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APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
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			3.3-1	Temperatures in the TN-BGC 1 package model in normal and accident conditions in transport ref. EMB TNBGC PBC DJS CA 000345 A of 07/08/03	104
			3.3-2	Thermal analysis of package TN-BGC1 in TAC ref. 477314C050263 Rev. B of 29/06/06	235
			3.3-3	Thermal analysis of package TN-BGC 1 ref. 472891C030118 rev. B of 26-Jan-04	59
			3.3-4	Additional calculations ref. EMB TNBGC PBC DJS CA 000388 A of 07/08/03	136
			3.3-5	Thermal analysis of fuel rods (contents no. 8) in TN-BGC 1 packaging ref. EMB TNBGC PBC DJS CA 000348 A of 07/08/03	9
			3.3-6	Thermal analysis of package TN-BGC 1 - Modelling an explosion in the internal arrangement ref. 472891C040024 rev. A of 26-Mar-04	21
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TABLE OF CONTENTS

1 SCOPE 5
2 GENERAL DESIGN HYPOTHESES 5
2.1 TRANSPORT CONDITIONS 5
2.2 TRANSPORTED POWER 5
2.3 PROPERTIES OF MATERIALS 5
2.4 MODELS 5
2.5 MODELLING HYPOTHESES 6
2.5.1 Packaging 6
2.5.2 Contents 6
2.5.3 Heat exchanges 6
3 DESIGN CONFIGURATIONS ADOPTED 6
4 TEMPERATURES OF ACCESSIBLE SURFACES WITHOUT INSULATION AT THE AMBIENT TEMPERATURE OF 38°C 7
5 AIR TRANSPORT 7
6 TEMPERATURES IN NORMAL TRANSPORT CONDITIONS 7
6.1 PACKAGING 7
6.1.1 Packaging joints 7
6.1.2 Other packaging constituent parts 7
6.2 INTERNAL ARRANGEMENTS AND CONTENTS 8
6.2.1 Nil power contents 8
6.2.2 Contents with power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-204) 8
6.2.3 Contents packed in vinyl wrapper - maximum power = 80 W 8
6.3 GAS IN PACKAGING AND INTERNAL ARRANGEMENT CAVITIES 9
6.3.1 Nil power contents 9
6.3.2 Contents with power limited to 340 W in TN90 - AA126-227 and to 170 W in AA41-203-204 9
6.3.3 Contents packed in vinyl wrapper - maximum power = 80 W 9
7 TEMPERATURES IN ACCIDENT CONDITIONS IN TRANSPORT 10
7.1 SEALS 10
7.2 OTHER PACKAGING CONSTITUENT PARTS 10
7.3 INTERNAL ARRANGEMENTS AND CONTENTS 10
7.3.1 Nil power contents 10
7.3.2 Contents with maximum power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-204) 11
7.3.3 Contents packed in vinyl wrapper - maximum power = 80 W 11
7.4 GAS IN PACKAGING AND INTERNAL ARRANGEMENT CAVITIES 12
7.4.1 Nil power contents 12
7.4.2 Contents with maximum power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-

204) 12
7.4.3 Contents packed in vinyl wrapper - maximum power = 80 W 12
8 CONCLUSIONS 12
9 REFERENCES 13

LIST OF TABLES

TABLE 3.3-1: CONFIGURATIONS STUDIED 14

1 SCOPE

The aim of this chapter is to study the thermal behaviour of the TN-BGC 1 packaging and the contents it transports. To cover all contents and existing configurations, the thermal calculations are performed on envelope configurations which cover all possible cases (see Table 3.3-1).

The special case of contents 1b and 3b is not dealt with in this chapter. It is presented in attachment 3.3-7.

The analysis takes the following into account:

- the maximum power likely to be released by the packaging contents,
- the packaging transport position, horizontal or vertical,
- the characteristics of the various internal arrangements and contents,
- normal and accident conditions in transport defined by the regulations.

