DIVISION OF NUCLEAR ENERGY
Department of Installation and Packaging projects
CEA Transport package service

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Reference: 160 EMBAL PFM DET 08000157	Issue A
Title: Safety file – TN-BGC 1 Chapter 0: introduction - contents	

Purpose of the document:	
The aim of this memo is to define applicable regulations and present the structure of the file	CEA/DEN/CAD/DPIE/SET DO 76 26/02/08 08PPFM000157

Field of application and summary:

APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
N°	TITLES	N° of pages	N°	TITLES	N° of pages

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1 REFERENCE DOCUMENTS

- [DR01] Regulations for the safe transport of radioactive material by the International Atomic Energy Agency from the Safety standards series N° TS-R-1 – 2005 edition

2 CONTEXT INFORMATION

Package TN-BGC 1 is used at both national and international level for the transport of fissile uranium-bearing and plutonium-bearing radioactive material.

TN-BGC 1 packages may be transported by road, rail, inland waterways and/or sea and by air with certain contents.

The TN-BGC 1 package model is approved until 30 June 2008. This file has been prepared in view of requesting extended approval.

3 SIMPLIFIED DESCRIPTION OF THE PACKAGE MODEL

3.1 TN-BGC 1 PACKAGE

The TN-BGC1 package consists of:

- a cage with a structure in welded aluminium tubes,
- a main section consisting of a shell and a base, coated with a resin-based mixture providing neutronic and thermal protection and with a wood damper integrated in the base; the main section is connected to the cage by attachment tabs welded under the main section and screwed to the cage,
- a closing system for the main section cavity, mainly consisting of a plug, a bronze clamp ring and a bayonet ring,
- a damper cover protecting the package in case of a fall on the plug side.

The main section and the closing system make up the containment.

Main dimensions:

- overall dimensions of the cage:
  - length: 600 mm
  - width: 600 mm
  - height: 1821 mm
- overall dimensions of the main section with the cover:
  - main diameter: 295 mm
  - cover diameter: 466 mm
  - height: 1808 mm

- working dimensions of the cavity:
  - length: 1475 mm
  - diameter: 178 mm

Masses:

- total empty mass of the package: 280 kg
- maximum total mass of the loaded package: 396 kg

The TN-BGC 1 package may be:

- B(M)F if the two o-rings restricting the containment are Viton,
- B(M)F if the two o-rings restricting the containment are very high temperature silicon,

3.2 CONTENT

The TN-BGC 1 package satisfies the applicable regulatory provisions:

- for B(U)F type packages for fissile radioactive materials for the transport of:
  - uranium oxide powder (content n°2),
  - metal uranium bars (content n°4),
  - rods or sections of rods or pellets of uranium oxide (content n°7),
  - solid uranium-bearing materials (content n°11),
  - TRIGA combustible (content n°26),
- for B(M)F type packages for fissile radioactive materials for the transport of:
  - plutonium oxide powder (content n°1),
  - mixed plutonium-uranium oxide powder (content n°3),
  - compact stacks of ZEBRA type plates (content n°5),
  - uranyl nitrate (content n°6),
  - rods or sections of rods or pellets of mixed plutonium oxide (content n°8),
  - plutonium oxide heterogenous mix (content n°9),
  - mixed plutonium and uranimum oxide heterogenous mix (content n°10),
  - radioactive sources in a special Pu-Ox-type format (content n°15),
  - plutonium tetrafluoride (content n°18),
  - mixed plutonium-uranium nitride (content n°19),
  - plutonium in metal form (content n°20),
  - oxide powder of plutonium, uranium, neptunium, americium or a mix of the former (content n°23),

in accordance with:

- the recommendations of the International Atomic Energy Agency [DR01] and all national regulations, accords and texts referring to the former,
- safety rules and regulations applicable to loading and unloading operations and regulations on lifting devices in the country where the packages are constructed in particular,
- Quality assurance rules from the safety standard section of IAEA n°50-C-QA.

If the package is of B(M) type, the package will not comply with the following provisions on B(U) type packages:

- articles 637 & 664 of [DR01]: the package seals are in FKM elastomer (Viton) and consequently the minimum ambient temperature required exceeds -40°C. The minimum temperature for the use of the seals of the package is equal to -27°C,
- article 662 [DR01]: due to the emission of gases in the cavity, the maximum normal service pressure as defined in article 228 cannot be guaranteed to be less than 7 bars.

4 KEY SAFETY POINTS

The safety functions of the package and parameters to be guaranteed are shown in the following table:

Safety functions	Key safety points	Parameters to be guaranteed
Control of the containment of radioactive materials	Internal o ring seals	Performance of seal properties (double o ring in the plug and quick connection cap; seal material)
	Containment	Embedded internal cavity (stainless steel head and base assembled with continuous welding; steel plug)

Safety functions	Key safety points	Parameters to be guaranteed
External exposure limits	<u>Lateral shielding</u>:	
	Thickness of the steel external shell	1.5 mm
	Thickness of the steel internal shell	6 mm
	Resin thickness	48 mm
	<u>Axial shielding (base)</u>:	
	Stainless steel in the base	8 mm
	Stainless steel in the two closing sheets	2 x 1.5 mm
	Carbon steel in the distribution plate	25 mm
	Resin	24 mm
	<u>Axial shielding (head)</u>:	
	Stainless steel in the plug	59 mm
	Resin	24 mm
Control of criticality safety	<u>Cage</u>	
	Width of the cage	60 cm x 60 cm (in NCT)
	<u>Radial part of the main package section</u>:	
	Working diameter of the cavity	178 mm (181 mm max.)
	Thickness of the internal stainless steel shell	6 mm
	Borated resin	in normal conditions of transport, thickness of 48 mm + composition; in transport accident conditions, thickness of 33 mm + composition
	Thickness of the external stainless steel shell	1.5 mm
	<u>Plug</u>: Stainless steel	thickness of 92 mm
	<u>Base (from the inside to the outside)</u>:	
	Stainless steel shell and carbon steel distribution plate	thickness = 33 mm
	Resin	thickness of 24 mm+ composition
	Stainless steel shell	thickness = 1.5 mm
	Working diameter and thickness of Al	
	Fissile material	mass and composition

Safety functions	Key safety points	Parameters to be guaranteed
Evacuation of residual power	Resin thickness Thickness of the inner shell Thickness of the outer shell	48 mm 6 mm 1.5 mm

5 CONTENTS

This file was drafted to demonstrate that the package model represented by TN-BGC 1 loaded with one of the contents described in **chapter 1**, complies with the provisions of applicable recommendations, accords and regulations as a fissile type B package.

Chapter 2 lays out the main properties of package TN-BGC1, which is designed to transport any uranium and/or plutonium-bearing radioactive materials in any of their multiple miscellaneous forms.

The safety substantiation and analyses demonstrating the conformity of the package model with regulations are described in **chapter 3** with the following breakdown:

- **chapter 3.1**: mechanical analysis of package TN-BGC 1,
- **chapter 3.2**: mechanical analysis of the content of package TN-BGC 1,
- **chapter 3.3**: thermal analysis of package model TN-BGC 1,
- **chapter 3.4**: analysis of the containment of package model TN-BGC 1,
- **chapter 3.5**: analysis of the radioprotection of package model TN-BGC 1,
- **chapter 3.6**: analysis of safety-criticality for package model TN-BGC 1,
- **chapter 3.7**: analysis of secondary risks.

Chapter 4 presents the applicable instructions for the correct use of package TN-BGC 1 and defines test programs, acceptance and commissioning as planned at the end of manufacturing for TN BGC 1 type packages and the maintenance program applied throughout the life cycle of the packages.

Finally, **chapter 5** reiterates the quality assurance provisions applicable to package model TN-BGC1.

The detailed contents of this safety file are listed in table 0-1.

6 APPLICABLE REGULATIONS

This file is established in accordance with the applicant's guide, reference DGSNR/SD1/TMR/REQ Rev.0 of March 2006.

It provides, as far as possible, answers to the complements requested by the ASN in the following communications:

- DGSNR/SD1/0680/2004 of 14 October 2004,
- ASN/DIT/0180/2007 of 3 April 2007.

Package TN-BGC 1 may be used for international transport, therefore this safety file is drafted with primary reference to the IAEA regulation [DR01].

The following regulations are also satisfied by package model TN-BGC 1:

- Order of 1 June 2001 modified on the transport of hazardous goods by road ("ADR order"),
- Order of 5 June 2001 modified on the transport of hazardous goods by rail ("RID order"),
- Order of 05 December 2002 modified on the transport of hazardous goods by inland waterways ("ADNR order"),
- Order of 23 April 2004 abrogating the order of 19 June 2003 modifying the order of 12 May 1997 on the technical conditions applicable to the operation of aircraft by a public air transport operator (OPS1),
- Order of 23 November 1987 modified on the safety of ships,
- European agreement on the international transport of hazardous goods by road (ADR),
- Regulation on the international transport of hazardous goods by rail (RID),
- International Maritime Dangerous Goods code by the International Maritime Organization (IMDG code),
- Technical instructions for the safety of the air transport of dangerous goods – International Civil Aviation Organization (ICAO-TI),
- 46th edition of the IATA-DGR regulations of the International Air Transport Association.

Correspondence between the different parts of the safety file and the paragraphs of [DR01] is indicated in table 0-2.

TABLE 0- 1: CONTENTS OF THE SAFETY FILE

Attachment 3.1-9 2BP6E042	Mechanical resistance of package TN-BGC 1 to explosions	02/05/2006
Attachment 3.1-10 159A3W03 Iss. B	Modal analysis of package TN-BGC 1	23/01/2003
Chapter 3.2 160 EMBAL PFM DET 08000164 A	Mechanical analysis of the content of package TN-BGC 1	26/02/2008
Attachment 3.2-1 EMB TNBGC PBC DJS CA 000339 A	Resistance of containers AA204, TN90, AA226, AA227, AA236 and AA303 to internal pressure	07/08/2003
Attachment 3.2-2 195H03W01 iss. A	Package TN-BGC 1 – Consequences of the combustion of hydrogen in internal installations TN90	12/08/2003
Attachment 3.2-3 NTC-07-00101341-002 Rev. 0	Structual resistance of internal installation TN998	15/11/2007
Chapter 3.3 160 EMBAL PFM DET 08000165 A	Thermal analysis of package model TN-BGC 1	26/02/2008
Attachment 3.3-1 EMB TNBGC PBC DJS CA 000345 A	Temperatures in the TN-BGC I package model in normal and accident transport conditions	07/08/2003
Attachment 3.3-2 477314C050263 Iss. B	Thermal analysis of package TN-BGC 1 in transport accident conditions	29/06/2006
Attachment 3.3-3 472891C030118 iss. B	Thermal analysis of package TN-BGC 1	26/01/2004
Attachment 3.3-4 EMB TNBGC PBC DJS CA 000388 A	Additional elements for calculations	07/08/2003
Attachment 3.3-5 EMB TNBGC PBC DJS CA 000348 A	Thermal analysis of combustible rods (content n°8) in package TN-BGC 1	07/08/2003
Attachment 3.3-6 472891C040024 iss. A	- Thermal analysis of package TN-BGC 1 - Modelling of an explosion in the internal installation	26/03/2004
Attachment 3.3-7 CAL-07-00090487-002 Rev. 0	Thermal analysis of package TN-BGC 1	30/10/2007

Reference	Title	Date
Chapter 3.4 160 EMBAL PFM DET 08000166 A	Analysis of the containment of package model TN-BGC 1	26/02/2008
Attachment 3.4-1 LNE report – file D031080 – document CM1/1	Dilatometry test report for STACEM seals	19/09/2003
Attachment 3.4-2 NTC-07-00101341-006 Rev. 0	Analysis of the containment	21/12/2007
Chapter 3.5 160 EMBAL PFM DET 08000167 A	Analysis of the radioprotection of package model TN-BGC 1	27/02/2008
Attachment 3.5-1 CEA DCE-S-UGSP-SPR-SRI-T-99-1172	Calculation of photon and neutron flows around a package TN-BGC 1 containing americium	21/10/1999
Attachment 3.5-2 CAL-07-00091006-002 Rev. 2	Study of the shielding of package TN-BGC 1	07/11/2007
Chapter 3.6 160 EMBAL PFM DET 08000168 A	Analysis of safety-criticality for package model TN-BGC 1	27/02/2008
Attachment 3.6-1 EMB TNBGC PBC DJS CA 000481 A	Additional criticality calculations	05/01/2004
Attachment 3.6-2 Note SGN NT.12862.00.008. Rev. A	Safety-criticality of package TN-BGC 1 - Study of allowable mass - content 8	19/11/2004
Attachment 3.6-3 Note SGN NT.12862.00.009. Rev. A	Safety-criticality of package TN-BGC 1 - Study of the allowable number of packages - content 8	19/11/2004
Attachment 3.6-4 Fax CEA/DEN/CAD/DTAP/SET DO 247	Criticality calculations for package TN-BGC 1	14/05/2004
Attachment 3.6-5 160 EMBAL PFM NOT 06001678 A	Criticality study of package TN-BGC 1 loaded with plutonium oxide powders	07/11/2006

Reference	Title	Date
Attachment 3.6-6 160 EMBAL PFM NOT 06001677 A	Criticality calculations for package TN-BGC 1 loaded with miscellaneous content: influence of the nature of blocks	07/11/2006
Attachment 3.6-7 160 EMBAL PFM NOT 06001679 A	Criticality study of package TN-BGC 1 loaded with content 6: uranyl nitrate solution	07/11/2006
Attachment 3.6-8 160 EMBAL PFM NOT 06001680 A	Criticality study for package TN-BGC 1 loaded with content 11: metal U environment at 100% ^{235}U	07/11/2006
Attachment 3.6-9 160 EMBAL PFM NOT 06001518 A	Criticality study for package TN-BGC 1 loaded with content 26: U-ZrH_2 environment	06/10/2006
Attachment 3.6-10 160 EMBAL PFM NOT 06001310 C	Criticality calculations for package TN-BGC 1 loaded with miscellaneous MCMF content in normal and accident transport conditions:	24/07/2007
Attachment 3.6-11 EMB TNBGC PBC DJS CA 000386 A	Safety-criticality study for package model TN-BGC 1 loaded with content n°26: TRIGA combustible	07/08/2003
Attachment 3.6-12 CAL-07-00090811-002 Rev. 00	Safety-criticality study of package TN-BGC 1	01/10/2007
Chapter 3.7 160 EMBAL PFM DET 08000169 A	Analysis of secondary risks	27/02/2008
Attachment 3.7-1 NTC-07-00101341-007 Rev. 1	Analysis of the risk of the emission of gases	28/01/2008
Chapter 4 160 EMBAL PFM DET 08000170 A	Instructions on how to use the package – test, acceptance and maintenance programs	27/02/2008
Chapter 5 160 EMBAL PFM DET 08000171 A	Quality assurance applicable to the package model	27/02/2008

TABLE 0- 2: CORRESPONDENCE BETWEEN THE ARTICLES OF THE APPLICABLE REGULATION AND THE PARAGRAPHS OF THE SAFETY FILE

IAEA 96 paragraphs (2005 edition)	Applicable paragraphs of the safety file
306	Chapter 5
508	Chapter 4
539	Chapter 2
540	Chapter 2
569	Chapter 3.6
570	Chapter 3.6
573	Chapter 3.5
501 a	Chapter 4
501 b	Chapter 4
501 c	Chapter 4
502 a	Chapter 4
502 b, c, d	Chapter 4
606	Chapter 4
607	Chapter 4
608	Chapter 4
609	Chapter 2
610	Chapter 2
612	Chapters 3.1 & 3.4
613	Chapters 1 & 2
615	Chapters 2, 3.1, 3.2 & 3.3
616	Chapter 3.7
634	Chapter 2
635	Chapter 2
636	Chapter 3.1
637	Chapters 2 & 3.1
638	Chapters 0, 2, 4 & 5
639	Chapters 2, 3.1 and 4
642	Chapters 2, 3.1 and 3.7
643	Chapters 3.1 & 3.4
646	Chapters 3.1, 3.2, 3.4 and 3.5
651	Chapters 3.1, 3.2, 3.3 & 3.4
652	Chapter 3.3
653	Chapter 3.3
654	Chapter 3.3
655	Chapter 3.3
656	Chapters 4 & 6
657	Chapters 3.4 & 3.5
658	Chapter 3.1
659	Chapters 2 & 3.4
660	Chapters 2 & 3.4
661	Not satisfied
662	Chapters 3.1 & 3.4

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IAEA 96 paragraphs (2005 edition)	Applicable paragraphs of the safety file
664	Chapters 1 & 3.1
671	Chapter 3.6
675	Chapter 3.6
677	Chapter 3.6
678	Chapter 3.6
679	Chapter 3.6
680	Chapter 3.6
681	Chapter 3.6
682	Chapter 3.6
676	Chapters 1 & 3.1
719 - 724	Chapter 3.1
726 - 729	Chapter 3.1
730	Chapter 3.1
731 - 733	Chapter 3.1
807 a	Chapter 1
807 b	Chapters 1 & 2
807 c	Chapters 3.1 & 3.3
807 d	Chapter 4
807 e	Chapter 3.1
807 f	Chapter 3.2
807 g	Chapter 4
807 h	Chapter 2
807 i	Chapter 5

DIVISION OF NUCLEAR ENERGY Department of Installation Projects and Packages CEA Transport Package Service	Classification: 7.4.1 — Page 1/63 Reference: 160 EMBAL PFM DET 08000158 — Issue A Title: Safety file – TN-BGC 1 Chapter 1: description of content

Purpose of the document: This chapter describes the content of package model TN-BGC 1	CEA/DEN/CAD/DPIE/SET DO 77 26/02/08 08PPFM000158

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APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
N°	TITLES	N° of pages	N°	TITLES	N° of pages
			1-1	Description of internal arrangements and relating packing ref. 160 EMBAL PFM DET 08000159 A of 26/02/08	40

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DIVISION OF NUCLEAR ENERGY
Department of Installation Projects and Packages
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CONTENTS

LIST OF FIGURES

1 INTRODUCTION

This chapter describes all content liable to be transported in package TN-BGC 1 and specifies the following for each content:

- physical and chemical characteristics,
- the isotopic properties of the radioactive materials transported,
- maximum quantities transported,
- thermal characteristics,
- compositions in fissile materials (uranium and plutonium content),
- any specific provisions,
- usable internal arrangements.

2 DESCRIPTION OF CONTENT

The following content may be transported in package TN-BGC 1:

- plutonium oxide powder (content n°1),
- uranium oxide powder (content n°2),
- mixed plutonium-uranium oxide powder (content n°3),
- metal uranium bars (content n°4),
- compact stacks of ZEBRA type plates (content n°5),
- uranyl nitrate (content n°6),
- rods or sections of rods or pellets of uranium oxide (content n°7),
- rods or sections of rods or pellets of mixed plutonium oxide (content n°8),
- plutonium oxide heterogenous mix (content n°9),
- mixed plutonium and uranimum oxide heterogenous mix (content n°10),
- solid uranium-bearing materials (content n°11),
- radioactive sources in a special Pu-Ox-type format (content n°15),
- plutonium fluoride (content n°18),
- mixed plutonium-uranium nitride (content n°19),
- plutonium in metal form (content n°20),
- oxide powder of plutonium, uranium, neptunium, americium or a mix of the former (content n°23),
- TRIGA fuel (content n°26).

2.1 CONTENT N° 1: PLUTONIUM OXIDE POWDER

2.1.1 Description

The powder may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

Traces of impurities may be present.

2.1.1.1 Isotopic composition and masses

Several cases may arise depending on the isotopic properties of the plutonium:

- 1st case, content 1a: the isotopic composition of plutonium verifies the following condition (% in mass)

  5 % ≤ ^{240}Pu.

  The maximum quantity of plutonium oxide powder which may be transported corresponds to a mass of:

  - 13 kg of the element Pu if the internal arrangement used is of type AA 226 or AA 227. The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized,
  - 17 kg with other types of internal arrangements authorized in the absence of materials with a hydrogen content exceeding that of water,
  - 5 kg with other types of internal arrangements authorized in the presence of materials with a hydrogen content exceeding that of water,

- 2nd case, content 1b: the isotopic composition of plutonium verifies the following condition (% in mass)

  17 % ≤ ^{240}Pu

  ^{241}Pu/^{240}Pu ≤ 64,7 %

  ^{242}Pu/^{241}Pu ≥ 9,1 %.

  The maximum quantity of plutonium oxide powder which may be transported corresponds to a mass of 5 kg of the element Pu: The internal arrangement is of type TN 90 or TN998.

  The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

- 3rd case, content 1c: the isotopic composition of the plutonium is not regulated.

  If the internal arrangements fitted are of type TN 90, AA 203, AA 204 or AA 41, the maximum quantity of plutonium oxide powder which may be transported corresponds to a mass of:

  - 5 kg of the element Pu in the absence of materials with a hydrogen content exceeding that of water,
  - 4 kg of the element Pu in the presence of materials with a hydrogen content exceeding that of water.

  Internal arrangements of type AA 226 and AA 227 are not authorized.

2.1.1.2 Physical properties

Maximum density of the powder: 3,5.

2.1.1.3 Chemical form

Oxide.

2.1.1.4 Special form

The material does not have a special form.

2.1.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

For information, for content 1b, residual fission products present in the powder are assimilated in a detrimental manner at 3.10^5 Bq of ^{106}Ru per gram of element of plutonium and americium.

2.1.1.6 Maximum thermal power emitted by content

The maximum total thermal power emitted by the PuO_2 powder depends on the internal arrangements used: For all content except content 1b:

- if the powder is packed with type AA 226, AA 227 or TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the powder is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,
- for content 1b, the maximum total thermal power per container is limited to:
  - 51 W if Model 2500 containers are used with tertiary packing TN 998. In this case, a maximum of 2 Model 2500 containers may be loaded per package,
  - 21 W if Model 1000 containers are used with tertiary packing TN 90. In this case, a maximum of three Model 1000 containers may be loaded per package,
  - 2.2 W if Model 200 containers are used with tertiary packing TN 90. In this case, a maximum of 5 Model 200 containers may be loaded per package,
  - if Model 5 containers are used with tertiary packing TN 90, the maximum thermal power per secondary packing container is:
    - 0.5 W, if the maximum number of Model 5 containers loaded per package is 10,
    - 0.25 W, if the maximum number of Model 5 containers loaded per package is 20.

The maximum mass power is 20 W/kg.

Transport in a caisson is only authorized for content 1b. If several packages are transported in a caisson, the maximum total thermal power emitted by all packages must be less than 468 W and the maximum power per package is 52 W.

2.1.1.7 Specific provisions

For all content with the exception of content 1b, if water content is less than 0.5%, no specific provisions are required. If powder with a humidity of between 0.5 and 3% of water and/or powder packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.
With regard content 1b, the specific provisions specified in attachment 3.7-1 limit transport time depending on quantities of materials, the type of packing used and the maximum thermal power of the load.

2.1.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

For all content with the exception of content 1b, limits are specified in the following tables.
<u>Water content of less than 0.5 % - absence of covers</u>

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2,66.10^{-4}	≤ **87**
1,33.10^{-4}	≤ **175**
6,65.10^{-5}	≤ **352**
1,33.10^{-5}	≤ **1799**

<u>Water content of more than 0.5 % - absence of covers</u>

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **15**
1.33x10^{-4}	≤ **31**
6.65x10^{-5}	≤ **63**
1.33x10^{-5}	≤ **331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **78**
1.33x10^{-4}	≤ **158**
6.65x10^{-5}	≤ **318**
1.33x10^{-5}	≤ **1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **14**
1.33x10^{-4}	≤ **28**
6.65x10^{-5}	≤ **56**
1.33x10^{-5}	≤ **296**

For content 1b, limits are specified in the following table:

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	**60**
1.33x10^{-4}	**121**
6.65x10^{-5}	**246**
1.33x10^{-5}	**1266**

2.1.2 Internal arrangements

For all content with the exception of content 1b, powder must be packed, as applicable, in an internal arrangement

with a maximum diameter of 130 mm and a minimum thickness of 5 mm (AA 226 & AA227) or in an internal arrangement with a maximum diameter of 120 mm and a minimum thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the powder **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [powder + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203, AA 41, AA 226 or AA 227.
  No heat sealed plastic material cover may be used to pack the material in containers AA 226 and AA 227. Secondary packing is mandatory for container AA 227. This secondary packing will consist of either an AA 236, or an AA 303, which are used with blocking devices, intended to prevent opening (Cf. attachment 1-1),
- the following **spacers** must be used to position the tertiary packing container in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10 or E6,
  - with the AA 203 : spacers E1 and E8,
  - with one AA 41 : spacers E1 and E11,
  - with two AA 41s : spacers E1, E12 and E13,
  - with three AA 41s : spacers E1, E9 & 2 × E13,
  - with the AA 226 : spacer E1,
  - with the AA 227 : spacer E1.

The total mass of the entire load of internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg, and the entire load of internal arrangements AA 226 and AA 227 is limited to 14 kg and 45 kg respectively.

For content 1b, powder must be packed, as applicable, in an internal arrangement with a maximum diameter of 120 mm and a thickness of 2 mm or in an internal arrangement with a maximum diameter of 143 mm and a thickness of 4 mm. The following principles apply for packing:

- the powder may be placed in closed boxes (primary packing) in stainless steel (Model 200, 1000 & 2500 boxes) or in brass (Model 5 boxes). Primary packing boxes may be surrounded by one or several covers in plastic materials (PVC). With Model 5 boxes, a glass container may be present between the powder and the primary packing.

The nominal dimensions of primary packing boxes are specified in attachment n°1-1

- these boxes are then placed in a secondary packing container consisting of a stainless steel box (Model 5, 200, 1000 & 2500 containers) with a screwed lid,
- the final assembly [powder + primary packing + covers + secondary packing] must then be placed in a stainless steel tertiary packing container consisting of a case closed with a lid equipped with seals. Two tertiary packing containers may be used. These containers are either of type TN 90 (for Model 5, 200 & 1000 assemblies), or of type TN998 (for Model 2500 assemblies),

  The nominal dimensions of secondary packing containers are specified in attachment n°1-1.

  Comments:

  - o Model 5 boxes are placed in Model 5 containers. The powder + Model 5 box + covers + Model 5 container assembly represents Model 5. The same applies for the Model 200, 1000 & 2500 assemblies,
  - o an external container may be combined with any primary box of a lower or equal Model (e.g.: a Model 2500 container may be combined with a Model 1000 box).

  Secondary packing containers are placed in a basket. This basket is intended to simplify the loading and unloading of containers.

- in the specific case of Model 1000 and 2500 assemblies, an aluminium ring is placed around the main section of the containers.
- the following spacers must be used to position the tertiary packing container in the package cavity:
  - ➢ with the TN 90 : spacers E1 and E2,
  - ➢ for the TN 998 : spacer E14.

The packages loaded with containers 1000 and 2500 must be inerted using helium.

Internal arrangement TN 998 must be inerted in helium.

Model 1000 and 2500 secondary packing containers must be inerted using helium.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

The entire load of internal arrangement TN 998 is limited to 65 kg.

2.2 CONTENT N° 2: URANIUM OXIDE POWDER

This content consists of uranium oxide powder in UO_2 or U_3O_8 format.

2.2.1 Description

The powder may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.2.1.1 Isotopic composition and masses

The enrichment of uranium 235 is not regulated.

Should the enrichment of the uranium be more than or equal to 20%, the maximum mass of uranium for transport is equal to 20 kg.

Should the enrichment of the uranium be less than 20%, the maximum mass of uranium for transport is equal to 40 kg.

2.2.1.2 Physical properties

Maximum density of the powder: 3,5.

2.2.1.3 Chemical form

Oxide.

2.2.1.4 Special form

The material does not have a special form.

2.2.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded. For information, it has been demonstrated that, if uranium is transported for reprocessing, the regulatory limits of dose rates are satisfied if the total equivalent activity of residual fission products is less than 2.52 GBq (68 mCi).

2.2.1.6 Specific activity

If the uranium is produced in reprocessing, the specific activity of the content must be less than 44 A_2/g.

2.2.2 Internal arrangements

The oxide powder is placed in boxes (primary packing).

These boxes are positioned in containers (secondary packing) of type TN 90, AA 204, AA 203 or AA 41.

The following spacers must be used to position the tertiary packing container in the package cavity:

- with the TN 90 : spacers E1 and E2,
- with the AA 204 : spacers E1 and E10 or E6,
- with the AA 203 : spacers E1 and E8,
- with one AA 41 : spacers E1 and E11,
- with two AA 41s : spacers E1, E12 and E13,
- with three AA 41s : spacers E1, E9 & 2 × E13,

The allowable mass of the entire load placed in the cavity in the package = 116 kg.

2.3 CONTENT N° 3: MIXED URANIUM-PLUTONIUM OXIDE POWDER

2.3.1 Description

The powder may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

Traces of impurities may be present.

2.3.1.1 Isotopic composition and masses

Several possibilities exist based on plutonium content and the isotopic properties of the plutonium and uranium:

- possibility 1: non-regulated enrichment in ^{235}U:
  - content 3a:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≥ 5%** (% in mass). The maximum quantity of mixed oxide powder for transport is such that mass (U + Pu) is equal to a maximum of 18 kg if the internal arrangements used are of type AA 226 or AA 227, and 20 kg with other authorized types of internal arrangements.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.
  - content 3b:
    plutonium content in the uranium-plutonium mixture and the isotopic composition of the plutonium are not regulated. The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 5 kg: The internal arrangement used must be of type TN 90.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

- possibility 2: the uranium is natural or depleted uranium:
  - content 3c:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≤ 5%** (% in mass). The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 40 kg irrespective of the internal arrangements used:
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.
  - content 3d:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 10 %** (in mass) and the isotopic composition of the plutonium is not regulated. The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 6.6 kg: Internal arrangements of type AA 226 and AA 227 are not authorized.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is authorized.

2.3.1.2 Physical properties

For content 3b, the maximum density of the powder is 3.5.

For other content, density is not regulated.

2.3.1.3 Chemical form

Oxide.

2.3.1.4 Special form

The material does not have a special form.

2.3.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

For information, for content 3b, residual fission products present in the powder are assimilated in a detrimental manner at 3.10^5 Bq of ^{106}Ru per gram of element of plutonium and americium.

2.3.1.6 Maximum thermal power emitted by content

The maximum total thermal power emitted by the $(U,Pu)O_2$ powder depends on the internal arrangements used:
For all content except content 3b:

- if the powder is packed with type AA 226, AA 227 or TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the powder is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,
- for content 3b, the maximum total thermal power per container is limited to:
  - 21 W if Model 1000 containers are used with tertiary packing TN 90. In this case, a maximum of three Model 1000 containers may be loaded per package,
  - 2.2 W if Model 200 containers are used with tertiary packing TN 90. In this case, a maximum of 5 Model 200 containers may be loaded per package,
  - if Model 5 containers are used with tertiary packing TN 90, the maximum thermal power per secondary packing container is:
    - 0.5 W, if the maximum number of Model 5 containers loaded per package is 10,

- 0.25 W, if the maximum number of Model 5 containers loaded per package is 20.

The maximum mass power is 20 W/kg.

Transport in a caisson is only authorized for content 3b. If several packages are transported in a caisson, the maximum total thermal power emitted by all packages must be less than 468 W and the maximum power per package is 52 W.

2.3.1.7 Specific provisions

For all content with the exception of content 3b, if water content is less than 0.5%, no specific provisions are required. If powder with a humidity of between 0.5 and 3% of water and/or powder packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.
With regard content 3b, the specific provisions specified in attachment 3.7-1 limit transport time depending on quantities of materials, the type of packing used and the maximum thermal power of the load.

2.3.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

For all content with the exception of content 3b, limits are specified in the following tables.

Water content of less than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
$2.66x10^{-4}$	≤ **87**
$1.33x10^{-4}$	≤ **175**
$6.65x10^{-5}$	≤ **352**
$1.33x10^{-5}$	≤ **1799**

Water content of more than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
$2.66x10^{-4}$	≤ **15**
$1.33x10^{-4}$	≤ **31**
$6.65x10^{-5}$	≤ **63**
$1.33x10^{-5}$	≤ **331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
$2.66x10^{-4}$	≤ **78**
$1.33x10^{-4}$	≤ **158**
$6.65x10^{-5}$	≤ **318**
$1.33x10^{-5}$	≤ **1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	**≤ 14**
1.33x10^{-4}	**≤ 28**
6.65x10^{-5}	**≤ 56**
1.33x10^{-5}	**≤ 296**

For content 3b, limits are specified in the following table:

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	**60**
1.33x10^{-4}	**121**
6.65x10^{-5}	**246**
1.33x10^{-5}	**1266**

2.3.2 Internal arrangements

The powder must be packed, as applicable, in an internal arrangement with a maximum diameter of 130 mm and a minimum thickness of 5 mm (AA 226 & AA227) or in an internal arrangement with a maximum diameter of 120 mm and a minimum thickness of 2 mm (TN 90, AA 204, AA 203, AA 41).

For all content with the exception of content 3b, packing principles are as follows:

- the powder **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [powder + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203, AA 41, AA 226 or AA 227.
  No heat sealed plastic material cover may be used to pack the material in containers AA 226 and AA 227. Secondary packing is mandatory for container AA 227. This secondary packing will consist of either an AA 236, or an AA 303, which are used with blocking devices, intended to prevent opening (Cf. attachment 1-1),
- the following spacers must be used to position the tertiary packing container in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10 or E6,
  - with the AA 203 : spacers E1 and E8,

- with one AA 41 : spacers E1 and E11,
- with two AA 41s : spacers E1, E12 and E13,
- with three AA 41s : spacers E1, E9 & 2 × E13,
- with the AA 226 : spacer E1,
- with the AA 227 : spacer E1.

For content 3b, packing principles are as follows:

- the powder may be placed in closed boxes (primary packing) in stainless steel (Model 200 & 1000 boxes) or in brass (Model 5 boxes). Primary packing boxes may be surrounded by one or several covers in plastic materials (PVC). With Model 5 boxes, a glass container may be present between the powder and the primary packing.

  The nominal dimensions of primary packing boxes are specified in attachment n°1-1
- these boxes are then placed in a secondary packing container consisting of a stainless steel box (Model 5, 200 & 1000 containers) with a screwed lid,
- the final assembly [powder + primary packing + covers + secondary packing] must then be placed in a stainless steel tertiary packing container consisting of a case closed with a lid equipped with seals. Two tertiary packing containers may be used. Tertiary containers are of type TN 90,

  The nominal dimensions of secondary packing containers are specified in attachment n°1-1.

  Comments:

  - Model 5 boxes are placed in Model 5 containers. The powder + Model 5 box + covers + Model 5 container assembly represents Model 5. The same applies for the Model 200 & 1000 assemblies,
  - an external container may be combined with any primary box of a lower or equal Model (e.g.: a Model 1000 container may be combined with a Model 200 box).
- secondary packing containers are placed in a basket. This basket is intended to simplify the loading and unloading of containers.
- in the specific case of Model 1000 assemblies, an aluminium ring is placed around the main section of the containers.
- spacers E1 & E2 must be used to block the TN 90.

The packages loaded with Model 1000 containers must be inerted using helium.

Model 1000 secondary packing containers must be inerted using helium.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.4 CONTENT N° 4: METAL URANIUM BARS

2.4.1 Description

This content consists of metal uranium bars.

The uranium is not produced in reprocessing.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.4.1.1 Isotopic composition and masses

The isotopic composition of the uranium is not regulated.

The maximum allowable mass corresponds to 9 bars of non-irradiated metal uranium, with a mass per unit of 5 kg (i.e. a total maximum mass of 45 kg of metal uranium loaded in the package)

2.4.1.2 Physical properties

Density is not regulated.

2.4.1.3 Chemical form

Metal.

2.4.1.4 Special form

The material does not have a special form.

2.4.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.4.1.6 Specific provisions

Specific attention will be paid to the condition of the surface of the content when loading in the package. The surface of the content must not have either scratches or traces of hydrides.

2.4.1.7 Specific activity

If the uranium is produced in reprocessing, the specific activity of the content must be less than 44 A_2/g.

2.4.2 Internal arrangements

The secondary packing container must be of type TN 90.

An E4 type full block must be placed between each bar to ensure a minimum edge-to-edge distance of 90 mm between bars in both normal and accident transport conditions (cf. attachment n°1-1).

In addition, all blocks intended for a maximum load must be compiled in the cavity of the container, even if the number of bars actually loaded in the container is not equal to the maximum allowable number of bars.

