	λ (W/m·K)	ρ (kg/m³)	Cp (J/Kg·K)	ρ (kg/m³)	Cp corrected to ρ cst (J/kg/K)
Steel 39 CD 4	20	32.8	7850	473.2	7850	473.2
	100	32.5	7820	484.9		483.0
	200	32.2	7785	523.6		519.0
	300	31.9	7750	554.7		547.6
	400	31.6	7780	594.7		589.4
	500	31.3	7690	658.6		645.2
	600	31.0	7663	739.5		721.9

Table 6: thermal properties of 39 CD 4 steel

3.1.7. Copper-aluminium

The plug clamp ring is in copper-aluminium.

	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
Copper-aluminium	37.6	376	7600

Table 7: thermal properties of copper-aluminium

3.1.8. Protection wood

Wood components are fitted in the head shock-absorbing cover and in the base of the package casing.

Wood	Temperature (°C)	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
Balsa wood	20	0.051	1100	150
	270	0.086		
ACT balsa	20	0.128		375
	270	0.215		
Poplar	20	0.13	450	460
	270	0.22		
Poplar ACT	20	0.325		1150
	270	0.55		

Table 8: thermal properties of the protection wood

3.1.9. Filling gas/Air

The thermal properties of air will be assumed for all the cavities of the package, AA99 and AA41.

	Operating temperature (°C)	Conductivity (W/m·K)	Density ρ (kg/m³)	Specific heat Cp (KJ/Kg·K)	Density ρ (kg/m³)	Cp corrected to ρ is (KJ/kg/K)
Air	20	0.0257	1.188	1.007	1.188	1.007
	50	0.0280	1.067	1.007		0.904
	100	0.0314	0.933	1.012		0.795
	150	0.0348	0.822	1.017		0.704
	200	0.0379	0.736	1.026		0.636
	300	0.0441	0.607	1.046		0.534
	400	0.0500	0.517	1.069		0.465
	500	0.0556	0.450	1.093		0.414
	600	0.0611	0.399	1.116		0.375
	700	0.0665	0.358	1.137		0.343
	800 and beyond	0.0715	0.324	1.155		0.315

Table 9: thermal properties of the air

3.1.10. Transport caisson wall steel (RCT and NCT)

Panelling on the internal and external walls is assumed to maintain a constant thickness (2.0 mm for the lateral walls and the top panel, 35 mm for the floor). Unlike other parts of the model, panelling is shown as shell components.

	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)	ε	α
Steel E24	54.1	450	7 850	0.2 internal 0.9 external	0.3

Table 10: thermal properties of caisson panelling steel

3.1.11. Thickness of the material insulating the transport caisson

The conductivity of the caisson walls is modulated depending on whether they are the lateral walls and the top panel or the rear door:

	λ (W/m·K)	Cp (J/Kg·K)	ρ (kg/m³)
Insulation	lateral walls and top panel: 0.13 Rear doors: 0.22	1 600	250

Table 11: thermal properties of the caisson insulation

3.2. Consideration of clearance between parts

Each package configuration is shown with its own content. The different air gaps between the components of the content transported and the package casing are shown, i.e.

- In the radial direction:
  - Between the housing containing the substance (AA99 in most of the cases studied) and the transport sheath (AA41, AA203 ; AA204, TN90, etc.),
  - Between the transport sheath and its shim system (shims E1, E2, etc.),
  - Between the shim system and the wall of the internal cavity of the TN-BGC 1,
  - Between the external wall of the TN-BGC 1 and the internal wall of the upper protective cover,
- In the axial direction, between the different parts of the closing system, in order to correctly represent the thermal bridges in the plug area.

Conduction in air gaps and radiation on opposing faces are taken into consideration.

With studies in RCT and NCT, in which several packages are represented in their transport caissons, the base of the package, consisting of an integrated shock absorbing cover, is not in direct contact with the floor, as a space of 5 mm exists between the contact zone of the cage and the package base. This space is represented as an air gap between the package base and the floor.

4. General study methodology

4.1. Common study assumptions

4.1.1. All studies

For the three study series, packages and their content are modelled in 3D in a sufficiently detailed manner, with representation of internal fittings and the gaseous cavities around these fittings, as well as contact areas between parts and the locations of joints.

Internal powers are applied in the corresponding areas of their internal fittings, and radioactive substances are not shown in 3D.

It is assumed that all components located in the TN-BGC1 package (Shims, AA41, AA99, substance) are displaced towards the head of the package. This assumption gives the worst-case scenario as it promotes the thermal path between the sources of heat and the joints of containers and the package.

The following configurations are studied:

Configuration to be studied	Power per package	Loading composition	Power in the transport caisson	Covers present
CA1	4x20 W	TN90 + 4 AA99	6x80 W	yes
CA2	2x20 W	2 AA41 + 2 AA99	6x40 W	yes
CA3	80 W	1 AA41 + 1 AA99	6x80 W	no
CA4	4x40 W	TN90 + 4 AA99	6 x 160 W	no
CA5	4x40 W	AA204 + 4 AA99	6 x 160 W	no
CA6	2x80 W	AA203 + 2 AA99	6 x 160 W	no
CA7	2x80 W	2 AA41 + 2 AA99	6 x 160 W	no
CA8	175 W	TN90 + E5	6x175 W	no
CA9	160 W	TN90 + Equivalent environment h = 1 m	6 x 160 W	no
CA10	4 W	TN90 + 2 AA97	12x4 W	Yes (potentially)
CA11	4 W	TN90+ E7	12x4 W	Yes (potentially)

Table 12: configurations studied

For configurations CA1 to CA9, the substance loaded in the package has a specific power of 20 W/kg, for a density of 3,500 kg/m^3. The quantity of substance varies between configurations, which implies that the height over which the surface flow representing the embedded power is applied must be adapted, waste is not therefore shown in 3D.

For configurations CA10 and CA11, specific power is 0.1 W/kg. It is applied over the entire height of the housings in question in the internal fittings.

4.1.2. In RCT and NCT

For each of these configurations, studies in RCT and NCT are carried out focusing on the transport of several TN-BGC 1 packages in their transport caisson. Depending on the powers transported, two loading plans are considered, with 6 packages (CA1 to CA9) or 12 packages (CA10 and CA11).

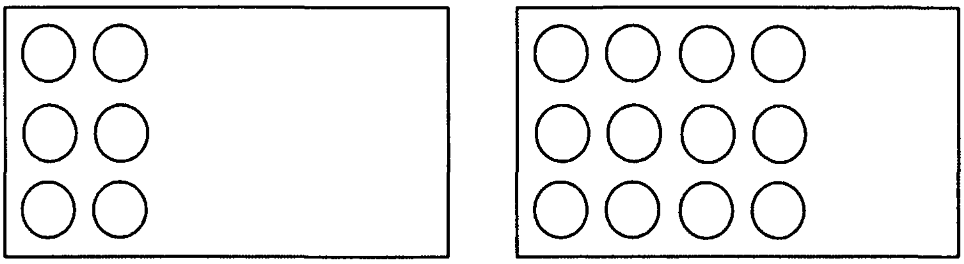


Figure 5: transport configuration with 6 or 12 packages

4.2. Study in RCT

4.2.1. Thermal exchanges between the TN-BGC1 package and its transport caisson

Thermal exchange assumptions in RCT are as follows:

- The natural convection of the air inside the caisson is not taken into consideration, neither for the TN-BGC 1 walls, nor the internal walls of the caisson.
- Only mutual radiation between the visible surfaces of the TN-BGC 1 and the internal wall of the caisson is taken into consideration, and is based on the assumption of a Kirchhoff grey body (emissivity = absorption coefficient). Wall emissivities are $\varepsilon_{TN\text{-}BGC1} = 0.3$ and $\varepsilon_{INTERNALCAISSON} = 0.2$.

The inner wall of the floor is integrated in this exchange based on radiation inside the cavity.

4.2.2. Thermal exchanges outside of the caisson

The heat flow is evacuated by natural convection and radiation to the external environment, assumed to be infinite, and at a temperature of 38°C. The external wall of the floor is insulated.

- Natural convection is represented by a flux in the form $\Phi = h \cdot \Delta T$ where:
  - $\Delta T = T_{wall} - T_{ext}$
  - $h = k \cdot (\Delta T)^n$ with the following values for k and n:
    - $h = 1.28\ (\Delta T)^{0.33}$ for flat vertical surfaces,
    - $h = 1.51\ (\Delta T)^{0.33}$ for flat upwards-facing horizontal surfaces,
- radiation to the external environment is represented by a flux in the form $\Phi = \varepsilon \cdot \sigma \cdot (T_{ref}^4 - T^4)$, where :
- ε is the emissivity of the wall ($\varepsilon = 0.9$ for the external walls of the caisson)
- σ is the Stephan Boltzmann constant, $\sigma = 5.6715 \cdot 10^{8}$ S.I.

On a conservative bases, the effective exchange surface coefficient calculated in section 2.2 is not taken into consideration in these exchanges with the external environment.

4.3. Study in NCT

The assumed sunlight is combined with the RCT assumptions, intervening in the form of successive 12-hour cycles of sunlight per 24 hours. The period of modelling is taken to represent a stabilised cycle of fluctuations covering at least seven 24-hour periods, to stabilise the near-permanent state.

Sunlight is taken into consideration in the form of the application of a regulatory flux of solar radiation on the walls of the caisson, representing:

- 800 W/m^2 x the absorption coefficient of the external surface of the top panel of the caisson x the effective exchange surface coefficient,
- 200 W/m^2 x the at auction coefficient of the external surface of the top panel of the caisson x effective exchange surface coefficient,

The absorption coefficient of the external surfaces of the caisson is defined as 0.3. The effective exchange surface coefficient was determined in a previous stage as 1.10. On a conservative basis, this coefficient is only taken into consideration when defining the solar flux applied, and is not used as input for radiation and natural convection with the external environment.

	Solar flux	Flux applied in NCT with the Package vertical
Flat horizontal surfaces	F_s = 800 W/m^2	F_{app} = 240 W/m^2
Vertical surfaces	F_s = 200 W/m^2	F_{app} = 60 W/m^2
Other surfaces	F_s = 400 W/m^2	-

Table 13: solar flux values applied in the model

4.4. Study in ACT

In ACT, the TN-BGC 1 package is studied alone. It is assumed that the transport caisson was damaged during the fall tests prior to the fire phase, and this caisson is no longer considered in the definition of the thermal exchanges characterising the package during the fire and cooling phases.

This situation comprises the following sequences:

- An initial phase for the package in its caisson at 38°C, in NCT, at the end of the period of sunlight, in a stabilised cycle.
- A 30-minute fire phase, during which the package is assumed to be in the middle of the area where the fire starts, represented by:
  - Forced convection with flames at a temperature of 800°C, modelled using Colburn's correlations on the walls of the damaged package,
  - Mutual radiation between the flames at 800°C and the package casing, with an equivalent emissivity coefficient of 0.818, corresponding to a flame emissivity of 0.9 and an emissivity for the package wall of 0.9.
- A package cooling phase, with the package assumed to be horizontal. This phase uses the same thermal exchange conditions taken into consideration in NCT, except:
  - modification of the emissivity of the external surfaces of the TN-BGC package, maintained at 0.9;
  - consideration of the natural convection occurring around the package, as the caisson is assumed to be damaged.

Finally, and specific to ACT, the following two assumptions must be taken into consideration:

- wood densification, due to the compacting of absorbing elements during the fall tests,
- the reduced thickness of the resin along the package casing, from 51 mm in NCT to 48 mm in ACT.

4.4.1. Fire phase

The package is subjected to flames over a period of 30 minutes (1800 s). The flames have an emissivity $\varepsilon_f = 0.9$ (see IAEA ref. [1]) and a temperature $T_f = 800°C$, and surround the entire surface of the package for which an absorption coefficient $\alpha_{Pack} = \varepsilon_{Pack} = 0.9$ is adopted (corresponding to a black metal surface). The net flux exchanged is therefore calculated as:

$$\Phi_{f->Emb}(T) = \varepsilon_{éq}.\sigma.\left(T_f^{\ 4} - T_{Emb}^{\ 4}\right) avec\ \varepsilon_{éq} = \frac{\varepsilon_f.\varepsilon_{Emb}}{1-\left((1-\varepsilon_f)(1-\varepsilon_{Emb})\right)}$$

where $\varepsilon_{eq} = 0.818$.