2 GENERAL DESIGN HYPOTHESES

2.1 TRANSPORT CONDITIONS

<u>Isolated transport</u>

The packaging, comprising a cylindrical body fixed to the interior of a cage, is transported vertically or horizontally.

<u>Transport in canister</u>

Transport in canister is authorised for contents 1b and 3b only and is dealt with in attachment 3.3-7.

Note: the various calculations presented in attachments 3.3-1 to 3.3-6 should not be taken into account for this type of transport as the thermal characteristics of the canister taken as input data do not relate to the containers used. However, the canister calculations cover air transport (see § 4.1.3).

2.2 TRANSPORTED POWER

The heat is dissipated by natural convection and radiation in the ambient air and transmitted by conduction through the main components of the packaging body.

The power released by the packaging contents can vary from 0 to 340 W.

2.3 PROPERTIES OF MATERIALS

The thermal properties of packaging and canister materials are taken from Chapter 2. The conductivity of the resin is determined according to the results of tests performed in 1998 at the Saclay Centre (test reports carry the references EMB TNBGC PBC DJS CA 000343 A and EMB TNBGC PBC DJS CA 000344 A). The thermal properties of materials making up the contents are indicated in Chapter 1.

2.4 MODELS

Temperatures reached in normal and accident conditions in transport are mapped in the majority of cases by finite element calculation.

Several models have been constructed according to the type of contents and internal arrangements found in the packaging cavity. They can be 3D or axisymmetric.

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These models and the results obtained are presented in attachment 3.3-1 and supplemented by the calculations presented in attachments 3.3-2 to 3.3-4.

The special case of the transport of mixed oxide fuel rods, for which a specific computer code gives us access to the cladding temperature in normal and accident conditions in transport (attachment 3.3-5) are calculated analytically.

2.5 MODELLING HYPOTHESES

2.5.1 Packaging

2.5.1.1 Normal transport conditions

The package is considered integrated as described in Chapter 2.

2.5.1.2 Accident conditions in transport

The following hypotheses were considered:

- the damping cover is reduced by 42 mm following the longitudinal axis (the balsa is assumed compressed by about 60%) following an axial drop on the damping cover,
- the damping cover is reduced by 33 mm along the radius following the fall on generatrix,
- part of the external shell of the body is pushed in following the impact by a bar,
- the damping part of the body is reduced by 39 mm along the longitudinal axis following an axial drop on the bottom of the body.

2.5.2 Contents

The assumptions made about the contents are stated in each attachment for the configurations studied.

The tertiary packing containers are considered as integrated in TAC.

2.5.3 Heat exchanges

Heat exchanges are normally by three methods:

- natural or forced convection,
- conduction,
- radiation.

The hypotheses adopted for taking these phenomena into account are specific to each attachment (for example, attachment 3.3-3 takes into account the radiation in the package cavity in NTC whereas attachment 3.3-1 ignores it, which is penalising in terms of temperature reached in the contents).

The hypotheses regarding the insolation, the ambient temperature, the various surface solar absorptivity coefficients (before, during and after the fire), the emissivity of the air or surfaces comply with regulatory stipulations [1].

3 DESIGN CONFIGURATIONS ADOPTED

Miscellaneous and varied configurations representative of the various types of possible packing and different permitted levels of thermal power in the TN-BGC 1 package have been defined and adopted.

These configurations are grouped into families based on the type of content they are covering.

Family 1 covers the **power contents** in general: contents 1,3, 5, 8 (pellets), 9, 10, 15, 18, 19, 20 and 23

Family 2 covers the special case of **mixed oxide rods**: content 8.

Family 3 covers **nil power** contents (or contents assimilated with a nil power with respect to the power released by the "power contents"): contents 2, 4, 7, 11 and 26

Family 4 covers the special case of **uranyl nitrate**: content 6.