Blocks E1 and E2 must be used to block the packing container TN 90 in the package cavity.

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg. The maximum allowable mass of the entire load placed in the cavity in the package (blocks + container + material transported) = 116 kg.

2.5 CONTENT N° 5: COMPACT STACKS OF ZEBRA TYPE PLATES

2.5.1 Description

This content consists of sub-assemblies including a compact stack of metal plutonium plates surrounded by a stainless steel duct, with a height less than or equal to 100 mm (= 31 plates).

The plutonium is produced in reprocessing, but must not have been subject to post-reprocessing irradiation.

The square plates have the following dimensions:

- total thickness : $e \leq 3.17$ mm,
- lateral dimension : $a \leq 50.7$ mm,
- thickness of the stainless steel duct : $e_{duct} \langle 0.40$ mm.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.5.1.1 Isotopic composition and masses

The isotopic composition of the plutonium obeys the following:

$$\frac{^{240}Pu}{Pu_{total}} \geq 0.15 \text{ (in mass)}$$

The maximum mass of Pu per plate is 83 g. A maximum of 7 sub-assemblies (7 plate stacks) may be transported per package TN-BGC 1, i.e. a total maximum mass of approximately 18 kg of Pu.

2.5.1.2 Physical properties

The density of the metal plutonium is less than or equal to 19.6.

2.5.1.3 Chemical form

Metal.

2.5.1.4 Special form

The material does not have a special form.

2.5.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.5.1.6 Maximum thermal power emitted by content

The maximum thermal power emitted by the content of a package must be less than 150 W.

Transport in a caisson is not authorized.

2.5.1.7 Specific activity

The specific activity of the content is limited depending on the leakage flux detected before dispatch.

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2.66×10^{-4}	≤ **87**
1.33×10^{-4}	≤ **175**
6.65×10^{-5}	≤ **352**
1.33×10^{-5}	≤ **1799**

2.5.2 Internal arrangements

Internal arrangements are intended to guarantee the longitudinal and radial positioning of plate stacks in normal and accident transport conditions. Stacks must be packed in an internal arrangement with a maximum diameter of 120 mm and a minimum thickness of 2 mm. The following packing principle applies:

- each plate stack is contained in a box (**primary packing** – Cf. attachment 1-1) guaranteeing the compactness of the stack,
- boxes **must** be mutually separated using full **spacers** of type E5 (Cf. attachment 1-1), which guarantee minimum spacing of 90 mm between each stack. All E5 spacers must be loaded in the container even if the number of stacks actually loaded is not the maximum allowable number of stacks,
- all of these elements must then be placed in a TN 90 type stainless steel container (**secondary packing**), which positions and blocks the plate stacks radially,
- **spacers** E1 and E2 must be used to block the secondary packing container in the package cavity.

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg. The maximum allowable mass of the entire load placed in the cavity in the package (blocks + container + material transported) = 116 kg.

2.6 CONTENT N° 6: URANYL NITRATE

2.6.1 Description

2.6.1.1 Chemical form

This liquid content consists of an aqueous solution of uranyl nitrate.

The uranium may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.6.1.2 Isotopic composition

Enrichment in ^{235}U is less than or equal to 95%.

2.6.1.3 Maximum quantity of uranyl nitrate transported

The maximum authorized quantity is 10 litres of aqueous solution of uranyl nitrate, with a concentration in uranium less than or equal to 500 $g.l^{-1}$.

2.6.1.4 Chemical form

$UO_2(NO_3)_2$-H_2O.

2.6.1.5 Special form

The material does not have a special form.

2.6.1.6 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.6.1.7 A_2

The volumic activity of the solution must be less than $1.64.10^{-1}$ A_2/m^3.

2.6.2 Internal arrangements

The uranyl nitrate solution is placed in one or several overlapping bottles (primary packing) in polyethylene (or equivalent material).

This or these bottles may be positioned in a storage rack and placed in a container (secondary packing) which must be of type TN 90.

Block E3 (Cf. attachment n°1-1) must be used to block the packing container TN 90 in the package cavity.

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg. The maximum

allowable mass of the entire load placed in the cavity in the package (block + container + material transported) = 116 kg.

2.7 CONTENT N° 7: RODS OR SECTIONS OF RODS OR PELLETS OF URANIUM OXIDE,

This content consists of uranium oxide (UO_2 only), which may occur in pellet format, as sections of rods or as a fuel rod cluster.

2.7.1 Description

The uranium is non-irradiated uranium. If the uranium is produced in reprocessing, the material must not have been subjected to post-reprocessing irradiation.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.7.1.1 Isotopic composition and masses

The enrichment of uranium 235 is not regulated.

Should the enrichment of the uranium be more than or equal to 20%, the maximum mass of uranium for transport is equal to 20 kg.

Should the enrichment of the uranium be less than 20%, the maximum mass of uranium for transport is equal to 40 kg.

2.7.1.2 Physical properties

The density of pellets is equal to 100% of the maximum theoretical density as a maximum (d=10.96).

The maximum internal pressure of rods is 3 bar absolute at 20°C.

The pellets may be damaged or possibly in debris format.

2.7.1.3 Chemical form

Oxide.

2.7.1.4 Special form

The material does not have a special form.

2.7.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.7.1.6 Specific activity

If the uranium is produced in reprocessing, the specific activity of the content must be less than 22 A_2/g.

2.7.2 Internal arrangements

The uranium oxide pellets may be placed in boxes (primary packing). The entire assembly will be placed in a container which acts as secondary packing.

Sections of rods may be placed in case tubes. The rods or case tubes may be placed in a storage rack.

Only the following types of secondary packing containers may be used: TN 90, AA 204, AA 203 or AA 41.

The following spacers must be used to position the tertiary packing container in the package cavity:

- with the TN 90 : spacers E1 and E2,
- with the AA 204 : spacers E1 and E10 or E6,
- with the AA 203 : spacers E1 and E8,
- with one AA 41 : spacers E1 and E11,
- with two AA 41s : spacers E1, E12 and E13,
- with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in the internal arrangements AA 204 & TN 90 is limited to 60 kg.

The allowable mass of the entire load placed in the cavity in the package = 116 kg.

2.8 CONTENT N° 8: RODS OR SECTIONS OF RODS OR PELLETS OF MIXED URANIUM-PLUTONIUM OXIDE,

2.8.1 Description of content

This content consists of mixed uranium-plutonium oxide (UO_2-PuO_2) which can be found in pellet format, as sections of rods or as a fuel rod cluster including a metal duct holding the pellets.

The pellets, whether raw or embedded in rods, may come from reprocessing, but must not have been subject to post-reprocessing irradiation. They may not contain carbon other than in trace format.

2.8.1.1 Isotopic composition and masses

Several possibilities exist based on plutonium content and the isotopic properties of the plutonium and uranium:

- possibility 1: non-regulated enrichment in ^{235}U:
  - content 8a:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≤ 5%** (% in mass).
    For N ≤ 25, maximum mass for transport is equal to:
    - 12.2 kg if the material is confined in a AA 226 or AA 227 type internal arrangement,
    - 15.6 kg with other authorized types of internal arrangements.

    For N ≤ 7, maximum mass for transport is equal to:
    - 18 kg if the material is confined in a AA 226 or AA 227 type internal arrangement,
    - 20 kg with other authorized types of internal arrangements.

    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

- possibility 2: the uranium is natural or depleted uranium:
  - content 8b:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≤ 5%** (% in mass). The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 40 kg irrespective of the internal arrangements used:
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.
  - content 8c:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 10 %** (in mass) and the isotopic composition of **the plutonium is not regulated**. The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 6.6 kg: Internal arrangements of type AA 226 and AA 227 are not authorized.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is authorized.

2.8.1.2 Physical properties

The density of pellets is equal to 100% of the maximum theoretical density as a maximum (d=10.96).

The maximum internal pressure of rods is 2 bar absolute at 20°C.

Pellets may be damaged or possibly in debris format.

2.8.1.3 Chemical form

Oxide.

2.8.1.4 Special form

The material does not have a special form.

2.8.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.8.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by this content depends on the internal arrangements used:

- if the content is packed with type AA 226, AA 227 or TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the content is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
    - 20 W if a tertiary packing container type AA41 is used,
    - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.8.1.7 Specific activity

In the absence of covers and if the rods are pressurized, the specific activity of the content is limited based on the controlled leakage flux prior to transport as specified in the table below.

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66×10^{-4}	**≤ 47**
1.33×10^{-4}	**≤ 94**
6.65×10^{-5}	**≤ 191**
1.33×10^{-5}	**≤ 987**

If covers are fitted, and if pellets and/or rod debris are transported, the specific activity of the content is limited based on the controlled leakage flux prior to transport as specified in the table below.

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66×10^{-4}	**≤ 78**
1.33×10^{-4}	**≤ 158**
6.65×10^{-5}	**≤ 318**
1.33×10^{-5}	**≤ 1635**

2.8.1.8 Specific provisions

If the material is packed with vinyl covers, the specific provisions described in chapter 3.7 limit transport time depending on quantities of material and the type of packing used.

2.8.2 Internal arrangements

Pellets of mixed uranium-plutonium oxide (or sections of rods or rods) must be packed in cylindrical internal arrangements. Packing must apply the following principles:

- **primary packing**:
  - pellets **may** be placed in boxes,
  - sections of rods are placed in case tubes. These case tubes **may** be placed in a storage rack,
  - The rods or case tubes **may** be placed in a storage rack.

  Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane),

- **secondary packing**: the boxes (or the set of boxes) **may** then be placed in other boxes,

- tertiary packing: the final assembly (pellets/sets of rods/rods + any primary packing + any secondary packing) must then be placed in a stainless steel case closed with a lid equipped with seals (controllable or otherwise). Six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203, AA 41, AA 226 or AA 227 (AA 227 containers may not be used to transport rods or sections of

rods).
No heat sealed plastic material cover may be used to pack the material in containers AA 226 & AA 227. Secondary packing is mandatory with container AA 227; this packing consists of an AA 236 container, an AA 303 container or an equivalent secondary container (welded stainless steel, with an internal diameter less than or equal to 113 mm) used with blocking devices intended to prevent opening (Cf. attachment 1-1),

- the following spacers must be used to position the tertiary packing container(s) in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10,
  - with the AA 203 : spacers E1 and E8,
  - with one AA 41 : spacers E1 and E11,
  - with two AA 41s : spacers E1, E12 and E13,
  - with three AA 41s : spacers E1, E12 & 2 × E13,
  - with the AA 226 : spacer E1,
  - with the AA 227 : spacer E1.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.9 CONTENT N° 9: HETEROGENEOUS PLUTONIUM OXIDE MIX

2.9.1 Description

This content consists of plutonium oxide in powder or pellet format, or as pellet segments, rod segments or as a heterogeneous mix of these materials.

The material may come from reprocessing, but must not have been subject to post-reprocessing irradiation. The powder may not contain carbon other than in trace format.

The presence of materials with a hydrogen content exceeding that of water is authorized.

2.9.1.1 Isotopic composition and masses

Type TN 90, AA 203, AA 204 or AA 41 internal arrangements are used.

If the isotopic composition of plutonium is not regulated, the maximum quantity of plutonium oxide which may be transported corresponds to a mass of 4 kg of the element Pu and N=1.

If the isotopic composition of plutonium is such that $^{240}Pu \geq 5$ %, the maximum quantity of plutonium oxide which may be transported corresponds to a mass of 5 kg of the element Pu and N=10.

Internal arrangements of type AA 226 and AA 227 are not authorized.

2.9.1.2 Physical properties

The density of pellets is equal to 100% of the maximum theoretical density as a maximum (d=10.96).

2.9.1.3 Chemical form

Oxide.

2.9.1.4 Special form

The material does not have a special form.

2.9.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

2.9.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by this mix depends on the internal arrangements used:

- if the material is packed with type TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the material is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal

power emitted is equal to 170 W,

- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

2.9.1.7 Specific provisions

If water content is less than 0.5%, no specific provisions are required. If material with a humidity of between 0.5 and 3% of water and/or material packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.

2.9.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

limits are specified in the following tables.

Water content of less than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2.66×10^{-4}	≤ **87**
1.33×10^{-4}	≤ **175**
6.65×10^{-5}	≤ **352**
1.33×10^{-5}	≤ **1799**

Water content of more than 0.5 % - absence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	≤ **15**
$1.33x10^{-4}$	≤ **31**
$6.65x10^{-5}$	≤ **63**
$1.33x10^{-5}$	≤ **331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	≤ **78**
$1.33x10^{-4}$	≤ **158**
$6.65x10^{-5}$	≤ **318**
$1.33x10^{-5}$	≤ **1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	≤ **14**
$1.33x10^{-4}$	≤ **28**
$6.65x10^{-5}$	≤ **56**
$1.33x10^{-5}$	≤ **296**

2.9.2 Internal arrangements

The material must be packed, as applicable, in an internal arrangement with a maximum diameter of 120 mm and a thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the material **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [powder + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203 or AA 41.
- the following **spacers** must be used to position the tertiary packing container in the package cavity:

- with the TN 90 : spacers E1 and E2,
- with the AA 204 : spacers E1 and E10 or E6,
- with the AA 203 : spacers E1 and E8,
- with one AA 41 : spacers E1 and E11,
- with two AA 41s : spacers E1, E12 and E13,
- with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in internal arrangements is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.10 CONTENT N° 10: MIXED PLUTONIUM AND URANIMUM OXIDE HETEROGENOUS MIX

2.10.1 Description

This content consists of mixed uranium and plutonium oxide as a heterogeneous mix of powder, pellets, pellet segments and rod segments.

The mix may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

The plutonium may not contain carbon other than in trace format.

2.10.1.1 Isotopic composition and masses

Several possibilities exist based on plutonium content and the isotopic properties of the plutonium and uranium:

- possibility 1: non-regulated enrichment in ^{235}U:
  - content 10a:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≤ 5%** (% in mass). In this case, for package N= 25, the maximum mass for transport is 9.6 kg if the material is confined in a type AA 226 or AA 227 internal arrangement, and 14.2 kg with other authorized types of internal arrangements.
    In other cases, the maximum mass for transport is 18 kg if the material is confined in a type AA 226 or AA 227 internal arrangement, and if N = 17, and 20 kg with other authorized types of internal arrangements if N = 20.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

- possibility 2: the uranium is natural or depleted uranium:
  - content 10b:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 30 %** (in mass) and the isotopic composition of the plutonium is such that **^{240}Pu ≤ 5%** (% in mass). The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 40 kg irrespective of the internal arrangements used:
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.
  - content 10c:
    plutonium content in the uranium-plutonium mixture is such that **Pu/U+Pu ≤ 10 %** (in mass) and the isotopic composition of the plutonium is not regulated. The maximum quantity of mixed plutonium oxide powder which may be transported is such that mass (U + Pu) is equal to a maximum of 6.6 kg: Internal arrangements of type AA 226 and AA 227 are not authorized.
    The presence of hydrogenated materials with a hydrogen content exceeding that of water is authorized.

2.10.1.2 Physical properties

Density is not regulated.

2.10.1.3 Chemical form

Oxide.

2.10.1.4 Special form

The material does not have a special form.

2.10.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

2.10.1.6 Maximum thermal power emitted by content

The maximum total thermal power emitted by the $(U,Pu)O_2$ mixture depends on the internal arrangements used:

- if the powder is packed with type AA 226, AA 227 or TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the powder is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.10.1.7 Specific provisions

If water content is less than 0.5%, no specific provisions are required. If material with a humidity of between 0.5 and 3% of water and/or material packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.

2.10.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

Limits are specified in the following tables.

Water content of less than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **87**
1.33x10^{-4}	≤ **175**
6.65x10^{-5}	≤ **352**
1.33x10^{-5}	≤ **1799**

Water content of more than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **15**
1.33x10^{-4}	≤ **31**
6.65x10^{-5}	≤ **63**
1.33x10^{-5}	≤ **331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **78**
1.33x10^{-4}	≤ **158**
6.65x10^{-5}	≤ **318**
1.33x10^{-5}	≤ **1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	≤ **14**
$1.33x10^{-4}$	≤ **28**
$6.65x10^{-5}$	≤ **56**
$1.33x10^{-5}$	≤ **296**

2.10.2 Internal arrangements

The mixture must be packed, as applicable, in an internal arrangement with a maximum diameter of 130 mm and a minimum thickness of 5 mm (AA 226 & AA227) or in an internal arrangement with a maximum diameter of 120 mm and a minimum thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the mixture **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [mixture + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203, AA 41, AA 226 or AA 227.
  No heat sealed plastic material cover may be used to pack the material in containers AA 226 and AA 227. Secondary packing is mandatory for container AA 227. This secondary packing will consist of either an AA 236, or an AA 303, which are used with blocking devices, intended to prevent opening (Cf. attachment 1-1),
- the following **spacers** must be used to position the tertiary packing container in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10 or E6,
  - with the AA 203 : spacers E1 and E8,
  - with one AA 41 : spacers E1 and E11,
  - with two AA 41s : spacers E1, E12 and E13,
  - with three AA 41s : spacers E1, E9 & 2 × E13,
  - with the AA 226 : spacer E1,
  - with the AA 227 : spacer E1.

The total mass of the entire load of internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg, and the entire load of internal arrangements AA 226 and AA 227 is limited to 14 kg and 45 kg respectively.
The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.11 CONTENT N° 11: SOLID URANIUM-BEARING MATERIALS

Content consists of uranium-bearing materials in solid form, to the exclusion of powders.

2.11.1 Description

The uranium is non-irradiated uranium and is not produced in reprocessing.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.11.1.1 Isotopic composition and masses

Enrichment in uranium 235 is not regulated, however only one single type of uranium-bearing material may be present per package (one single isotopic composition).

For air transport: the maximum quantity of uranium 235 transported per TN-BGC 1 package is 7 kg;

For all types of transport other than air: the maximum quantity transported per TN-BGC 1 package depends on the guaranteed confinement diameter, which is resumed in the following table:

Guaranteed confinement diameter (mm)	Maximum quantity transported (kg)
100 < ∅ ≤ 120	Mass $^{235}U \leq 7$
60 < ∅ ≤ 100	Mass $^{235}U \leq 15$
∅ ≤ 60	Mass ^{235}U not regulated

Should it not be possible to guarantee the presence of one single isotopic composition per package, the following mass limitations apply:

- if the uranium enrichment exceeds 20%, the maximum mass of uranium for transport is equal to 7 kg.
- if the uranium enrichment of each type of uranium-bearing material is less than or equal to 20%, the maximum mass of uranium for transport is equal to 40 kg.

2.11.1.2 Physical properties

The density of the material is not regulated.

2.11.1.3 Chemical form

The material may only occur in one of the following chemical forms:

- metal uranium,
- uranium oxides: UO_2, UO_3, U_3O_8,
- uranium tetrafluoride: UF4;
- uranium nitrides: UN, U_2N_3, UN_2,

- uranium carbides: UC, UC_2 and U_2C_3,
- uranium alloys with several of the following metals: aluminium (Al), molybdenum (Mo), silicon (Si).

2.11.1.4 Special form

The material does not have a special form.

2.11.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.11.2 Internal arrangements

Metal uranium powders are placed in boxes (primary packing); These boxes are then placed in a secondary packing container.

Only the following types of secondary packing containers may be used: TN 90, AA 204, AA 203 or AA 41.

If the diameter required is strictly less than 120 mm, an E7 spacer will be used to ensure the positioning and radial blocking inside the TN 90 packing container (Cf. attachment 1-1).

The following spacers must be used to position the tertiary packing container in the package cavity:

- with the TN 90 : spacers E1 and E2,
- with the AA 204 : spacers E1 and E10 or E6,
- with the AA 203 : spacers E1 and E8,
- with one AA 41 : spacers E1 and E11,
- with two AA 41s : spacers E1, E12 and E13,
- with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.12 CONTENT N° 15: RADIOACTIVE SOURCES IN A SPECIAL PU-OX-TYPE FORMAT

2.12.1 Description of content

The content consists of Pu-Ox type sources approved for dimension F/003/S.

Each source consists of three envelopes, including two welded in stainless steel, with a minimum thickness of 2 mm.

Each source is packed in an ORIS type CIS-BIO box (Cf. attachment 1-1).

The presence of a large quantity of highly reflective materials such as beryllium, graphite and heavy water is excluded.

2.12.1.1 Isotopic composition and masses

Sources may contain the following radioelements: ^{237}Np, ^{238}Pu, ^{239}Pu, ^{242}Pu, ^{241}Am, ^{243}Am, ^{242}Cm, ^{244}Cm.

Each embedded source contains a maximum of 30 grams of radioactive material in powder format.

The load consists of a maximum of seven Pu-Ox type sources approved for dimension F/003/S.

2.12.1.2 Physical form

The material is in powder format.

2.12.1.3 Chemical form

The material is in oxide format.

2.12.1.4 Special form

The material is in special format.

2.12.1.5 Specific activity

The specific activity of the content is limited depending on the leakage flux detected before dispatch.

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2.66×10^{-4}	≤ **87**
1.33×10^{-4}	≤ **175**
6.65×10^{-5}	≤ **352**
1.33×10^{-5}	≤ **1799**

2.12.1.6 Thermal power and activity

The maximum activity of each source, in accordance with the certificate of approval F/003/S, is 18.5 TBq (500 Curies) as a maximum. The activity of the content must be such that, in view of the nature and energy of the

radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

The thermal power is less than 120 W.

2.12.2 Internal arrangements

The secondary packing container must be of type TN 90. Spacers E1 and E2 must be used to block the container TN 90 in the package cavity.

The useful height of container TN 90 is equal to 1397 mm, therefore the 7 boxes containing sources must be blocked using a spacer of a suitable length.

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg. The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.12.3 Documentation

The certificate of approval of the type of source in special format loaded in the package must be valid and available from the sender. The identification marking must appear on the transport document [ADR - paragraph 5.4.1.2.5.1j] and the sender must be able to present this certificate to the carrier prior to loading [ADR - paragraph 5.4.1.2.5.3]. Copies of these certificates must be submitted to the competent authority in the relevant country in the initial territory of the package by the sender prior to initial dispatch [ADR - paragraph 5.1.5.2.4].

2.13 CONTENT N° 18: PLUTONIUM FLUORIDE

This content consists of plutonium tetrofluoride powder or plutonium fluoride oxide or a mix of the 2.

2.13.1 Description

The powder may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

The powder may not contain carbon other than in trace format.

2.13.1.1 Isotopic composition and masses

Several cases may arise depending on the isotopic properties of the plutonium:

- 1st case, content 18a: the isotopic composition of plutonium verifies the following condition (% in mass)

  $5\ \% \leq {}^{240}Pu$.

  The maximum quantity of plutonium oxide powder which may be transported corresponds to a mass of:

  - 13 kg of the element Pu if the internal arrangement used is of type AA 226 or AA 227. The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized,
  - 17 kg with other types of internal arrangements authorized in the absence of materials with a hydrogen content exceeding that of water,
  - 5 kg with other types of internal arrangements authorized in the presence of materials with a hydrogen content exceeding that of water,

- 2nd case, content 18b: the isotopic composition of the plutonium is not regulated.

  If the internal arrangements fitted are of type TN 90, AA 203, AA 204 or AA 41, the maximum quantity of plutonium oxide powder which may be transported corresponds to a mass of:

  - 5 kg of the element Pu in the absence of materials with a hydrogen content exceeding that of water,
  - 4 kg of the element Pu in the presence of materials with a hydrogen content exceeding that of water.

  Internal arrangements of type AA 226 and AA 227 are not authorized.

2.13.1.2 Physical properties of the powder

Maximum density of the powder: 3,5.

2.13.1.3 Chemical form

The material is in fluoride and oxifluoride format.

2.13.1.4 Special form

The material does not have a special form.

2.13.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

2.13.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by the powder depends on the internal arrangements used:

- if the powder is packed with type AA 226, AA 227 or TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the powder is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
    - 20 W if a tertiary packing container type AA41 is used,
    - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.13.1.7 Specific provisions

If water content is less than 0.5%, no specific provisions are required. If powder with a humidity of between 0.5 and 3% of water and/or powder packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.

2.13.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

Limits are specified in the following tables.

<u>Water content of less than 0.5 % - absence of covers</u>

Pre-transport check (SLR) in Pa.m³.s⁻¹	Specific activity in A2/g
2.66×10^{-4}	**≤ 87**
1.33×10^{-4}	**≤ 175**
6.65×10^{-5}	**≤ 352**
1.33×10^{-5}	**≤ 1799**

Water content of more than 0.5 % - absence of covers

Pre-transport check (SLR) in Pa.m³.s⁻¹	Specific activity in A2/g
2.66×10^{-4}	**≤ 15**
1.33×10^{-4}	**≤ 31**
6.65×10^{-5}	**≤ 63**
1.33×10^{-5}	**≤ 331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m³.s⁻¹	Specific activity in A2/g
2.66×10^{-4}	**≤ 78**
1.33×10^{-4}	**≤ 158**
6.65×10^{-5}	**≤ 318**
1.33×10^{-5}	**≤ 1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in Pa.m³.s⁻¹	Specific activity in A2/g
2.66×10^{-4}	**≤ 14**
1.33×10^{-4}	**≤ 28**
6.65×10^{-5}	**≤ 56**
1.33×10^{-5}	**≤ 296**

2.13.2 Internal arrangements

The powder must be packed, as applicable, in an internal arrangement with a maximum diameter of 130 mm and a minimum thickness of 5 mm (AA 226 & AA227) or in an internal arrangement with a maximum diameter of 120 mm

and a minimum thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the powder **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [powder + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, six tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203, AA 41, AA 226 or AA 227.
  No heat sealed plastic material cover may be used to pack the material in containers AA 226 and AA 227. Secondary packing is mandatory for container AA 227. This secondary packing will consist of either an AA 236, or an AA 303, which are used with blocking devices, intended to prevent opening (Cf. attachment 1-1),
- the following **spacers** must be used to position the tertiary packing container in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10 or E6,
  - with the AA 203 : spacers E1 and E8,
  - with one AA 41 : spacers E1 and E11,
  - with two AA 41s : spacers E1, E12 and E13,
  - with three AA 41s : spacers E1, E9 & 2 × E13,
  - with the AA 226 : spacer E1,
  - with the AA 227 : spacer E1.

The total mass of the entire load of internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg, and the entire load of internal arrangements AA 226 and AA 227 is limited to 14 kg and 45 kg respectively.
The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.14 CONTENT N° 19: MIXED URANIUM-PLUTONIUM NITRIDE

2.14.1 Description

This content consists of mixed uranium-plutonium nitride in solid format (powders, pellets, possibly damaged, debris, etc.) . .).

The plutonium may not contain carbon other than in trace format.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.14.1.1 Isotopic composition and masses

The isotopic composition of the plutonium is not regulated. Enrichment in ^{235}U is not regulated.

The plutonium content of the mix is not regulated.

Maximum allowable mass is equal to 4 kg.

2.14.1.2 Physical properties of the material

The maximum density of pellets is equal to 100% of maximum theoretical density (d=14).

2.14.1.3 Chemical form

The material is in nitride format.

2.14.1.4 Special form

The material does not have a special form.

2.14.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

2.14.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by the content depends on the internal arrangements used:

- if the material is packed with type TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the material is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type

AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.14.1.7 Specific provisions

If the material is packed with vinyl covers, the specific provisions described in chapter 3.7 limit transport time depending on quantities of material and the type of packing used.

To avoid the prior measurement of the shortest dimensions of the objects transported and to prevent any increase in temperature caused by friction, which is complex to quantify, the risks of pyrophoricity in the air will be treated by inerting the package cavity and the internal arrangements (nitrogen, argon, etc.), prior to transport.

2.14.1.8 Specific activity

The specific activity of the content is limited depending on:

- the possible presence of covers,
- leakage flows identified prior to dispatch.

Limits are specified in the following tables.

<u>Absence of covers</u>

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2.66×10^{-4}	≤ **87**
1.33×10^{-4}	≤ **175**
6.65×10^{-5}	≤ **352**
1.33×10^{-5}	≤ **1799**

<u>Use of covers</u>

Pre-transport check (SLR) in Pa.m^3.s^{-1}	**Specific activity in A2/g**
2.66×10^{-4}	≤ **78**
1.33×10^{-4}	≤ **158**
6.65×10^{-5}	≤ **318**
1.33×10^{-5}	≤ **1635**

2.14.2 Internal arrangements

The content must be packed in an internal arrangement with a maximum diameter of 120 mm and a thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the content **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [material + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Four tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203 or AA 41.
- the following **spacers** must be used to position the tertiary packing container in the package cavity:
  - ➢ with the TN 90 : spacers E1 and E2,
  - ➢ with the AA 204 : spacers E1 and E10 or E6,
  - ➢ with the AA 203 : spacers E1 and E8,
  - ➢ with one AA 41 : spacers E1 and E11,
  - ➢ with two AA 41s : spacers E1, E12 and E13,
  - ➢ with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in the internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.15 CONTENT N° 20: PLUTONIUM IN METAL FORMAT

Content consists of plutonium in metal state.

2.15.1 Description

The plutonium may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

The plutonium may not contain carbon other than in trace format.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.15.1.1 Isotopic composition and masses

The isotopic composition of the plutonium is not regulated. Maximum allowable mass of plutonium is equal to 4 kg.
Should the plutonium not contain fissile isotopes (absence of ^{239}Pu and ^{241}Pu), beryllium may be present.
Should the mass of fissile plutonium carried imply exemption to the regulatory provisions applicable to fissile materials, the presence of beryllium will be authorized up to a maximum of 0.1 % of the mass of fissile material; should this not be the case, the presence of beryllium is not authorized.

2.15.1.2 Physical properties

The content is a solid in any format.

2.15.1.3 Chemical form

Metal.

2.15.1.4 Special form

The material does not have a special form.

2.15.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.
The presence of 50 g of americium 241 is authorized.

2.15.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by the material depends on the internal arrangements used:

- if the material is packed with type TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the material is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a

thermal power per secondary packing container limited to :

- 20 W if a tertiary packing container type AA41 is used,
- 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.15.1.7 Specific provisions

If the material is packed with vinyl covers, the specific provisions described in chapter 3.7 limit transport time depending on quantities of material and the type of packing used.

To eliminate any trace of humidity, the metal plutonium will be packed in the presence of a powerful dessicant.

To avoid the prior measurement of the shortest dimensions of the objects transported and to prevent any increase in temperature caused by friction, which is complex to quantify, the risks of pyrophoricity in the air will be treated by inerting the package cavity and the internal arrangements (nitrogen, argon, etc.), prior to transport.

2.15.1.8 Specific activity

The specific activity of the content is limited depending on:

- the possible presence of covers,
- leakage flows identified prior to dispatch.

Limits are specified in the following tables.

Absence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	≤ **87**
$1.33x10^{-4}$	≤ **175**
$6.65x10^{-5}$	≤ **352**
$1.33x10^{-5}$	≤ **1799**

Use of covers

Pre-transport check (SLR) in Pa.m^3.s^{-1}	Specific activity in A2/g
2.66x10^{-4}	≤ **78**
1.33x10^{-4}	≤ **158**
6.65x10^{-5}	≤ **318**
1.33x10^{-5}	≤ **1635**

2.15.2 Internal arrangements

The content must be packed in an internal arrangement with a maximum diameter of 120 mm and a thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the content **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [material + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Four tertiary packing containers may be used. These containers are of type TN 90, AA 204, AA 203 or AA 41.
- the following **spacers** must be used to position the tertiary packing container in the package cavity:
    - with the TN 90 : spacers E1 and E2,
    - with the AA 204 : spacers E1 and E10 or E6,
    - with the AA 203 : spacers E1 and E8,
    - with one AA 41 : spacers E1 and E11,
    - with two AA 41s : spacers E1, E12 and E13,
    - with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in the internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.16 CONTENT N° 23: OXIDE POWDER OF PLUTONIUM, URANIUM, NEPTUNIUM, AMERICIUM OR A MIX OF THE FORMER

The content consists of oxide powder of uranium, plutonium, neptunium, americium or a mix of the former.

2.16.1 Description

These powders may come from reprocessing, but must not have been subject to post-reprocessing irradiation.

They may not contain carbon other than in trace format.

The americium must come from either the treatment of irradiated fuel, to the exclusion of any isotopic separation, or from the desamericiation tof plutonium.

The neptunium must come from the treatment of irradiated fuel and not have been subjected to isotopic separation.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.16.1.1 Isotopic composition and masses

The isotopic composition of the uranium and plutonium is not regulated.

Masses are limited as follows:

- mass of uranium of less than 200 g,
- mass of plutonium of less than 200 g,
- mass of (Neptunium + Americium) of less than 50g.

2.16.1.2 Physical properties

Maximum density of the powder: 3,5.

2.16.1.3 Chemical form

Oxide.

2.16.1.4 Special form

The material does not have a special form.

2.16.1.5 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

The presence of 50 g of americium 241 is authorized.

2.16.1.6 Maximum thermal power emitted by content

The maximium total thermal power emitted by the powder depends on the internal arrangements used:

- if the powder is packed with type TN 90 containers, the maximum total thermal power emitted is equal to 340 W,
- if the powder is packed with type AA 41, AA 203 or AA 204 containers, the maximum total thermal power emitted is equal to 170 W,
- if covers are used, the maximum total thermal power emitted by content is reduced to 80 W, with a thermal power per secondary packing container limited to :
  - 20 W if a tertiary packing container type AA41 is used,
  - 71.4 W/m in length of secondary packing container if the tertiary packing container is of type AA203, AA204 or TN 90,

The maximum mass power is 20 W/kg.

Transport in a caisson is not authorized.

2.16.1.7 Specific provisions

If water content is less than 0.5%, no specific provisions are required. If powder with a humidity of between 0.5 and 3% of water and/or powder packed in the presence of vinyl covers are transported, this operation will be subject to the specific provisions listed in chapter 3.7 to limit transport time depending on quantities of material and the type of packing used.

2.16.1.8 Specific activity

The specific activity of the content is limited depending on:

- water content,
- the possible presence of covers,
- leakage flows identified prior to dispatch.

Limits are specified in the following tables.

<u>Water content of less than 0.5 % - absence of covers</u>

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	**≤ 87**
$1.33x10^{-4}$	**≤ 175**
$6.65x10^{-5}$	**≤ 352**
$1.33x10^{-5}$	**≤ 1799**

Water content of more than 0.5 % - absence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	**≤ 15**
$1.33x10^{-4}$	**≤ 31**
$6.65x10^{-5}$	**≤ 63**
$1.33x10^{-5}$	**≤ 331**

Water content of less than 0.5 % - presence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	**≤ 78**
$1.33x10^{-4}$	**≤ 158**
$6.65x10^{-5}$	**≤ 318**
$1.33x10^{-5}$	**≤ 1635**

Water content of more than 0.5 % - presence of covers

Pre-transport check (SLR) in $Pa.m^3.s^{-1}$	Specific activity in A2/g
$2.66x10^{-4}$	**≤ 14**
$1.33x10^{-4}$	**≤ 28**
$6.65x10^{-5}$	**≤ 56**
$1.33x10^{-5}$	**≤ 296**

2.16.2 Internal arrangements

The powder must be packed in an internal arrangement with a maximum diameter of 120 mm and a thickness of 2 mm (TN 90, AA 204, AA 203, AA 41). Packing must apply the following principles:

- the powder **may** be placed in closed aluminium or stainless steel boxes (**primary packing**). Primary packing boxes may be surrounded by one or several covers in heat sealed plastic materials (PVC or polyurethane). A maximum of 2 covers may be used per primary packing box,
- these boxes **may** then be placed in **secondary packing** consisting of a box or case (in stainless steel) with an embedded, screwed or welded lid,
- the final assembly [powder + any primary packing + any secondary packing] **must** then be placed in a stainless steel **tertiary packing** container consisting of a case closed with a lid equipped with seals (controllable or otherwise). Depending on the isotopic composition, four tertiary packing containers may be used. TN 90, AA 204, AA 203 or AA 41 type containers must be used.
  the following **spacers** must be used to position the tertiary packing container in the package cavity:
  - with the TN 90 : spacers E1 and E2,
  - with the AA 204 : spacers E1 and E10 or E6,
  - with the AA 203 : spacers E1 and E8,
  - with one AA 41 : spacers E1 and E11,
  - with two AA 41s : spacers E1, E12 and E13,
  - with three AA 41s : spacers E1, E9 & 2 × E13,

The total mass of the entire load placed in the internal arrangements AA 203, AA 204, AA 41 & TN 90 is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

2.17 CONTENT N° 26: TRIGA FUEL

This content consists of bars in non-irradiated TRIGA fuel elements.