In accordance with IAEA requirements (ref. [1]), all package surfaces are also subjected to forced convection with flames at 800°C. According to ref. [8], the horizontal position is the worst-case scenario, therefore the package is assumed to be placed horizontally within the area where the fire starts.

The exchange coefficients used are based on the usual correlations, and are as follows:

- $h = 1.28\ (\Delta T)^{0.33}$ for flat vertical surfaces,
- $h = 1.22\ (\Delta T)^{0.33}$ for cylindrical surfaces.

4.4.2. Cooling phase:

The cooling phase occurs in ambient air at 38°C with cyclical sunlight for 12 hours every 24 hours, in the same manner as in NCT. The period of modelling is taken to represent a stabilised cycle of fluctuations covering at least five 24-hour periods, to stabilise the near-permanent state.

The package surface retains its emissivity and absorption coefficient inherited from the fire phase: $\alpha_{Pack} = \varepsilon_{Pack} = 0.9$.

	Solar flux	Flux applied in ACT during the cooling phase with the Package horizontal
Flat horizontal surfaces	$F_s = 800\ W/m^2$	-
Vertical surfaces	$F_s = 200\ W/m^2$	$F_{app} = 180\ W/m^2$
Other surfaces	$F_s = 400\ W/m^2$	$F_{app} = 360\ W/m^2$

Table 14: solar flux values applied in the model

The heat flow is evacuated by natural convection and radiation to the external environment, assumed to be infinite, and at a temperature of 38°C. The exchange coefficients used are based on the usual correlations, and are as follows:

- $h = 1.28\ (\Delta T)^{0.33}$ for flat vertical surfaces,
- $h = 1.22\ (\Delta T)^{0.33}$ for cylindrical surfaces.

5. Results

They are presented in form of a sheet. A few images illustrate the temperature spans obtained.

5.1. Model CA1

5.1.1. Configuration

CA1	Internal fittings	Shims	Packaging housing	Power contained
TNBGC1	TN90 + Frame P1	E1 + E2	AA99	20 W / housing

CA1	No. of TN-BGC transported	Power / package	Total power transported
CB9 caisson	6	80 W	480 W

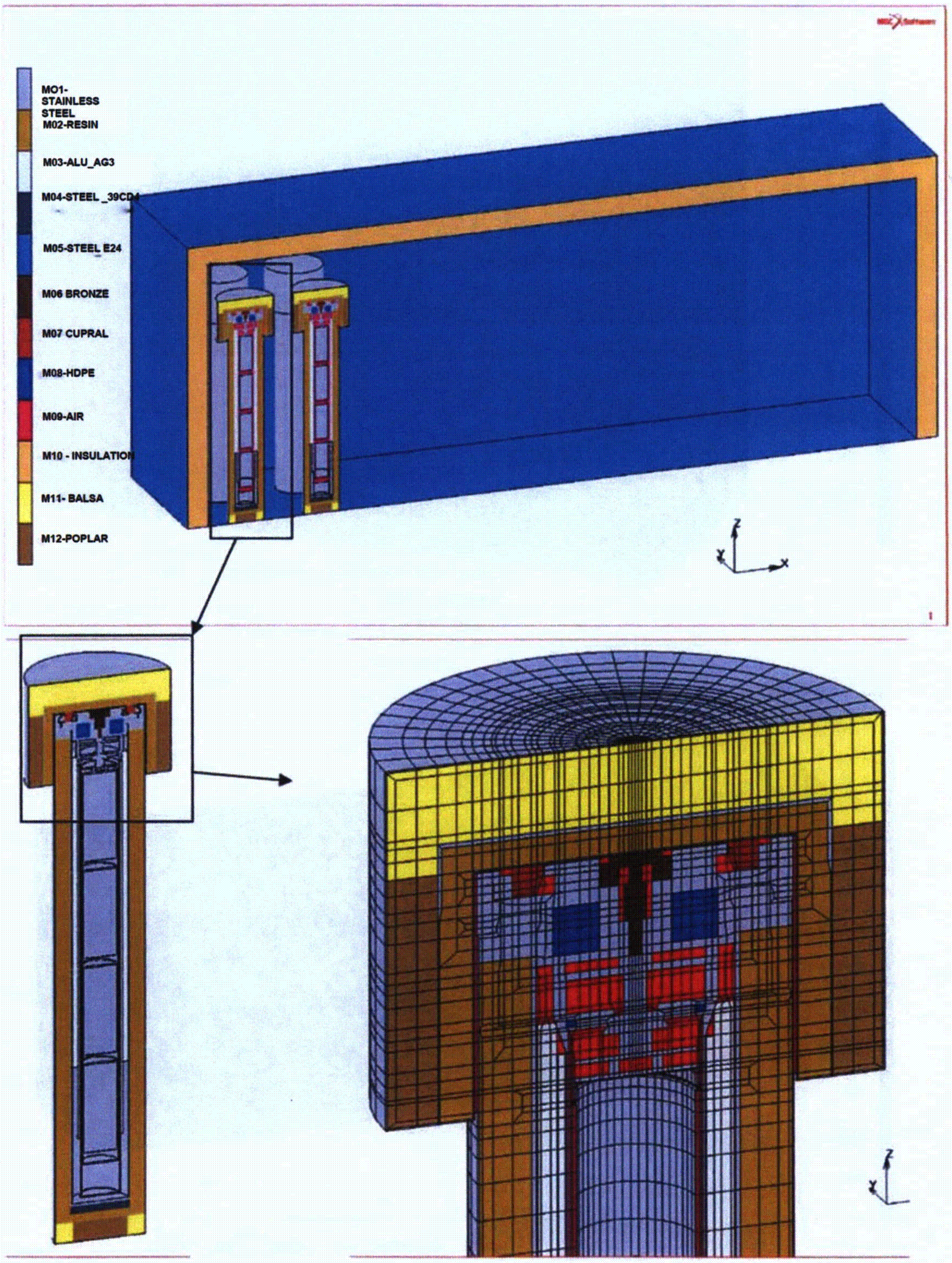
5.1.2. Summary of results

CA1					
TN-BGC 1 - CA1		NCT	RCT	ACT	
		Temp (°C)	Temp (°C)	Temp (°C)	Time [s]
TN-BGC1	External surfaces	75.3	69.9	799.1	1 800
	Outer shell	75.8	70.4	781.3	1800
	Resin	80.6	75.4	781.0	1 800
	Inner shell	80.6	75.5	171.7	4 200
	Clamp ring	76.0	70.6	122.5	12 600
	Joints	83.0	78.1	136.6	8 100
	Head internal surface	78.2	72.8	125.6	11 400
	Package cavity gas	113.2	108.1	171.7	4 200
	Base	64.9	59.5	164.7	4 800
Internal fittings	Frame	121.8	116.9	176.8	8 700
	TN90 shell	91.8	86.8	151.6	7 800
	Spacers	85.5	80.5	146.7	7 800
	Head	89.0	83.8	140.5	8 700
	TN90 cavity gas	121.7	116.8	176.7	8 700
	TN90 joint	83.8	78.6	137.0	8 100
	Content	N.C.	N.C.	N.C.	N.C.
	Covers	121.9	116.9	176.8	8 400

CA1		
CB9 caisson	NCT	RCT
	Temp (°C)	Temp (°C)
Lateral walls	56.7	49.4
Door	52.4	40.7
Base	59.0	52.0
Top panel	61.1	45.9
Floor	55.6	49.4
Package	75.3	69.9

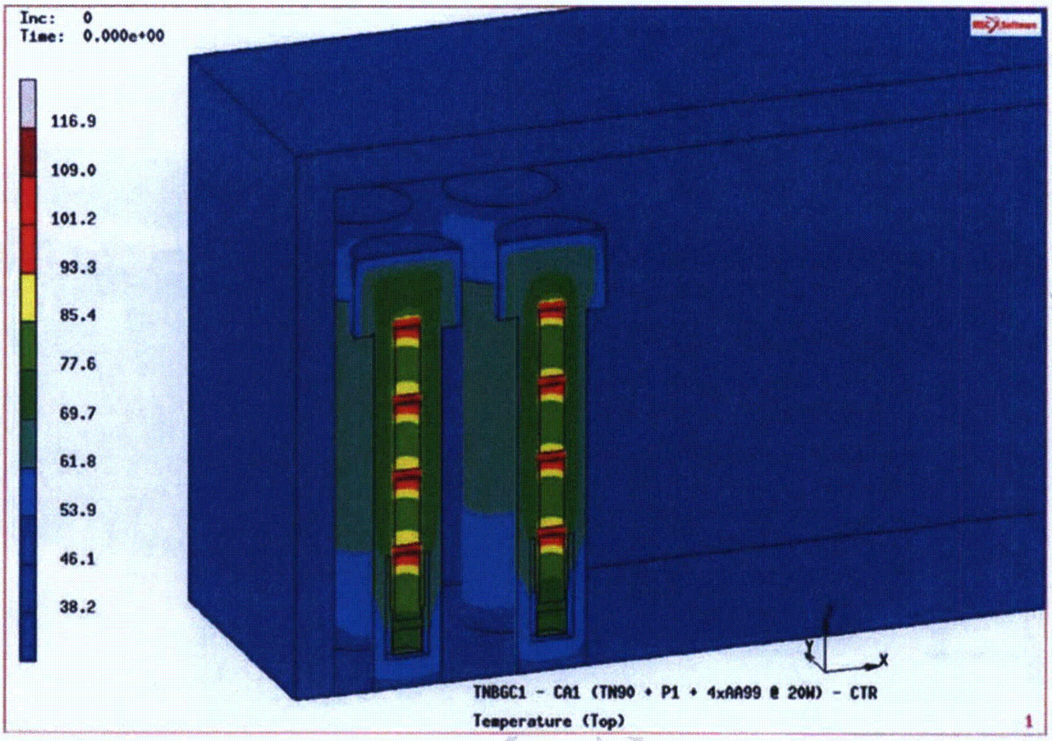
5.2. Figures CA1

5.2.1. Modelling

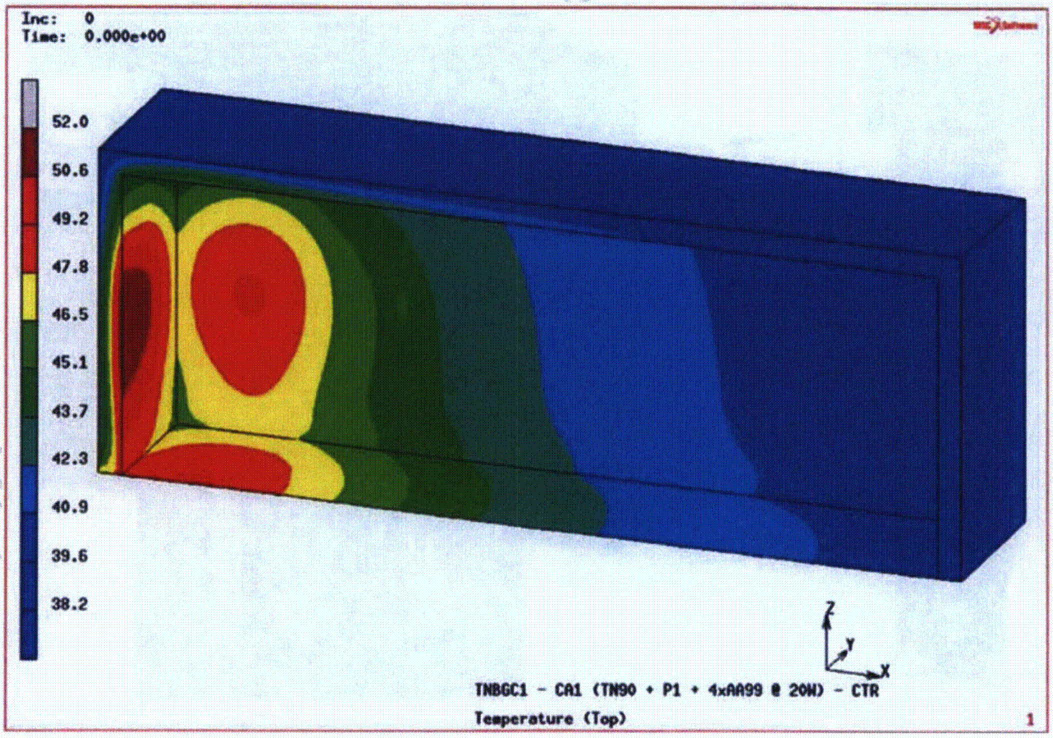


5.2.2. Results

- in RCT:

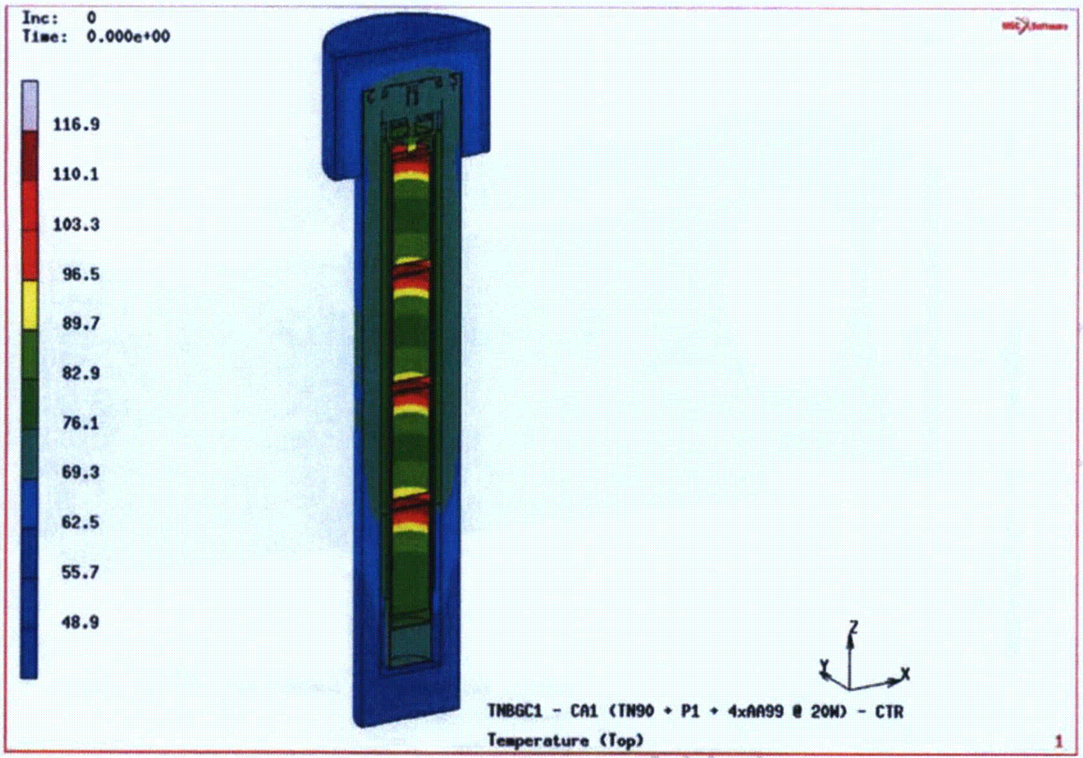


Assembly



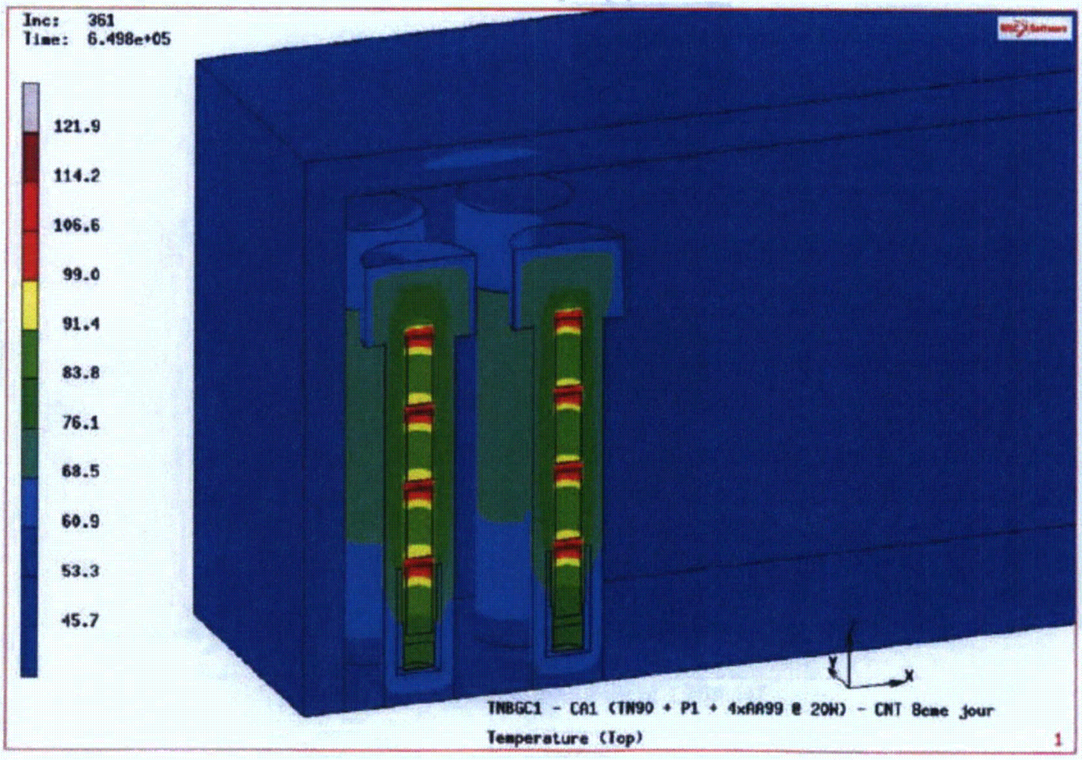
Caisson alone

DO NOT COPY - EXEMPLARY N° 1

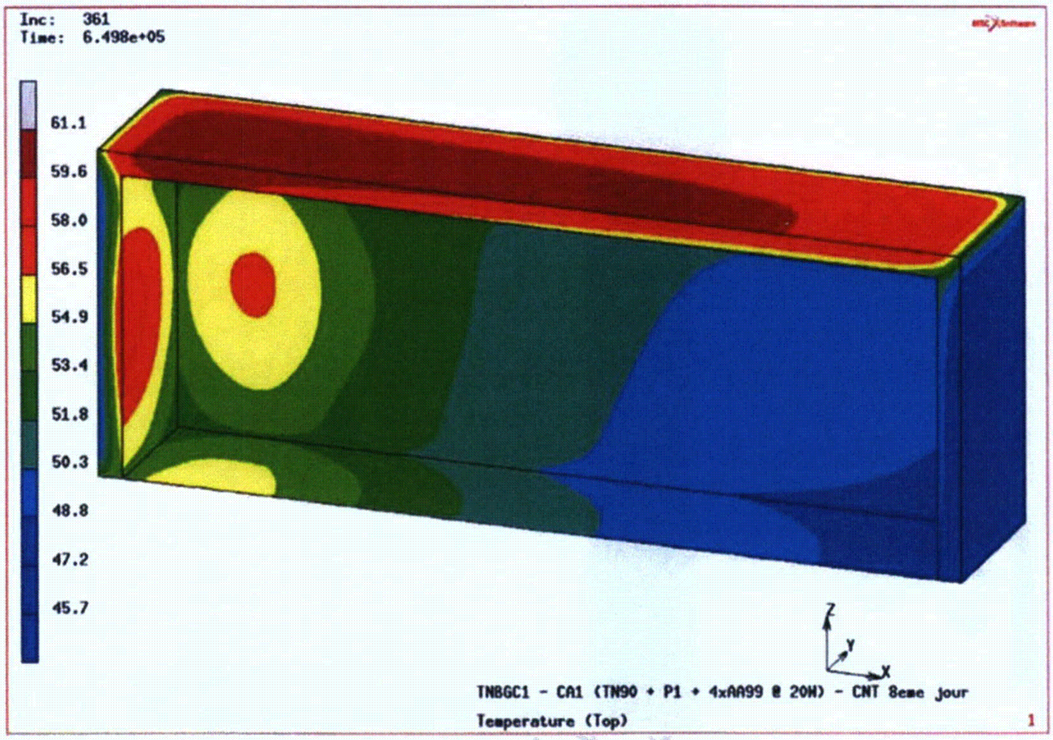


Hottest TN-BGC 1 (centre, rear)

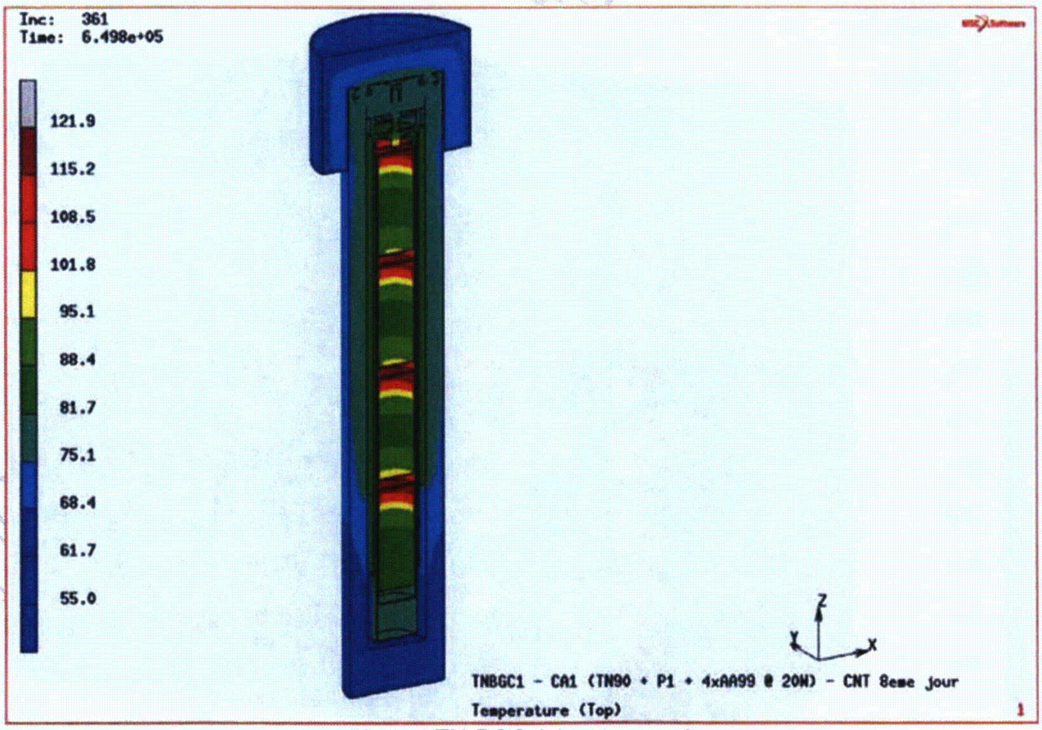
- In NCT:



Assembly

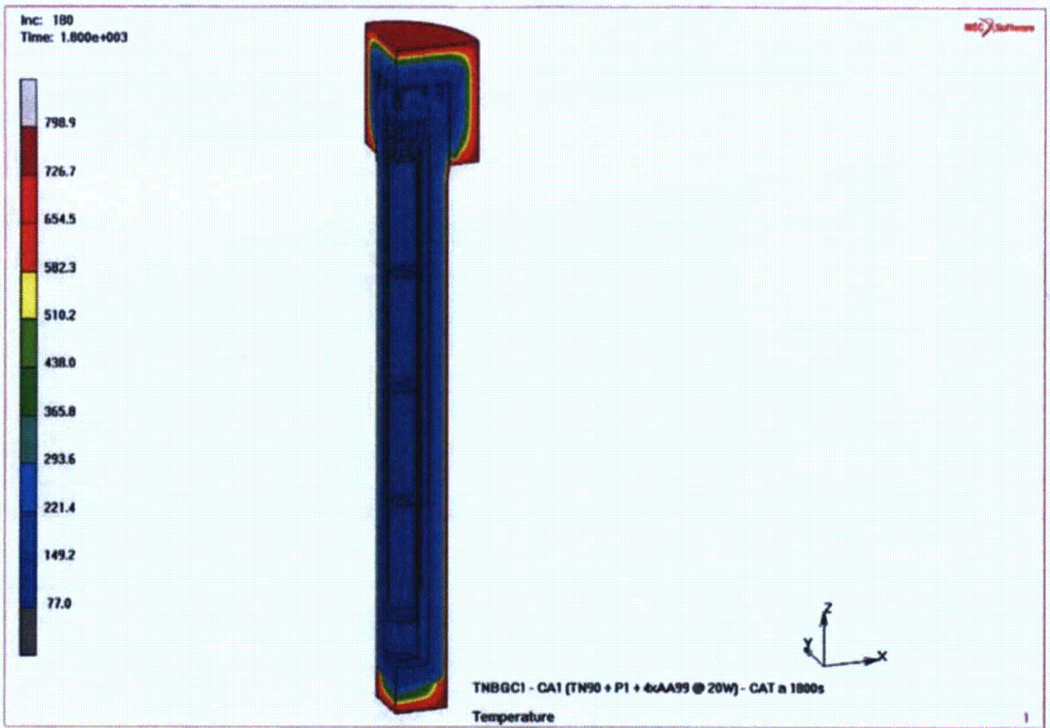


Caisson alone

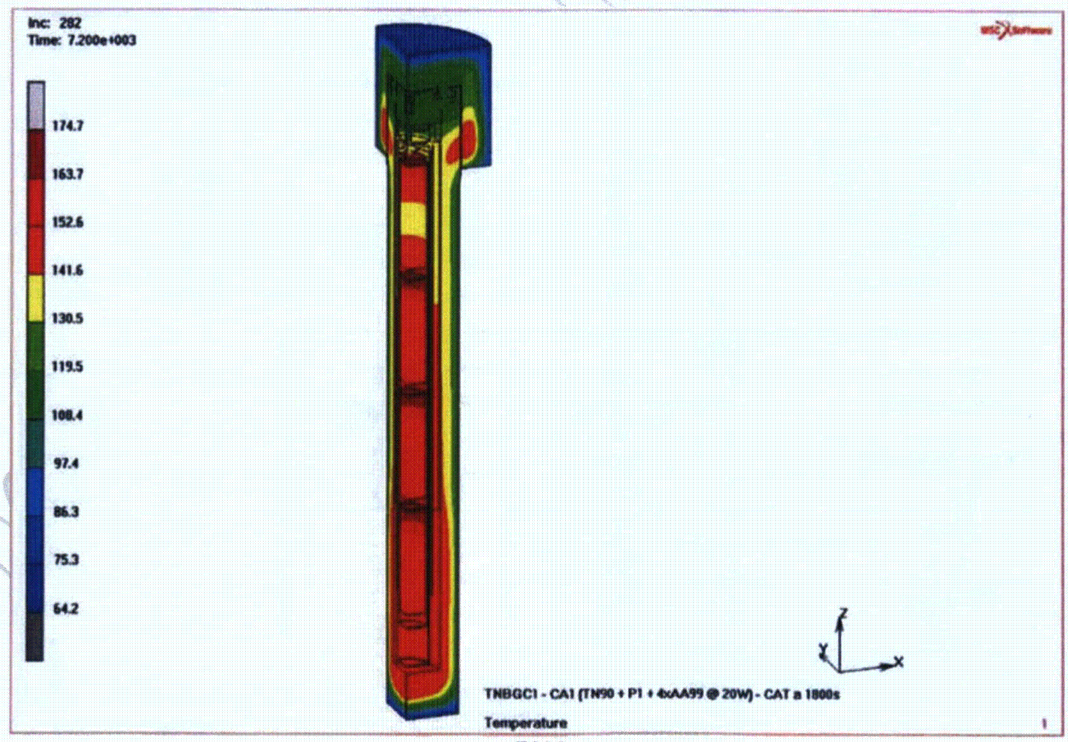


Hottest TN-BGC 1 (centre, rear)

- In ACT:



at 1800 s



at 7200 s

5.3. Model CA2

5.3.1. Configuration

CA2	Internal fittings	Shims	Packaging housing	Power contained
TNBGC1	AA41	E1 + E12	AA99	20 W / housing

CA2	No. of TN-BGC transported	Power / package	Total power transported
CB9 caisson	6	40 W	240 W

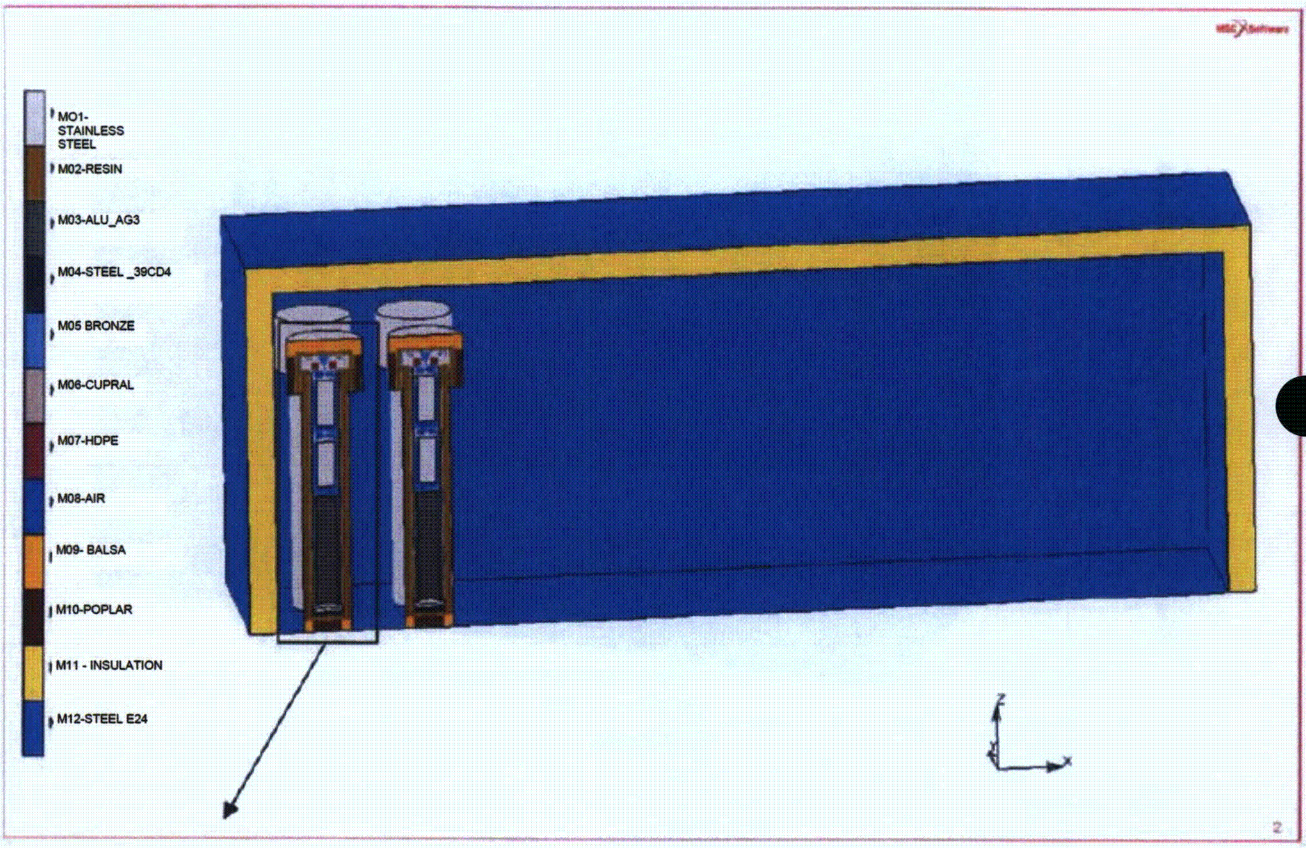
5.3.2. Summary of results

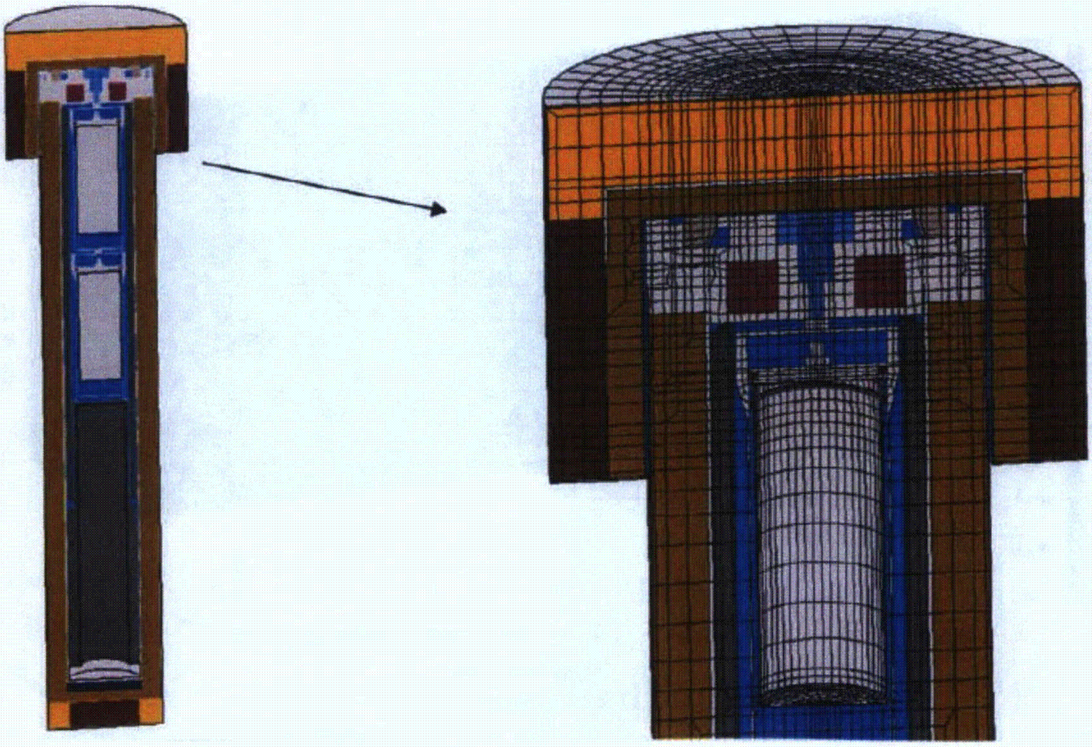
CA2					
TN-BGC 1 - CA2		NCT	RCT	ACT	
		Temp (°C)	Temp (°C)	Temp (°C)	Time [s]
TN-BGC1	External surfaces	60.9	54.6	799.1	1 800
	Outer shell	63.3	57.4	780.3	1 800
	Resin	64.7	58.8	780.0	1800
	Inner shell	64.7	58.8	152.1	5 100
	Clamp ring	63.6	57.6	150.5	6 900
	Joints	63.9	58.1	161.7	9 000
	Head internal surface	67.0	61.2	151.1	6 300
	Package cavity gas	80.0	74.3	152.2	5 700
	Base	52.9	47.2	152.1	5 100
Internal fittings	Spacer E12	57.8	52.2	135.7	6 600
	AA41 shell	83.3	77.6	159.1	8 700
	Spacer E1	66.0	60.2	147.9	6 600
	Head	89.9	84.2	164.1	9 000
	AA41 cavity gas	99.2	93.5	171.0	8 700
	AA41 joint	87.1	81.4	161.7	9 000
	Content	N.C.	N.C.	N.C.	N.C.
	Covers	99.2	93.5	171.0	8 700