Studying these different configurations can determine exhaustively the maximum temperatures reached by the various constituent package components for all the transportable contents.

These configurations are shown in Table 3.3-1.

4 TEMPERATURES OF ACCESSIBLE SURFACES WITHOUT INSULATION AT THE AMBIENT TEMPERATURE OF 38°C

These temperatures, which are the same as for the package cage, are not determined in the context of this chapter. Chapter 4 provides for measuring the temperatures of accessible surfaces at thermal equilibrium and checking their admissibility in terms of regulatory limits, which makes the lack of evaluation acceptable.

5 AIR TRANSPORT

When being transported by 'plane, the regulatory ambient temperature is 55°C and the insolation is not taken into account; this case is widely covered whatever the position - horizontal or vertical - of the package by transport in canister (the air temperature in the canister equal to the maximum of 71°C for nil power contents - See note EMB TNBGC PBC DJS CA000346 A of 07/08/03).
The results obtained for transport in canister are therefore envelope and it is clear that they are not dimensioning for a nil thermal power.

6 TEMPERATURES IN NORMAL TRANSPORT CONDITIONS

6.1 PACKAGING

6.1.1 Packaging joints

The maximum temperature reached by the packaging joints is **124°C** (attachment 3.3-4) for configuration 3.1 as defined in the Table 3.3-1 (Family 1). This is lower than the maximum service temperature for the joints (250°C for Viton – 300°C for silicon).

6.1.2 Other packaging constituent parts

The maximum temperatures of miscellaneous packaging constituent parts for the various loading scenarios are summarised in the table below. This gives the configuration which generates these maximum temperatures. The temperatures are acceptable for the materials used.

Packaging component	Maximum temperature	Family	Reference attachment

Inner shell	158°C	1 (config. 1.2, 2.1, 2.2, 3.1, 4.2, 4.4, 4.6, 4.8, 4.10, 5)	3.3-1
Inner shell	69°C	1 (config. 1.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.7, 4.9)	3.3-3
Outer shell	117°C	1 and 2	3.3-1

In particular, at a temperature of 158°C, the neutron-absorbing resin is not degraded and retains all its properties.

6.2 INTERNAL ARRANGEMENTS AND CONTENTS

6.2.1 Nil power contents

The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Internal arrangement	Reference attachment
3	45°C	47°C	3.3-1
4	55°C	55°C	3.3-1

These temperatures are widely admissible both for the contents and their packing and for the internal arrangements.

6.2.2 Contents with power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-204)

The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Primary packing (stainless steel or aluminium box)	Internal arrangement	Internal arrangement joint	Reference attachment
11 (config. 1.2, 2.1, 2.2, 3.1, 4.2, 4.4, 4.6, 4.8, 4.10)	606°C	405°C	260°C	198°C	3.3-4
1 (config. 5)	164°C		116°C		3.3-1
2	415°C		247°C		3.3-5

These temperatures are widely admissible both for the contents and their packing and for the internal arrangements, especially their joints.

The temperature of the ZEBRA plates (family 1, configuration 5) is very much lower than the temperature of 430°C; there is therefore no risk of these plates degrading through formation of a eutectic salt between the plutonium and the stainless steel of the cladding. The maximum temperature of the rod cladding - 415°C - remains admissible.

6.2.3 Contents packed in vinyl wrapper - maximum power = 80 W

PVC or polyurethane wrappers are likely to be used around primary packing containers for family 1 contents (configurations 1.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.7, 4.9 - see Table 3.3-1).
The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Wrappers	Secondary packing (stainless steel or aluminium box)	Internal arrangement	Internal arrangement joint	Reference attachment
1 (config. 1.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.7, 4.9)	229°C	142°C	135°C	120°C	80°C	3.3-3

The maximum temperature reached by the PVC or polyurethane wrappers is 142°C. It does not therefore exceed the maximum service value of the PVC or polyurethane (150°C).