2.17.1 Description

These bars are in a U-ZrHx-based material (with x between 0 & 2); they are cylindrical and either standard or narrow, with the following dimensions:

- standard: diameter = 3.63 cm; length = 12.7 cm,
- narrow: diameter = 1.29 cm; length = 18.6 cm,

The uranium is not produced in reprocessing.

Standard bars are perforated prior to hydriding in the center. The hole has a diameter of 6.35 mm.

Figure 1-1 shows standard and narrow TRIGA fuel elements.

The presence of hydrogenated materials with a hydrogen content exceeding that of water is not authorized.

2.17.1.1 Isotopic composition and masses

Maximum enrichment in uranium 235 is limited to 20%.

Content by mass in U_{total} varies between 8 and 47%, depending on the type of element:

TYPE	U (% in mass)	ZrH_X (% in mass)	U-Zr (g/cm^3)	U-ZrH_2 (g/cm^3)
Composition of standard TRIGA elements				
103	8	92	6.9	6.04
105	12	88	7.1	6.22
107	12	88	7.1	6.22
117	21	79	7.4	6.64
119	31	69	8.1	7.24
Composition of the narrow TRIGA element				
424	47	53	9.3	8.40

Maximum quantities for transport are specified in the following tables.

- For **air transport**: the maximum mass of uranium transported per TN-BGC 1 package depends on the type of element, according to the following table:

TYPE	Maximum mass of U (kg)
103	1.1
105	1.7
107	1.7
117	3.3
119	5.3
424	6.6

- For all types of **transport other than air**: the maximum mass of uranium transported per TN-BGC 1 package depends on the type of element, according to the following table, up to the maximum mass indicated in paragraph 2.17.2 for the loading of internal arrangements and the entire package:

TYPE	Maximum mass of U (kg)
103	9
105	14
107	14
117	27
119	43
424	76

2.17.1.2 Chemical form

Metal.

2.17.1.3 Special form

The material does not have a special form.

2.17.1.4 Activity

The activity of the content must be such that, in view of the nature and energy of the radiation emitted, the regulatory limits for dose rates around the package are not exceeded.

2.17.1.5 Specific provisions

With air transport, the water mass present with the fissile material, irrespective of the water mass contained in the hydrogenated materials in the package, is less than 1200 g or 1950 g, depending on whether the element is standard or narrow.

2.17.2 Internal arrangements

The TRIGA bars are placed in carton protective cases; these cases are placed in a secondary packing container.

TN 90, AA 204, AA 203 or AA 41 secondary packing containers may be used. E7 type primary packing containers may be used with TN 90 for the packing of uranium-bearing material.

The following blocks must be used to block the packing container in the package cavity:

- with TN 90 : E1 blocks + block E2,
- with AA 203 : E1 blocks + block E8,
- with AA 204 : E1 blocks + block E10,
- with one AA 41 : E1 blocks + block E11,
- with two AA 41s : E1 blocks + block E12 + block E13,
- with three AA 41s : E1 blocks + block E9 + two E13 blocks,

The total mass of the entire load placed in the internal arrangement TN 90 is limited to 60 kg.

The maximum allowable mass of the entire load placed in the cavity in package TN-BGC 1 (blocks + containers + material transported) = 116 kg.

3 DESCRIPTION OF INTERNAL ARRANGEMENTS

Each of the content mentioned above will be fitted in packing (with one or several internal arrangements). This packing is described in detail in attachment n°1-1.

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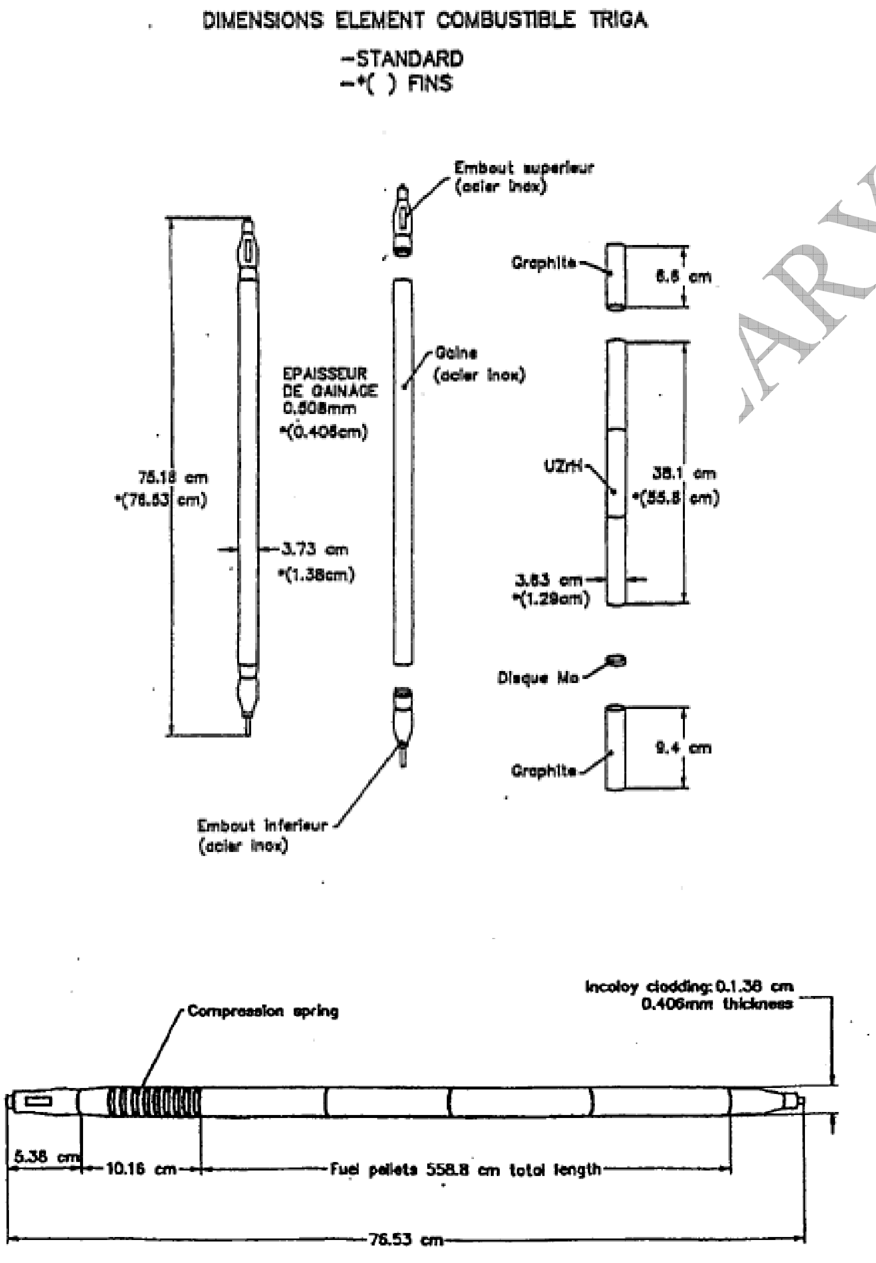
FIGURE 1.1: DIAGRAM OF TRIGA ELEMENTS



FUEL ROD DESIGN
TRIGA fuel rod for 16-rod cluster

Dimensions element combustible TRIGA	Dimensions of the TRIGA fuel component
Standard	Standard
Fin	Narrow
Embout supérieur	Upper end fitting
(acier inox)	(Stainless steel)
Graphite	Graphite
Gaine	Duct
(acier inox)	(Stainless steel)
Epaisseur de gainage	Thickness of ducts
Embout inférieur	Lower end fitting
(acier inox)	(Stainless steel)

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Title: Safety file – TN-BGC 1
Attachment 1-1: description of internal installations

Purpose of the document:

This chapter describes the usable internal installations in package model TN-BGC 1

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Field of application and summary:

APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
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1 INTRODUCTION

Content transported in package TN-BGC1 is mainly packed prior to being placed in the cavity. The following components are used (from the inside to the outside):

- **primary packing** (primary packing may be placed in baskets, storage racks or covers using blocks),
- **secondary packing containers** which may be AA 99, AA 213, AA 236 or AA 303 cases (this packing may then be placed in baskets or storage racks using blocks),
- **tertiary packing containers** of type TN90, AA41, AA203, AA204, AA226, AA227 or TN998. These containers may be blocked in the cavity of the package using external spacers,
- **blocks and spacers**, which enable the axial and radial positioning of the different packing containers listed above.

These different internal installations are shown below.

2 GENERAL DESCRIPTION OF INTERNAL INSTALLATIONS

2.1 PRIMARY PACKING

This packing consists of boxes in stainless steel or aluminium. Their dimensions are limited by the internal dimensions of secondary packing containers.

With certain content, specific primary packing containers are used. These containers are shown in figures 1-1.1 to 1-1.6.

2.2 SECONDARY PACKING

The different secondary packing containers which may be used in package TN-BGC 1 are shown in figures 1-1.3 to 1-1.10.

2.3 TERTIARY PACKING

The different tertiary packing containers which may be used in package TN-BGC 1 are shown in figures 1-1.11 to 1-1.17.

2.4 BLOCKS AND SPACERS

Different blocks and spacers are used to position the content in the cavity axially and laterally. These devices are shown in figures 1-1.18 to 1-1.28.

3 PROPERTIES OF INTERNAL INSTALLATIONS

The minimum mechanical and thermal properties of the materials of packing used:

- for thermal transfers (spacers E1, E2 and E14 – rings B1 and B2),
- to retain the material transported (tertiary packing containers),
- for insulation (spacers E3 and E3 bis),

are shown in tables 1-1.1 and 1-1.2.

Table 1-1.3 specifies the volume of the cavity of TN-BGC 1 and the different internal installations used when beneficial for safety demonstrations. Table 1-1.4 specifies masses.

TABLE 1-1.1 : LIST OF MATERIALS USED FOR INTERNAL INSTALLATIONS

Component	Material
Spacers E1 and E2,	Aluminium alloy AG3
Spacers E4, E5, E6, E7, E8, E9, E10, E11, E12, E13 and E14	Aluminium alloy AU4G
Spacers E3 and E3$_{bis}$: . inner rings . intermediate rings . outer rings	 Polyamide 6.6 (Nylon) Aluminium alloy AG3 Polytetrafluororethylene (Teflon)
Aluminium rings B1 and B2	Aluminium alloy AU4G
Ring TN 998	Bronze Cu Al 10 Ni5 Fe4
Containers AA 226 - AA 227	Stainless steel Z2 CN 18.10
Containers TN 90 and TN998	Stainless steel Z6 CN 18.09 (main section)
Containers AA 204, AA 203 and AA 41	Stainless steel Z2 CN 18.10 (main section)
Seals for containers AA 225, AA 227, TN 90, TN 998, AA 204, AA 203 and AA 41	Ethylene-propylene, silicon, viton or metal joints
Container AA 213	Stainless steel Z6 CN 18.09
Seal for container AA 213	Silicon
Primary packing box	Aluminium AS or stainless steel Z2 CN 18.10 or Brass
Containers AA 236 – AA303 or other secondary packing	Stainless steel Z2 CN 18.10
Container AA 303	Stainless steel Z2 CN 18.10
Basket P1- P2, storage rack R1, R1$_{bis}$	Stainless steel Z2 CN 18.10
Container AA 99	Stainless steel Z2 CN 18.10
Bottle AA 97	Polyethelene
Covers	PVC or polyurethane

TABLE 1-1.2 : MECHANICAL AND THERMAL PROPERTIES OF THE MATERIALS USED IN INTERNAL INSTALLATIONS

	Temperature (°C)	Elastic limit (Mpa)	Rupture limit (Mpa)	Elongation at rupture (%)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Wall emissivity	Max. temp. of use (°C)
Stainless steel Z2 CN 18.10 (or equivalent)	40° 200° 240° 250° 300° 340°	≥ 172 - ≥ 115 ≥ 108 ≥ 100 -	≥ 448 ≥ 404 ≥ 400 ≥ 400 ≥ 395 ≥ 390	≥ 20	≥ 15	≥ 502	≥ 0.26 or ≥ 0.55	-
Aluminium AG3 / AU4G (or equivalent)	40° 140° 190° 260°	≥ 250 ≥ 125 ≥ 90 ≥ 50	≥ 390 ≥ 110 ≥ 60	-	≥ 134	≥ 962	≥ 0.55	-
Teflon (or equivalent)	40°	-	≥ 10 compression	≥ 90 traction	≤ 0.25	≥ 1045	≥ 0.8	260
Nylon (or equivalent)	40°	-	≥ 10 compression	≥ 20 traction	≤ 0.25	≥ 1045	≥ 0.8	130
Stainless steel Z12 CN 18.09 (or equivalent)	20° 50° 100° 200° 250°	≥ 245 ≥ 215 ≥ 210 ≥ 190 ≥ 185	≥ 560 ≥ 630 ≥ 610 ≥ 590 ≥ 580	≥ 45 - - - -	-	-	-	-
Stainless steel Z6 CNU 17.04 (or equivalent)	20° 100° 200° 250°	≥ 520 ≥ 500 ≥ 480 ≥ 470	≥ 800 - - -	≥ 10 - - -	-	-	-	-
Stainless steel I3 CN 18.10 Az (or equivalent)	20° 50° 100° 200° 250°	≥ 270 ≥ 245 ≥ 205 ≥ 157 ≥ 145	≥ 570 ≥ 520 ≥ 490 ≥ 430 ≥ 420	≥ 45 - - - -	-	-	-	-
Stainless steel Z6 CNDT 17.12	250° 300°	≥ 155 -	≥ 435 ≥ 430					
Stainless steel Z6 CN 18.09	150° 200°	>142 >127	>420 ≥ 400					
Bronze Cu Al 10 Ni5 Fe4 Or equivalent		≥ 480	≥ 680					
Low density polyethylene	20°				0.334	2299	0.92	108

	Temperature (°C)	Elastic limit (Mpa)	Rupture limit (Mpa)	Elongation at rupture (%)	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Wall emissivity	Max. temp. of use (°C)
High density polyethylene	20°				0.460	1881	0.92	130
Stainless steel ZI 1 CN 17.08	250°	≥ 165	≥ 455					
PVC and polyurethane	-	-	-	-	0.2		0.95	175

TABLE 1-1.3 : VOLUMES OF INTERNAL INSTALLATIONS AND BLOCKS

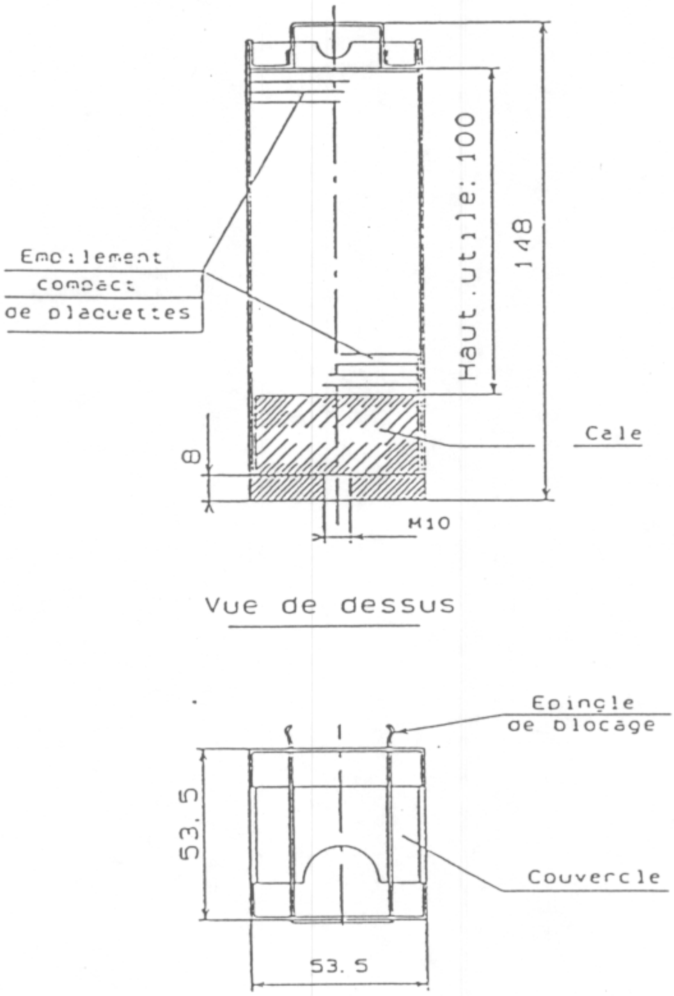
Inner installation	Volume (l)
Cavity TN-BGC 1	37.6
Spacer E1	9.4
E2 spacer	3.2
Spacer E6	0.9
Spacer E10	2.5
Spacer E8	2.1
Spacer E11	2.8
Spacer E12	1.9
Spacer E13	0.15
Spacer E9	1.3
Spacer E14.	8.4
External AA 227 and AA 226	22.2
External TN 90	17.9
Internal TN 90	15.8
External AA 204	12.9
Internal AA 204	11.6
External AA 203	8
Internal AA 203	7
External AA 41	3.8
Internal AA 41	3.2
External TN 998	26.8
AA 99	2

Note: external volume refers to the overall volume of the container, i.e. the internal volume plus the volume of the walls

TABLE 1-1.5 : MASS OF THE INTERNAL INSTALLATIONS

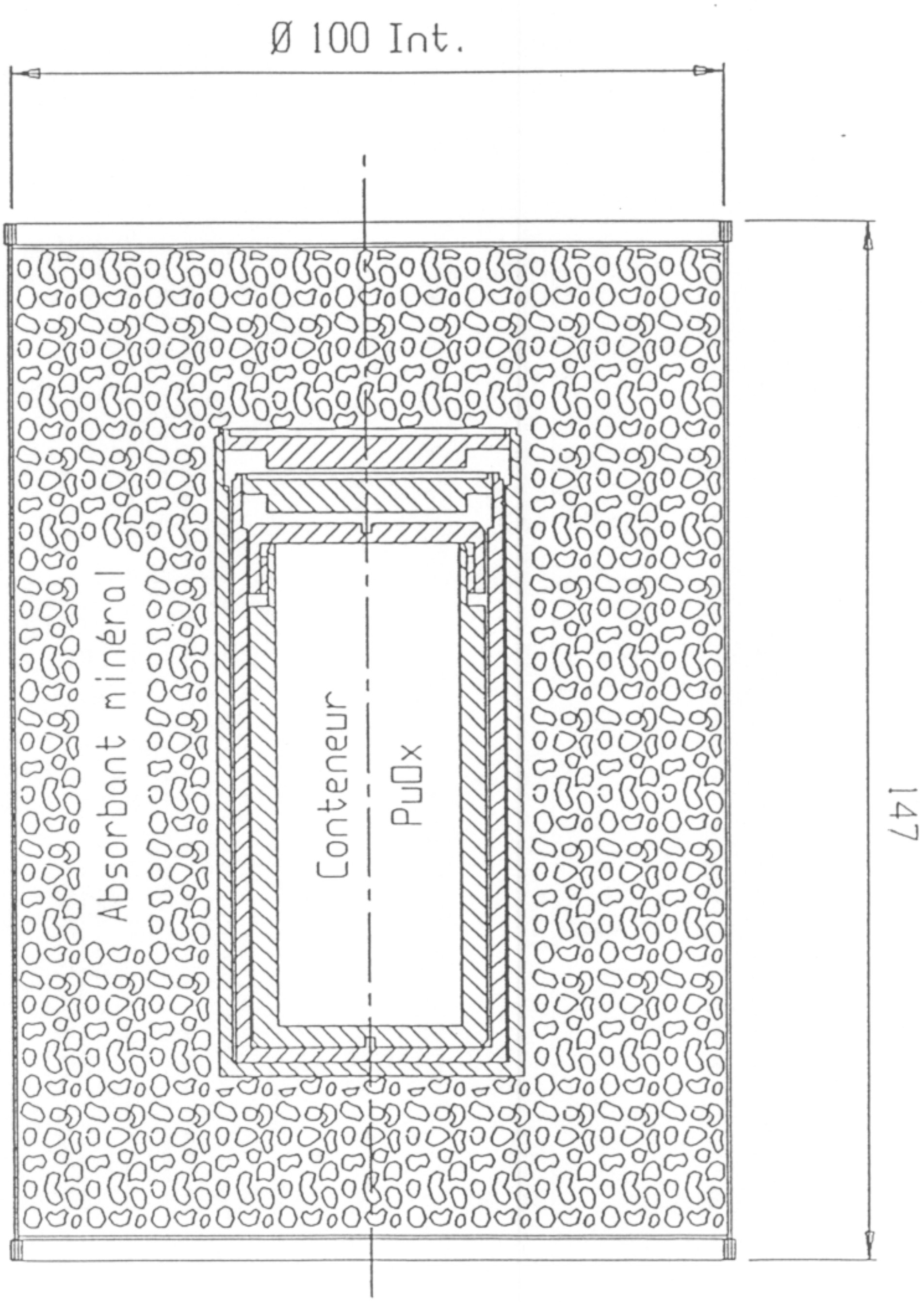
INNER INSTALLATION	MASS (KG)
Spacer E1	25
Spacer E2	9
Spacer E6	3
Spacers E3 and $E3_{bis}$	5
Spacer E7	6.5 (AA203) – 10.5 (AA204)
Spacer E10	2.2
Spacer E8	5.7
Spacer E11	7.5
Spacer E12	5.2
Spacer E13	0.26
Spacer E9	2.75
Spacer E14.	24
AA 227	45
AA 226	70
TN 90	14
AA 204	10
AA 203	8
AA 41	5
TN 998	31
AA236	21
AA303	23
AA 99	0.4
AA 213	5.3

FIGURE 1-1.1: DIAGRAM OF THE BOX CONTAINING A STACK OF ZEBRA PLATES



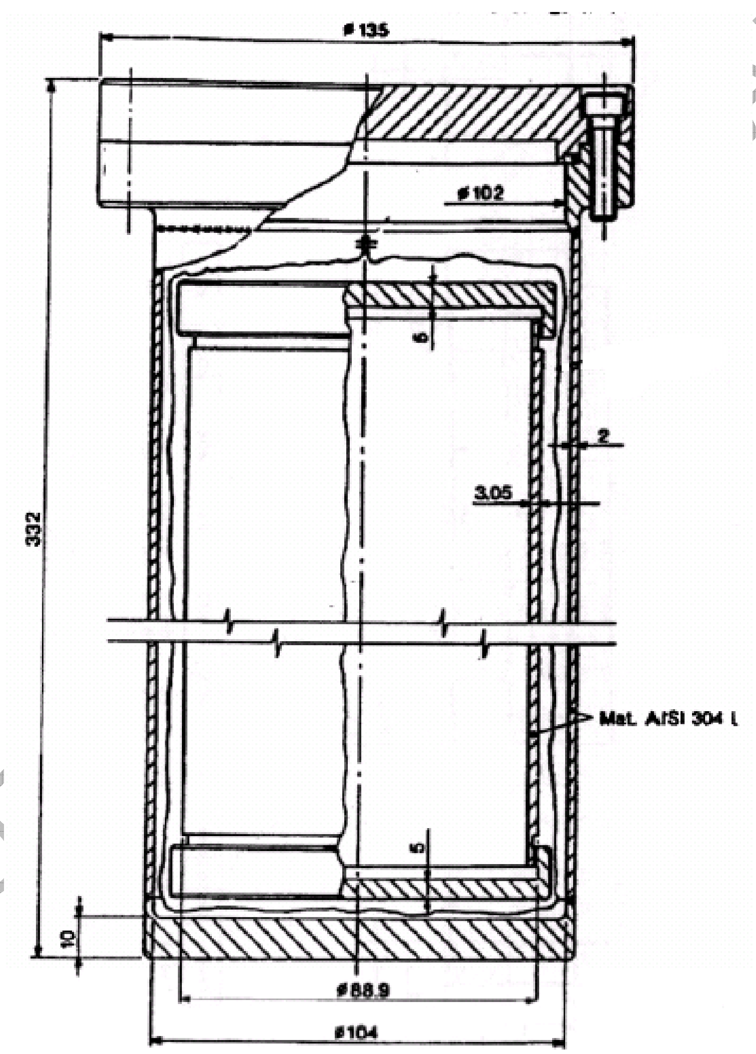
Empilement compact de plaquettes	Compact plate stack
Haut. utile	Useful height
Cale	Block
Vue de dessus	Top view
Epingle de blockage	Blocking pins
Couvercle	Cover

FIGURE 1-1.2: ORIS TYPE CIS-BIO BOX



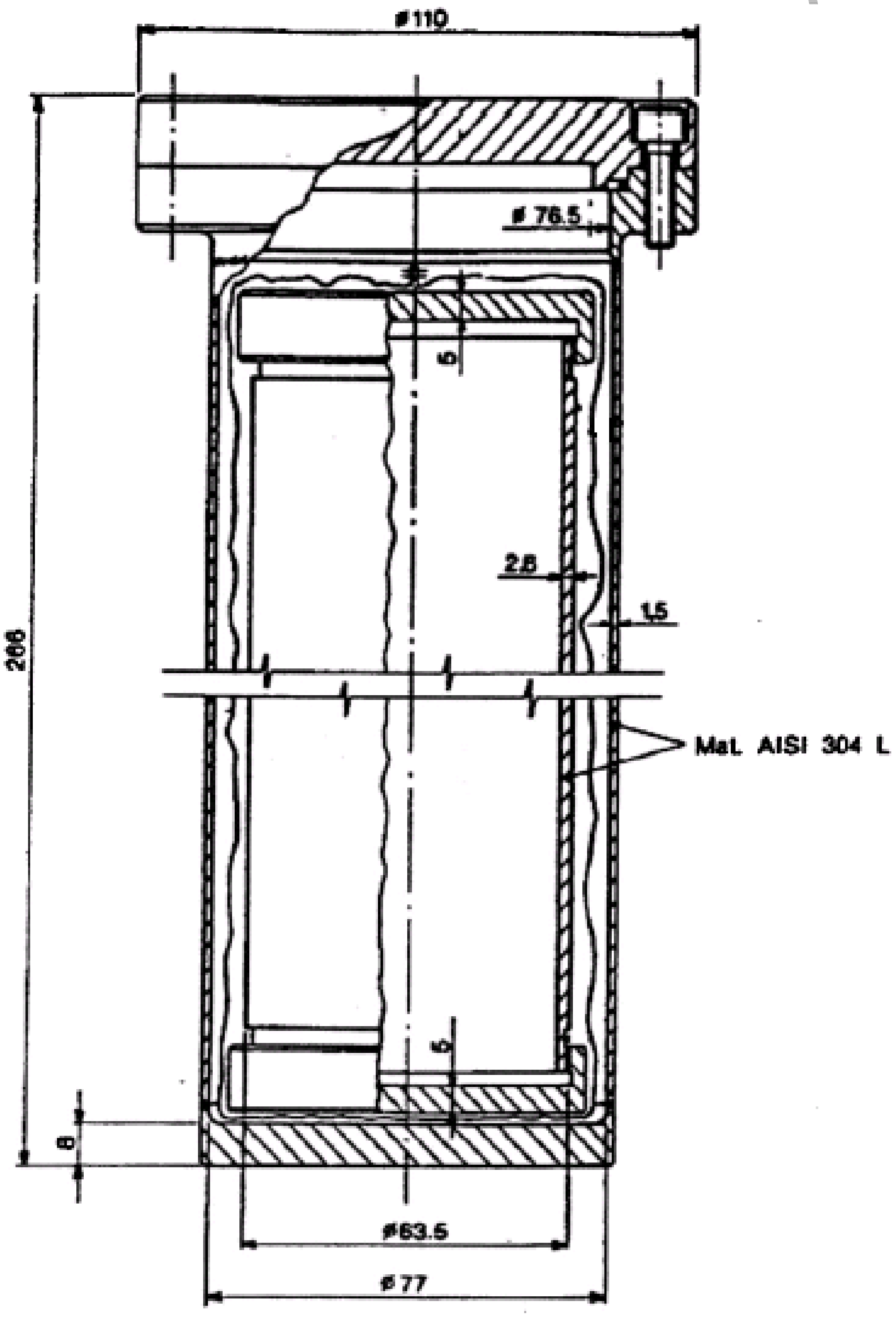
Absorbant minéral O 100 int. Conteneur	Mineral absorber int. O 100 Container

FIGURE 1-1.3: DIAGRAM OF MODEL 2500 PRIMARY AND SECONDARY CONTAINERS



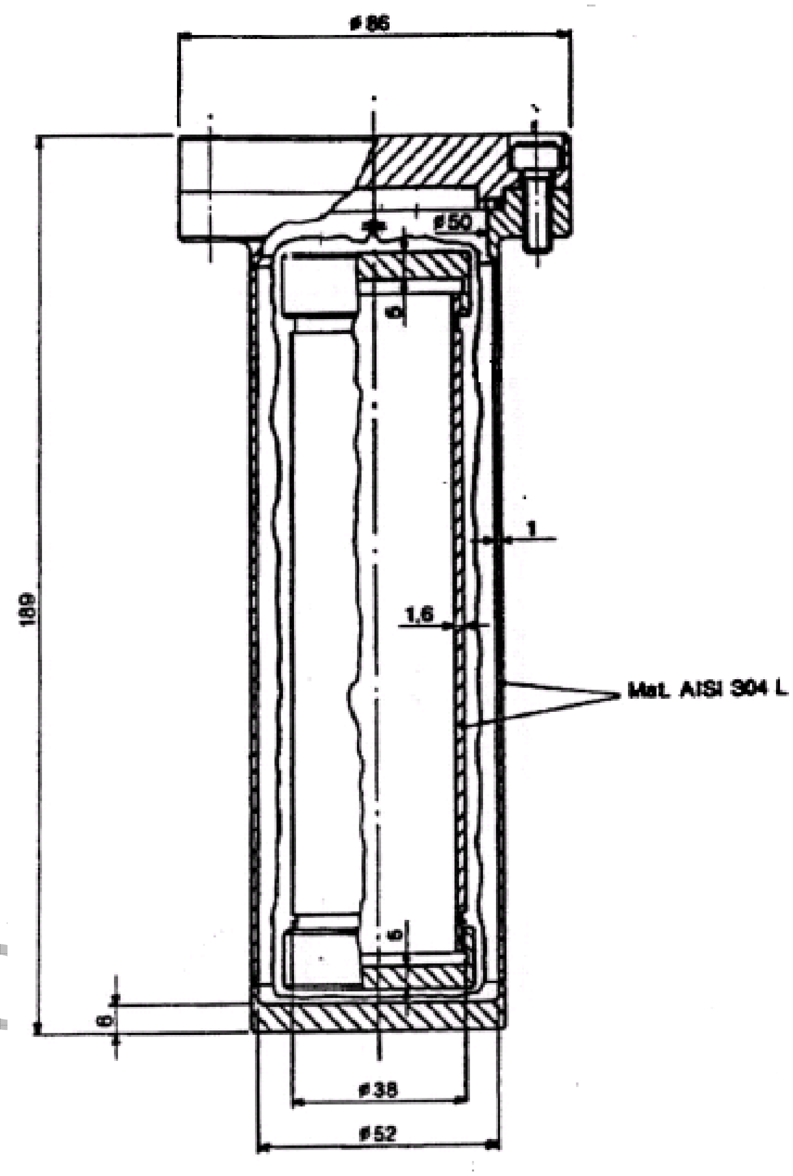
Mat AiSi 304 L	AiSi 304L mat.

FIGURE 1-1.4: DIAGRAM OF MODEL 1000 PRIMARY AND SECONDARY CONTAINERS



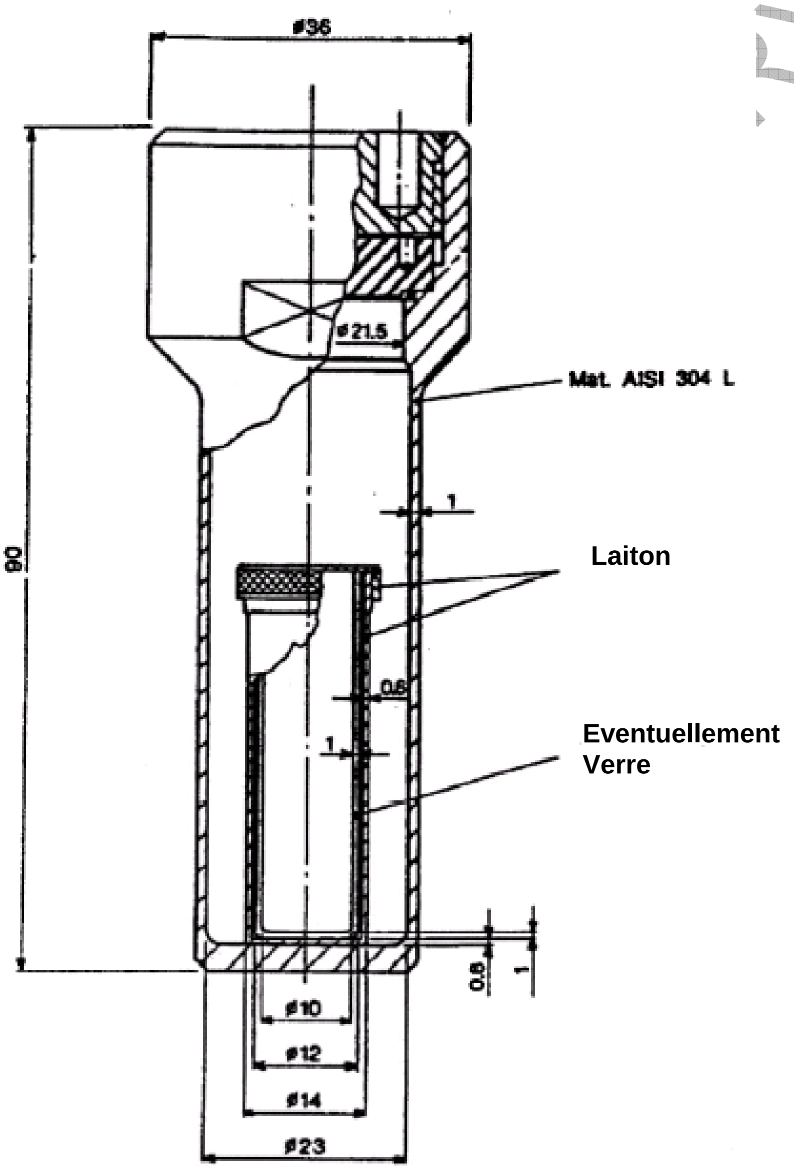
Mat AiSi 304 L	AiSi 304L mat.

FIGURE 1-1.5: DIAGRAM OF MODEL 200 PRIMARY AND SECONDARY CONTAINERS



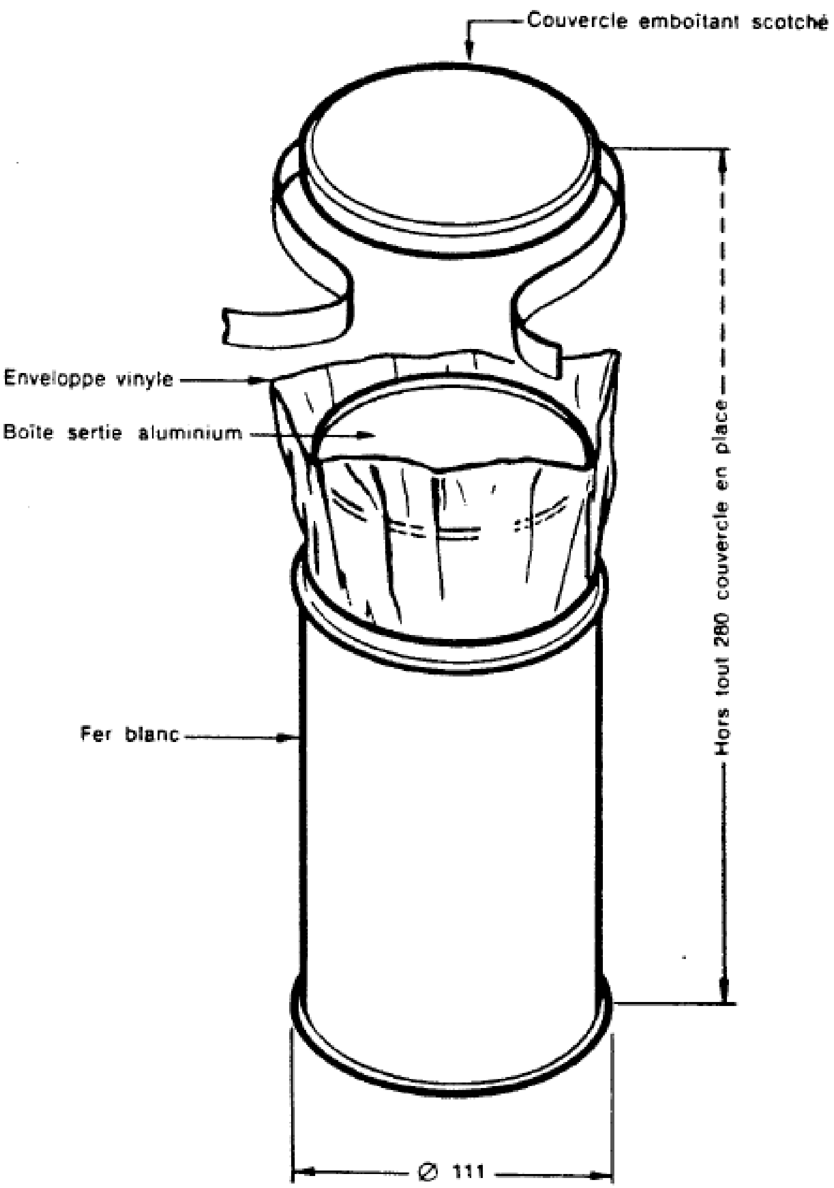
Mat AiSi 304 L	AiSi 304L mat.