CA2		
CB9 caisson	NCT	RCT
	Temp (°C)	Temp (°C)
Lateral walls	53.1	43.2
Door	51.4	39.3
Base	54.2	44.6
Top panel	56.6	42.0
Floor	49.3	42.7
Package	60.9	54.6

5.4. Figures CA2

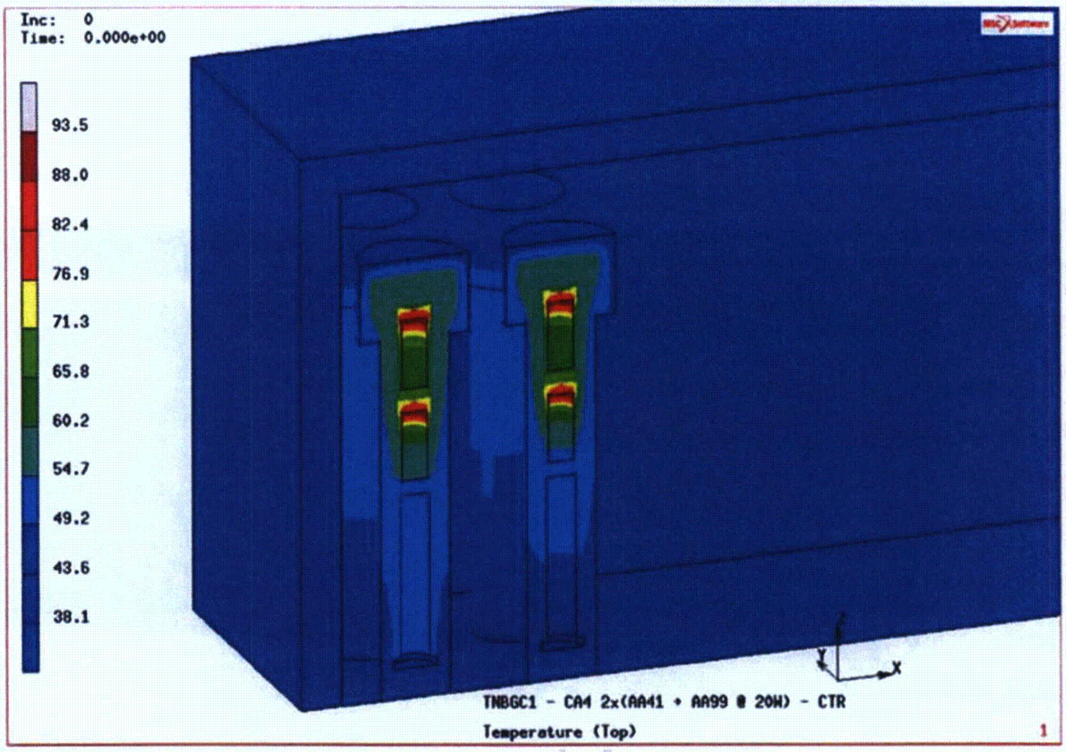
5.4.1. Modelling



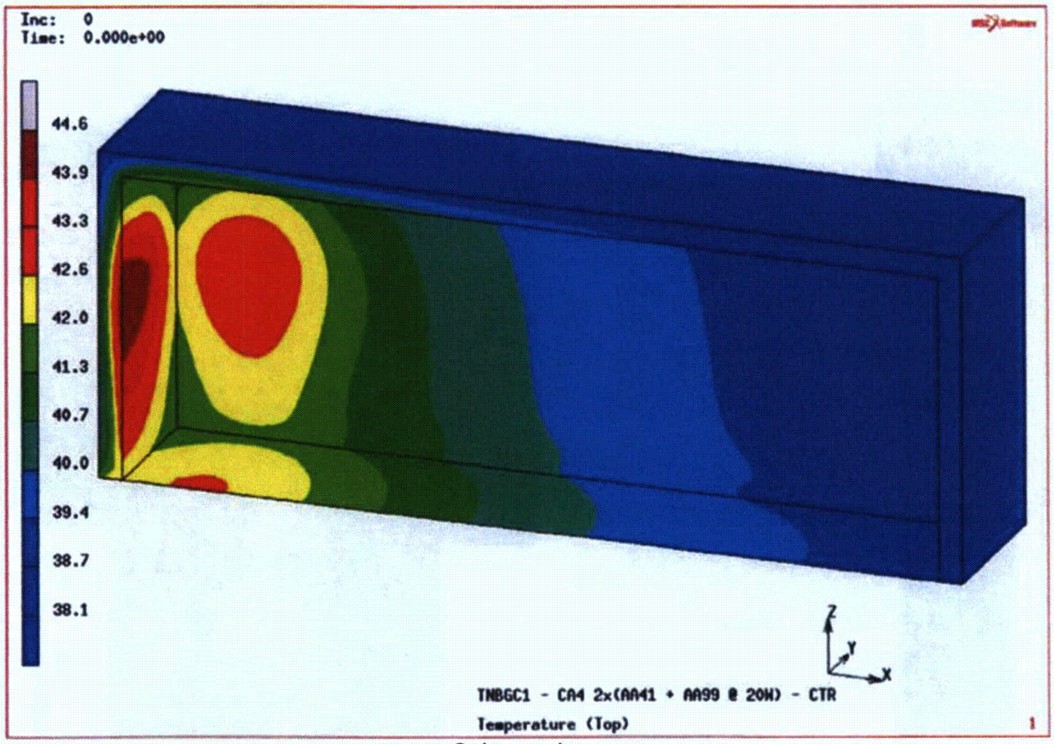


5.4.2. Results

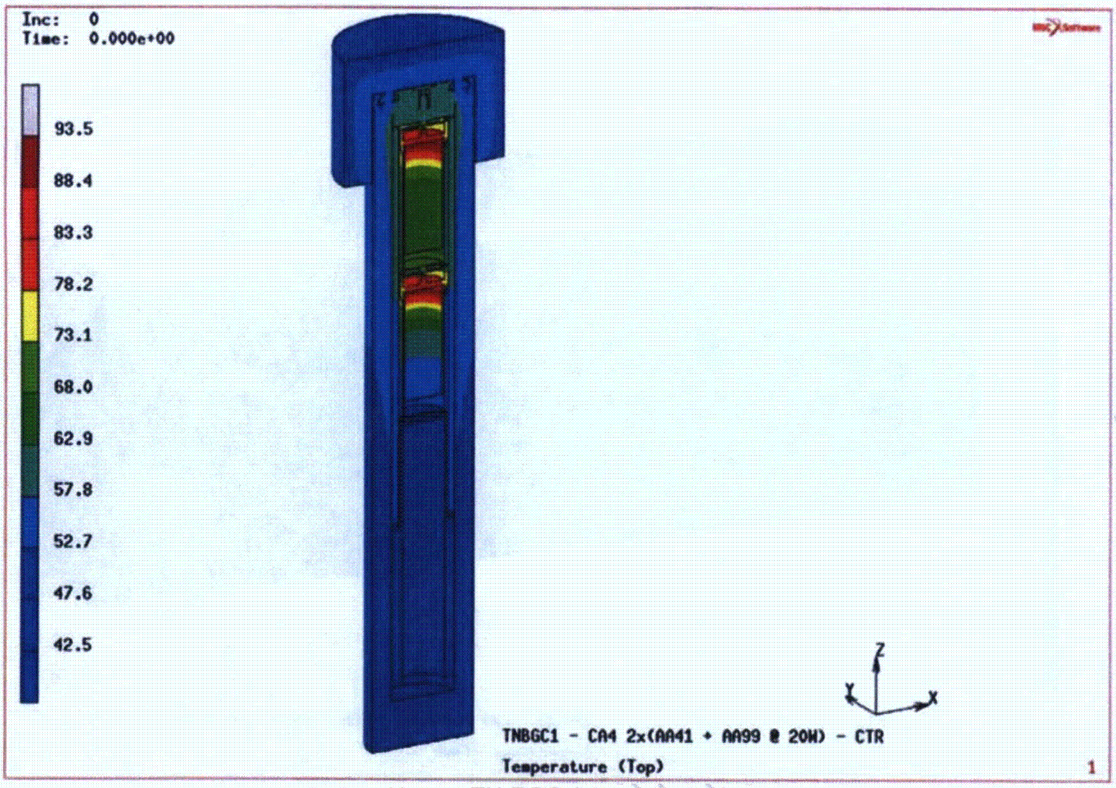
- in RCT:



Assembly

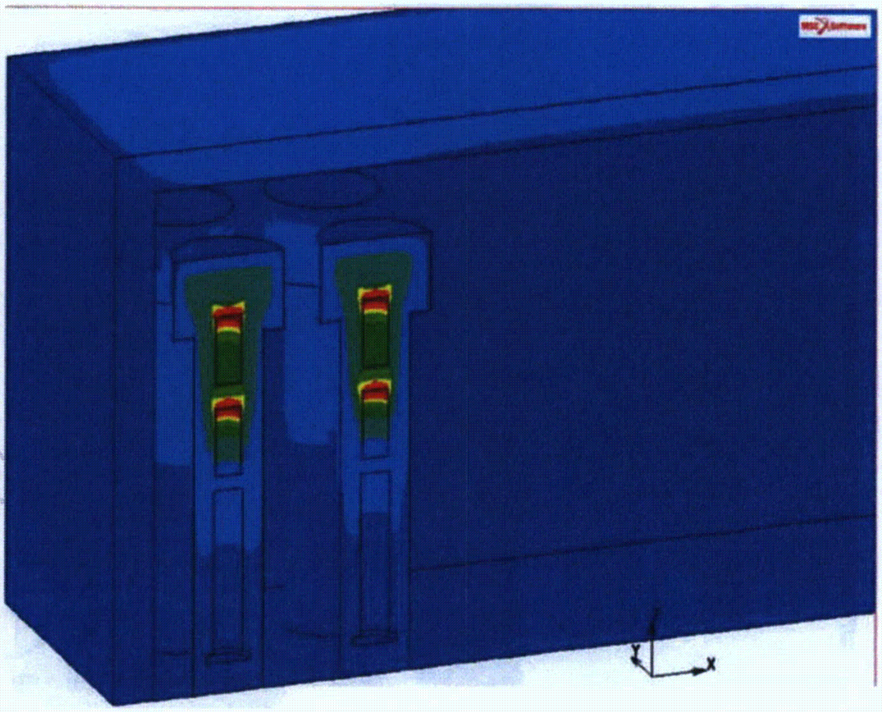


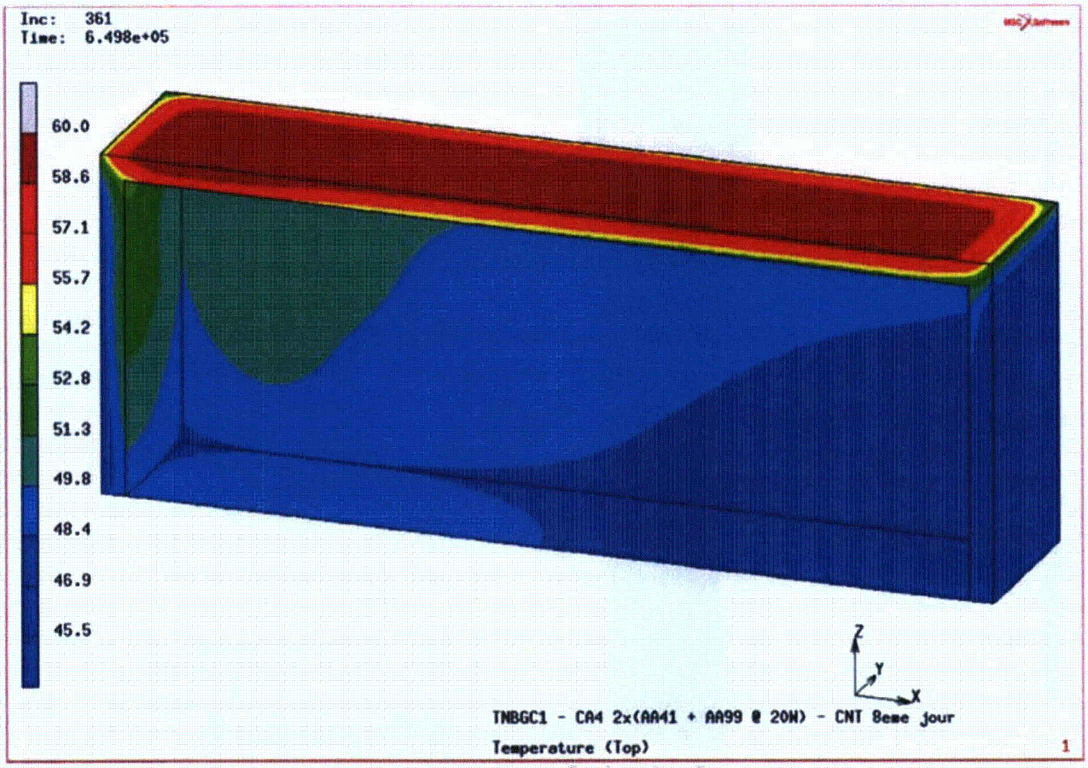
Caisson alone



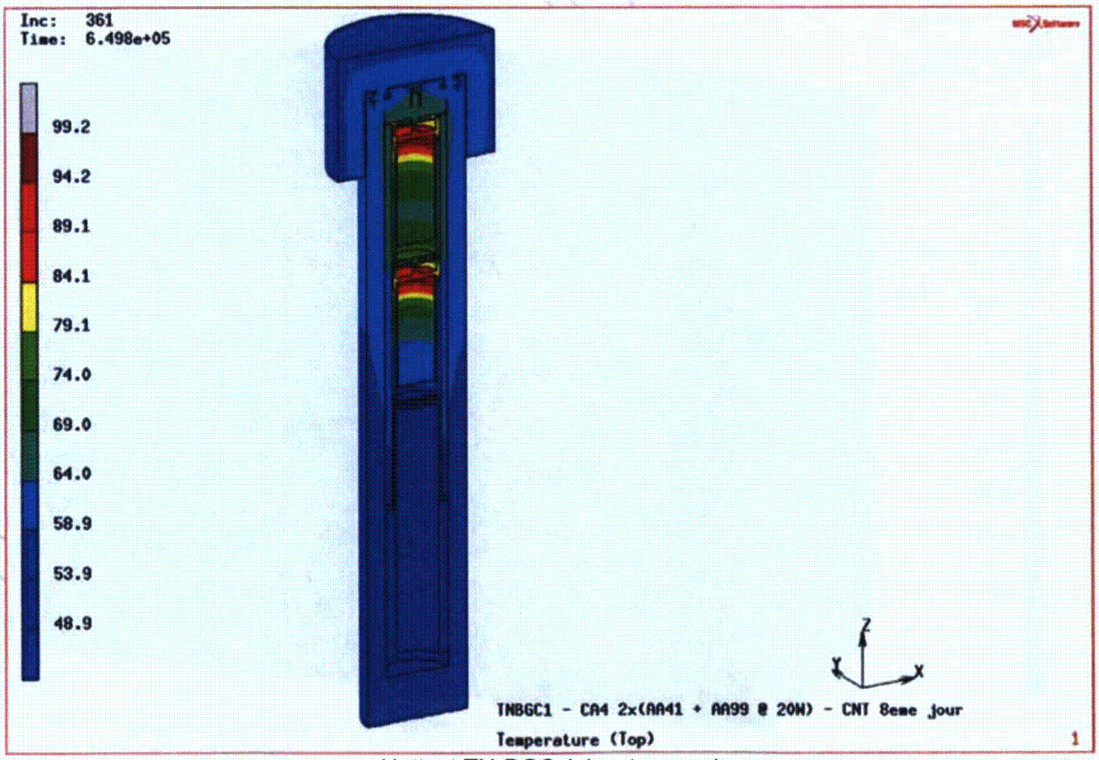
Hottest TN-BGC 1 (centre, rear)

- In NCT:


Assembly

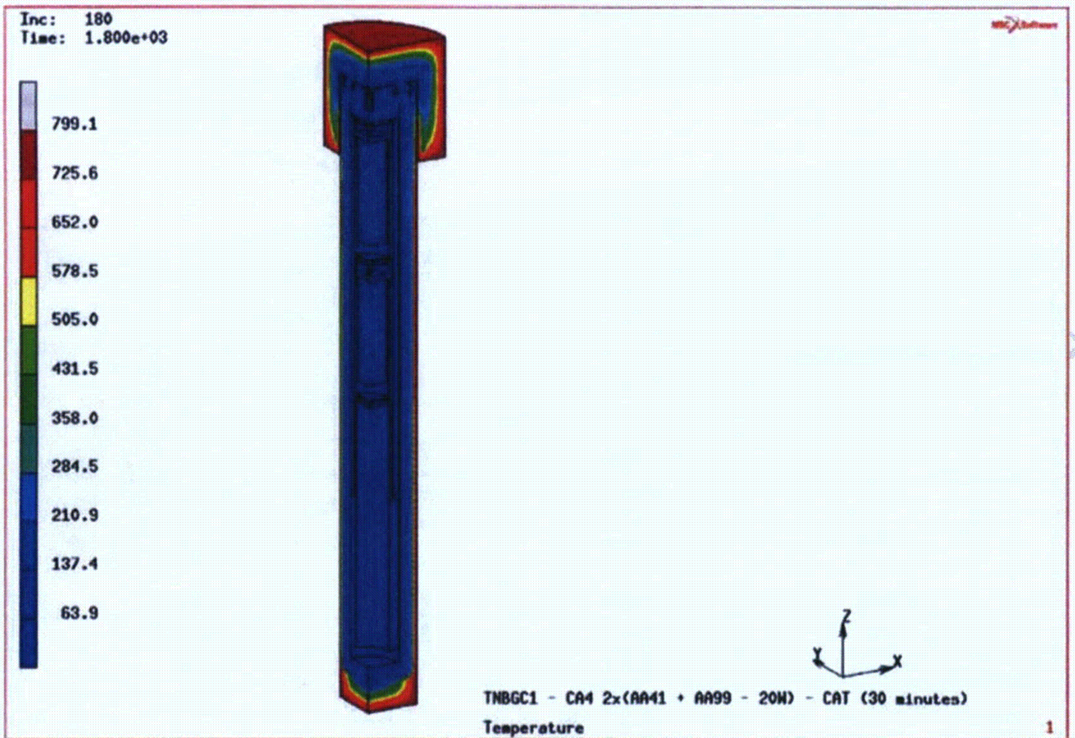


Caisson alone

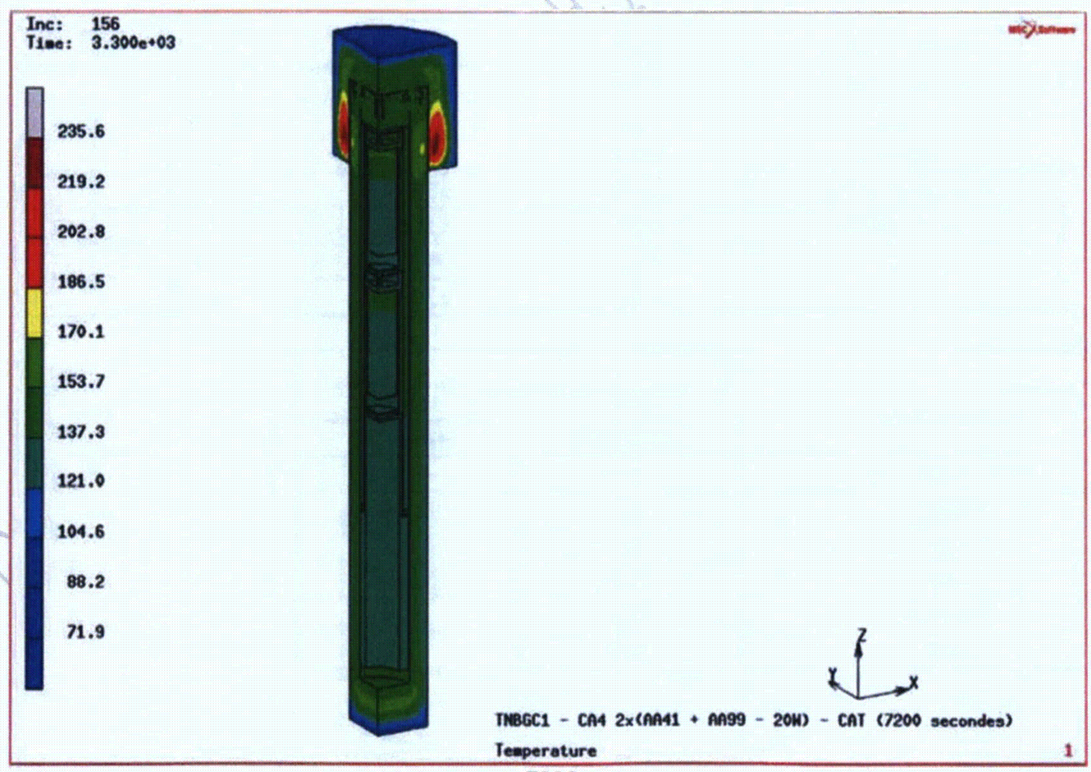


Hottest TN-BGC 1 (centre, rear)

- In ACT:



at 1800 s



at 7200 s

5.5. Model CA3

5.5.1. Configuration

CA3	Internal fittings	Shims	Packaging housing	Power contained
TNBGC1	AA41	E1 + E11	AA99	80 W / housing

CA3	No. of TN-BGC transported	Power / package	Total power transported
CB9 caisson	6	80 W	480 W