The other temperatures are widely admissible both for the contents and their packing and for the internal arrangements.

6.3 GAS IN PACKAGING AND INTERNAL ARRANGEMENT CAVITIES

The temperature of the gas in the packaging cavity is obtained by calculating the average of maximum temperatures of the internal shell of the packaging, the tertiary packing wall and the spacers.
The temperature of the gas in the tertiary packing container cavity is obtained by calculating the average of maximum temperatures of the tertiary packing, the basket (possibly) and the secondary packing (or failing that the primary).

6.3.1 Nil power contents

The results are summarised in the table below.

Family	Packaging cavity gas	Internal arrangement cavity gas
3 and 4	57°C	55°C

6.3.2 Contents with power limited to 340 W in TN90 - AA126-227 and to 170 W in AA41-203-204

The results are summarised in the table below.

Family	Packaging cavity gas	Internal arrangement cavity gas
1 and 2	181°C	302°C

6.3.3 Contents packed in vinyl wrapper - maximum power = 80 W

Conservatively, they are considered equal to that of contents with power limited to 340 W.

7 TEMPERATURES IN ACCIDENT CONDITIONS IN TRANSPORT

Note: reference is made to attachment 3.1-1 only to determine temperatures in family 4 (contents 6 - uranyl nitrate). The calculations for the TAC presented in this note are readjusted from results obtained during fire tests in 1998 for which the CEA cannot guarantee the representativeness. The CEA has therefore decided to base its approach exclusively on calculations *ex nihilo* presented in attachments 3.3-2 and 3.3-3.

7.1 SEALS

The maximum temperature reached by the packaging joints is **161°C** (attachment 3.3-2) for configuration 6.1 as defined in the Table 3.3-1 (Family 2). This is lower than the maximum service temperature for the joints (250°C for Viton – 300°C for silicon).

7.2 OTHER PACKAGING CONSTITUENT PARTS

The maximum temperatures of the miscellaneous constituent packaging parts for the various loading scenarios are summarised in the table below. The temperatures are acceptable for the materials used.

Packaging component	Maximum temperature	Family	Reference attachment
Inner shell	187°C	1 (config. 1.2, 2.1, 2.2, 3.1, 4.2, 4.4, 4.6, 4.8, 4.10, 5)	3.3-2
Inner shell	226°C	2	3.3-2
Inner shell	174°C	1 (config. 1.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.7, 4.9)	3.3-2
Outer shell	798°C	1 and 2	3.3-2

The surface of the resin is subjected to temperatures in the order of 800°C. Fire tests by the owner of this resin show that when subjected to an outside temperature of 800°C, the surface of the resin carbonises and is degraded over a thickness of 10 mm, with the rest of the resin keeping its nominal neutron-absorbing properties.

7.3 INTERNAL ARRANGEMENTS AND CONTENTS

7.3.1 Nil power contents

The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Internal arrangement	Reference

			attachment
3	131°C	142°C	3.3-2
4	97°C	126°C	3.3-1

These temperatures are widely admissible both for the contents and their packing and for the internal arrangements. Checks are made especially that the average maximum temperature reached by the uranyl nitrate does not exceed 118°C (uranyl nitrate boiling point, equal to 118°C [3]), thereby avoiding its pressurisation. Should the primary container lose its leaktightness (AA97), given that the secondary packing container maintains its leaktightness in accident conditions in transport, the uranyl nitrate will reach a temperature of between 97°C (temperature reached by the uranyl) and 126°C (temperature reached by the gas inside the container).

7.3.2 Contents with maximum power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-204)

The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Primary packing (stainless steel or aluminium box)	Internal arrangement	Internal arrangement joint	Reference attachment
1	522°C	336°C	205°C	188°C	3.3-2
1 (config. 5)	252°C		183°C		3.3-2
2	376°C		312°C		3.3-2

These temperatures are widely admissible both for the contents and their packing and for the internal arrangements, especially their joints.
The temperature of the ZEBRA plates (family 1, configuration 5) is very much lower than the temperature of 430°C; there is therefore no risk of these plates degrading through formation of a eutectic salt between the plutonium and the stainless steel of the cladding. The maximum temperature of the rod cladding - 376°C - remains admissible.