FIGURE 1-1 6: DIAGRAM OF MODEL 5 PRIMARY AND SECONDARY CONTAINERS



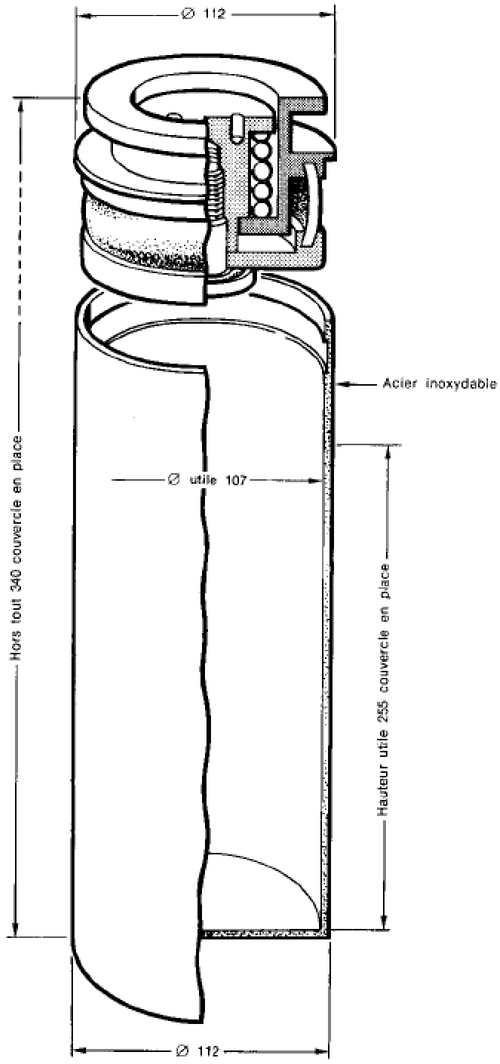
Mat AiSi 304 L **Eventuellement Verre** **Laiton**	AiSi 304L mat. **Possibly glass** **Brass**

FIGURE 1-1.7: DIAGRAM OF CONTAINER AA99



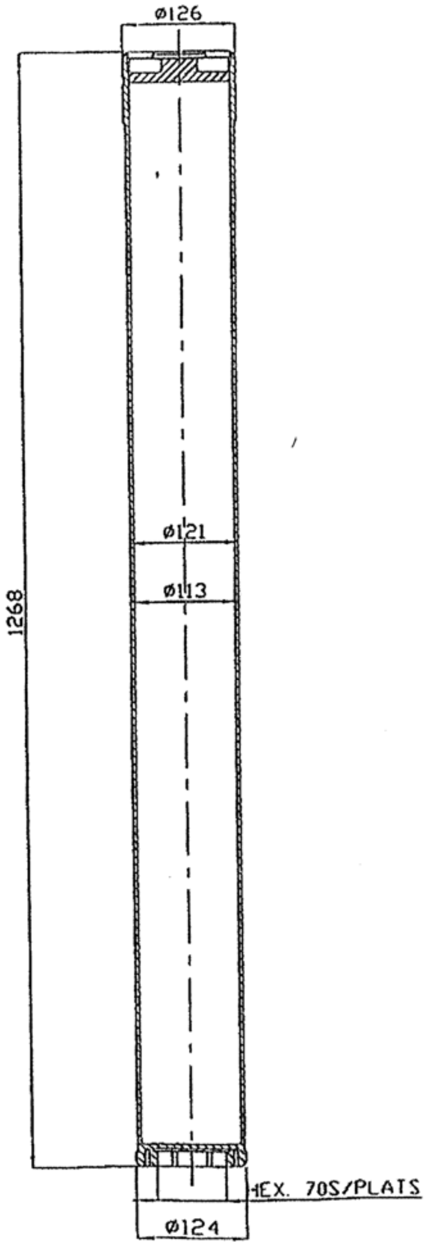
Couvercle emboîtant scotché Enveloppe vinyle Boîte sertie aluminium Fer blanc Hors tout 260 couvercle en place	Taped embedded cover Vinyl containment Aluminium crimped box Tinplate Overall 260 with cover fitted

FIGURE 1-1.8: DIAGRAM OF AA213



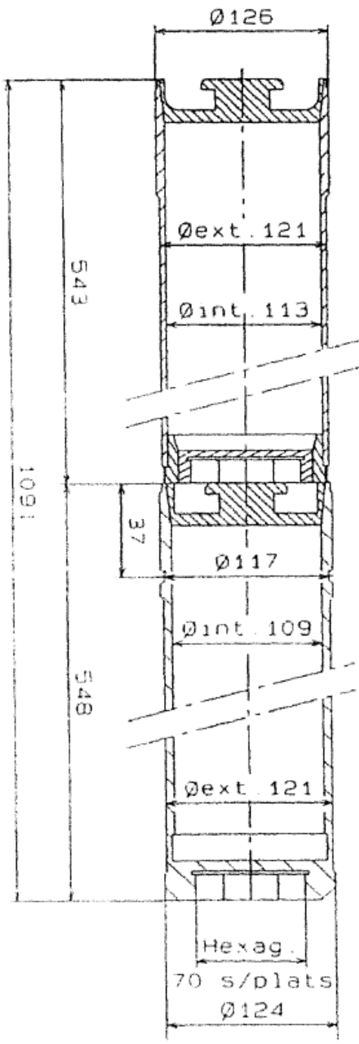
Hors tout 340 couvercle en place Acier inoxydable O utile 107 Hauteur utile 255 couvercle en place	Overall 340 with cover fitted Stainless steel Useful O 107 Useful height 255 with cover fitted

FIGURE 1-1.9: DIAGRAM OF AA 236



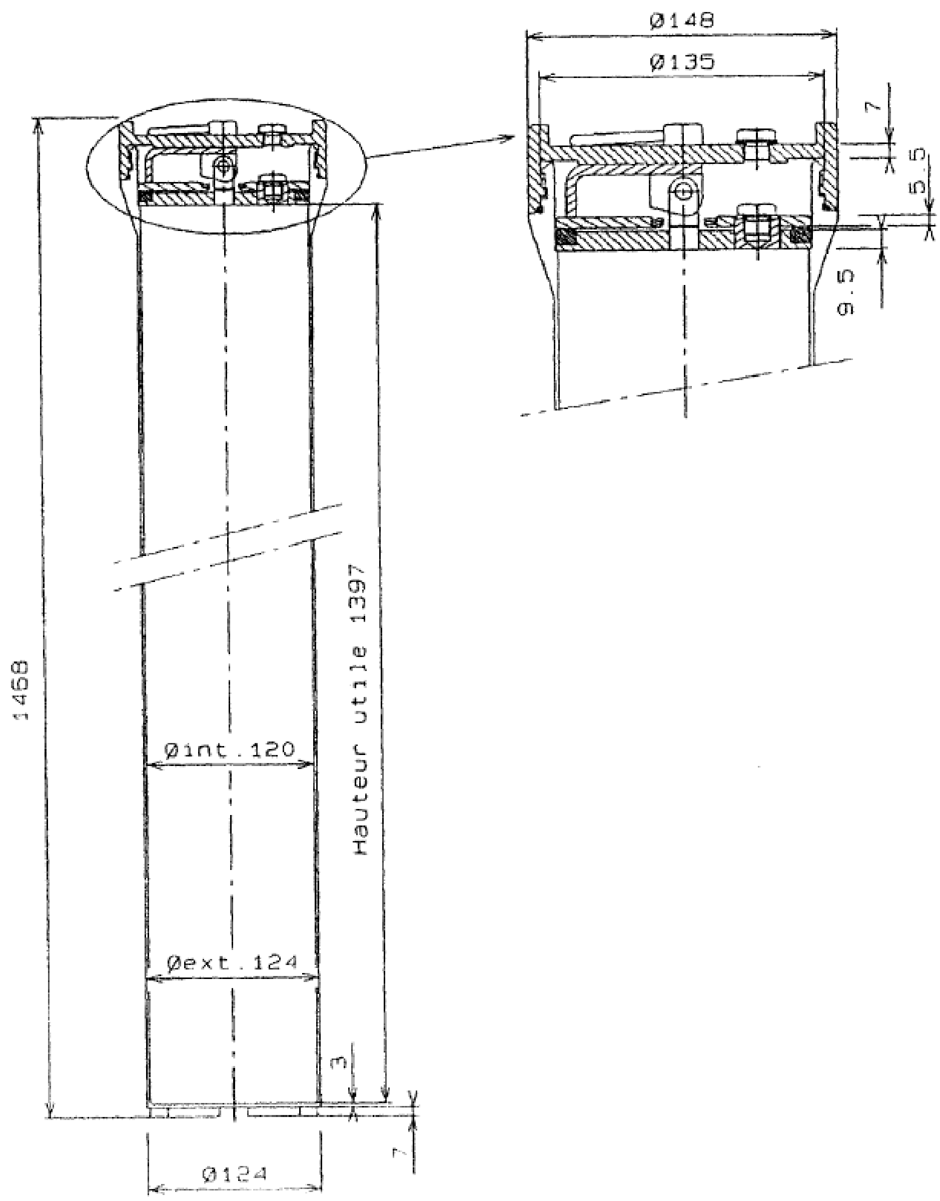
HEX. 70S/PLATS	HEX. 70S/FLAT

FIGURE 1-1.10: DIAGRAM OF AA 303



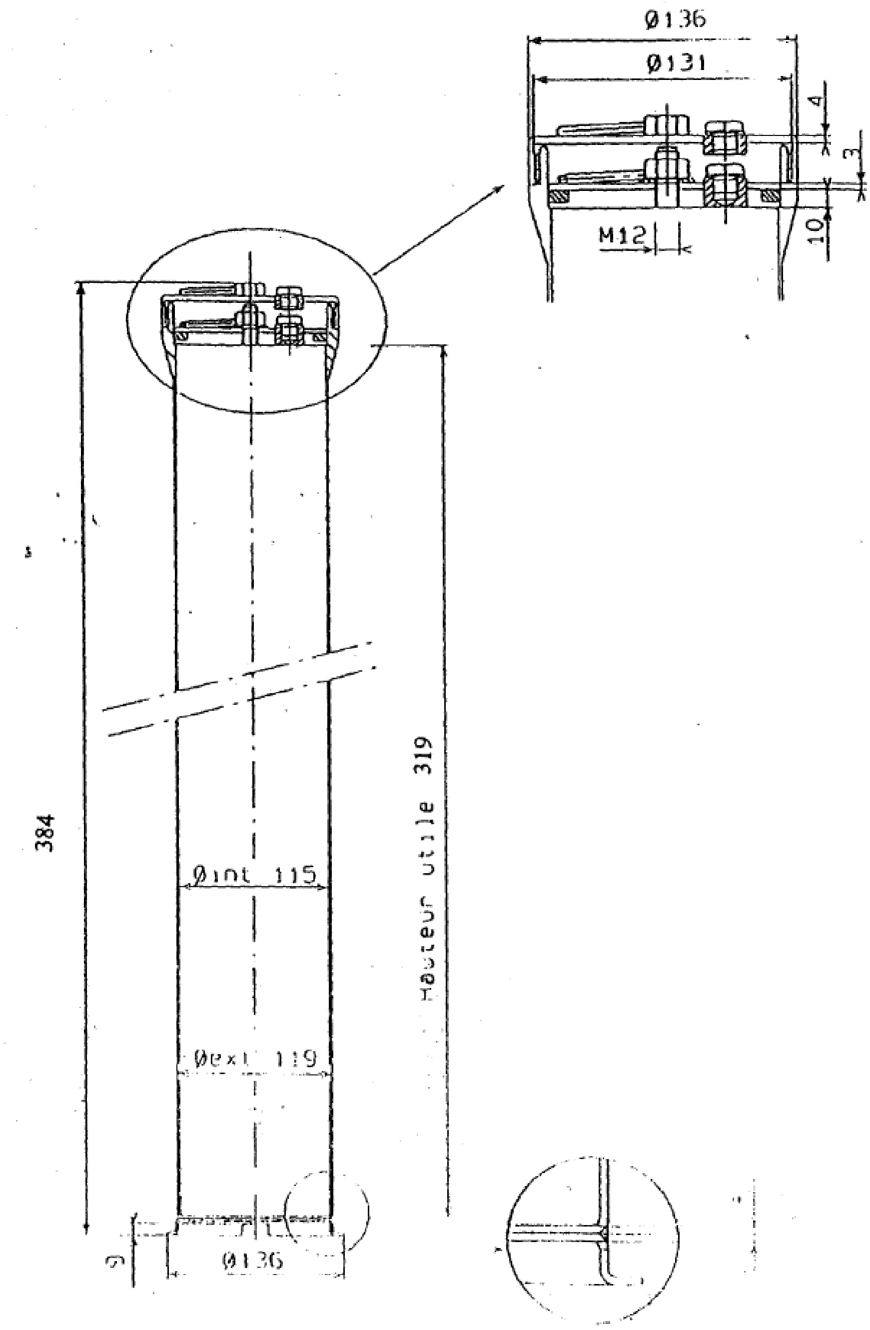
O ext. 121 O int. 113 Hexag. 70S/plats	ext.O 121 int. O 113 Hex. 70S/flat

FIGURE 1-1.11: DIAGRAM OF TN 90



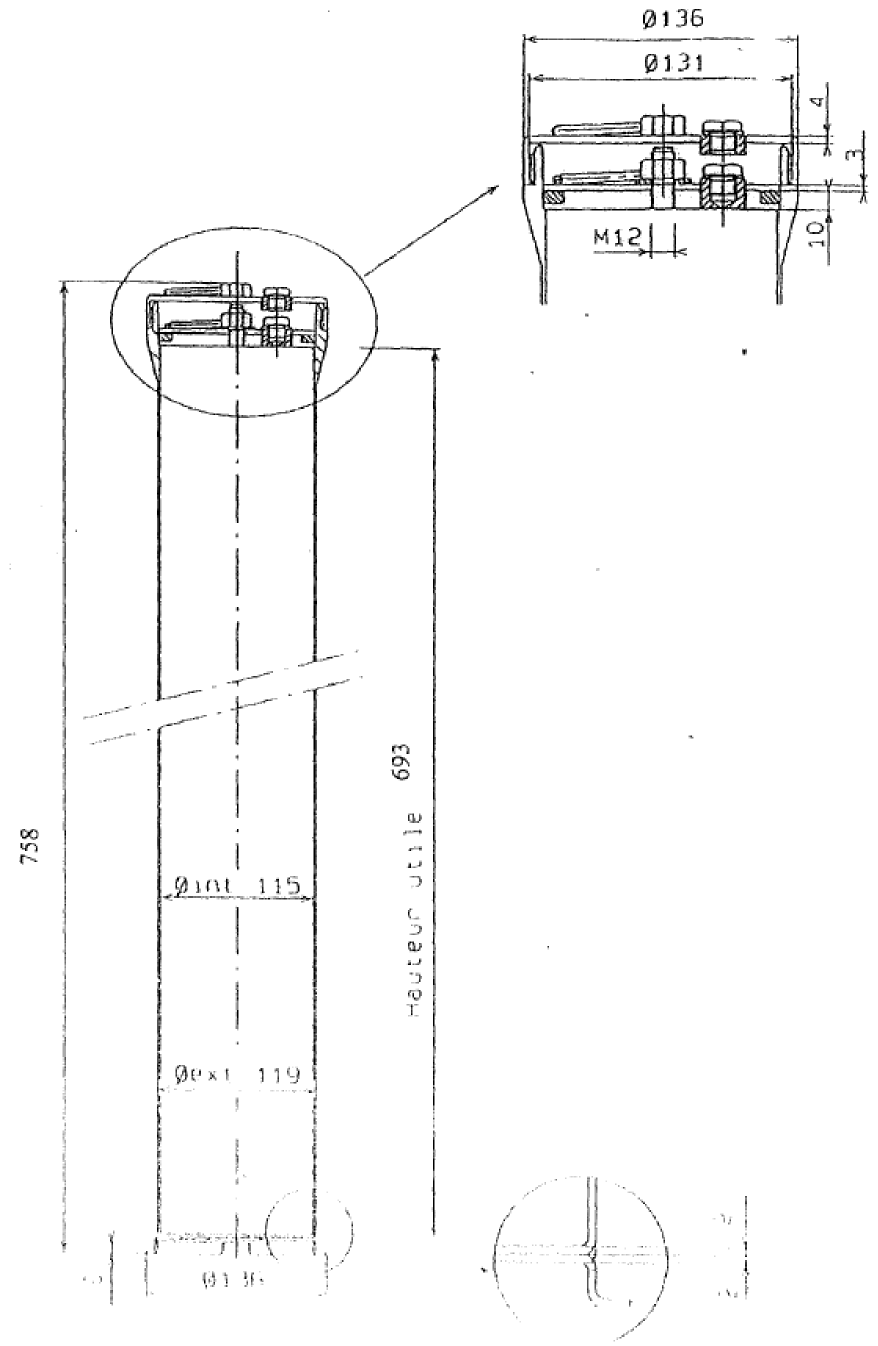
Hauteur utile O int. 120 O ext. 124	Useful height int.O 120 ext. O 124

FIGURE 1-1.12: DIAGRAM OF AA 41



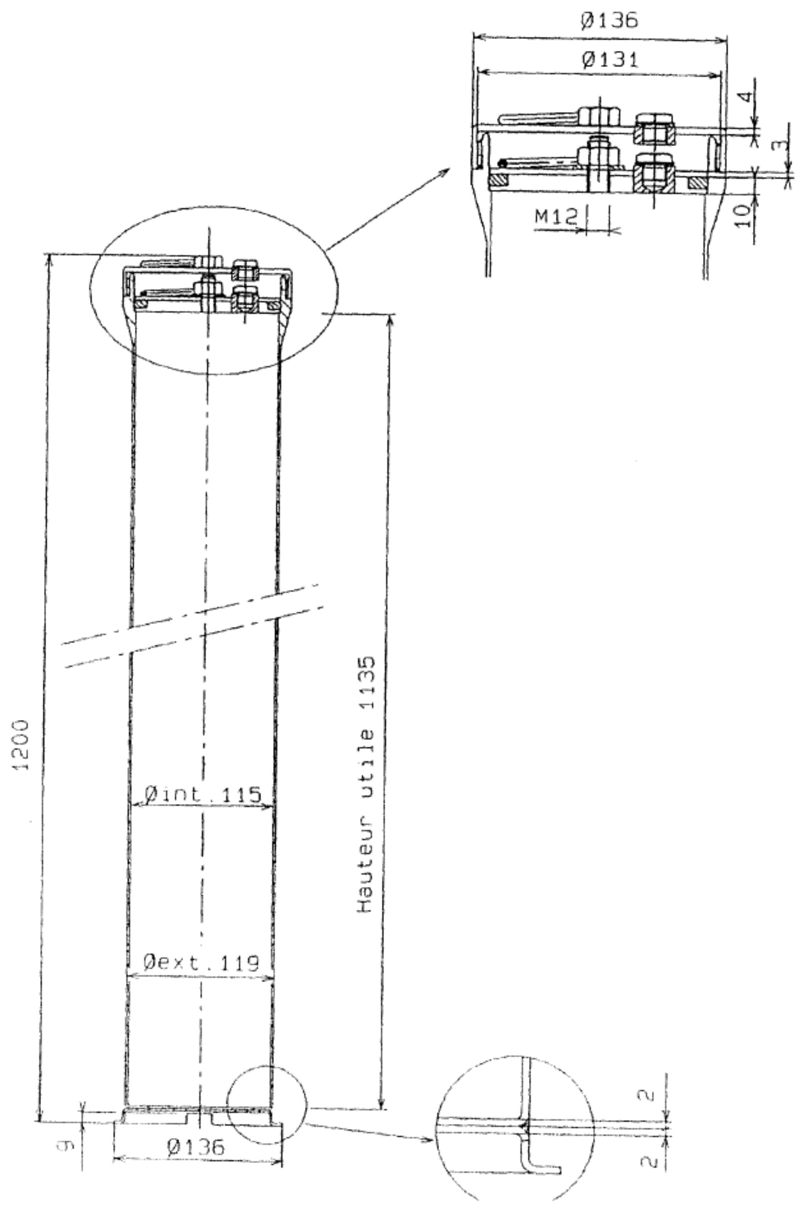
Hauteur utile O int. 115 O ext. 119	Useful height int.O 115 ext. O 119

FIGURE 1-1.13 : FIGURE OF AA203



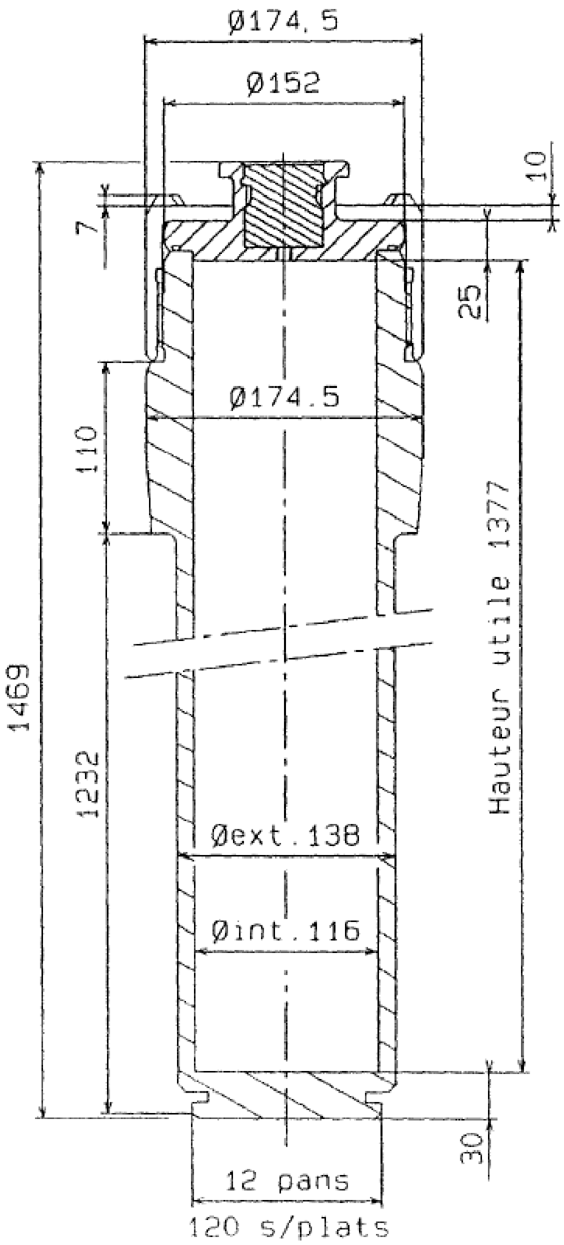
Hauteur utile O int. 115 O ext. 119	Useful height int.O 115 ext. O 119

FIGURE 1-1.14: DIAGRAM OF AA 204



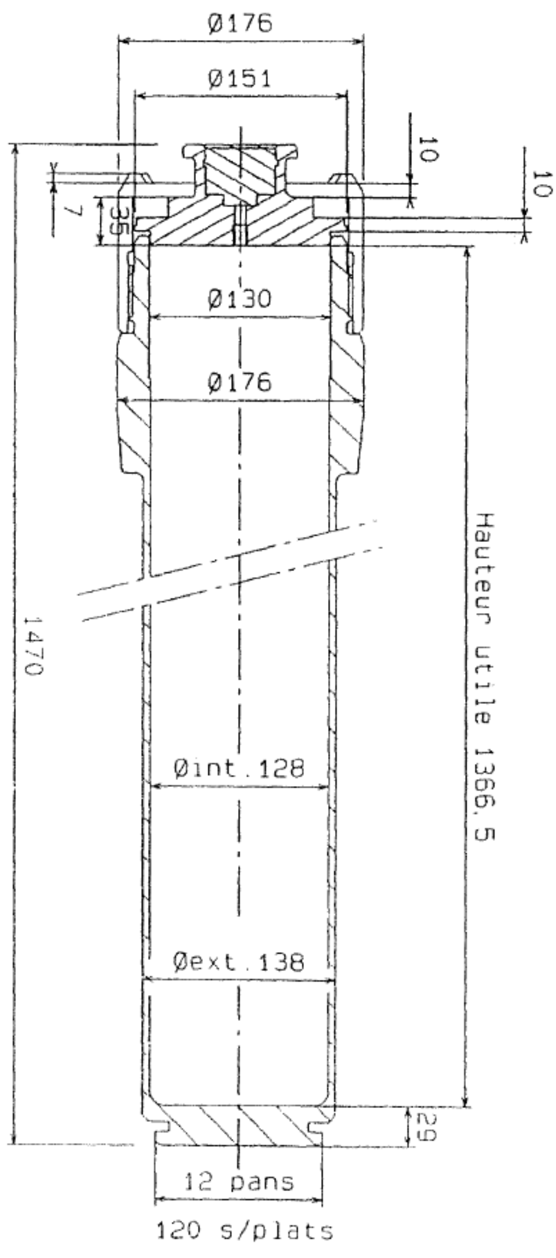
Hauteur utile O int. 115 O ext. 119	Useful height int.O 115 ext. O 119

FIGURE 1-1.15: DIAGRAM OF AA 226



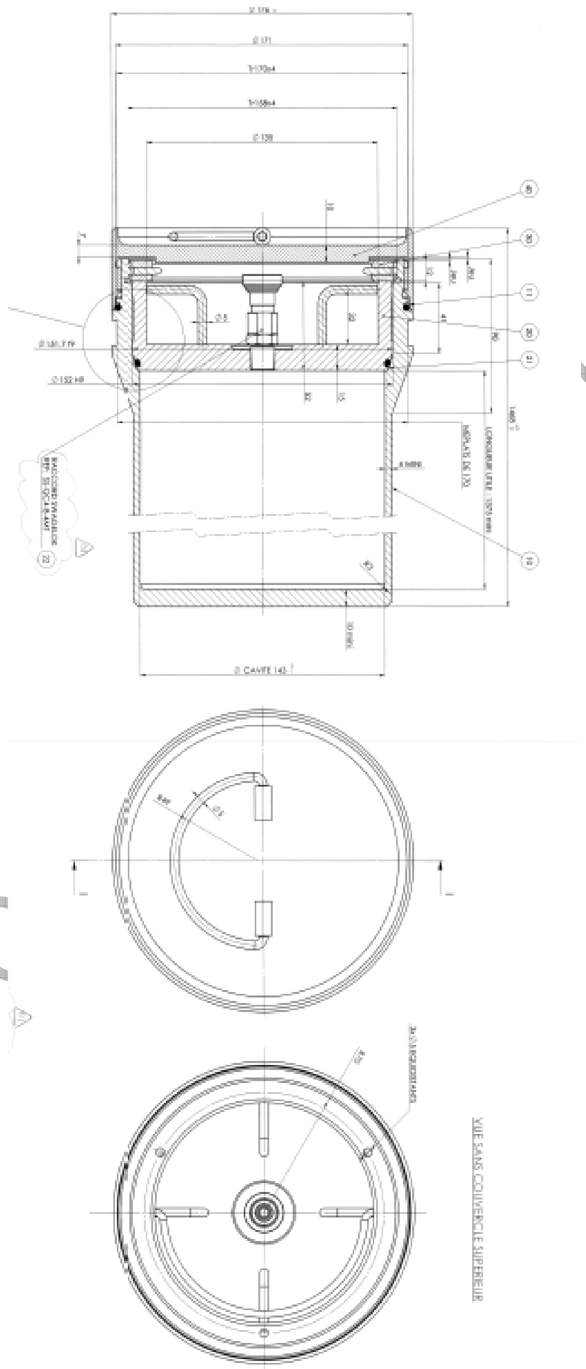
Hauteur utile O int. 138 O ext. 116 12 pans 120 s/plats	Useful height int.O 138 ext. O 116 12 sides 120 s/flat

FIGURE 1-1.16: DIAGRAM OF AA227



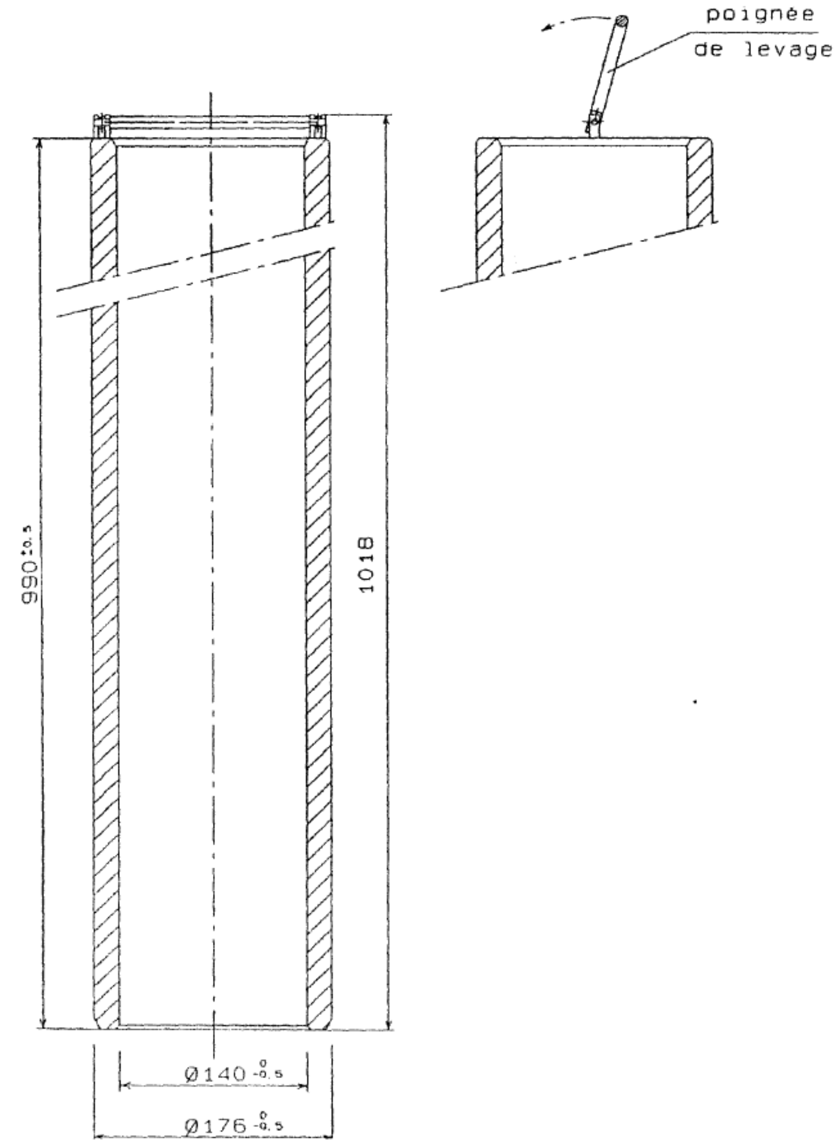
Hauteur utile O int. 138 O ext. 116 12 pans 120 s/plats	Useful height int.O 138 ext. O 116 12 sides 120 s/flat

FIGURE 1-1.17: DIAGRAM OF TN 998



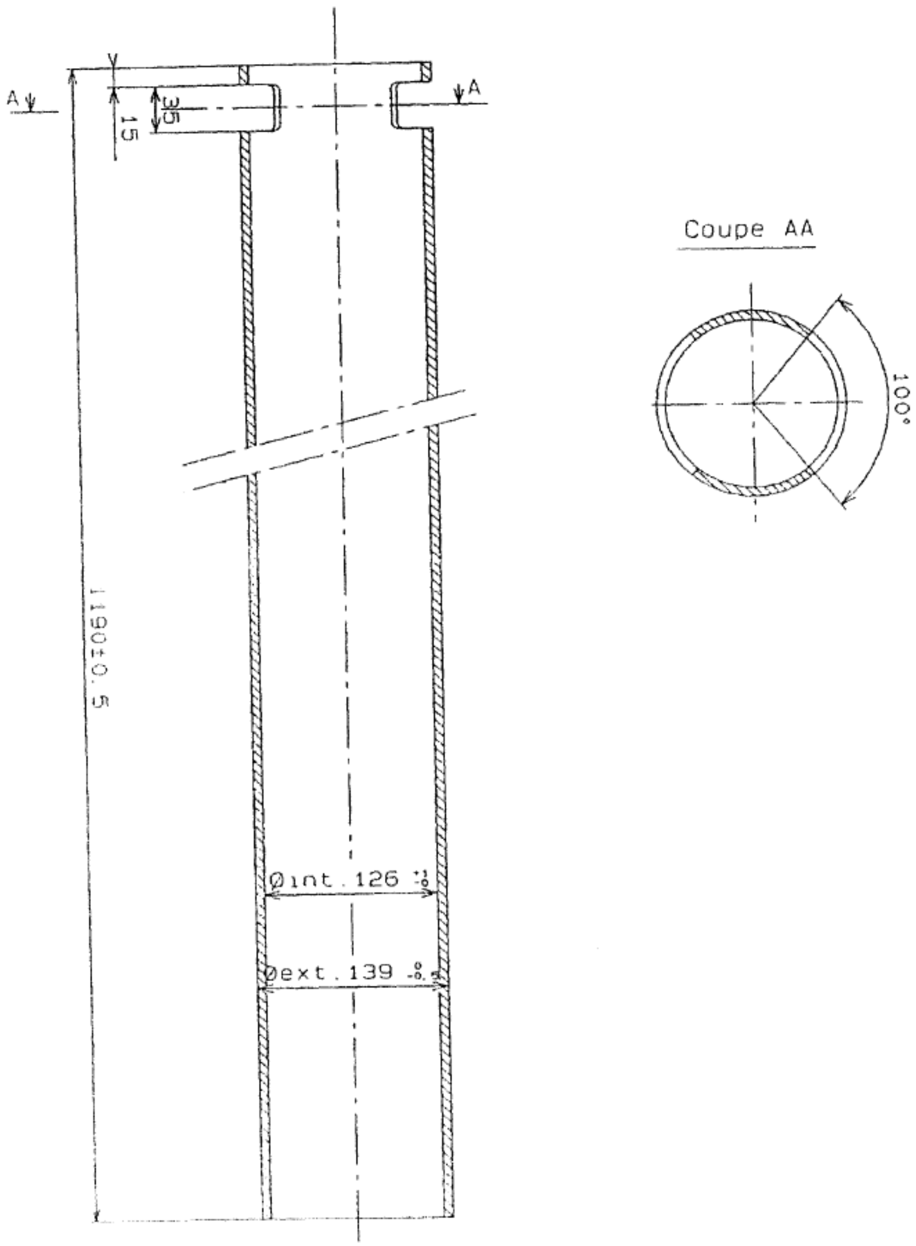
Vue sans couvercle supérieur	View without upper cover