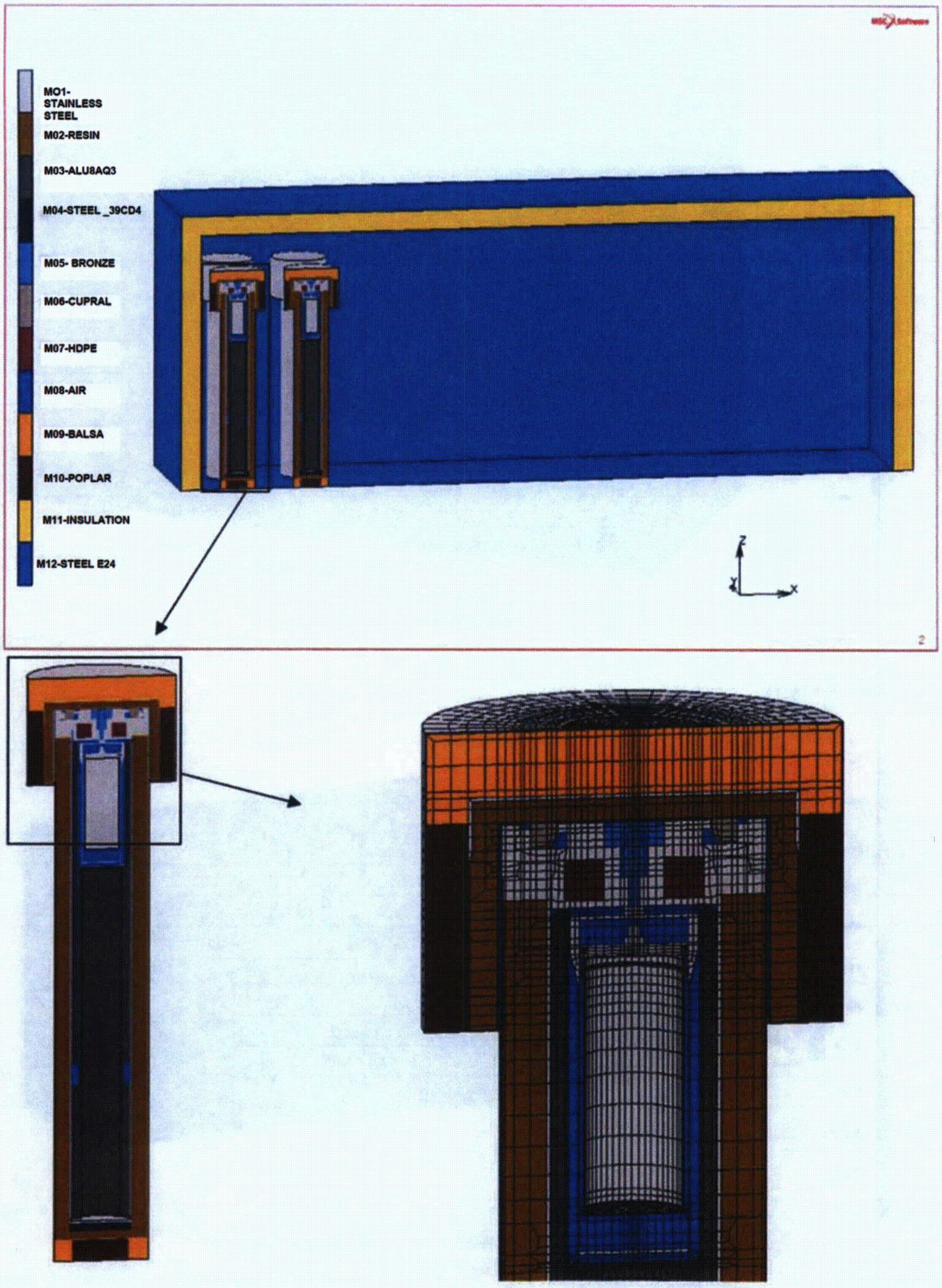
5.5.2. Summary of results

CA3					
TN-BGC 1 - CA3		NCT	RCT	ACT	
		Temp (°C)	Temp (°C)	Temp (°C)	Time [s]
TN-BGC1	External surfaces	76.5	70.8	799.1	1 800
	Outer shell	83.8	78.4	781.3	1 800
	Resin	86.5	81.1	781.0	1800
	Inner shell	86.5	81.1	153.8	4 200
	Clamp ring	84.3	78.9	131.5	12 300
	Joints	85.3	80.0	132.4	13 200
	Head internal surface	92.8	87.5	143.1	8 100
	Package cavity gas	160.9	156.0	199.8	8 400
	Base	62.9	57.6	154.1	5 100
Internal fittings	Spacer 1	89.5	84.2	147.3	6 900
	AA41 shell	161.0	156.1	199.8	9 000
	Spacer 11	75.4	70.2	143.3	6 600
	Head	144.6	139.5	186.7	10 300
	AA41 cavity gas	226.7	222.0	246.2	10 300
	AA41 joint	140.7	135.6	180.2	9 900
	Content	N.C.:	N.C.:	N.C.:	N.C.:
	AA 99	226.7	222.1	246.3	9 000

CA3		
CB9 CAISSON	NCT	RCT
	Temp (°C)	Temp (°C)
Lateral walls	55.7	48.0
Door	52.2	40.4
Base	58.0	50.7
Top panel	59.9	45.6
Floor	53.1	46.6
Package	76.5	70.8

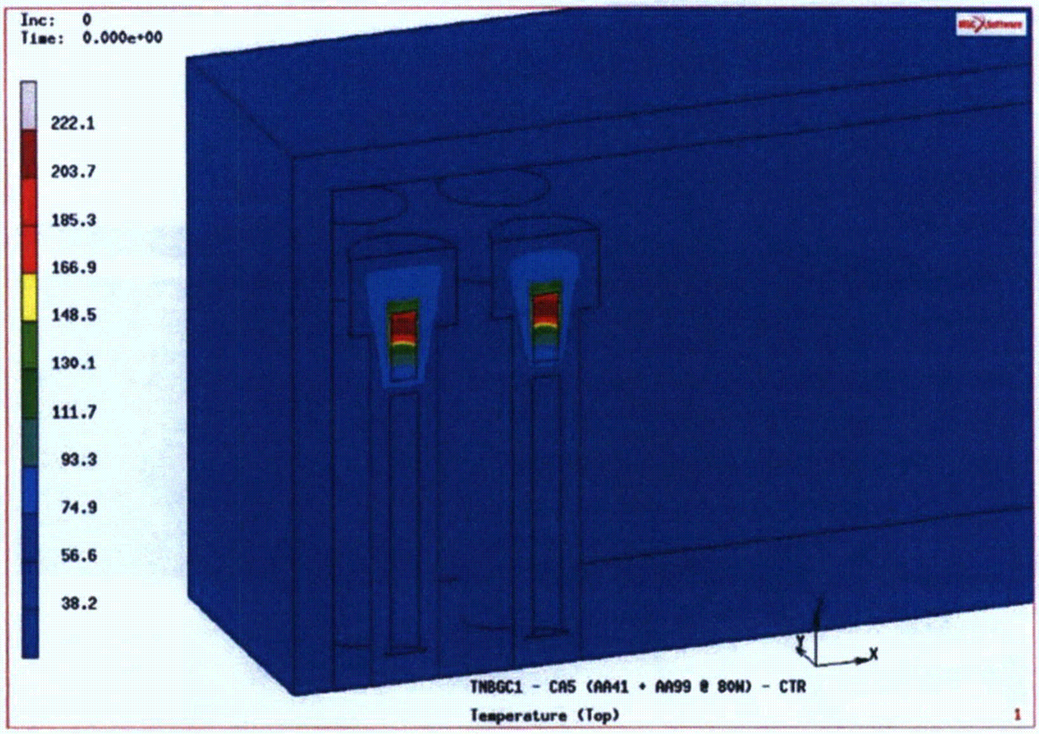
5.6. Figures CA3

5.6.1. Modelling

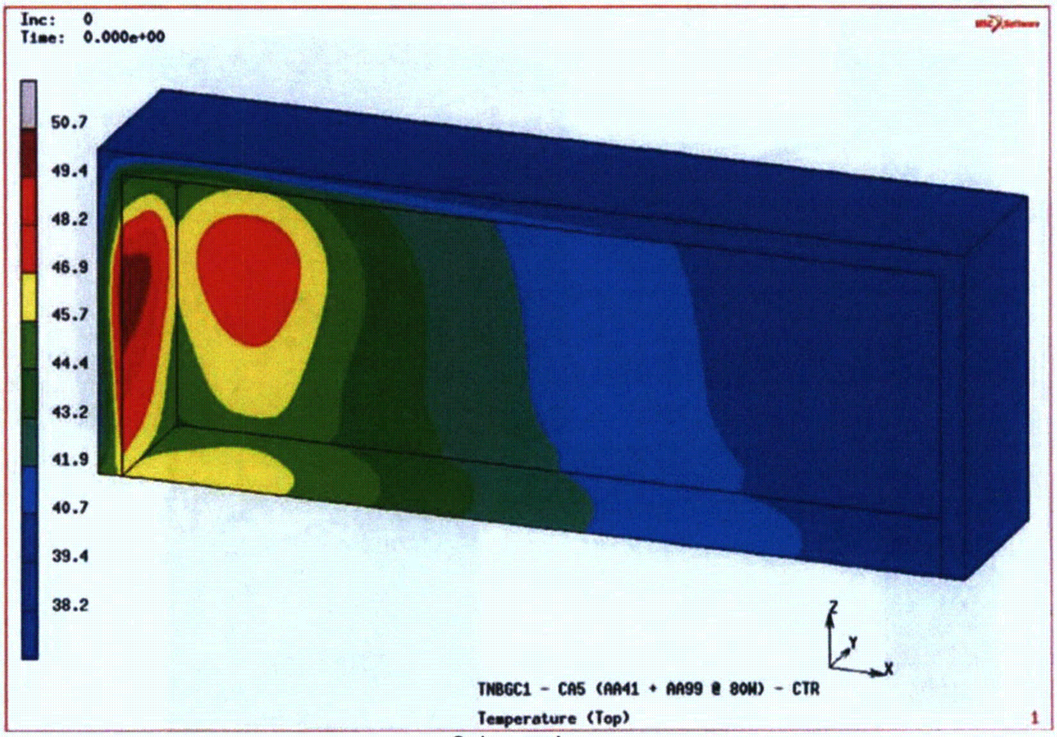


5.6.2. Results

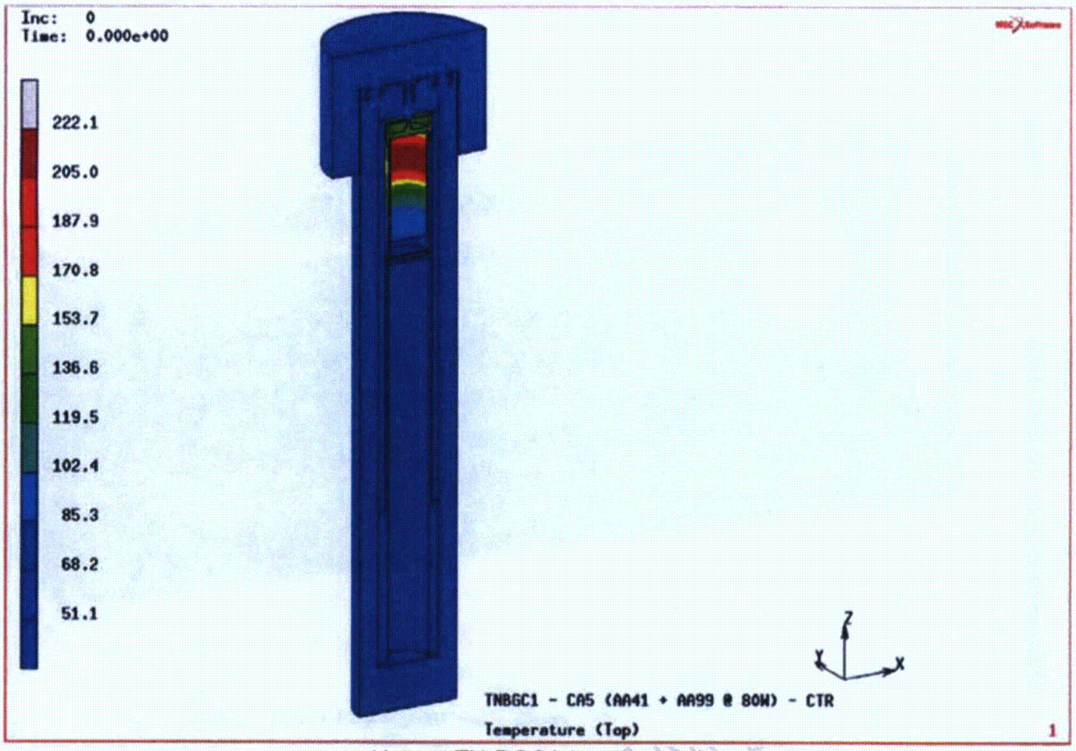
- in RCT:



Assembly

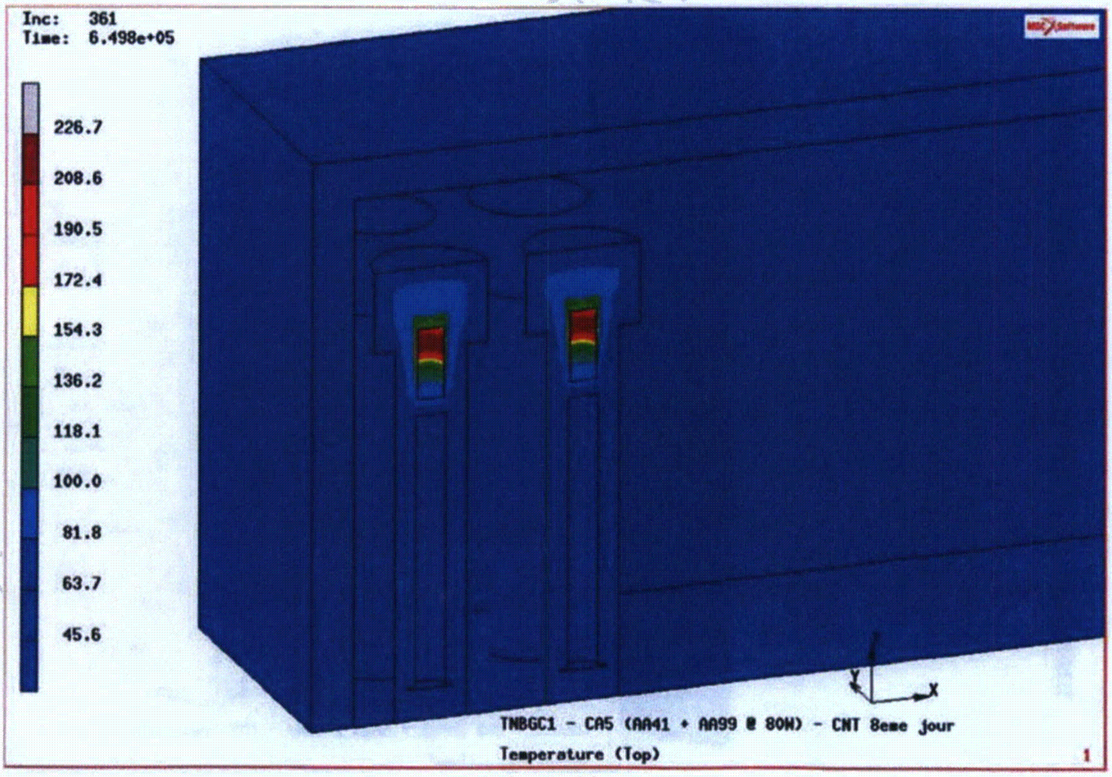


Caisson alone

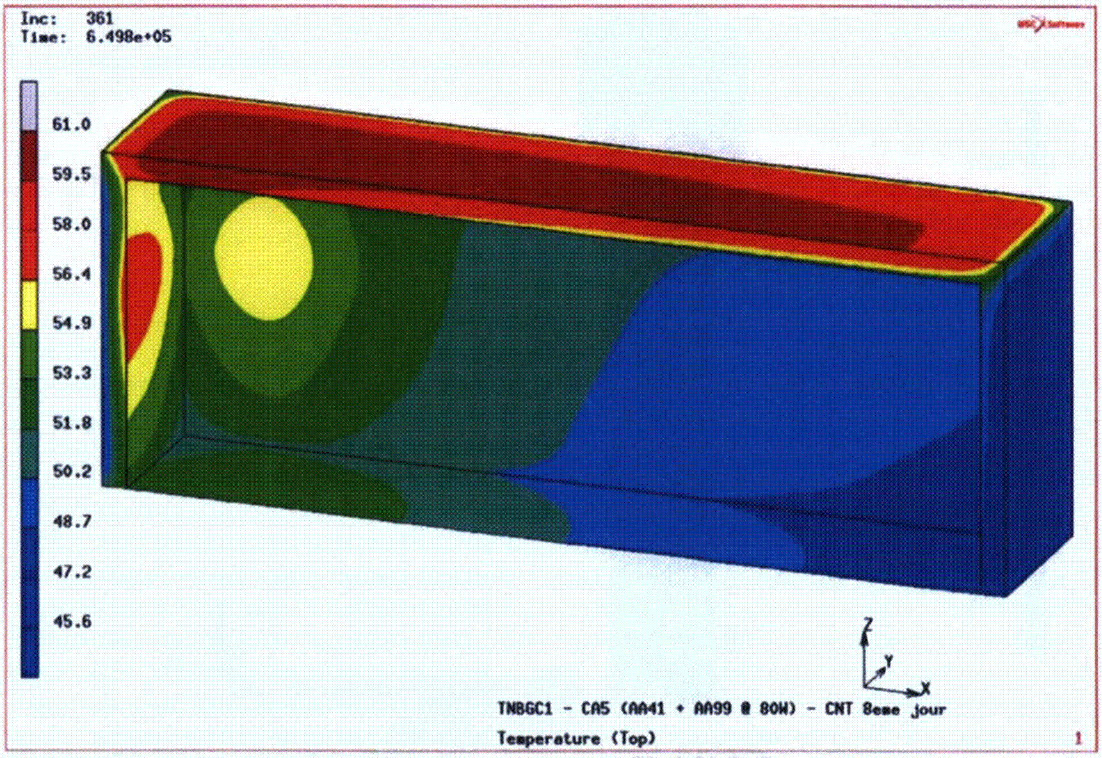


Hottest TN-BGC1 (centre, rear)

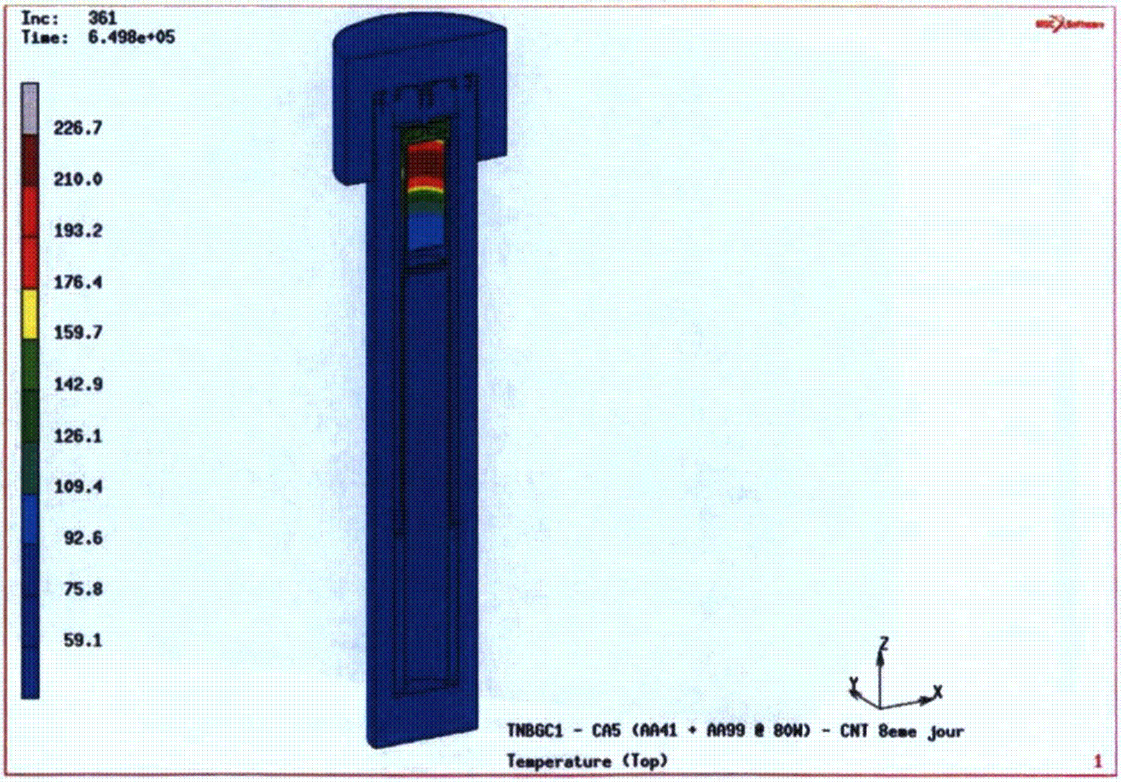
- Under NCT



Assembly

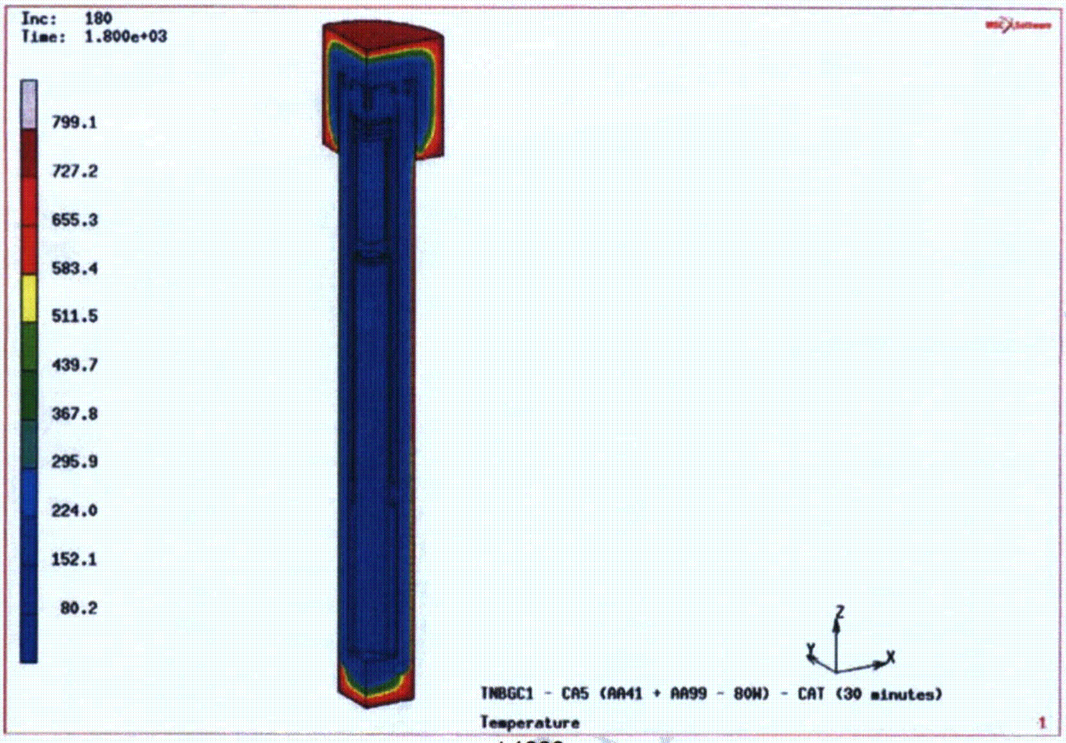


Caisson alone

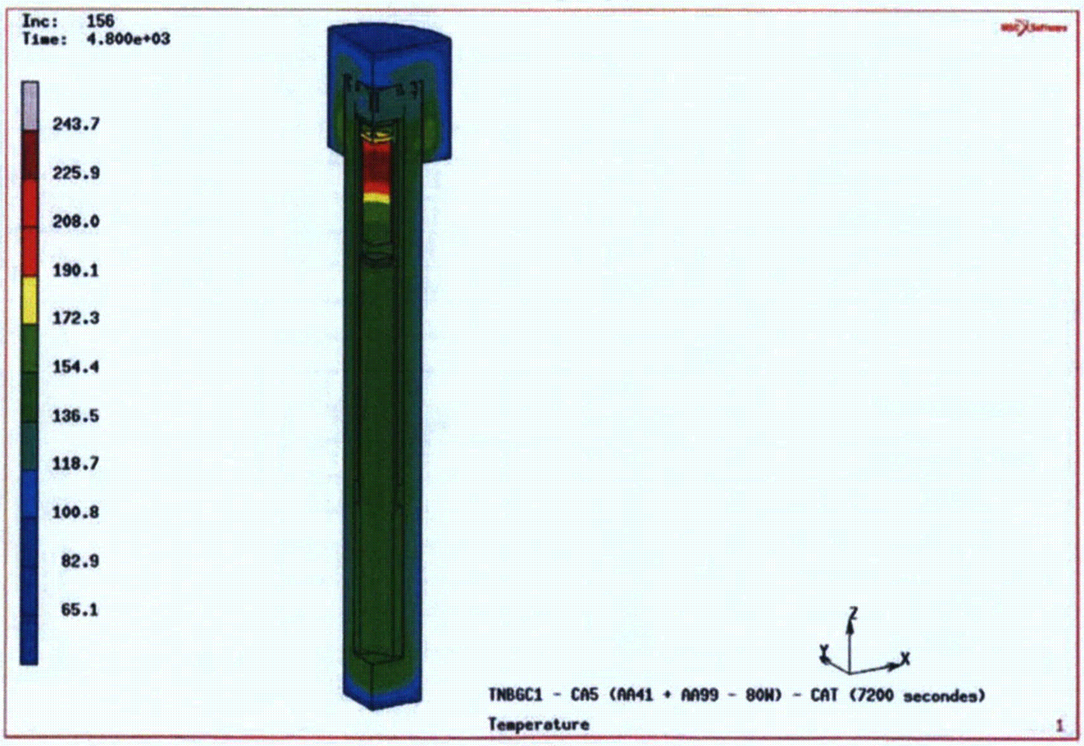


Hottest TN-BGC1 (centre, rear)

- In ACT:



at 1800 s



at 7200 s