Note: any temperatures less than those obtained in NTC are due to the assumptions made in attachment 3.3-2 which are more representative of phenomena in play that those made in attachments 3.3-1, 3.3-3 or 3.3-5, which are very penalising.

7.3.3 Contents packed in vinyl wrapper - maximum power = 80 W

PVC or polyurethane wrappers are likely to be used around primary packing containers for family 1 contents (configurations 1.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.7, 4.9 - see Table 3.3-1).
The maximum temperatures of internal arrangements and the contents for the various loading scenarios are summarised in the table below.

Family	Contents	Wrappers	Secondary packing (stainless steel or aluminium box)	Internal arrangement	Internal arrangement joint	Reference attachment
1	235°C	207°C	204°C	198°C	158°C	3.3-2

The maximum temperature reached by the PVC or polyurethane wrappers is 207°C. It will therefore be necessary to take account of gaseous releases from their decomposition under temperature in Chapter 3.7. The other temperatures are widely admissible both for the contents and their packing and for the internal arrangements.

7.4 GAS IN PACKAGING AND INTERNAL ARRANGEMENT CAVITIES

The gas temperature in the packaging cavity and in the tertiary packing cavity are specified in attachment 3.3-2.

7.4.1 Nil power contents

The results are summarised in the table below.

Family	Packaging cavity gas	Internal arrangement cavity gas	Reference attachment
3	171°C	144°C	3.3-2
4	183°C	112°C	3.3-1

7.4.2 Contents with maximum power limited to 340 W (in TN90 - AA226-227) and to 170 W (in AA41-203-204)

The results are summarised in the table below.

Family	Packaging cavity gas	Internal arrangement cavity gas	Reference attachment
1	211°C	344°C	3.3-2
2	268°C	335°C	3.3-2

7.4.3 Contents packed in vinyl wrapper - maximum power = 80 W

The results are summarised in the table below.

Family	Packaging cavity gas	Internal arrangement cavity gas	Reference attachment
1	164°C	246°C	3.3-2

8 CONCLUSIONS

Transport packaging

The various analyses in this chapter and its attachments show that the temperatures reached in both normal and accident conditions in transport by the various parts of the TN-BGC 1 packaging are acceptable for the materials used in them and that the temperature boundaries imposed by the regulations are not exceeded. Following the fire test, the resin will be considered degraded over a thickness of 10 mm.

Internal arrangements and contents

Tables 3.3-2 and 3.3-5 conclude that the temperatures reached by the internal arrangement materials do not exceed the permitted boundaries. In particular, the maximum temperature of tertiary packing joints remains less than 198°C in normal transport conditions and 158°C in accident conditions in transport (**Note**: this difference in temperature is explained by the fact that the TAC in attachment 3.3-2 was calculated with new, less conservative hypotheses, especially the taking into account of the radiation in the cavity which was ignored in NTC in attachment 3.3-4.

These temperatures reached by the joints ensure isolation of the powder (for criticality) or the uranyl nitrate.

The following is checked in this chapter:

- the maximum temperature reached by the PVC or polyurethane wrappers does not exceed the maximum service value of the PVC or polyurethane (150°C), in NTC,
- the average maximum temperature reached by the TN 90 containing uranyl nitrate does not exceed 97°C , thereby avoiding its pressurisation (value lower than boiling point: 118°C [3]),
- the temperature of ZEBRA plates remains below 430°C where there is a risk of degradation through formation of a eutectic salt between the plutonium and the stainless steel of the cladding,
- the maximum temperature reached by the fuel rod cladding remains admissible.