FIGURE 1-1.18: DIAGRAM OF BLOCK E1



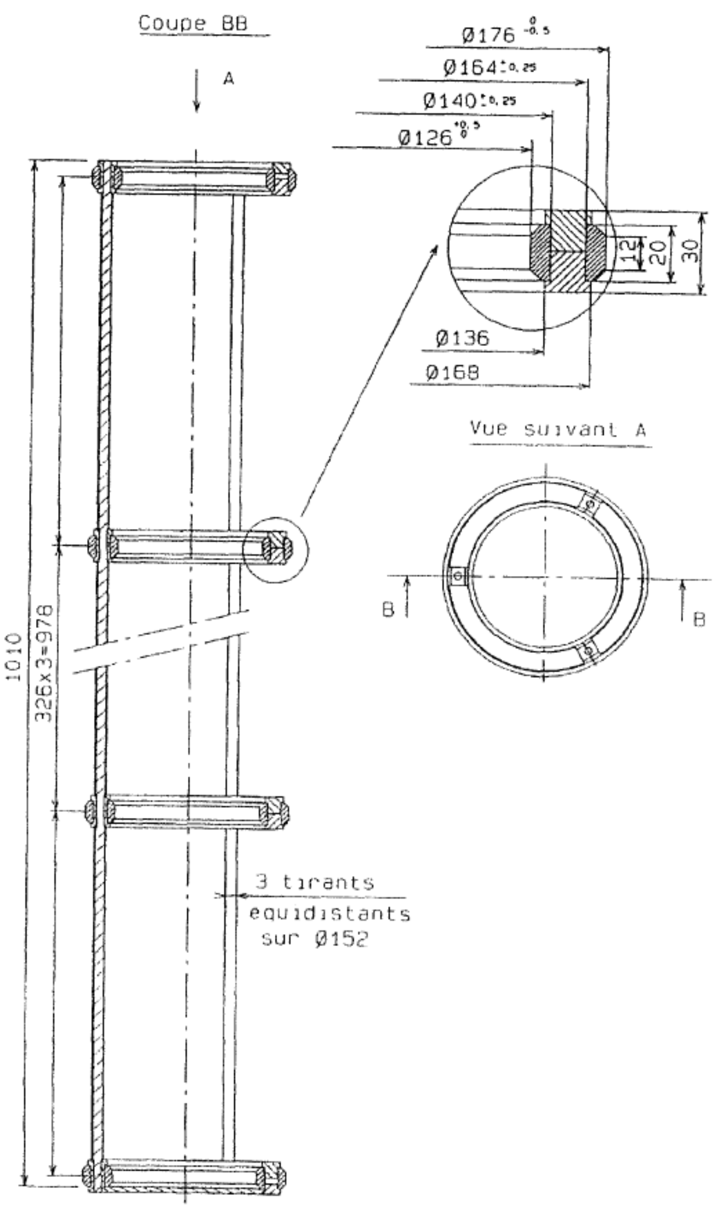
Poignée de levage	Lifting handle

FIGURE 1-1.19: DIAGRAM OF BLOCK E2



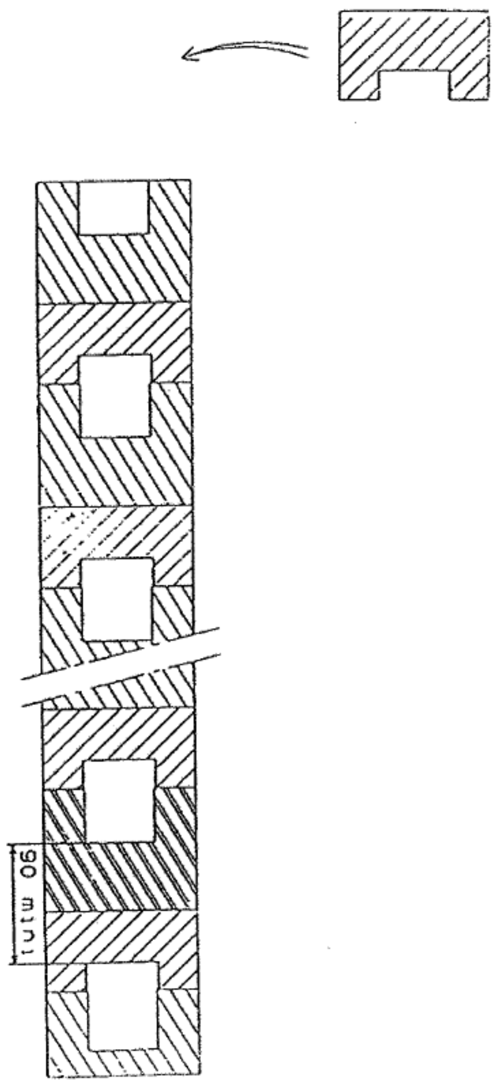
Coupe AA	Section AA
O int. 126 O ext. 139	int.O 126 ext. O 139

FIGURE 1-1.20: DIAGRAM OF BLOCK E3



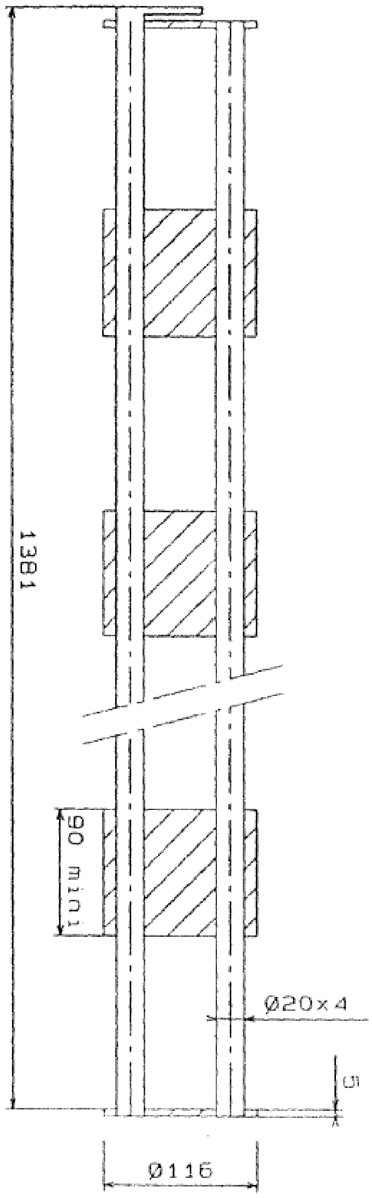
Coupe BB Vue suivant A 3 tirants equidistants sur O152	Section BB Next view A 3 equidistant levers over 0152

FIGURE 1-1.21: DIAGRAM OF BLOCK E4



90 mini	min. 90

FIGURE 1-1.22: DIAGRAM OF BLOCK E5



90 mini	min. 90

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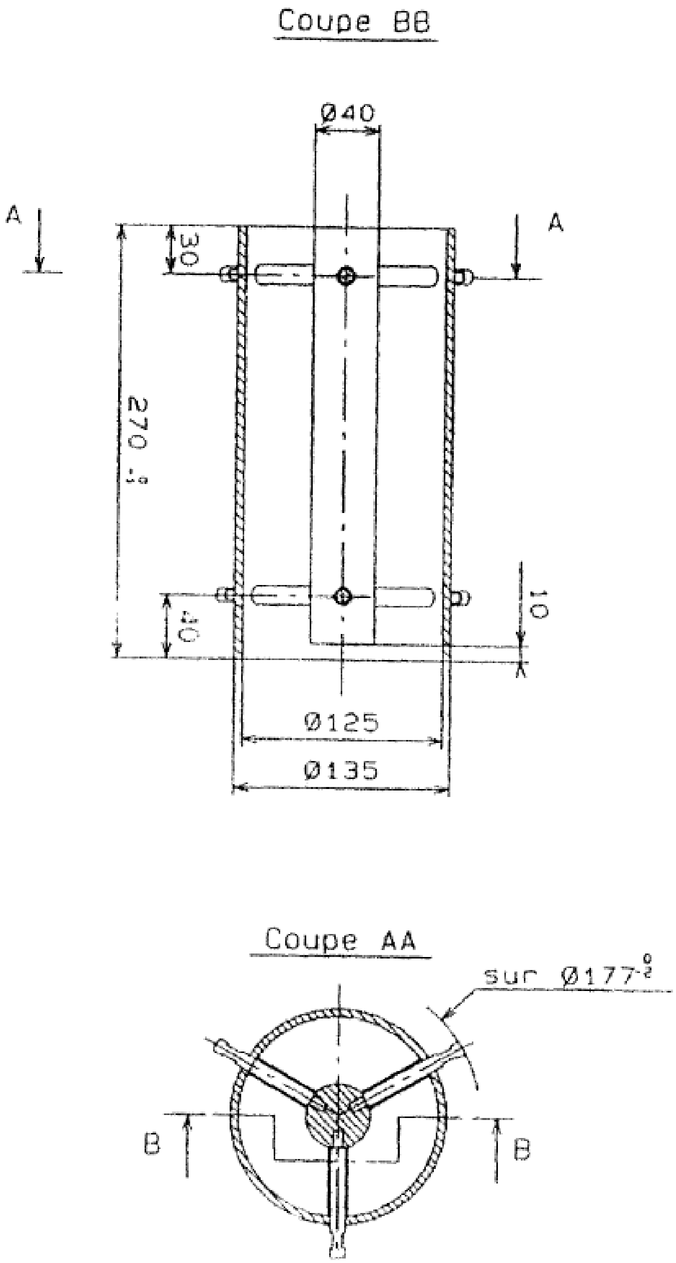
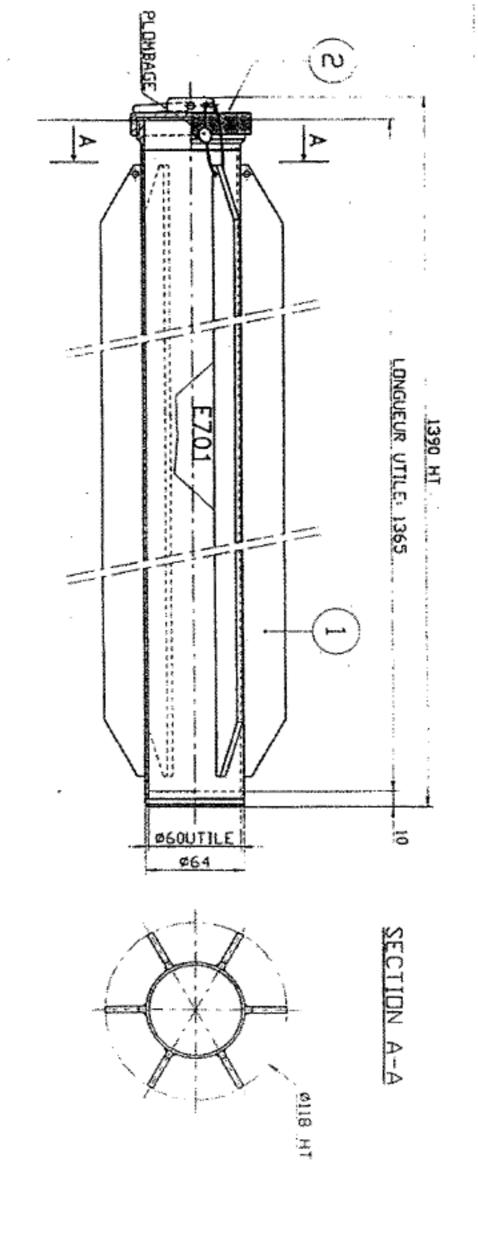
FIGURE 1-1 23: DIAGRAM OF BLOCK E6



Coupe BB Coupe AA sur O177	Section BB Section AA over 0177

FIGURE 1-1.24: DIAGRAM OF BLOCK E7



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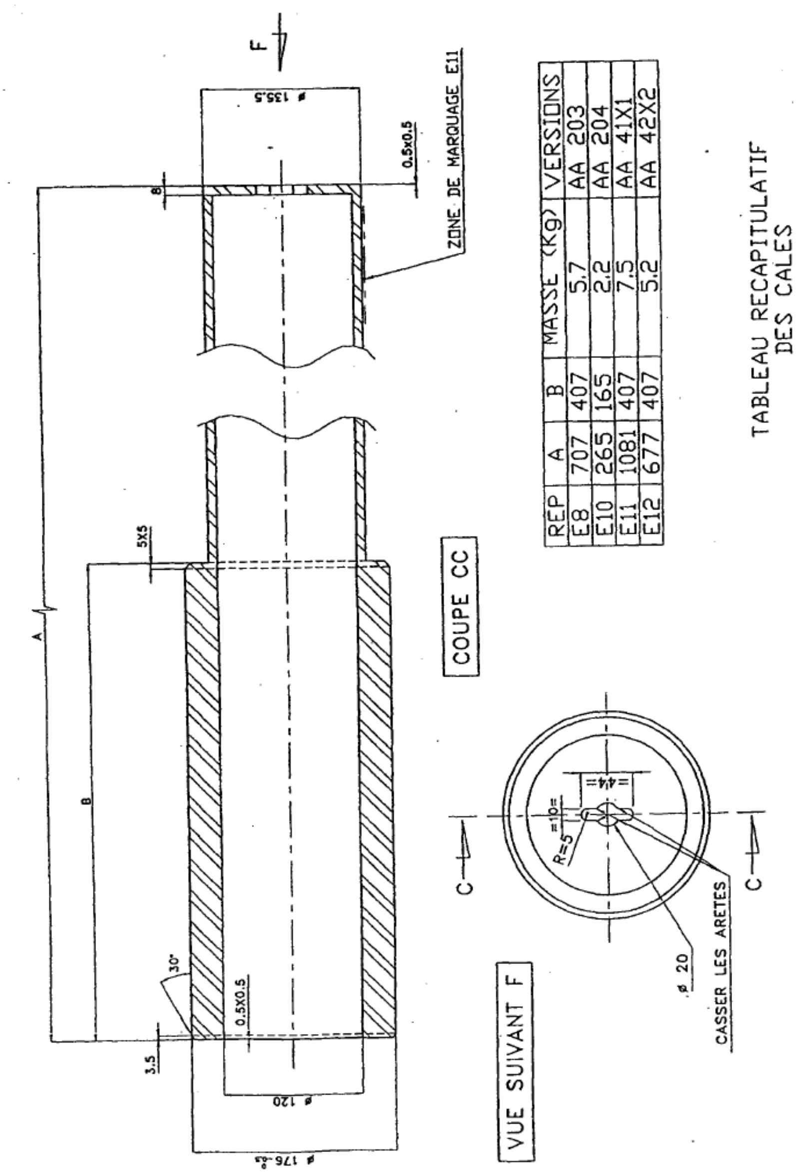
Plombage Longueur utile Section A-A O6 utile	Plumb Useful length Section A-A Useful O6

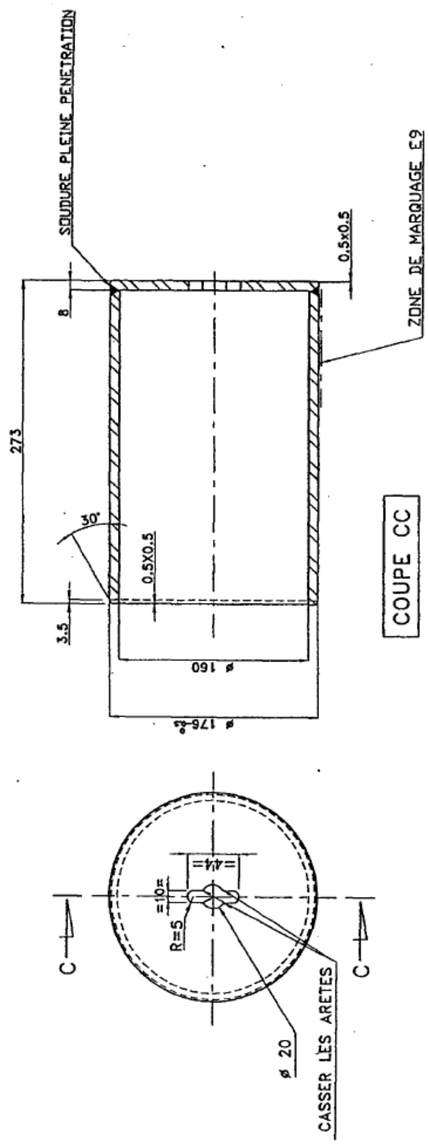
FIGURE 1-1.25: SCHEMA DES CALES E8 – E10 – E11- E12



REP	A	B	MASSE (Kg)	VERSIONS
E8	707	407	5.7	AA 203
E10	265	165	2.2	AA 204
E11	1081	407	7.5	AA 41X1
E12	677	407	5.2	AA 42X2

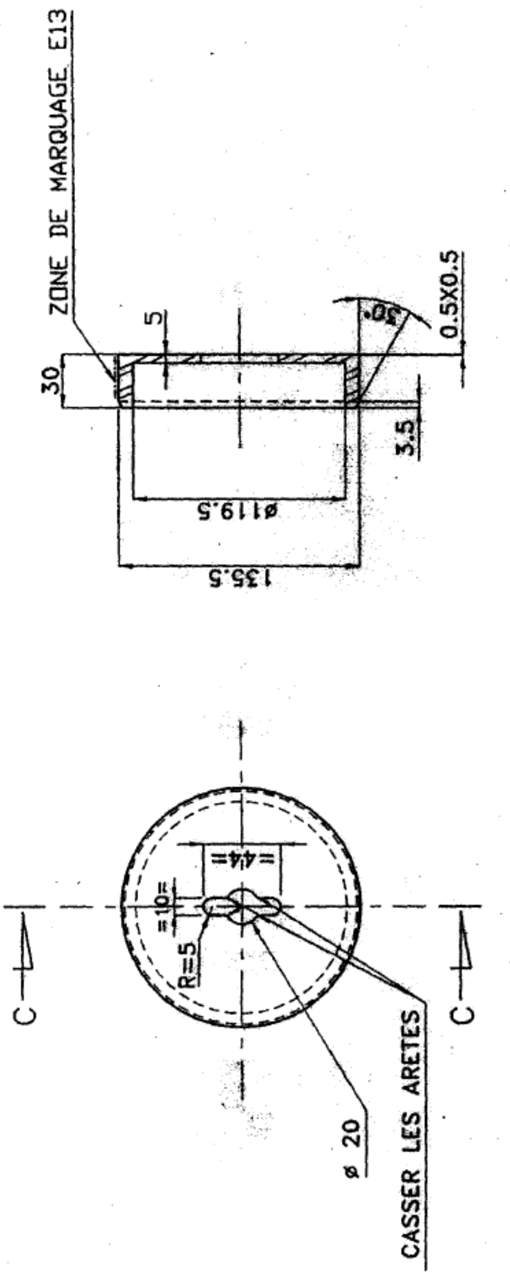
Zone de marquage Coupe CC Vue suivant F Casser les aretes Tableau recapitulatif de cales Rep. Masse (Kg) Versions	Marking area Section CC Next view F Round off sharp edges Summary of blocks Mar. Mass (Kg) Versions

FIGURE 1-1.26: DIAGRAM OF BLOCK E9



Soudure pleine penetration Zone de marquage Coupe CC Casser les aretes	Full depth weld Marking area Section CC Round off sharp edges

FIGURE 1-1.27: DIAGRAM OF BLOCK E13



Zone de marquage Casser les aretes	Marking area Round off sharp edges

FIGURE 1-1.28: DIAGRAM OF BLOCK E14

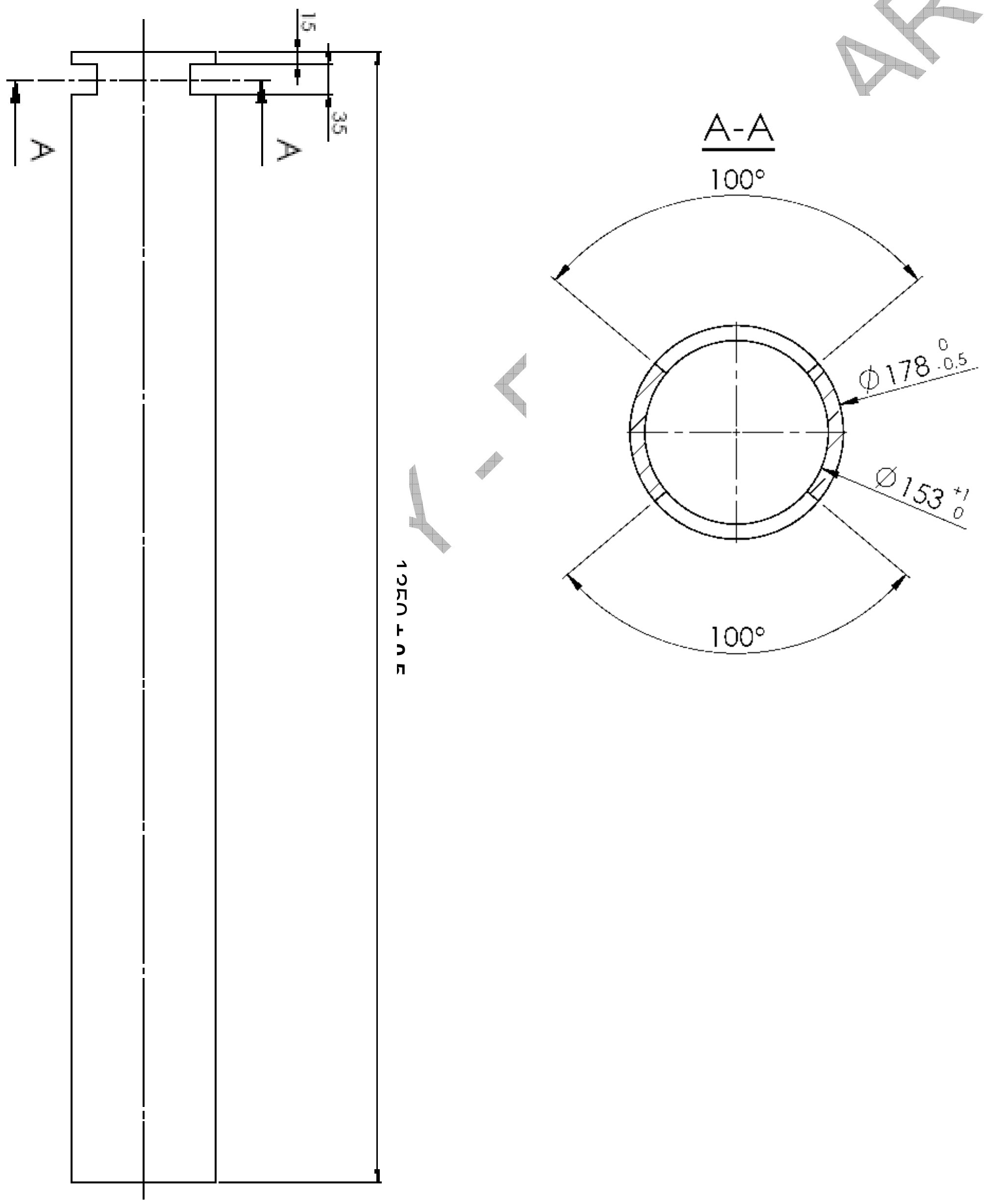
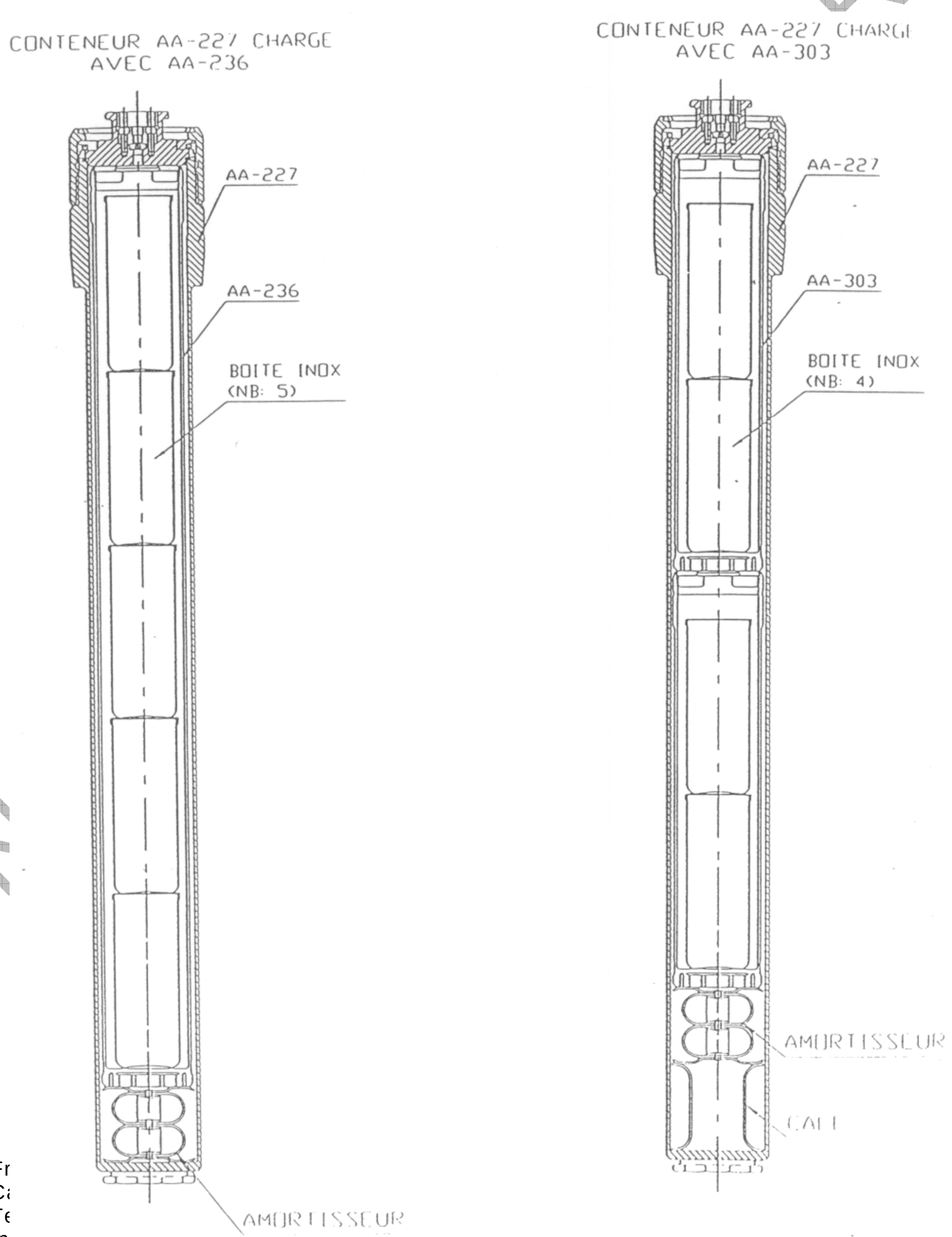


FIGURE 1-1.29: DIAGRAM OF BLOCKING DEVICES FOR AA 236 AND AA 303 INSIDE CONTAINER AA 227

Conteneur AA 227 chargé avec AA 236 Boite inox (NB 5) Amortisseur Conteneur AA 227 chargé avec AA 303 Boite inox (NB 4) Amortisseur Cale	Container AA 227 loaded with AA 236 Stainless steel (NB 5) Damper Container AA 227 loaded with AA 303 Stainless steel (NB 4) Damper Block



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Classification: 7.4.1	Page 1/23
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Title: Safety file– TN-BGC 1 Chapter 2: description of the package	

Purpose of the document:

This chapter provides the description of the package and its components

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Field of application and summary:

APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
N°	TITLES	N° of pages	N°	TITLES	N° of pages
			2-1	Concept plans for the package: Drawing 9990-65 issue C - Assembly Drawing 9990-118 issue B - cage Drawing 9990-117 issue B - assembled plug	3

History of changes

Issue	Date	Comments/Purpose of the change of issue
A		Creation of the document

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Signature		Cf. page 2	
	WRITTEN BY	**CHECKED BY**	**APPROVED BY**

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Issue	Checked by	Signature
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	S. CLAVERIE-FORGUES (CEA/DEN/DPIE/SET)	

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1 INTRODUCTION

Package model TN-BGC 1 is intended for the transport and storage of fissile materials in various forms such as bars of plutonium or metal uranium, plutonium oxide powders and highly enriched uranium, or liquids such as uranyl nitrate. The fissile material is always contained in packing (see chapter 1) placed in the cavity of package TN-BGC 1.

This chapter includes a brief description of the package, and all of its characteristics (dimensions, materials, etc.) required for safety substantiation in the continuation of the file.

2 CONCEPT PLANS FOR THE PACKAGE

Package TN-BGC 1 is shown on the concept plans included in attachment 2-1. These plans indicate:

- dimensions and tolerances relating to the use of the package and the analysis of safety included in this file,
- the identification markers of the different components. These markers will be used later in this file.

3 GENERAL DESCRIPTION

The TN-BGC1 package model consists of:

- a **cage** with a structure in welded aluminium tubes,
- a **main section** with one of the internal installations described in chapter 1 placed in its cavity; this main section consists of a shell and a base, coated with a resin-based mixture providing neutronic and thermal protection and with a wood damper integrated in the base; the main section is connected to the cage by attachment tabs welded under the main section and screwed to the cage,
- a **closing system** for the main section cavity, mainly consisting of a plug, a bronze clamp ring and a bayonet ring,
- a damper **cover** protecting the package in case of a fall on the plug side.

Main dimensions (see figure 1):

- overall dimensions of the cage:
  - length: 600 mm,
  - width: 600 mm,
  - height: 1821 mm,
- overall dimensions of the main section with the cover:
  - main diameter of the main section: 295 mm,

- ➢ cover diameter: 466 mm,
- ➢ height: 1808 mm,

- working dimensions of the cavity:
  - ➢ length: 1475 mm,
  - ➢ diameter: 178 mm.

Masses:

- total empty mass of the package: 280 kg
- maximum total mass of the loaded package: 396 kg

The maximum load on the ground due to the package is:

- in a vertical position: 1.1 t/m²
- in a horizontal position: 0.4 t/m²

4 DESCRIPTION OF THE MAIN COMPONENTS

The markers indicated in this paragraph are indicated on the drawings enclosed in attachment 2-1.

4.1 CAGE (3)

Two types of cages are defined. The two types only differ in terms of minor modifications. We specify the differences between the two options when applicable (options 1 and 2 defined in attachment 2-1).

The cage is a structure with dimensions 600 x 600 x 1821 mm^3, formed out of tubes welded together. The tubes are laminated aluminium tubes with a square section of 30 x 30 mm² and a thickness of 2 mm. The cage is mainly formed of vertical uprights and horizontal bars defining three "levels". Tubes are placed diagonally to ensure the lateral rigidity of this structure.

Passages, reinforced with corners of 40 x 40 x 4 mm^3, (and corners of 60 x 40 x 4 for option 2), also in aluminium, are fitted in the lower section and up to approximately two thirds of the height to allow for the insertion of the forks of a forklift truck and therefore the handling of the package.

An opening of 200 x 125 mm² has been created in the upper section to enable the extraction of internal installations while reducing the height of lift required for handling using a crane.

With option 2, the 3 other surfaces are modified as follows:

- a horizontal square aluminium tube (30 x 30 x 2) is added at 95 mm under the upper square tube (at the same level as the horizontal square tube on the front surface). Two vertical square tubes are

placed between the horizontal tubes per surface,

- the transversal squares on the three upper lateral surfaces are therefore modified together with the protective sheets.

The vertical uprights are closed at their upper end with a plastic or aluminium end-fitting (3e) to avoid the penetration of water and at their lower end with an aluminium base (3g) to reinforce the tube in this zone and therefore avoid crushing due to impact during handling; the uprights are perforated to avoid the accumulation of water.

Frames have been fitted inside the cage to connect the cage to the main section:

- these frames are offset from the cage by 45° and are drilled to enable the use of the main section attachment screws (1u),
- inclined tubes are welded between the frames and the rest of the structure to ensure the satisfactory transmission of mechanical forces from the main section to the cage; the part of the non-welded end on the frames is closed by plastic rectangular end-fittings (3i).

If the package is vertical, the cages may be handled using a suitable lifting beam or straps or slings passed around tubes reinforcing the corners of the upper section of the cage. If the package is horizontal, handling is possible using straps around the cage.

Package model TN-BGC 1 is designed to enable transport in a metal-clad caisson to physically protect the content. Packages must be placed vertically in the transport caisson. Specific securing is required for the packages in this caisson; this securing is described in detail and justified in chapter 3.1.

A device is placed between the aluminium tubes of the structure of the cage to prevent contact between parts of the human body and the main section of the package and therefore restricting the outer surface of the package. This device may consist of a set of cut aluminium plates or any other resource intended to fulfil this function. This device is such that the additional stiffness of the cage structure is insignificant and more than 40% of the external surface of the cage is clear.

4.2 MAIN SECTION (1)

The cavity of the main section is formed of a stainless steel shell (rolled and welded sheet) with a minimum thickness of 6 mm and a useful inner diameter of 178 mm. The stainless steel base has a minimum thickness of 8 mm and all parts are joined with a circular weld.

A second stainless steel shell has a thickness of 1.5 mm and an inner diameter of 292 mm and, in combination with the first shell, outlines a space filled with loaded resin which acts as a neutronic absorber and active thermal insulation.

A distribution plate (1d) of 25 mm, in special steel, is fixed on the base (with 4 studs (1j) welded to the base) to reinforce the former in case the package falls and impacts the base.

A caisson (1h) consisting of a central poplar disk and an outer balsa ring acts as a damper for falls impacting the lower part of the main section.

A machined stainless steel flange in the upper section is welded to the two shells to receive the closing system described below and provide a satisfactory bearing surface for the seals.
This flange also includes four 50° indents to enable the introduction and axial blocking of the bayonet ring in the plug clamp system. These indents are perforated with 4 tapped holes to enable the fitting of the packaging closing tool. They also include a hole with a diameter of 6 mm for the visual inspection of the quality of the contact of the plug on the flat surface of the flange.

To ensure the attachment of the cover (see paragraph 4.4), the outer shell includes two grips (1l), screwed or welded, ((1w) + (1x)) on the outer shell and two attachment tabs (1t) to fit two bent rods (4h) embedded in the cover.

Attachment tabs (1m) will be used to link the cage. These tabs are folded stainless steel sheets and are welded to the outer shell and screwed to the cage using one HM6-50 screw (1u) each and one permanent H6 (1v) nut. Neoprene pads (1p) are used to ensure contact with the cage and compensate for clearance between the cage and the main section.

Two identification plates (1n) and one manufacturer's plate (1o) in stainless steel are fitted on the main section with rivets, engraved in compliance with regulations.

Sintered gas permeable stainless steel pellets (1s), are fitted on the outer walls of the main section (via supports (1q) welded on the outer shell) to enable the degassing of solvents trapped in the resin during initial use.

Plastic fusible plugs (1r) enable the evacuation of burnt gases in case of fire and therefore prevent overpressure.

4.3 CLOSING SYSTEM

The cavity of the main section is closed with a system consisting of 3 main parts: a plug (2), a clamp ring (6) and a bayonet ring (5).

The plug is machined in a stainless steel disk with a thickness of 92 mm.

This disk has a peripheral 20 mm-thick shoulder which is in contact with the main section flange.

A mushroom head is fitted on the upper surface for the use of an automatic tool.

A polyethylene ring placed inside the plug completes the axial neutronic shielding of the package.

A hole fitted with a quick connection (10) (equipped with an o ring (16)) in the centre of the plug enables pressure inside the package to be reduced prior to dispatch and an increase to atmospheric pressure at arrival prior to unloading.

The sealing of the plug on the main section and the orifice equipped with the quick connection is ensured by two o

rings (11) and (12) fitted in two concentric trapezoidal throats machined in the shoulder of the plug and by a quick connection cap (7) with a double o ring ((13) and (14)). The spaces between the seals (11)/(12) and (13)/(14) both intercommunicate with a common control orifice blocked by the bronze control plug (9) M20 (equipped with a cleanliness seal (15)) accessible at the upper surface of the plug.

The quick connection cap (7) is machined in stainless steel and includes a semi-circular throat to enable handling with an automatic ball tool if necessary.

It is held in place with a bronze tightening nut (8) M72 x 2 (to avoid any risk of jamming with the plug (2) in stainless steel) clamped with a tool placed in the four 6 mm holes located at regular intervals around the 56 mm diameter and drilled in the upper surface.

This plug is held in place with a bronze clamp ring (6) which screws in the stainless steel bayonet ring (5). This ring (6) (in bronze to avoid any risk of jamming during movement in the stainless steel bayonet ring (5)) includes four tapped M10 holes to attach the connection screws using the tool for handling and tightening.