Lastly, this chapter determines the temperatures reached in the packaging and internal arrangement cavities in NTC and TAC, which are used in the release and radiolysis studies.

Note also that the maximum temperature of the internal shell of the packaging and of the internal arrangement is used as input data for the mechanical studies in Chapters 3.1 and 3.2.

9 REFERENCES

[1] International Atomic Energy Agency Regulations for the transport of radioactive materials, Safety standards collection, no. TS-R-1 - 1996 edition (amended in 2005)

[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] Handbook of CHEMISTRY and PHYSICS - D. R. LIDE - 73rd Edition - 1992-1993

TABLE 3.3-1: CONFIGURATIONS STUDIED

Family	Configuration	Primary packings	Baskets or wrappers	Tertiary packings	Baskets, spacers or wedges	Tertiary packings	External spacers	Thermal power
1 (contents 1, 3, 8-pellets, 9, 10, 15, 18, 19, 20, 23)	1.1	Boxes (x4)	Wrappers (x8)	AA 213 (x4)		AA 226	E1	4 x 20 W
	1.2	Boxes (x4)		AA 213 (x4)		AA 226	E1	4 x 85 W
	2.1	Boxes (x5)		AA 236	Blocks	AA227	E1	5 x 68 W
	2.2	Boxes (x4)		AA303	Blocks	AA 227	E1	4 x 85 W
	3.1	Boxes (x4)		AA 99 (x4)	P1	TN 90	E1 + E2	4 x 85 W
	to	Boxes (x4)	Wrappers (x8)	AA 99 (x4)	P1	TN 90	E1 + E2	4 x 20 W
	3.3	Boxes (x4)	Wrappers (x8)	AA 99 (x4)	P1	TN 90	E1 + E2	4 x 20 W
	4.1	Boxes (x4)	Wrappers (x8)	AA 99 (x4)		AA 204	E1+E10	4 x 20 W
		Boxes (x4)		AA 99 (x4)		AA 204	E1+E10	4 x 42.5 W
	to	Boxes (x2)	Wrappers (x4)	AA 99 (x2)		AA 203	E1+E8	2 x 20 W
		Boxes (x2)		AA 99 (x2)		AA 203	E1+E8	2 x 85 W
	4.10	Box (x1)	Wrappers (x2)	AA 99 (XI)		AA 41 (XI)	E1+E11	20 W
		Box (x1)		AA 99 (XI)		AA 41 (XI)	E1+E11	100 W
		Boxes (x2)	Wrappers (x4)	AA 99 (x2)		AA 41 (x2)	E1+E12+E13	2 x 20 W
		Boxes (x2)		AA 99 (x2)		AA 41 (x2)	E1+E12+E13	2 x 85 W
		Boxes (x3)	Wrappers (x6)	AA 99 (x3)		AA 41 (x3)	E1+E9+E13	3 x 20 W
		Boxes (x3)		AA 99 (x3)		AA 41 (x3)	E1+E9+E13	3 x 56.6 W
1 (content 5)	5	E5		TN 90			E1 + E2	150 W
2 (content 8 - rods)	6.1	R1		TN90			E1 + E2	340 W
	6.2	R1		AA204			E1 + E10	
3 (content 4)	7	E4		TN 90	P4		E1 + E2	5 W
3 (contents 2, 11 and 26)	8.1	E7		TN 90			E1 + E2	16 W
	to	$E7_{bis}$		AA204			E1+E10	0
	8.6	$E7_{bis}$		AA203			E1+E8	0
		$E7_{bis}$ (x1)		AA 41 (XI)			E1+E11	0
		$E7_{bis}$ (x2)		AA 41 (x2)			E1+E12+E13	0
		$E7_{bis}$ (x3)		AA 41 (x3)			E1+E9+E13	0
4 (content 6)	9	AA 97 (x2)	P2	TN 90		-	E3 or E3bis	2 x 2 W

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