The bayonet ring (5) includes an internal thread M 230 x 4 with a height of 26 mm and a width of 12 mm and four outer male indents of 40° with a thickness of 15 mm and a width of 6 mm inserted in the corresponding marks in the package main section flange. The ring is blocked in rotation with a stop pin (5a) forced into the flange.

4.4 DAMPER COVER (4)

A damper cover is fitted on the head of the main section and the closing system.

This cover consists of two caissons in stainless steel sheets with a thickness of 1.5 mm with the exception of the intermediate flat sheet which has a thickness of 4 mm to ensure the satisfactory transmission and distribution of forces. The nearest caisson to the main section is filled with 25 mm of resin (min. 24 mm) in the upper section and 23.5 mm (min. 22 mm) of resin in the lateral section (resin identical to that surrounding the main section), to ensure the thermal protection of the closing system. The second caison contains wood: poplar, with radially directed fibres in the lateral section (thickness: 55 mm), and balsa in the upper section, with longitudinally directed fibres on the outer ring and traversally directed fibres in the centre (thickness: 70 mm).

Two folding handles (4f) are fixed at the top of the cover for handling.

The cover is connected to the main section as follows (also see paragraph 4.2):

- two grips (11) screwed and welded on the main section are attached to tabs welded to threaded rods (4h) screwed and blocked (by the nut (4i)) in the pads (4g) welded to the cover (seals may be added between the grip handles and the main section),
- two bent and partially threaded rods fixed to the cover in the above manner, penetrate the attachment tabs (1t) welded to the main section.

5 CONTAINMENT

The containment of package TN-BGC1 consists of an inner shell and the base of the main section, the plug and the quick connection cap (figure 2).

The sealing of the containment is ensured by specific o rings (11) for the plug and (13) the quick connection cap, in silicon for B(U) type packages and in Viton for B(M) type packages. These seals are doubled with a second o ring ((12) and (14)), in Viton, to create a controllable space (presence of a common control orifice for the two inter-seal spaces).

The inner shell of the main section and its base are in stainless steel. The same applies to the plug and quick connection cap.

The plug is maintained on the main section (1) by the clamp ring (6) which is screwed in the bayonet ring (5) supported by the main section flange. The quick connection cap (7) is fixed on the plug using the tightening nut (8) which screws into the plug.

The inner volume of the empty containment is equal to 37.6 litres.

6 SHIELDING

6.1 LATERAL SHIELDING

The lateral shielding against gamma radiation mainly consists of the stainless steel of the inner shell (6 mm) and outer shell (1.5 mm) and of resin (48 mm) for shielding against neutron radiation.

6.2 BASE SHIELDING

The base shielding against gamma radiation mainly consists of the stainless steel of the cavity base (8 mm) and the two closing sheets (2 x 1.5 mm) and of the carbon steel of the distribution plate (min. 24 mm). Shielding against neutron radiation mainly consists of resin (25 mm) and wood (65 mm).

6.3 HEAD SHIELDING

Head shielding consists of the stainless steel of the plug (59 mm) and the cover sheets (2 x 1.5 mm) for gamma protection and of the resin (24 mm) and wood (70 mm) contained in the cover for neutronic protection.

7 HANDLING AND SECURING POINTS

If the package is vertical, two handling methods are possible:

- using a forklift truck whose forks enter the passages intended for this purpose (two possible levels) as described in paragraph 4.1,
- using straps or slings attached to the middle of the tubes reinforcing the corners of the upper section of the cage.

If the package is horizontal, the package may be handled by passing two straps around the cage:

If the package is transported vertically, two types of securing are possible:

- by blocking the base and maintaining the straps at mid-height,
- by blocking the cross beams at two different levels.

If the package is transported horizontally, it may be secured with ground blocks around the cage and straps over the cage:

The package is designed to ensure that constraints do not exceed the elastic limit at any point if the package is subjected to regulatory accelerations.

Refer to chapter 3.1 for a precise description of handling and blocking modes and the justification of constraints.

8 CHARACTERISTICS OF THE MATERIALS USED FOR THE PACKAGE

The materials used to manufacture the package are as follows:

- steels,
- aluminium,
- bronze,
- welding material,
- resin,
- wood,
- elastomer,
- plastic materials.

All these materials have the mechanical and thermal properties indicated in tables 2-2 and 2-3 respectively.

Equivalent materials to those indicated in this safety file may be used if the deviations required are justified.

8.1 STEELS

8.1.1 Stainless steel

Steels are of type Z2 CN 18.10 (NFA 35-575) or Z6 CN 18.09 (or equivalent) for all shells, base and sheets.

Screws and rivets, together with grips, attachment tabs and regulatory plates are also in stainless steel of the above types.

8.1.2 Carbon steel

The distribution plate is in 39 CD 4 type carbon steel (or equivalent).

8.2 BRONZE

The tightening nut (8) of the quick connection cap is CuSn12 (or equivalent) known as bronze B.

The plug clamp ring (6) is Cu AI9 Ni5 Fe5 Y20 (or equivalent) known as bronze A.

8.3 ALUMINIUM

8.3.1 Structure of the cage

The aluminium used for the cage structure is grade 6082, hardened and quenched. Tube extrusion is carried out to ensure the integrity of the properties of the metal.

8.3.2 Flat plates, corners and bases

Grade and condition: grade 6060 (or equivalent).

8.4 WELDING MATERIALS

Welding materials comply with the requirements of CODAP or the ASME code for constructions with sheet metal work in stainless steel or aluminium. To give an example, AFNOR NF A 81-329E (or equivalent) applies for stainless steel and AFNOR NF A 81-331 (or equivalent) applies for aluminium.

8.5 RESIN

Properties are as follows:

- minimum density: 1,6,
- tolerance: -40°C / +160°C with a continuous regime,
- composition: see table 2-7,
- implementation: the resin is prepared based on the above composition and forms a viscous liquid which is poured between the walls of the main section and the cover. Polymerization occurs once the resin is between the walls of the main section. The preparation and pouring operations are carried out as per the TRANSNUCLEAIRE 9990-P-19 procedure,
- inspection: the effectiveness of the resin is inspected by measuring the attenuation of radiation from an internal source outside of the main section. This operation applies the following procedures: TRANSNUCLEAIRE 9990-P-6 and 9990-P-12,

8.6 WOOD

Poplar and balsa wood are used in the cover and in the base of the package, depending on the zones in question. They have the properties indicated in table 2-4.

8.7 SEALS

Seals are in "Viton" type (or equivalent) fluorocarbonaceous elastomer for B(M) type packages or in silicon for B(U) type packages. Their respective properties are listed in table 2-5.

8.8 SMALL COMPONENTS

8.8.1 Fusible plugs

Fusible plugs are in polyethylene or another material with a fusion temperature of less than 150°C.

8.8.2 Pads

Pads are in Neoprene or another elastomer material with a shore hardness of between 30 and 70.

8.8.3 Plastic end fittings

These end fittings are intended to prevent the penetration of water in the cage.

8.8.4 Polyethylene disk

This disk is included in the plug and completes the axial shielding of the package.

9 TRANSPORT IN A CAISSON

If the package is used to transport fissile materials subject to physical protection requirements, it may be contained in a metal-clad caisson. This configuration only relates to vertical transport. Table 2-6 resumes the thermal properties of the caisson.

10 MANUFACTURE OF THE PACKAGE

Packages are manufactured on the basis of the general specification drafted by TRANSNUCLEAIRE with the reference 9990-A-1, which defines the general principles applicable to the composition of packages and their components. This specification required the following checks in particular:

- visual inspection of all cage welds
- liquid penetrant test of welds on the cover and accessories by sampling,
- liquid penetrant test at 100% of accessible welds for the inner and outer shells and the plug,
- sealing of containment welds,
- effectiveness of resin,
- functional testing,
- helium sealing testing of each package at completion of manufacture.

Each package component (cage, main section, resin, wood, small components, etc.) has been subject to manufacturing specifications and special installation procedures.

TABLE 2- 1 : LIST OF THE MAIN COMPONENTS OF THE PACKAGE

Comment: Not all indices are used. This numbering is taken from other documents using the entire list of identifiers.

Marker n°	Component name	Material (for information)
	ASSEMBLY	
1	MAIN SECTION	
	Flange, shells, bases, closing sheets	Z6 CN 18.09 or Z2 CN 18.10
1d	Distribution plate	39 CD 4
1g	Resin filler	Resin
1h1	Wood filler	Poplar
1h2	Wood filler	Balsa
1j	M8 axis	Z6 CN 18.09 or Z2 CN 18.10
1k	M8 nut	Z6 CN 18.09 or Z2 CN 18.10
1l	Grips	Z6 CN 18.09 or Z2 CN 18.10
1m	Attachment tab	Z6 CN 18.09 or Z2 CN 18.10
1n	Identification plate	Z6 CN 18.09 or Z2 CN 18.10
1o	Regulatory plate	Z6 CN 18.09 or Z2 CN 18.10
1p	Rubber pad	Neoprene 40sh
1q	Pellet holder	Z6 CN 18.09 or Z2 CN 18.10
1r	Plastic plug 0 9	Polyethelene
1s	Poral pellet	Sintered stainless steel
1t	Cover stop	Z6 CN 18.09 or Z2 CN 18.10
1u	HM6 - 50 screw	Z6 CN 18.09 or Z2 CN 18.10
1v	Permanent H6 nut	Z6 CN 18.09 or Z2 CN 18.10
1w	Sheet screw	Z6 CN 18.09 or Z2 CN 18.10
1x	Washer	Z6 CN 18.09 or Z2 CN 18.10
2	PLUG	
2a	Blocking plate	Z6 CN 18.09 or Z2 CN 18.10
2b	Polyethylene disk	HD 100
2c	Closing sheet	Z6 CN 18.09 or Z2 CN 18.10

Marker n°	Component name	Material (for information)
3	CAGE	
	Structure	6082
3e	Square end fittings	Polyethylene or aluminium
3f	Flat plates	6060
3g	Bases	6060
3h	Corner plates	6060
3i	Plastic rectangular end fittings	Polyethelene
3j	Cut plates	Aluminum
4	DAMPER COVER	
	Bases and shells	Z6 CN 18.09 or Z2 CN 18.10
4e1	Wood filler	Poplar
4e2	Wood filler	Balsa
4f	Folding handle	Stainless steel 304
4g	Pad for grip and stop	Z6 CN 18.09 or Z2 CN 18.10
4h	Threaded rod	Z6 CN 18.09 or Z2 CN 18.10
4i	Stop nut	Z6 CN 18.09 or Z2 CN 18.10
4j	Resin filler	Resin
5	BAYONET RING	Z6 CN 18.09 or Z2 CN 18.10
5a	Stop pin	Z6 CN 18.09 or Z2 CN 18.10
6	CLAMP RING	Cu Al9 Ni5 Fe5 Y20
7	STAUBLI PLUG	Z6 CN 18.09 or Z2 CN 18.10
8	TIGHTENING NUT	CuSn12
9	TEST PLUG	Bronze ASTM BI 51
10	STAUBLI COUPLING	Stainless steel 304
11	O ring with $\varnothing_{int}$ of 196.25	Viton (low temperature) or silicon
12	O ring with $\varnothing_{int}$ of 228	Viton
13	O ring with $\varnothing_{int}$ of 32.915	Viton (low temperature) or silicon
14	O ring with $\varnothing_{int}$ of 53.57	Viton

TABLE 2- 2 : MECHANICAL PROPERTIES OF THE MATERIALS USED IN THE PACKAGE

Material	Temperature (°C)	Elastic limit (MPa)	Young's modulus (MPa)	Poisson's ratio	Expansion coefficient ($°C^{-1}$)
Aluminium 6082 (ou équivalent)	20° - 70°	260 (état écroui) 110 (état recuit)	> 69500	0,33	-
Acier inoxydable Z2 CN 18.10 (ou équivalent)	20° - 160°	> 220	200000	0,33	< 16 x 10^{-6}
	240	> 115	-	-	-
	250°	> 108	-	-	-
Acier 39 CD 4 (ou équivalent)	20° - 150°	> 500	180000	0,33	-
Bronze A	20° - 160°	> 250	115000	-	-
Bronze B	20° - 150°	> 60	-	-	-

TABLE 2- 3 : THERMAL PROPERTIES OF THE MATERIALS USED IN THE PACKAGE

Material	Thermal conductivity (W/m.K)	Specific heat (J/kg)	Surface emissivity	Coefficient of absorption of solar heat
Stainless steel	≥ 15	≥ 500	≥ 0.26	≤ 0.45
Aluminum	134	950	0,55	
Resin	≥ 0.66* (intact) ≥ 0.57 mean over the thickness during fire testing ≥ 0.29 mean over the thickness after fire testing	≥ 1250	-	-

*: *Only this conductivity value for resin will be considered as an essential parameter.*

TABLE 2- 4 : PROPERTIES OF WOOD SPECIES

(values obtained for a number of samples representative of manufacture)

Properties	Balsa	Poplar
Density	0,11 ± 0,03	0,36 ± 0,03
Maximum percentage of humidity before installation	12	12
Mean crushing stress (MPa)	7 ± 2	23 ± 2
Minimum crushing stress (%)	60	45

TABLE 2- 5: SEAL PROPERTIES

Properties	Value
Properties shared by all seals	
"Shore" "A" hardness	70 ± 5
Interval for use for seals restricting the containment	
Case 1: Viton	-25°C / +250°C
Case 2: Silicon	-45°C / +315°C
Expansion coefficient	
Case 1: Viton	227.10^{-6} m.K^{-1}
Case 2: Silicon	274.10^{-6} m.K^{-1}

TABLE 2- 6 : PARAMETERS RELATING TO THE USE OF A CAISSON

(the outer dimensions of the caisson must be identical to those of an ISO20 foot type caisson)

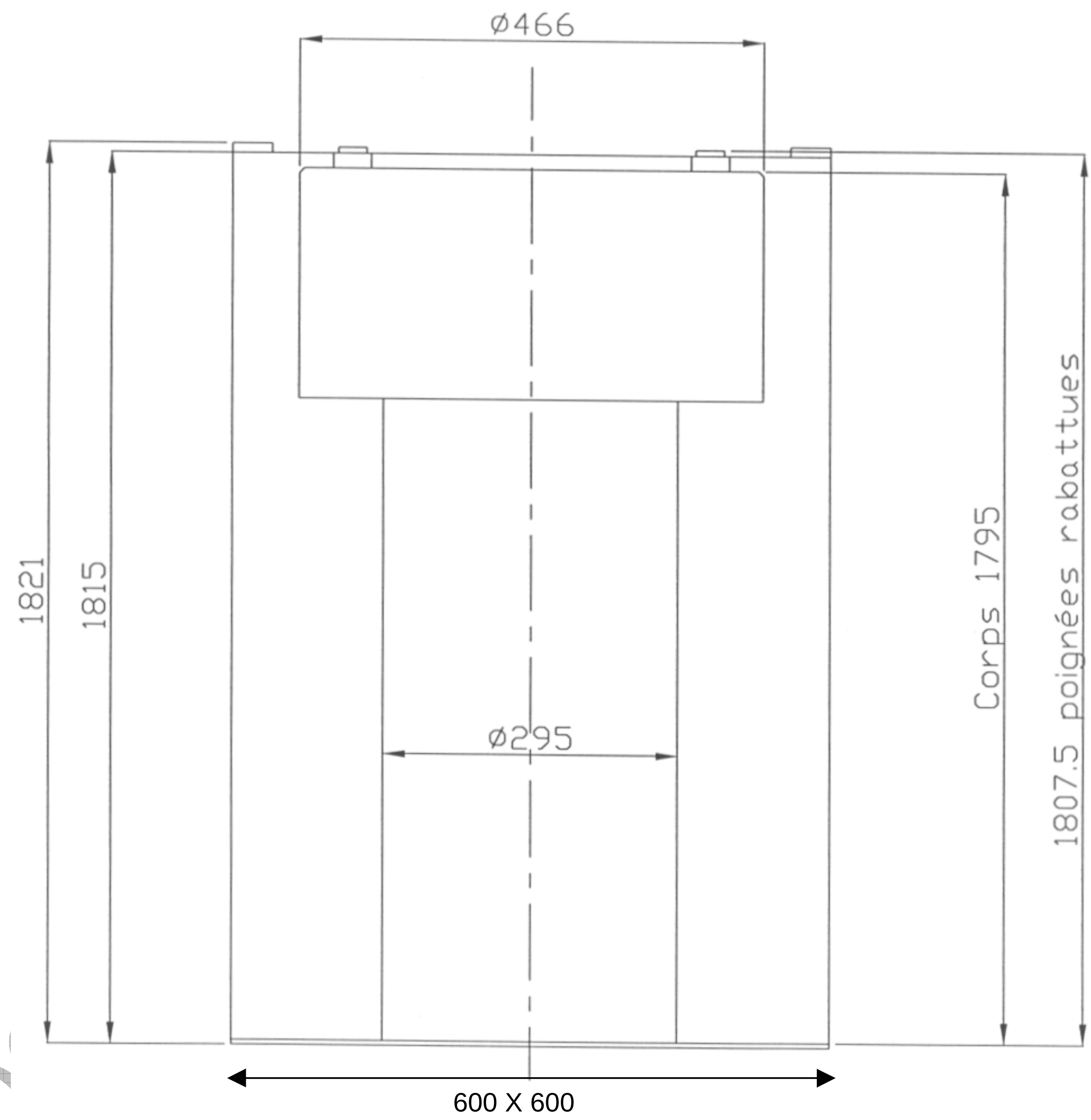
External emissivity of the caisson		0,9
Internal emissivity of the caisson		0,2
Solar absorptivity		0,3
Conductivity (W/m^2.K)	Roof and lateral walls	0,13
	Doors	0,22

TABLE 2- 7: PROPERTIES OF THE RESIN

Nominal composition	
Products	(%) en poids (à +/- 5%)
Norsodyne M 0070C resin by CDF Chimie	35
Monomer styrene C_8H_8	5
Zinc borate 4ZnO, $6B_2O_3$, $7H_2O$	15
Aluminium hydrate $A1_2O_3$, $3H_2O$	44,8
Cut fibre glass	0,2
Accelerator	
Catalyst	
Minimum values for the finished product	
density	1,6
number of atoms of hydrogen per cm^3	$4,06.10^{22}$
number of atoms of boron per cm^3	$9,45.10^{20}$

The resin mentioned can be replaced by an equivalent resin.

FIGURE 2- 1 : DIMENSIONS



Corps 1795	Main section 1795

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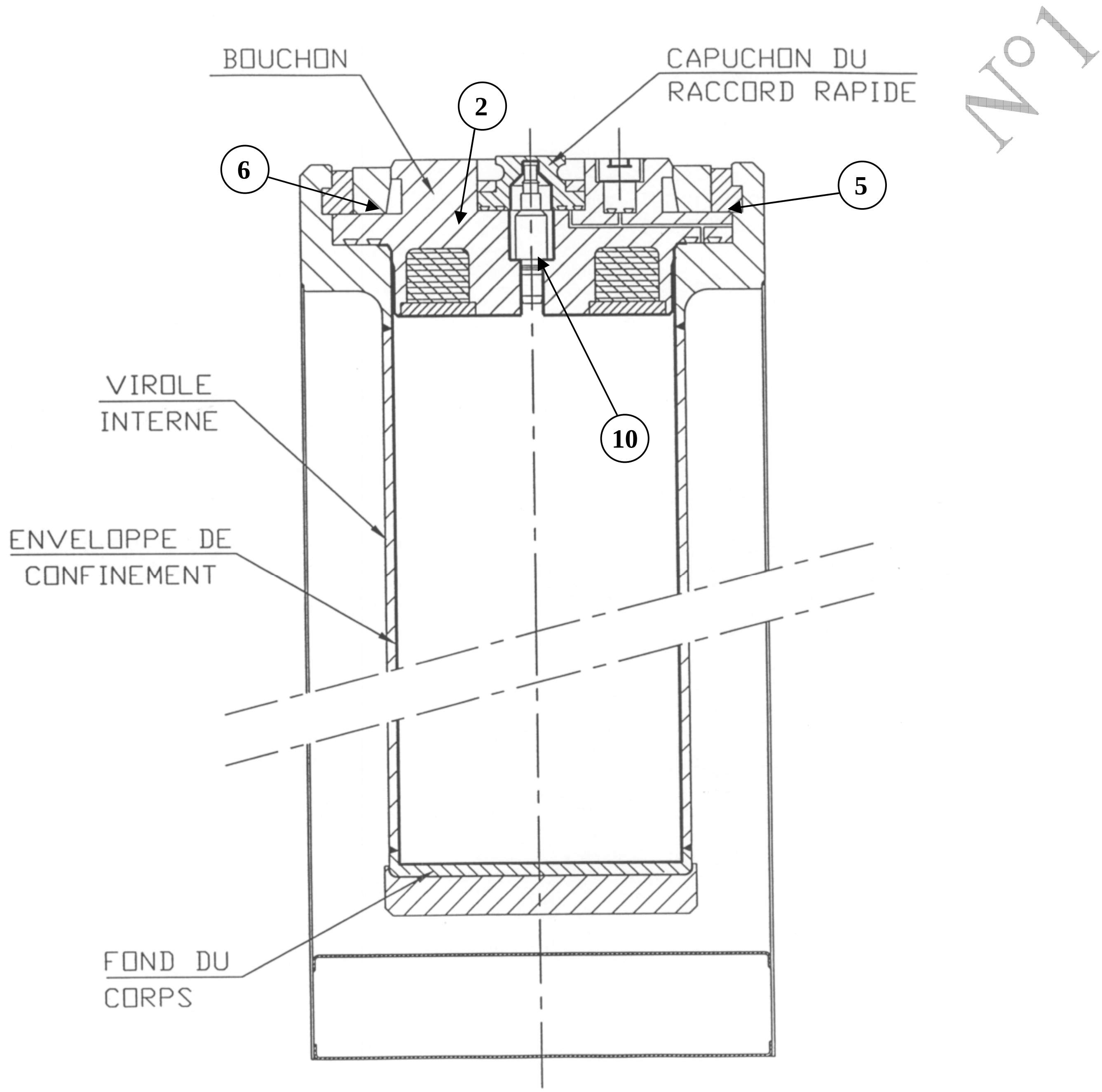
poignées rabattues	Folding handles

FIGURE 2- 2 : CONTAINMENT



Capuchon du raccord rapide Bouchon Virole interne	Quick connection cap Plug Inner shell

Enveloppe de confinement Fond du corps	Containment Base of the main section

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Purpose of the document: This chapter includes a mechanical analysis of the package TN-BGC 1	CEA/DEN/CAD/DPIE/SET DO 80 26/02/08

Field of application and summary:

APPENDICES (included in this document and therefore in global page numbers)			ATTACHMENTS (separate page numbers, identification and formal procedures)		
N°	TITLES	N° of pages	N°	TITLES	N° of pages
			3.1-1	Fall testing for TN-BGC 1 – overview of testing, ref. EMB TNBGC PBC NTT CA000524 A of 20/02/04	8
			3.1-2	Report on fall testing with prototypes of package TN-BGC 1, ref. EMB TNBGC PBC DJS CA 000333 A of 07/08/03	40
			3.1-3	Report on additional fall testing with package TN-BGC 1, ref. EMB TNBGC PBC DJS CA 000334 A of 07/08/03	153
			3.1-4	Mechanical study of a vertical drop of 9 m for the TN-BGC1 package with the cover facing down, ref. 2CE3E100 rev. 2 of 16/02/04	58
			3.1-5	Study of the continued sealing of package TN-BGC 1 after a fall of 9 m from an oblique position, ref. G03CAL022A Iss. 2.0 of 30/05/2007	56
			3.1-6	Mechanical resistance of the containment during immersion, ref. 160 EMBAL PFM DETT 08000162 A of 26/02/08	8
			3.1-7	Resistance of handling devices, ref. 160 EMBAL PFM DETT 08000163 A of 26/02/08	19
			3.1-8	Mechanical studies of the securing of package TN/BGC 1 - Combined accelerations, ref. 299E05W03 of 17/08/05	57
			3.1-9	Mechanical resistance of package TN-BGC 1 during an explosion, ref. 2BP6E042 of 02/05/06	40
			3.1-10	Analyse modale réf. **159A3W03 Ind. B du 17/01/03**	20

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CONTENTS

1 INTRODUCTION

The aim of this chapter is to analyse the mechanical resistance of package TN-BGC 1 and to demonstrate that this package satisfies regulatory requirements for type B packages for fissile radioactive materials.

This chapter also aims to identify the condition of the package following regulatory fall tests in normal and accident transport conditions.

The mechanical resistance of package TN-BGC 1 is assessed in terms of the following:

- forces and stresses created by the different types of authorized content:
  - thermal gradients,
  - internal pressure due to the rise in temperature in the cavity, and by the generation of gases in the containment,
  - internal overpressure due to an explosion caused by hydrogen released in the cavity by radiolysis,
- normal handling and transport operations,

in view of the ambient pressure and temperature conditions defined in regulations.

The conformity of package TN-BGC 1 is also assessed in terms of the following regulatory tests defined in regulations:

- in normal transport conditions:
  - water spray testing (sub-paragraph 721 of [1]),
  - free fall testing from a height of 1.2 m (sub-paragraph 722 a) of [1]),
  - stacking testing (sub-paragraph 723 of [1]),
  - penetration testing (sub-paragraph 724 of [1]),
- in accident transport conditions:
  - the free fall test from a height of 9 m on a non-deformable target (sub-paragraph 727 a) of [1]), applicable in this safety file for all content holding less than 1000 A_2,
  - the dynamic crushing test involving a mass of 500 kg falling 9 m (sub-paragraph 727 c) of [1]), applicable in this safety file for all content holding less than 1000 A_2,
  - free fall testing from a height of 1 m on a punch (sub-paragraph 727 b) of [1]),
  - immersion testing under a height of water of 15 m for 8 hours (sub-paragraph 729 of [1]),
  - extensive immersion testing under a height of water of 200 m for 1 hour, which applies in this case for certain content holding more than 10^5 A_2 (sub-paragraph 730 of [1]).

Note: in the context of air transport, the package must resist PNUM + 95 kPa. As air transport concerns content with no risk of gas emissions, this requirement is covered by the analysis of the resistance to internal pressure.

2 RESISTANCE TO INTERNAL PRESSURE

2.1 CALCULATION CONDITIONS

A description of the containment is included in chapter 2.

The following calculations are carried out on the basis of a relative pressure of 10 bars. This pressure is within the maximum pressure envelope liable to be faced by the package in normal and accident transport conditions.

2.2 MATERIALS

The mechanical properties of the materials, as defined in chapter 2, are listed below:

- Steel Z2 CN 18 10: elastic limit: 130 Mpa at 160 °C (envelope temperature of the components of the containment in normal transport conditions), and 100 Mpa at 300 °C (envelope temperature of the components of the containment in accident transport conditions),
- Bronze A: elastic limit: 150 MPa at 160 °C and 290 °C.

2.3 RESISTANCE OF THE INNER SHELL

The formula from [2] (table 13.5) enable the determination of the maximum circumferential stress (σ2) on the walls of the inner shell, and shear (τ) using:

$$\sigma_2 = p.\frac{D_e^2 + D_i^2}{D_e^2 - D_i^2}$$

$$\tau = p\,\frac{{D_e}^2}{{D_e}^2 - {D_i}^2}$$

Where
p : Internal pressure p = 1 Mpa,
D_i : Internal diameter D_i = 180 mm (conservative value),
D_e : External diameter D_e = 192 mm.

I.e.: $\sigma_2 = 1 \cdot \frac{192^2 + 180^2}{192^2 - 180^2} = 15.52\,MPa$ and $\tau = 1\frac{192^2}{192^2 - 180^2} = 8.26\,MPa$

Maximum radial stress is equal to: σ_3 = - p = - 1 MPa.

Equivalent Von Mises stress is therefore equal to:

$$\sigma = \sqrt{(\sigma_2 - \sigma_3)^2 + 3\tau^2} = 21.9\,MPa$$

This stress is substantially lower than the elastic limit of stainless steel Z2 CN 18.10: Re = 130 MPa at 160°C and R'e = 100 MPa at 300°C.

2.4 RESISTANCE OF THE BASE OF THE SHELL

We can consider that the base is embedded in the shell.

The formula indicated in column l0b of table 11.2 of [2] enables the determination of stresses.

Flexural moments per unit are equal to:

At embedding point: $$Me = \frac{p.D_i^2}{32} = \frac{1 \cdot 180^2}{32} = 1012.5\, mm.N$$

At the center: $$\mathrm{Mc} = \frac{\mathrm{p.D_i^2}\,(1+\nu)}{64}$$ where Poisson's ratio ν = 0.3

$$Mc = \frac{1 \cdot 180^2\ (1+0.3)}{64} = 658.2\, mm.N$$

Maximum flexural constraint occurs at the embedding point and is equal to:

$$\sigma_f = \frac{6 \cdot Me}{e^2}$$ where the base thickness e = 8 mm

$$\sigma_f = \frac{6 \cdot 1012.5}{8^2} = 94.9\ MPa$$

Shear stresses at the embedding point are equal to:

$$\tau = \frac{p.D_i}{4.e} \therefore \tau = 5.6\ MPa$$

Equivalent Von Mises stress is therefore equal to:

$$\sigma = \sqrt{\sigma_f^2 + 3\tau^2} = 95.4\ MPa$$

This stress is lower than the elastic limit of stainless steel Z2 CN 18.10: Re = 130 MPa at 160°C and R'e = 100 MPa at 300°C.

2.5 RESISTANCE OF THE PLUG

We can consider that the plug is embedded in the shell. Given that the diameter of the area of application of pressure (180 mm) is identical to that of the base (Cf. § 2.4) and that the minimum thickness of the cover (13 mm) is thicker than the minimum thickness of the base (8 mm), the Von Mises stress on the plug is less than the Von Mises stress on the base and is therefore less than the elastic limit of the steel Z2 CN 18.10 in normal and accident transport conditions.

2.6 RESISTANCE OF THE BAYONET RING AND ITS ATTACHMENT TO THE PACKAGE

The bayonet ring consists of a cylindrical washer with an internal thread and with four flat external plates creating a clover format indent.

The upper flange of the main section of the package has a collar with identical indents. The bayonet ring is attached to the flange of the package using these indents.

Tightening is achieved using a bronze ring with an externel thread, screwed on the bayonet ring and in contact with the plug.

<u>The closing system is subjected to a maximum force due to pressure of:</u>

$$F_p = p\,\frac{\pi \cdot D_m^2}{4}$$

With a mean diameter of the internal seal throat of the plug: Dm = 203.5 mm

$$F_p = 1\,\frac{\pi \cdot 203.5^2}{4} = 32525\ N$$

<u>The tightening force of seals is equal to:</u>

$$F_S = s.L_d$$

Where:

Tightening force per unit s = 12 N/mm,

Extended length of the cover seals Ld = 1 380 mm,

Fs = 12 x 1380 = 16 560 N.

<u>Total force (tightening of seals and pressure) is equal to:</u>

Fsp = Fs + Fp = 16 560 + 32525 = 49 085 N

2.6.1 Constraints in indents

<u>Bending</u>

Each indent has a thickness h = 15 mm and a length L = 86 mm (corresponding to an angle of 40° over ∅ 254).

The force is applied over a mean diameter (Øm 260.5 mm) i.e. at a distance d = 3 mm from the external diameter of the cylindrical washer (Øi 254.5 mm) of the bayonet ring.

Each of the four indents is intended to be embedded in the collar of the ring.

The load per unit at the contact points is equal to:

$$q = \frac{F_{sp}}{4 \cdot L} = \frac{49085}{4 \cdot 86} = 142.7\,N$$

The bending moment per unit is equal to:

Mu =q . d =142.7 x 3 = 428.1 mm.N

Bending stresses are equal to:

$$\sigma_f = \frac{M_u}{I_u / v}$$

with an inertia module per unit

$$\frac{I_u}{v} = \frac{1 \cdot h^2}{6} = \frac{1 \cdot 15^2}{6} = 37.5\,mm^3$$

$$\sigma_f = \frac{428.1}{37.5} = 11.4\,MPa$$

<u>Shear</u>

Shear stresses at each indent are equal to:

$$\tau = \frac{F_{sp}}{4 \cdot S} = \frac{49085}{4 \cdot 86 \cdot 15} = 9.5\ MPa$$

<u>Equivalent Von Mises stress is therefore equal to:</u>

$$\sigma = \sqrt{\sigma_f^2 + 3\tau^2} = 20\ MPa$$

This stress is lower than the elastic limit of stainless steel Z2 CN 18.10: Re = 130 MPa at 160°C (normal conditions) and R'e = 100 MPa at 300°C (accident conditions).

2.6.2 Thread shear

The threads of the bayonet ring and the clamp ring are of ISO type (as per NFE 03-001) M230 with a pitch of P = 4 mm, and diameter on thread sides df = 227.4 mm. Length of the thread = 26 mm.

The minimum length in the thread is equivalent to:

lp = L – P = 26 – 4 = 22 mm

The section of thread shear is equal to:

$$S_f = \frac{\pi \cdot d_f \cdot 1_p}{2} = \frac{\pi \cdot 227.4 \cdot 22}{2} = 7\,858\,mm^2$$

Shear stress is equal to:

$$\tau = \frac{F_{sp}}{S_f} = \frac{49085}{7\ 858} = 6.3\,MPa$$

The intensity of stresses is equal to:

I = 2τ = 12.6 MPa.

This constraint is less than the elastic limit of bronze: Re = 150 MPa at 160°C (normal conditions) and 290 °C (accident conditions).

2.7 RESISTANCE OF THE CLAMP RING OF THE QUICK CONNECTION CAP

The quick connection cap and its clamp ring are subjected to a force due to pressure p, equal to:

$$F'_p = p\frac{\pi d_m^2}{4} = 1\ \frac{\pi \cdot 57^2}{4} = 2551.8\,N$$

The tightening force of seals is equal to:

$$F'_S = s' \mathrm{x}\, l'_d$$

Where:

Tightening force per unit s' = 6 N/mm,

Extended length of the cap seals l'd = 294 mm,

F'S = 6 x 294 = 1 764 N.

Total force (tightening of seals and pressure) is equal to:

F'sp = F's + F'p = 1764 + 2552 = 4316 N

<u>Shear</u>

The tightening ring has a M72 thread (ISO type) with a pitch P' = 2 mm, and diameter on thread sides d'f = 70.7 mm. Thread length L' = 12 mm.

The length in the thread is equivalent to:

l'p = L' - P' = 12 - 2 = 10 mm

The section of thread shear is equal to:

$$S'_f = \frac{\pi \cdot d'_f \cdot l'_p}{2} = \frac{\pi \cdot 70.7 \cdot 10}{2} = 1111 mm^2$$

Shear stress is equal to:

$$\tau = \frac{F'_{sp}}{S'_f} = \frac{4316}{1111} = 3.9\ MPa$$

The intensity of stresses is equal to:

$I = 2\tau = 7.8$ MPa

This constraint is less than the elastic limit of bronze A: Re = 150 MPa at 160°C (normal conditions) and 290 °C (accident conditions).

2.8 MECHANICAL RESISTANCE OF THE PACKAGE TO AN EXPLOSION CAUSED BY HYDROGEN

Attachment 3.1-9 includes an analysis of the resistance of the containment to a pressure of 88(*) bars for a duration of 100 ms, which is more than the maximum duration of overpressure following a hydrogen explosion in the cavity. In addition, materials have been considered at the maximum temperature obtained after the fire test. This attachment thereby demonstrates that:

- maximum opening between the plug and the flange during the explosion was 1.34 mm (for approx. 1 ms), leading to seal crushing of 10% (30% under normal circumstances),
- after the explosion, a residual opening of 0.29 mm remained, caused by the slight caulking of the flange and bayonet ring. This corresponds to seal compression of 25%,
- stress levels in all parts during the explosion remained low. The elastic limit of materials was not reached in most cases. Deformation was local near to the closing system: the main section flange, bayonet ring and plug are slightly caulked in their respective support zones, causing slight plastic deformation of approximately 0.7%. This plastic deformation is less than 1% and is not significant for package sealing during and after the explosion. Table 10 below lists Von Mises stresses and maximum plastic deformations for all parts during the explosion.

The resistance of the containment of package TN-BGC 1 to pressure in case of an internal explosion subsequent to the possible accumulation of hydrogen causing a pressure peak of 88 bars was demonstrated.

(*) 88 bars corresponds to an initial relative pressure of 10 bars as the initial pressure in the cavity of the package may be multiplied by a factor of 8.8 during an explosion.

2.9 CONCLUSION

The resistance of the containment to a relative pressure of 10 bars is confirmed including if the gas mixture liable to

form explodes.

3 EFFECT OF THERMAL GRADIENTS

The largest thermal gradient between the two shells (external and internal) remains less than 41 K (mean value) in normal transport conditions (see chapter 3.3).

The length of the internal shell is L1 = 1515 mm and the length of the external shell L2 = 1573 mm.

Differential expansion is approximately equal to:

$\Delta l = a\ L2\ (t1 - t2)$ where $a = 16.10^{-6}\ K^{-1}$ the thermal expansion coefficient

$\Delta l = 16 \cdot 10\text{-}6 \times 1\ 573 \times 41 = 1.04$ mm

3.1 TRACTION IN THE EXTERNAL SHELL

Elongation per unit is equal to:

$$\varepsilon = \frac{\Delta l}{L2} = \frac{1.04}{1573} = 65 \cdot 10^{-5}$$

Traction stresses are equal to:

$a = E \times \varepsilon = 1.8 \cdot 10^{5} \times 65 \cdot 10^{-5} = 118.1$ MPa

3.2 COMPRESSION IN THE INNER SHELL

The reduction in length per unit is equal to:

$$\varepsilon = \frac{\Delta l}{L1} = \frac{1.04}{1515} = 68 \cdot 10^{-5}$$

Compression stresses are equal to:

$\sigma = E \times \varepsilon = 1.8 \cdot 10^{5} \times 68 \cdot 10^{-5} = 122.6$ MPa

3.3 CONCLUSION

Stress values obtained remain substantially lower than the elastic limit of steel Z2 CN 18.10 which is Re = 130 MPa at 160°C.

4 RESISTANCE OF THE PACKAGE IN HANDLING AND IN NORMAL TRANSPORT CONDITIONS

The package is designed to be handled and transported vertically or horizontally.

4.1 HANDLING

If the package is vertical, handling is possible:

- either using four-strand slings, at an angle equal to or less than 45° from vertical,
- or using a forklift truck via the cage. The truck may grip the package at one of two different levels.

If the package is horizontal, handling is possible using straps around the cage.

4.2 SECURING

If the package is vertical, it may be secured during transport:

- either via blocking at two levels using crossbeams if the package is transported in a caisson,
- or by blocking the base and maintaining straps at mid-height.

If the package is transported horizontally, it may be secured with ground blocks around the cage and straps over the cage:

4.3 RESULTS

4.3.1 Handling

Attachment 3.1-7 demonstrates that with the different potential handling configurations, the stresses in the main section and the cage remain less than or equal to the elastic limit of the material.

4.3.2 Securing

Attachment 3.1-8 considers the resistance of the securing devices of package TN-BGC 1 at the regulatory accelerations in the different transport configurations. The following table shows acceptable and non-acceptable configurations in terms of the integrity of the cage and the main section of the package.

	Acceptance criteria satisfied				
Configuration N°	Road transport	Railway transport	Maritime transport	Air transport with net	Air transport without net
N°1: 1 vertical package	yes	no	yes		
N°2: 2 vertical packages	yes	no	yes		
N°3: 4 vertical packages	no	no	no		
N°4: 3 horizontal packages				yes	no
N°5: 1 horizontal package	yes	yes	yes	yes	yes

5 CONFORMITY OF THE PACKAGE IN THE CONDITIONS OF REGULATORY TESTING

The conformity of provisions is analysed if this package model is subjected to the conditions of regulatory testing.

5.1 TESTING FOR NORMAL TRANSPORT CONDITIONS

This includes:

- water spray testing,
- free fall testing from a height of 1.2 m,
- stacking testing,
- penetration testing.

5.1.1 Water spray

The plug and its orifice are sealed.

All of the external walls of the package and the covers are in stainless steel with sealed welds.

It would appear that, in view of the sealing created, the water spray test has no impact on the behaviour of the package during the following tests.

5.1.2 Free fall of 1.2 m

Fall test campaigns on prototypes of package TN-BGC 1, resumed in attachment n° 3.1-1 and analysed in attachments 3.1-2 and 3.1-3, demonstrate that the package resists this test with no alteration of safety functions.

5.1.3 Stacking testing

If the package accepts a load equivalent to five times its mass (5g), this mass is integrally absorbed by the four uprights of the cage if the package is vertical and by eight uprights if the package is horizontal.

If the package is vertical, the study therefore covers horizontal situations.

Total load is equal to:

F = 400 x 9.81 x 5 = 19 620 N

Compression stresses per upright are equal to:

$$\sigma = \frac{19\ 620}{4 \cdot 224} = 21.9\, MPa$$

Uprights are locally supported by the cross beams in intermediate frames.

The longest free length is equal to 550 mm and minimum inertia is equal to 35 998 mm^4.

Critical Euler stresses are equal to:

$$\sigma_c = \frac{\pi^2 EI}{L^2} = \frac{\pi^2 \cdot 69\ 500 \cdot 35\ 998}{550^2} = 81\ 627\, MPa$$

The safety coefficient exceeds 3727 in this case and no risk of buckling exists.

The main section of the package is suspended inside the cage and does not support a load during this test as the cage absorbs the entire main section.

It is apparent that this test has no impact on the main section of the package and consequently has no influence on the content retention function.

5.1.4 Penetration testing

The fall test run on the prototype package, described in attachment 3.1-2, demonstrates that this test has no substantial damage on the external surface of the hull of the package, irrespective of the impact point.

5.2 TESTING FOR ACCIDENT TRANSPORT CONDITIONS

This includes:

- the free fall test from a height of 9 m on a non-deformable target, applicable for all content holding less than 1000 A_2,
- the dynamic crushing test involving a mass of 500 kg falling 9 m, applicable for all content holding more than 1000 A_2,
- free fall testing from a height of 1 m on a punch,
- immersion testing under a height of water of 15 m for 8 hours,
- extensive immersion testing under a height of water of 200 m for 1 hour, which applies in this case for certain content holding more than 10^5 A_2).

5.2.1 Fall tests

The different fall test campaigns, resumed in attachment n° 3.1-1 and analysed in attachments 3.1-2 and 3.1-3, demonstrate that the package resists regulatory mechanical tests (fall of 1 m on a punch and falls of 9 m).

Additional studies carried out during a vertical fall of 9 m on the cover (attachment n° 3.1-4) and from an oblique position (attachment n° 3.1-5) confirm the satisfactory behaviour of the package model after fall tests reflecting accident transport conditions, and the containment maintains its dimensions and leakage flux remains acceptable in particular.

<u>Consideration of the temperature of –40°C:</u>

Two components particularly play a role in the absorption of impact: the aluminium cage and the covers.

With regard aluminium, its mechanical properties increase at low temperature (elastic limit, rupture load). The mechanical properties of aluminium increase slightly in comparison with ambient conditions at -40° C. However, the mechanical resistance of this cage is low enough for its contribution to the decelerations incurred by the closing system to be insignificant.

With regard covers, the mechanical properties of wood at 20°C are increased by 40% to account for the hardening of wood at –40°C (Cf. [3]).

The notes included in attachments n°3.1-4 (for which the fall configuration studied is the most sensitive to the hardening of the damper wood) and n°3.1-5 demonstrate that the behaviour of the package model with an axial fall inclined at –40°C is satisfactory.

Therefore, the mechanical resistance of package TN-BGC 1 is proved in accident transport conditions.

<u>Justification of the selection of cutout frequencies:</u>

This substantiation is included in attachment 3.1-10. This demonstrates that the natural frequencies of the package liable to be used in an axial fall are less than 432 Hz.

5.2.2 Immersion test

The package immerged under 15 m of water is subjected to a relative external pressure of 1.5 bar. This increases to 20 bar under 200 m. This latter pressure is considered in this paragraph.

Attachment 3.1-6 demonstrates that the containment resists a relative pressure of 20 bars without applying stresses to the materials of the components which exceed the relevant elastic limits.

Consequently, the package remains sealed following immersion tests.

5.2.3 Water sealing testing

The containment does not suffer rupture, however, in terms of criticality, in view of the leakage flux with air; a certain

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CEA Transport Package Service

volume of water may penetrate in the package cavity.

Safety-criticality studies carried out in this file assume the penetration of water in the package cavity in a detrimental manner. In accordance with § 731 of [DR01], package TN-BGC 1 is exempted from this test.

6 CONCLUSION

This chapter enables the demonstration that package TN-BGC 1 satisfies the applicable requirements, and maintains leakage flux and the dimensions of the containment in particular.

The modelling assumptions obtained in regulatory mechanical testing and integrated in thermal (chapter 3.3), discharge (chapter 3.4), radioprotection (chapter 3.5) and criticality (chapter 3.6) studies are listed below. .

Thermics

An intact package with no particular damage is considered in normal transport conditions. The following assumptions are made in accident transport conditions:

- the damper cover is reduced by 42 mm longitudinally (compression of approximately 60% is assumed for the balsa) following an axial fall on the damper cover,
- the damper cover is reduced by 33 mm radially following a fall on the top or bottom,
- part of the external shell of the main section is indented following impact on a bar,
- the damper part of the main section is reduced by 39 mm longitudinally following an axial fall on the main section base.

Discharge

The maintaining of leakage flux following normal and accident transport conditions is considered. In fact:

- the rings, which tighten and seal, are not subjected to forces beyond their elastic limit,
- the sealing of the containment is maintained,
- only secondary devices (e.g. covers) suffer from significant deformation together with certain parts of the package which do not contribute to supporting the containment (cage).

Radioprotection

In normal transport conditions, no local significant reductions in the thickness of shielding are considered. The following assumptions are considered in accident transport conditions:

- the resin of the main section of the package is not considered (to take indenting by the punch into account, but also to integrate the results of thermal testing – Cf. chapter 3.3),
- the wood and resin of covers are not considered

Criticality

To avoid satisfying requirements for the water sealing test, in normal and accident transport conditions for the package cluster, water penetration in all free spaces in the package is assumed in a detrimental manner. The dimensions of the cavity are maintained and the covers are ignored in normal and accident transport conditions.

In accident conditions, for isolated packages and the cluster, a reduction in the thickness of the resin of the main section of the package of 15 mm is assumed (to take indenting by the punch into account, but also to integrate the results of thermal testing – Cf. chapter 3.3),

For package cluster configurations in accident transport conditions, the cage is not considered.

7 REFERENCES

[1] : Regulations for the safe transport of radioactive material by the International Atomic Energy Agency from the Safety standards series N° TS-R-1 – 2006 edition (amended in 2005)

[2] : Roark's Formulas for stress and strain - Young and Budynas - 7th edition.

[3] : “Wood compression testing according to temperature”, reference 160 EMBAL PFM NOT 04001858 A of 29/11/2004.

ORIGINAL

COPY

PROGRAMME: RENEWAL OF THE CEA PACKAGING STOCK

TITLE:

TN-BGC 1 DROP TESTS
SUMMARY OF THE TESTS CARRIED OUT

Summary:

- This note summarises all drops carried out using the TN-BGC 1. It justifies the correct behaviour of packages during CAT, accidental transportation conditions.

Initials			
Date	18/02/04	30/02/04	20/02/2004
Name	T. CUVILLIER	V. PAUTROT	D. LALLEMAND
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E	M	B		T	N	B	G	C		P	B	C		N	T	T		C	A	0	0	0	5	2	4	A
1	2	3		4	5	6	7	8		9	10	11		12	13	14		15	16	17	18	19	20	22	22	23

LIST OF CHANGES

ISSUE	DATE	Type of change	Pages modified
A	20/02/2004	Document issued	

CONTENTS

I PURPOSE

This note summarises all drop tests representative of CAT carried out on the TN-BGC 1 in order to check the comprehensiveness of the drop configurations to which the TN-BGC 1 were subjected.

The purpose of this note is not to give a detailed summary of the consequences of each drop, but to assess the drops carried out and to check on their character which if not comprehensive, shall at least be very serious and cover the most detrimental drop cases.

II REFERENCE DOCUMENTS

The documents detailing the drop configurations or analysing the results of the different tests are as follows:

- Note EMB TNBGC PBC DJS CA000333A, dated 07/08/2003 ([2]),
- Note EMB TNBGC PBC STE CA000001A, dated 17/10/2000 ([1]),
- Note EMB TNBGC PBC CRX CA000018A, dated 09/02/2001,
- Note EMB TNBGC PBC NTT CA000149C, dated 30/09/2002,
- Note EMB TNBGC PBC CRX CA000304A, dated 03/06/2003.

III DETAILS OF THE DROPS CARRIED OUT

The TN-BGC 1 was subjected to four series of tests, namely:

- one series in February 1988,
- a second in March 1988,
- a third in December 2000,
- a fourth in January 2003.

The tables shown below summarise the drop configurations representative of accidental conditions. The shaded boxes correspond to the first series of tests which resulted in the distortion of the locking flange and, therefore, the loss of the locking system leaktightness. However, the containment enclosure (inner shell and welding) remained sound. The distortion recorded does not render the packaging useless and was taken into account in the safety studies carried out in addition to the tests. The locking system was modified following these drops. The result was that described in the current design. It was tested in the second, third and fourth series of tests. Thus the conclusions of the first series of drops are not all positive. However, we have included them in the table as they made it possible to validate the drop configurations adopted for the following series (drops coming predominantly into contact with the locking system).

The drops representative of CAT are:

- free dropping of a 500 kg plate from a height of 9 metres,
- dropping on to a sharp edge from a height of 1 metre,
- free dropping from a height of 1 metre.

1 <u>Dropping of a 500 kg plate from a height of 9 metres</u>

	Type of drop	Date	A 1	Accumulation	Results	Comments
1	Packaging vertical	February 1988	TN 90	After tests representative of CNT	General crushing of the structure. Protective barrier sound	
2	Packaging horizontal on to sharp edge	February 1988	TN 90	At the end of the previous drop	Shearing of the cage by the plate and crushing of the lid	This drop, not involving the locking system, was not repeated in March 1988
3	Packaging vertical	March 1988	TN 90	Nil	Idem drop 1 + packaging leaktightness maintained	Same drop configuration as for drop 1
4	Packaging tilted at an angle of 15° in relation to the vertical	December 2000	TN 90	Nil	Denting of the cover and the base with distortion of the cage. Packaging leaktightness maintained, radiological barrier sound.	
5	Packaging horizontal	January 2003	TN 90	After a CNT drop from 1 metre 20	Crushing of the cage and the cover. Packaging and AI leaktightness maintained, radiological barrier sound.	

In conclusion, all serious configurations were tested (packaging in vertical, horizontal and tilted positions). The angle of the drop for drop 4 was determined in agreement with the IRSN (see [1]). Some drops were not preceded by drops representative of CNT, normal transportation conditions, this is of no consequence as the latter are not of the sort to distort package shock absorbing components (see [2]).

2 Dropping on to a sharp edge from a height of 1 metre

	Type of drop	Date	A 1	Accumulation	Results	Comments
1	Drop on to the cover, packaging vertical to the centre of the cover	February 1988 (2 drops of this type)	TN 90 & AA227	After plate drops (TN90) or free dropping from 9 metres (AA227)	Slight denting of the cover	
2	Drop on to the base, packaging vertical to the centre of the base	February 1988	TN 90	After plate drops	Very slight denting of the base	
3	Drop on to generator, packaging horizontal	February 1988 (2 drops of this type)	TN 90 & AA227	After plate drops (TN90) or free dropping from 9 metres (AA227)	No visible consequences	
4	Drop on to the cover, packaging vertical, with the sharp edge /cover off-centred	February 1988	AA227	After free dropping from 9 metres	Slight denting of the cover	Results compare with drop 1
5	Drop on to the cover, packaging vertical, with the cover centred	March 1988	AA227	After free dropping from 9 metres	Slight denting of the cover. Packaging and AI leaktightness maintained	Idem drop 1. Compared with drops 1, 2, 3, 4, this was the most likely to come into contact with the locking system
6	Drop on to a sharp edge, packaging vertical, cover side, angle of 14° to the vertical	January 2003	TN 90	After free dropping from 9 metres	Limited denting of the cover. Cover not perforated. Good packaging and AI leaktightness	
7	Drop on to generator, angle of 21° to the horizontal	January 2003	TN 90	After plate drop	Slight denting of the resin. Good packaging and AI leaktightness	
8	Drop on to generator, angle of l35° to the horizontal	January 2003	TN 90	After plate drop	More marked denting of the resin and baring of resin in places	

This table shows that the sharp edge came into contact with the most vulnerable parts of the packaging (cover, base, body) with and without the involvement of angles. However, these drops were always accumulated with other drops representative of CAT in accordance with regulatory controls. The dropping on to sharp edges always took place AFTER free dropping or the dropping of a plate to ensure the worst case scenario. All these drops, therefore, make it reasonably possible to cover the configurations of the most serious drops likely to be encountered during transportation.

3 Free dropping from a height of 9 metres

	Type of drop	Date	A 1	Accumulation	Results	Comments
1	Vertical drop on to the cover	February 1988	AA227	Nil	Shortening of the cage - Denting of the cover	
2	Horizontal drop with whipping (angle of 10°)	February 1988	AA227	After drop no.1	Shearing of a majority of the body-cage screws	
3	Drop at an angle on to the base end	February 1988	AA227	Nil	Denting of the base and buckling of the cage upright having been subjected to the impact	
4	Drop at an angle on to the cover end	February 1988	AA227	After drop no.3	Crushing of the cover and the cage	
5	Vertical drop on to the cover	March 1988	AA227	Nil	Crushing of the cover and bending of one of the uprights. Packaging and AI leaktightness	Repeat of drop 1
6	Drop at an angle on to the cover end	March 1988	AA227	Nil	Crushing of the cover. Packaging and AI leaktightness	Repeat of drop 4
7	Vertical drop on to the cover	January 2003	TN 90	Nil	Distortion of the cage and denting of the cover. Packaging and AI leaktightness	Repeat of drop 1
8	Horizontal drop with whipping (angle of 10°)	January 2003	TN 90	After free dropping from 9 metres and dropping on to a sharp edge	Shearing of the cage-body screws and off-centring of the packaging body. Packaging and AI leaktight	Repeat of drop 2

The configurations adopted, therefore, make it possible either to maximise the deceleration on the locking system (drops with whipping and vertical drops), or to maximise the distortion of the shock absorbing components (drops at an angle). Some drops were repeated in order to check that the packaging locking system and internal installation behaved correctly. The two main types of internal installation used in the package were tested (TN90 representative of the thin-walled AI and AA227 representative of the thick-walled AI).

IV CONCLUSION

This summary shows that the drop sequences carried out make it possible to justify the correct behaviour of packages during CAT.

Packages generally maintain satisfactory leaktightness and the radiological protection is not damaged (thicknesses of steel and resin).

The distortion noted as regards the cage was taken into account in the criticality studies.

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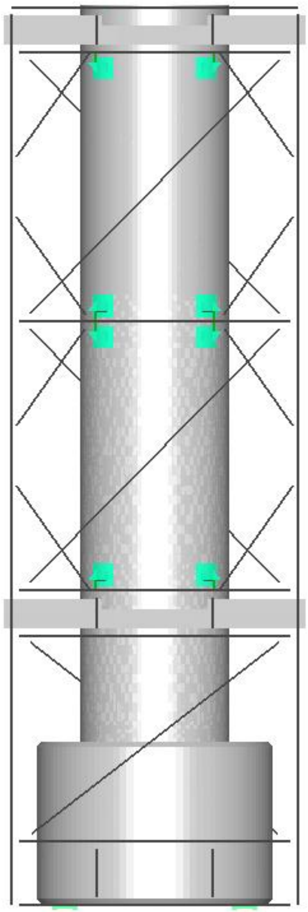
CEA

Mechanical study of a vertical drop of 9 metres for the TN-BGC1 package with the cover facing down



Issue	Date	Drafted by:	Validated by:	Approved by:
Rev. 2	16/02/04	S.BREYSSE	S.THOLANCE	S.DIET

Mechanical study of a vertical drop of 9 metres for the TN-BGC1 package with the cover facing down

Objectives:

This study aims to check the seals of the containment used for the TN-BGC1 package in a vertical drop of 9m with the cover facing down.

Summary of the study:

Initial calculations were carried out at a temperature of 20°C to correlate the finished model with physical testing carried out for this same drop by Robatel Industries. Following the validation of the model, a low-temperature fall was simulated. The mechanical properties of the wood were modified to account for changes at low temperatures. Results were compared to the calculation at 20°C and testing at 20°C.

Results:

In view of the results of the calculation at -40°C, the package will not suffer a loss of sealing. In addition, the level of stresses in cover attachments is similar at 20°C and -40°C, therefore the cover will not open.

TABLE OF CONTENTS

1. Presentation of the study and references

1.1. Presentation of the study

This study aims to check that the TN-BGC1 package remains leakproof following a vertical fall of 9m, at an ambient temperature of -40°C.

The study will be organised as follows based on a finished model of the package fitted with traditional internal packing:

- correlate the calculation for a vertical drop of 9.02 m with the cover facing down, at an ambient temperature of 20°C, based on the results of testing by ROBATEL Industries,
- modify the mechanical properties of package components to extrapolate the results at a temperature of -40°C,
- analyse the behaviour of the package and deformation of containment at -40°C,
- check that no residual opening remains in the cover seals at -40°C.

1.2. References

- CEA specifications: EMB TNBGC PBC CDC CA000398A
- Eurosim sales offer: E032004
- Description of the TN-BGC1 package: EMB TNBGC PBC DJS CA000311A chapter 2
- Robatel Industries fall test report
- Plans n° 0892-44, 0892-57, 0892-46, 0892-56, PLA267 (1 and 2/3), PLA286 (p. 2/6), 9990-65, 0892-21, 0892-45 and 0892-4
- Mechanical characteristics of steel 304 and resin: page 18/33 of note 1169/NT/008
- Engineering technique/metallurgy treaty- M438-19 Properties at low temperatures

2. Modelling and hypotheses

2.1. Presentation of the TN-BGC1 package

The TN-BGC1 package consists of:

- a rhomb cage with a structure in aluminium tubes with a 30 x 30 mm square section and a thickness of 2 mm. The cage has a section of 600x600 mm. The overall height of the cage represents 1815 mm. The cage mainly consists of vertical uprights and horizontal bars defining 3 levels. Tubes are placed diagonally to ensure the lateral rigidity of this structure. Holes for fork lift trucks are reinforced with corner plates. A frame system attached to the main section transmits stresses between the main section and the cage. Cut sheets are placed around the periphery of the cage to prevent contact between personnel and the package and to reduce radiation exchange between the main section of the package and the surrounding environment.

- a cylindrical cavity intended to house a TN90-type load with an external diameter of 295 mm. This section consists of an internal stainless steel shell with a working inner diameter of 178 mm, an external shell with a diameter of 295mm, a steel distribution plate, a wooden caisson and resin filler.

- a closing system involving a stainless steel plug, a bronze clamp ring and a stainless steel bayonet ring

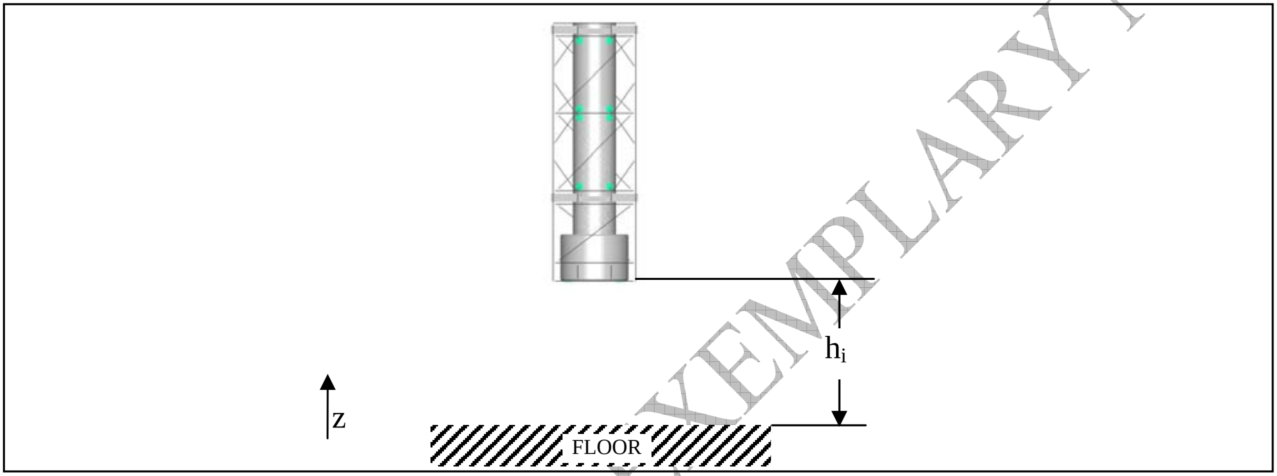
- a damper cover with an external diameter of 466 mm, consisting of two stainless steel caissons. The area around the main section is filled with the same resin as the main package. The inner cover has a diameter of 300 mm. The outer caisson contains poplar and balsa wood and this cover is fitted with two folding handles at the peak. The cover is attached to the main section by two bent rods and two grips

- loads consist of a TN90-type container with a plug-side diameter of 148 mm and a distribution plate side diameter of 124 mm. Loads are surrounded with two spacers (E1 and E2), both of which are cylindrical. Spacer E1 has an internal diameter of 140 mm and an external diameter of 176 mm. Spacer E2 has an internal diameter of 126 mm and an external diameter of 139 mm.

2.2. Fall configuration

2.2.1. Positioning of the package and fall height

The TN-BGC1 package is fitted with a TN90-type unit and a blocking system. The theoretical height of the fall is 9 m (between the lowest point of the package and the floor). The package is placed in a vertical position, with the cover facing downwards. The height of the fall measured during testing represented 9.02m.



2.2.2. Global mass of the system

The global mass of the package and its load is theoretically 396 kg. 400 kg was measured during fall testing.

2.2.3. Impact speed and energy

The principle of the conservation of mechanical energy applies as follows between the point where the package is dropped (no initial speed) and the point of impact:

$$\frac{1}{2}mv_f^2 = mgh_i$$

I.e. $v_f = \sqrt{2gh_i}$

Where m is the mass of the loaded package, v_f the speed at impact and h_i the fall height.
Impact energy represents E_{choc}=mgh$_i$

2.2.4. Temperature

The ambient temperature modifies the mechanical properties of the materials in the package (wood, steel, aluminium, bronze, etc.). The aim is to identify the influence of temperature on deceleration levels and seals on the package. Calculations will be carried out at two ambient temperatures: 20°C (test temperature) and -40°C.

2.3. Hypotheses and simplifications

2.3.1. Materials

Materials were separated into two categories:

- metals and resins: elasto-plastic materials
- wood (balsa and poplar) is an orthotropical material, and close attention was paid to the direction of the wood fibres

The transition to an ambient temperature of -40°C had no substantial influence on the mechanical properties of the metals used. Young's modulus varied slightly for aluminium down to -80°C (cf.: engineering technique-M438-19). Woods were the most sensitive materials to drops in temperature, only their mechanical properties were modified for the calculation at -40°C.

2.3.2. Simplified modelling

2.3.2.1. Modelling of the cage

The cage is a structure which consists of aluminium tubes with a section of 30x30 and a thickness of 2 mm.

The cage was modelled using columns with no initial forces equivalent to a square section of 30x30 and a length of 20 mm. No strapping was detected in testing at 20°C. The modelling of beams is precise enough to represent tube buckling.

Links between the different tubes (structural nodes) are shown as rigid elements (no consideration of ruptures of welded links).

Cut sheets do not add substantial rigidity to the structure and are not modelled.

2.3.2.2. Modelling of screws and attachments for the cover/main section

Screws and attachments are modelled using stiff springs and with no consideration of rupture. This enables the measurement of stress levels during the two calculations.

2.3.2.3. Modelling of the load

The load may come into contact with the plug in case of impact. It is therefore important to consider load. However, simplified modelling is adequate. The internal unit and the system of spacers are modelled as a cylinder with an equivalent mass and identical contact surface to the plug.

2.3.2.4. The floor

The floor is assumed to be infinitely rigid. The energy of the impact is therefore entirely transformed into energy absorbed by the package or kinetic rebound energy.

2.3.3. Efforts due to the tightening of plugs

The tightening of the package cover is shown by connecting the clamp ring and the bayonet ring. Pre-stressing is equivalent to 30 kN and is considered to be uniformly distributed over the contact surface. Local resistance provided by the rubber seal is not taken into account as the impact stresses act perpendicularly to this contact surface.

In the same way, pre-stressing in the Staubli plug is shown by linking the Staubli plug and the blocking plate. Pre-stressing is equivalent to 3520 N. This corresponds to the minimum effort transmitted by the plug clamp torque (50 Nm).

2.3.4. Correlation hypotheses at 20°C

Results obtained for a temperature of 20°C will be compared with the results of testing by Robatel Industries in terms of quality. Testing does not identify stresses in screws nor dynamic deformation, but rather residual deformation (measured after the impact) and information on the rupture or non-rupture of the screw.

The digital model at 20°C is adjusted to the tests in terms of residual deformation. Correlation parameters include the energy absorbed by the cover (depends on the properties of the wood) and the type of deformation of the cage. The hypothesis remains valid as there is little elastic yield in wood.

Stress levels measured for attachments can enable the anticipation of risks of rupture. Stresses detected at 20°C will be compared with stresses at -40°C in this study. If stresses detected at -40°C are similar to stresses at 20°C, attachments will not break at -40°C as rupture did not occur in testing at 20°C.

The results of the calculation at 20°C and testing will be used as a basis for comparison for calculations at -40°C.

2.4. Output criteria

2.4.1. Deformation of the package assembly

The calculation at -40°C particularly enables deformation of the cage and cover to be forecast and compared with results at 20°C.

2.4.2. Deceleration levels

Deceleration was not identified during testing, and particular attention must be paid to the use of these results at both temperatures.

2.4.3. Contact with cover seal supports and the Staubli plug

Changes in the distance between the two cover/flange contact parts and contact stresses at the two temperatures are measured. This measurement enables the quantification of the possible opening of the cover.

In the same way, with the Staubli plug, the distance between the plug and the blocking plate is measured together with contact stresses between the two parts.

2.5. Modelling

2.5.1. Unit system

The unit system used for this study is:

- Mass in grams **[g]**
- Distance in millimetres **[mm]**
- Density in grams per millimetre cubed **[g/mm^3]**
- Speed in millimetres per millisecond **[mm/ms]**
- Stresses in Mega Pascals **[MPa]**

2.5.2. Meshing

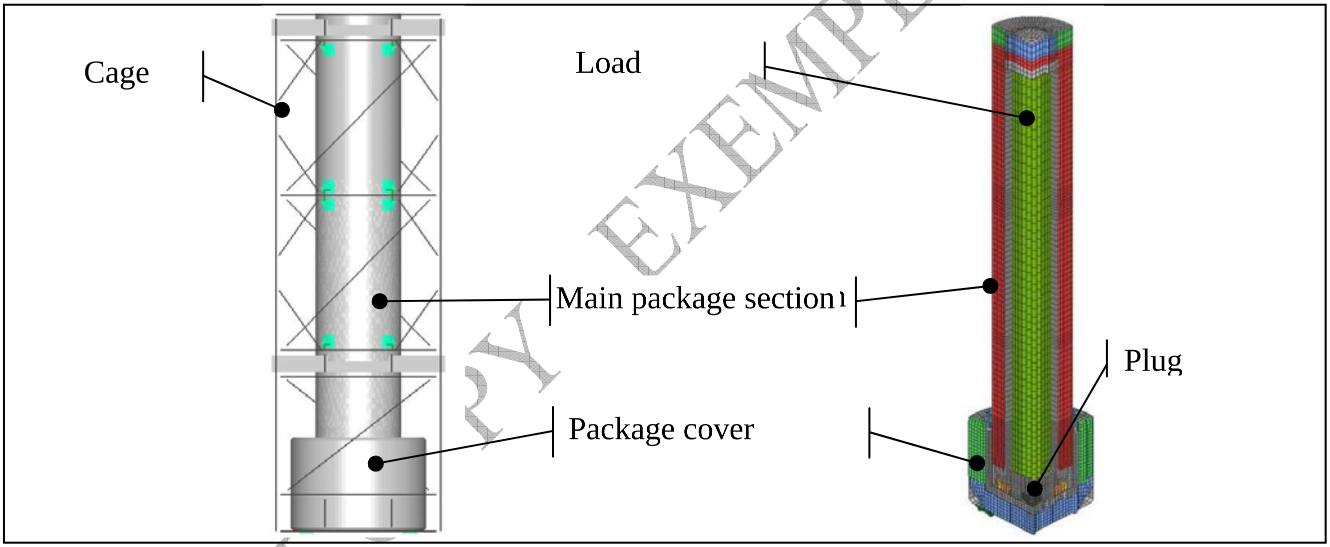


figure 1. *Sub-assemblies of the model*

2.5.2.1. TN BGC1 package cage:

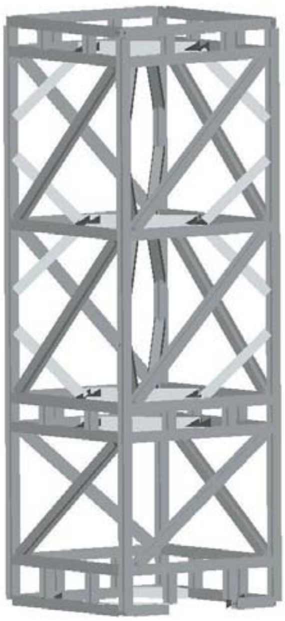


figure 2. Modelling of the package cage

Part number	Part name	Parent structure	Number of elements	Size of elements (mean)	Material
3	Structure of the cage	column	2222	20 mm	Aluminium 6082
3f, 3g, 3h	Flat and corner plates	hull	1560	10 - 20 mm	Aluminium 6060

2.5.2.2.
Welds were modelled using rigid elements.

2.5.2.3. Package cover

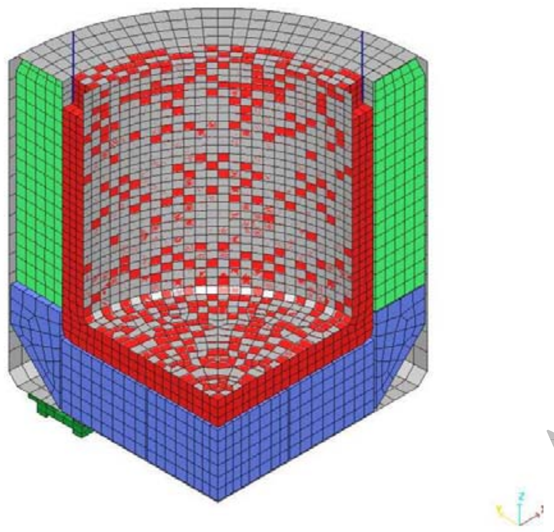


figure 3. Modelling of the package cover

Part number	Part name	Parent structure	Number of elements	Size of elements	material
	Base and shell	Hulls (4 mm, 1.5 mm, etc.)	12308	6 - 10 mm	Z2 CN 18.10
4e1	Wood filler (poplar)	Volume	11970	10 mm	Poplar
4e2	Wood filler (balsa)	Volume	7548	6 - 10 mm	Balsa
4j	Resin filler	Volume	12744	6 - 10 mm	Resin
4f	Folding handles	Volume	88	3 - 10 mm	Stainless steel 304
	Cover attachments	Spring	4		

The shells and the cover base have been modelled using hulls due to their low thickness (e < 5 mm).

The resin was modelled in terms of volume with three elements in the thickness. The resin is linked to the shells via common nodes.

Wood/shell and wood/wood clearance has been accounted for.

The direction of wood fibres has been modelled, giving the following radial models for fibres in the central sections of the balsa and the poplar (red arrow):

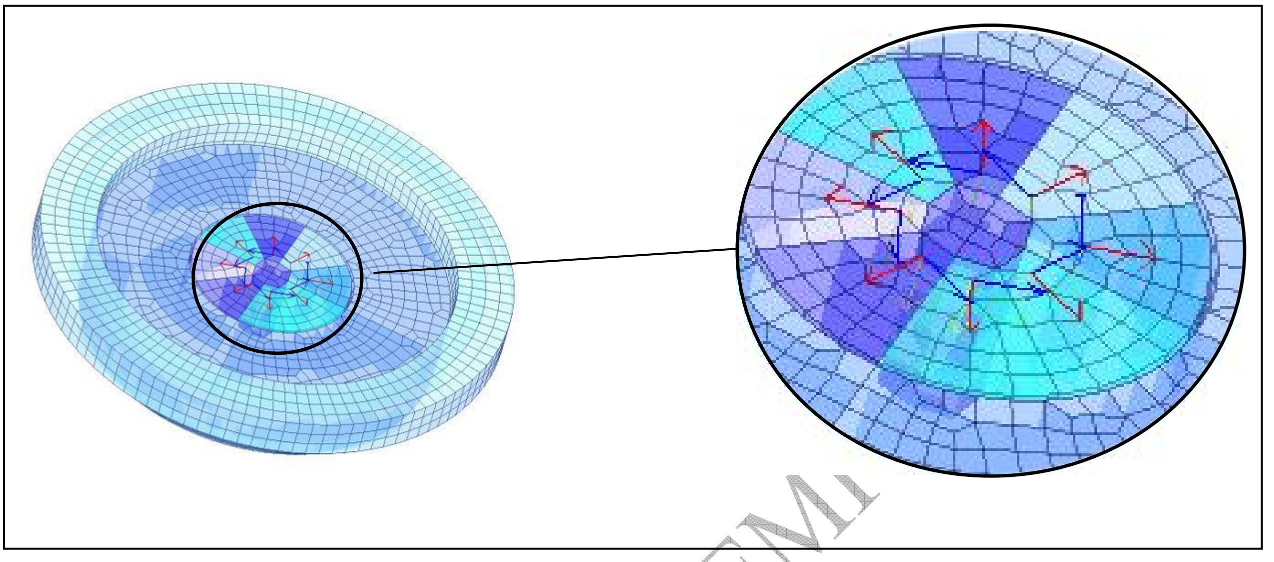


figure 4. Modelling of balsa cover filler showing the direction of fibres

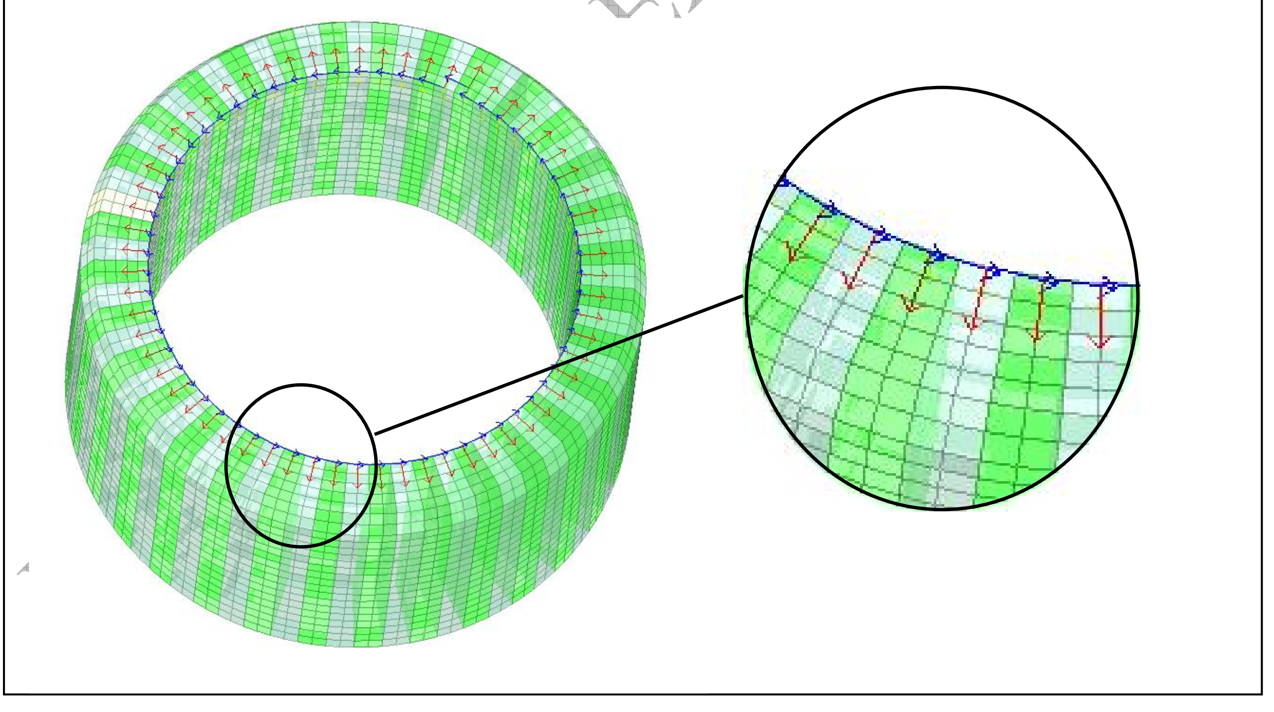


figure 5. Modelling of poplar cover filler showing the direction of fibres

Cover attachments are shown as springs.

2.5.2.4. TN-BGC1 package plug

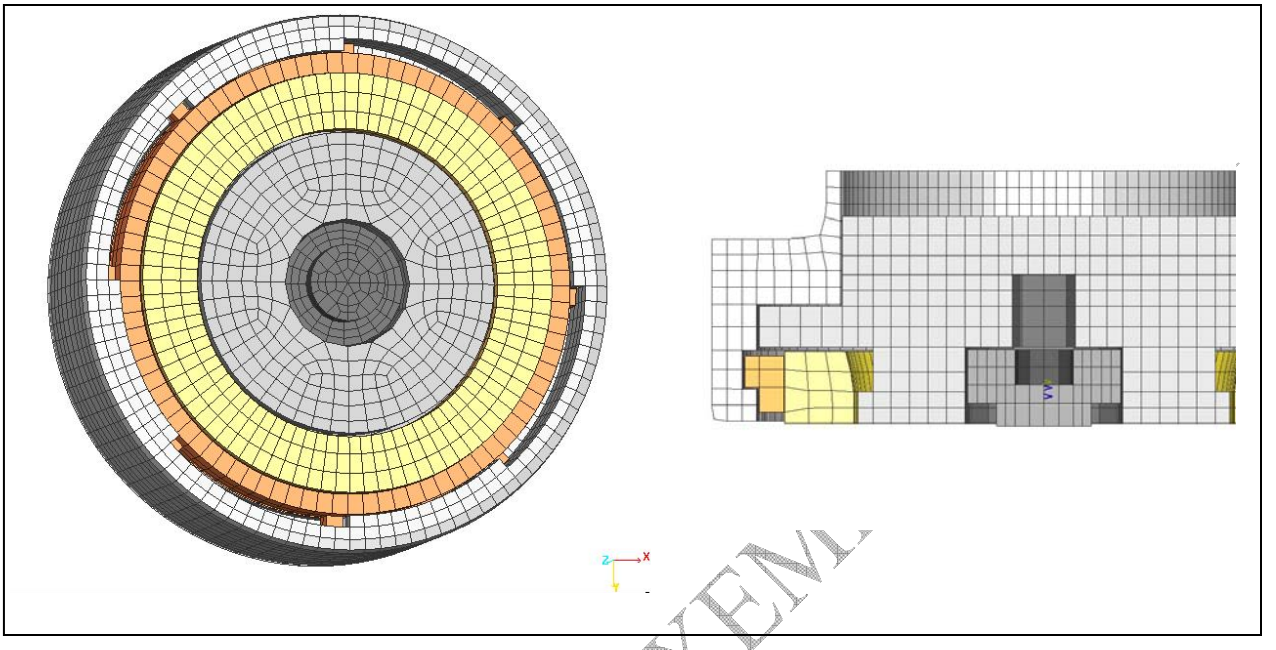


figure 6. Modelling of the package plug

Part number	Part name	Parent structure	Number of elements	Size of elements	material
2	Plug	volume	3868	6 - 12 mm	Z2 CN 18.10
5	Bayonet ring	volume	360	6 - 10 mm	Z2 CN 18.10
6	Clamp ring	volume	1056	6 - 10 mm	CuA19Ni5Fe5Y20
7	Staubli plug	volume	328	3 - 8 mm	Z2 CN 18.10
1	Flange	volume	5296	5 - 10 mm	Z2 CN 18.10

Clearance and support between the different parts were modelled. Seals are not shown, but were identified.

2.5.2.5. TN-BGC1 main package section and load

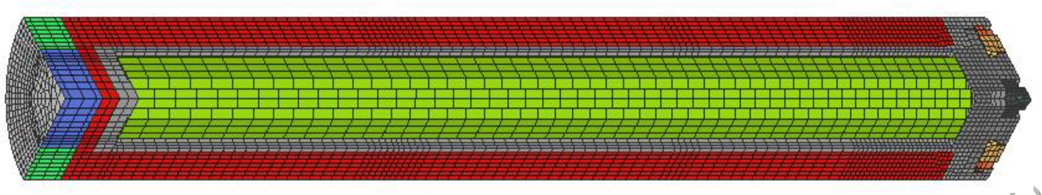


figure 7. Modelling of the main package section

Part number	Part name	Parent structure	Number of elements	Size of elements	material
1	External shell	Hull	13504	7 - 20 mm	Z2 CN 18.10
	Internal shell (containment) and flange	volume	10800	7 - 20 mm	Z2 CN 18.10
1d	Distribution plate	volume			
1g	Resin filler	volume	74656	7 - 20 mm	Resin
1h1	Wood filler	volume	3328	10 - 25 mm	Poplar
1h2	Wood filler	volume	1840	10 - 25 mm	Balsa
1m	Cage attachment tab	3 mm hull	736	4 - 10 mm	Stainless steel 304
	Load	volume	5200	20 - 30 mm	Fictitious material

Modelling of the distribution plate has been simplified by integrating the component in the internal shell base. This simplification has no impact on the study given the distance from the impact zone.

The internal unit and system of spacers are modelled as one part. The internal diameters of the two spacers (E1 and E2) are less than the maximum diameter of the load. Spacers may not therefore have a direct impact on the plug without touching the load beforehand. The three parts form one block at the time of impact. Modelling using a cylinder with an equivalent mass and identical contact surface is therefore adequate to validate leaktightness. The material used for the calculation has the same mechanical properties as the steel and a density ensuring that the global mass corresponds to the mass of container TN90 and spacers E1 and E2.

2.5.3. Materials

2.5.3.1. Balsa

The direction of balsa fibres is integrated based on a local marker. The same material is used for all parts in balsa, only the direction of the local marker will change.
The direction of the fibre is 1, therefore E_{11}, Young's modulus is in the same direction as the fibre.
The elastic part is described using the traction and shear modules E_{ii} and G_{ij}.
The plastic part is described using the following chart:

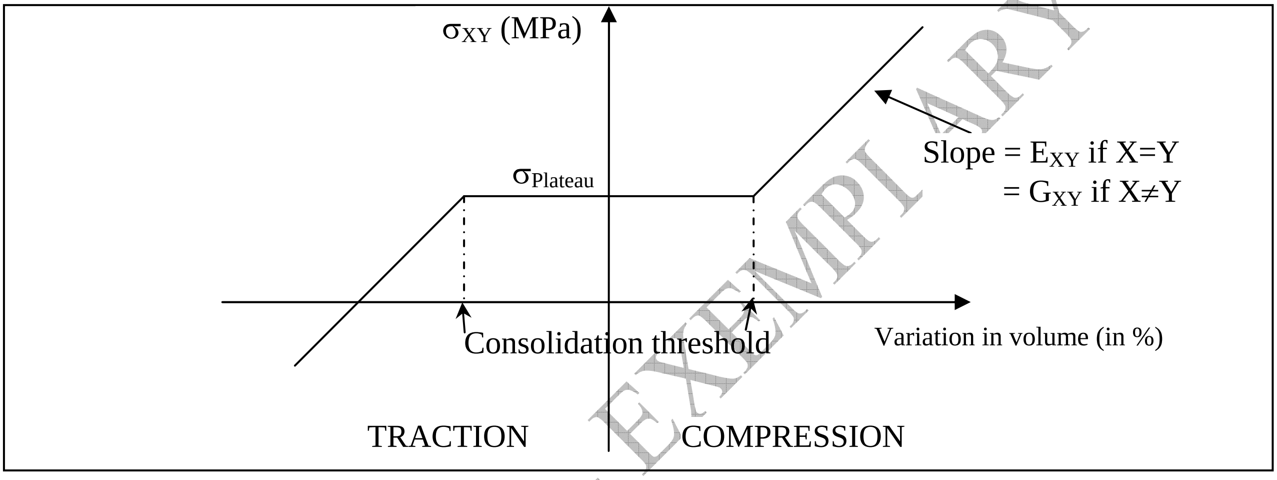


figure 8. Stress chart depending on variation in volume

The compression consolidation threshold for balsa is crushing of over 60%. Behaviour with traction and compression are considered as identical.

	Density (g/mm^3)	0.00015
Elastic part	E_{11} (in MPa)	2300
	E_{22} (in MPa)	460
	E_{33} (in MPa)	460
	G_{12} (in MPa)	120
	G_{23} (in MPa)	120
	G_{31} (in MPa)	120
Elastic part	σ_{11} (plateau) (in MPa)	9,5
	σ_{22} (plateau) (in MPa)	2
	σ_{33} (plateau) (in MPa)	2
	σ_{12} (plateau) (in MPa)	3
	σ_{23} (plateau) (in MPa)	0,6
	σ_{31} (plateau) (in MPa)	3

It is assumed that changes in the mechanical properties of balsa between an ambient temperature of 20°C and an ambient temperature of -40°C will lead to the multiplication of stresses by 1.4.

2.5.3.2. The poplar

As is the case for balsa, the direction of poplar fibres is integrated based on a local marker. In the same way, the direction of the fibre is marked 1. The poplar stress chart based on variation in volume is similar to the balsa chart.
The consolidation threshold for poplar represents crushing of over 45%.

	Density (g/mm^3)	0,00036
Elastic part	E_{11} (in MPa)	3500
	E_{22} (in MPa)	350
	E_{33} (in MPa)	350
	G_{12} (in MPa)	700
	G_{23} (in MPa)	140
	G_{31} (in MPa)	700
Elastic part	σ_{11} (plateau) (in MPa)	50
	σ_{22} (plateau) (in MPa)	10
	σ_{33} (plateau) (in MPa)	10
	σ_{12} (plateau) (in MPa)	18
	σ_{23} (plateau) (in MPa)	10
	σ_{31} (plateau) (in MPa)	18

It is also assumed that changes in the mechanical properties of balsa between an ambient temperature of 20°C and an ambient temperature of -40°C will lead to the multiplication of stresses by 1.4.

2.5.3.3. Aluminium 6082 and 6060:

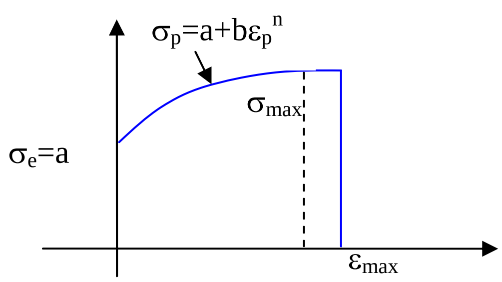
The general mechanical properties of aluminium 6082 and 6060 are as follows:

Young's modulus = 70 000 MPa
Poisson's ratio = 0.33
Density = 0.0027 g/mm^3

The plastic section of aluminium is defined by a Johnson-Cook's law as follows:

$\sigma_p = a + b\varepsilon_p^{\,n}$

Where a = 260
b = 158
n = 0.5
where σ_{max} = 310
ε_{max} = 10%



2.5.3.4. Z2Cn18-10

The general mechanical properties of Z2C18-10 are:

Young's modulus = 200,000 MPa
Poisson's ratio = 0.29
Density = 0.0079 g/mm^3

This steel is defined by a Johnson-Cook's law as follows:
$\sigma_p = a + b\varepsilon_p^n$
Where a = 220
b = 448
n = 0,5
where σ_{max} = 520
ε_{max} = 45%

2.5.3.5. Cu A19Ni5Fe5Y20: Bronze

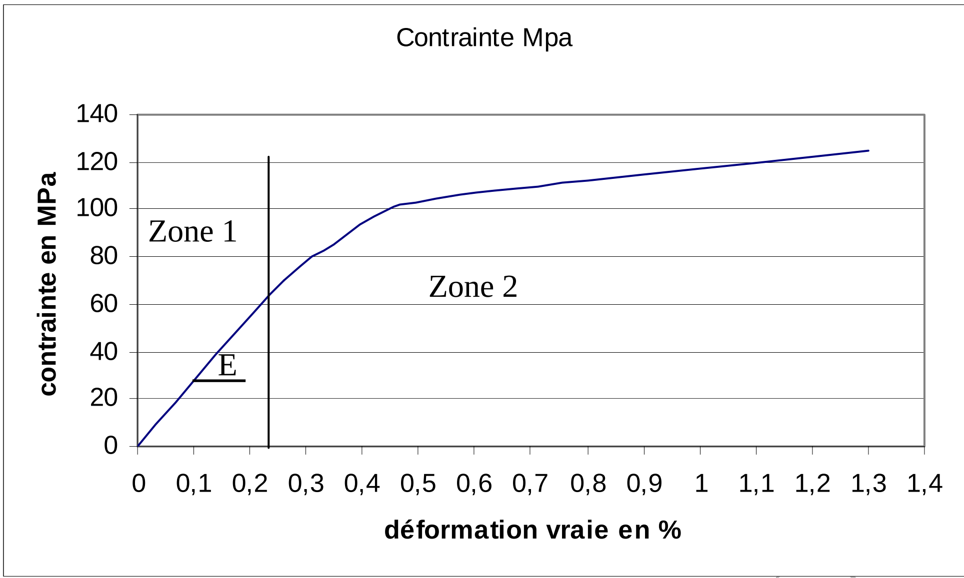
The general mechanical properties of bronze are:

Young's modulus = 124,000 MPa
Poisson's ratio = 0.35
Density = 0.0089 g/mm^3

This steel is defined by a Johnson-Cook's law as follows:
$\sigma_p = a + b\varepsilon_p^n$
Where a = 90
b = 29
n = 0.31

2.5.3.6. Resin

Young's modulus: 26 000 MPa
Poisson's ratio: 0.33
Density: 0.0016 g/mm^3
Resin is defined by a user-type law based on the specimen traction test chart:

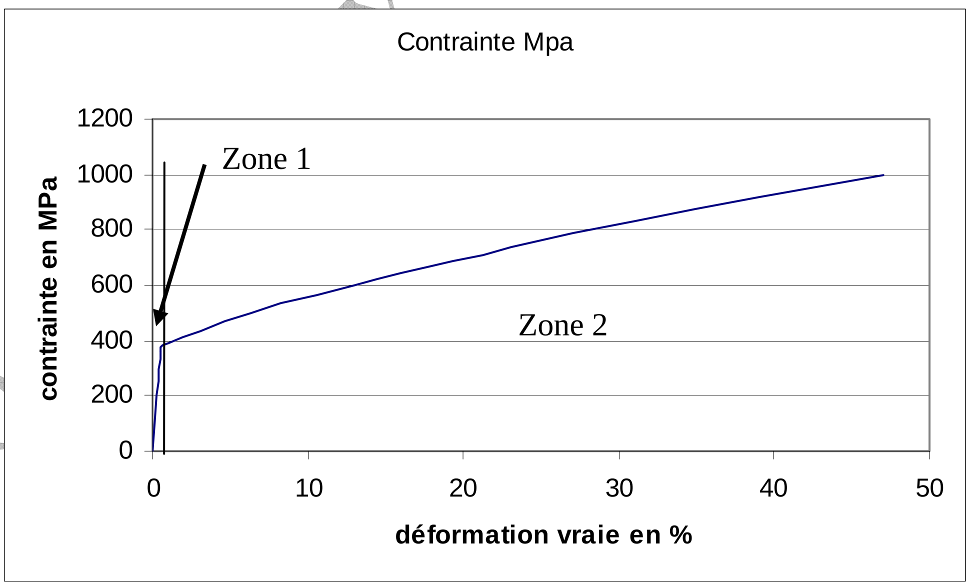


The elastic part (1) is described by the Young's modulus and the plastic part (2) is described by the chart in zone 2.

2.5.3.7. <u>Stainless steel 304</u>

Young's modulus: 200,000 MPa
Poisson's ratio: 0,3
Density: 0.0078 g/mm^3

Stainless steel is also defined by a user-law:



Contrainte Mpa Contraine en MPa Zone 1 Zone 2 Déformation vraie en %	Stress MPa Stress in MPa Zone 1 Zone 2 Actual deformation in %

2.5.4. 2.5.4 Contact management

Contacts are managed via a digital RADIOSS tool known as an interface. Several types of interfaces exist depending on the type of contact between the parts. "Adhesive" interfaces force the parts in contact to move in an identical manner. General interfaces prevent two parts from interlinking during impact. Repulsion, proportional to the rigidity of the parts, is generated by contact surfaces from a minimum gap between the two parts.

2.5.4.1. Using kinematic adhesive interfaces

The only parts concerned by this modelling are the main section and the attachment tabs.

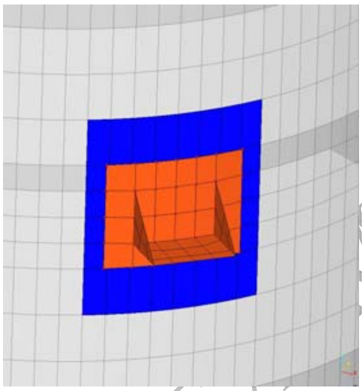


figure 9. Kinematic adhesive interface

2.5.4.2. Using contact interfaces

In our studies, these interfaces are used to manage contact between parts in the package liable to move on impact.
This type of modelling also enables the identification of forces on surfaces in contact. It can be used, for example, between the bayonet ring and the main section flange, or between the floor and the package.

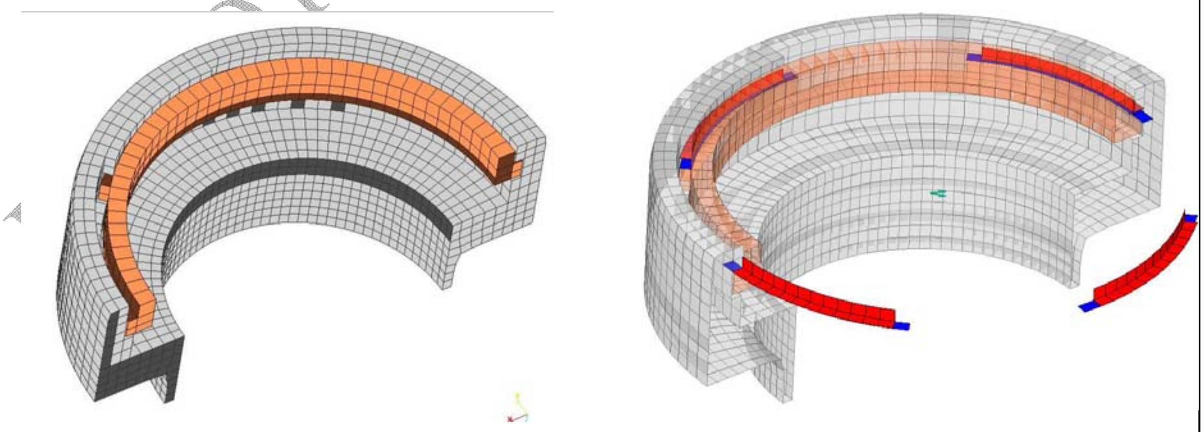


figure 10. Contact management interface

2.5.5. Modelling of pre-stresses in plugs

Modelling accounts for pre-stresses due to cover grips and the Staubli plug.

2.5.5.1. Pre-stresses in the cover

A rigid element links all of the nodes of the clamp ring threads. Another rigid element links all of the nodes of the bayonet ring threads. A compressed spring is placed between these two rigid elements. This spring will attempt to return to its rest position, i.e. extend. It pushes the bayonet ring against the flange and the clamp ring against the plug. This modelling may be used thanks to the symmetry of the main section and cover.

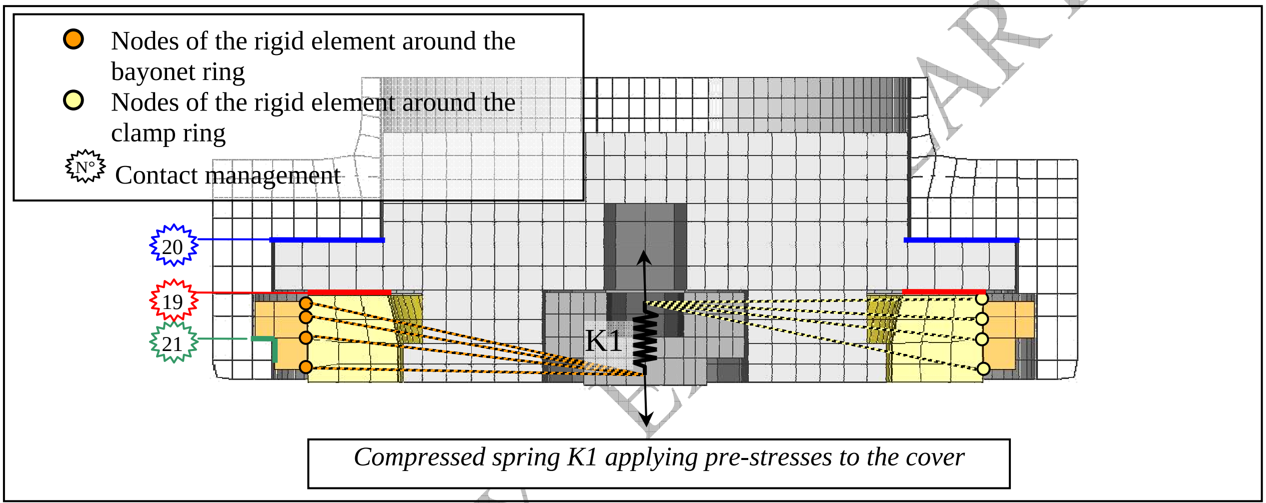


figure 11. Modelling of pre-stresses in the cover

Spring K1 is defined as follows:

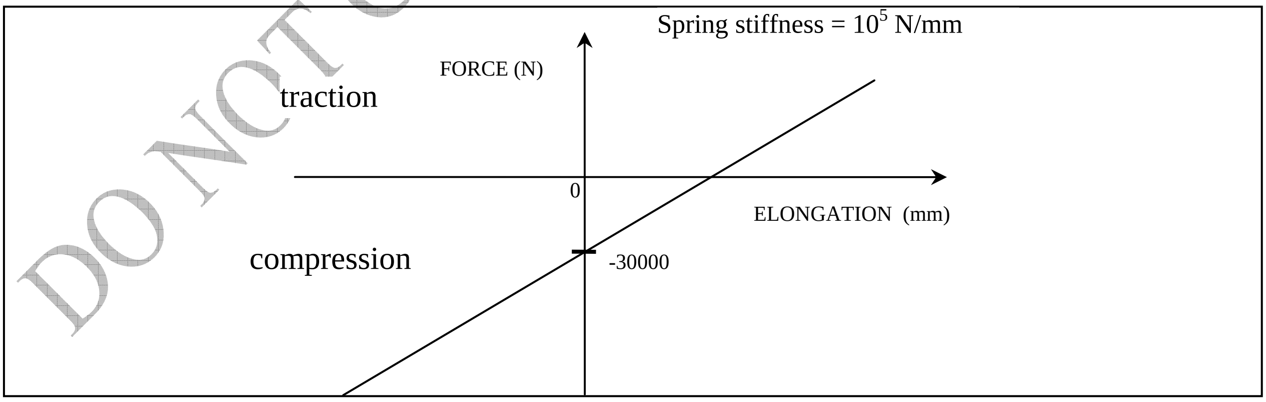


figure 12. Cover pre-stresses definition chart for spring K1

The first part of the calculation involves loading the plug and waiting until the spring force balances the forces on the contact surfaces. Oscillations are controlled by a damper.

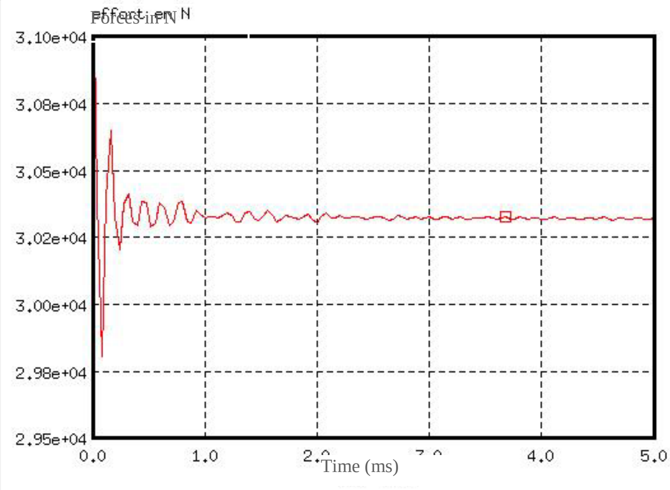


figure 13. *Force in spring K1 over time*

It must then be checked that forces are correctly distributed over the different contact surfaces. The following interfaces are affected by the loading of the cover:

- the interface between the main section flange and the bayonet ring (interface 21),
- the interface between the clamp flange and the plug (interface 20),
- the interface between the plug and the main section (interface 19),

The forces applied by the spring are also transmitted to these interfaces, therefore the pre-stressing of 30 kN is transferred between the plug and the main section.

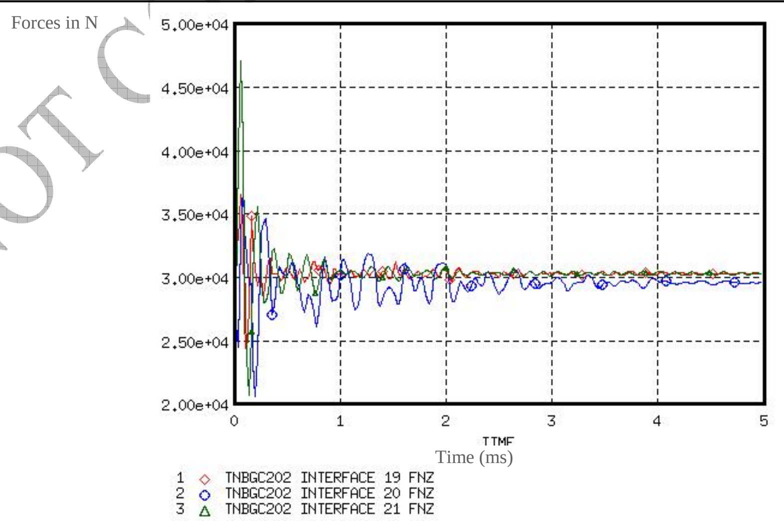


figure 14. *Forces on interfaces 19, 20 and 21 due to pre-stressing in the plug*

2.5.5.2. Pre-stresses in the Staubli plug

In the same way as for the pre-stressing in the cover, the pre-stressing of the Staubli plug is modelled using two rigid elements and a spring. One of the rigid elements links the nodes of the Staubli plug threaded surface. The second rigid elements links the nodes of the plug threaded surface. A compressed spring links the two nodes for the rigid elements.
Torque of 50 Nm is applied and minimum pre-stresses for the total surface area is 3520N.

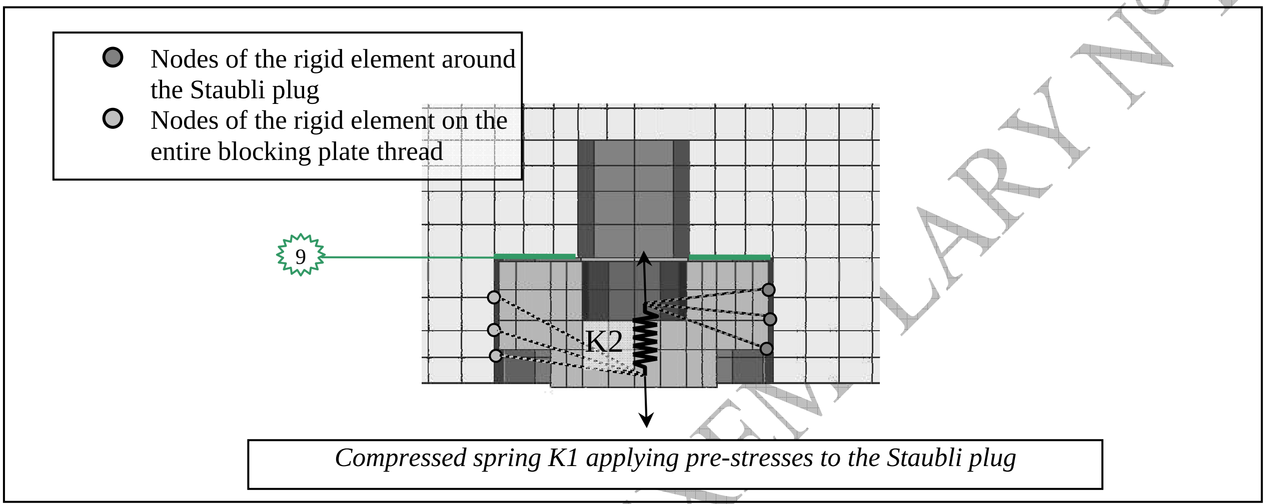


figure 15. Modelling of pre-stresses in the Staubli plug

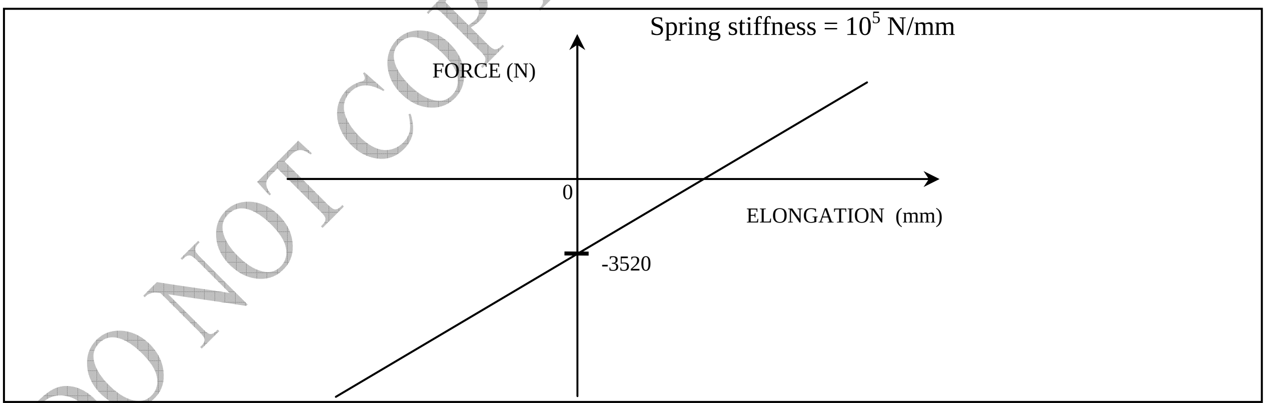


figure 16. Cover pre-stresses definition chart for spring K2

The first part of the calculation involves loading the plug and waiting until the forces balance.

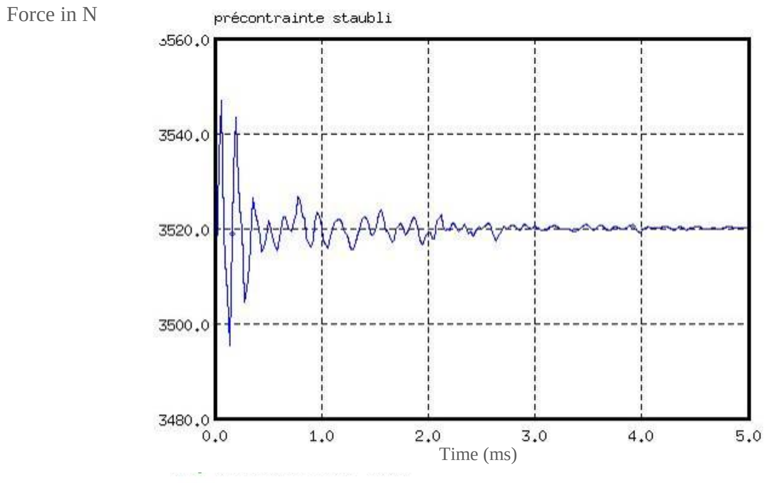


figure 17. *Force in spring K2 over time*

précontrainte staubli	staubli pre-stressing

In the same way, the forces applied by the spring are integrally transmitted to the interface (9).

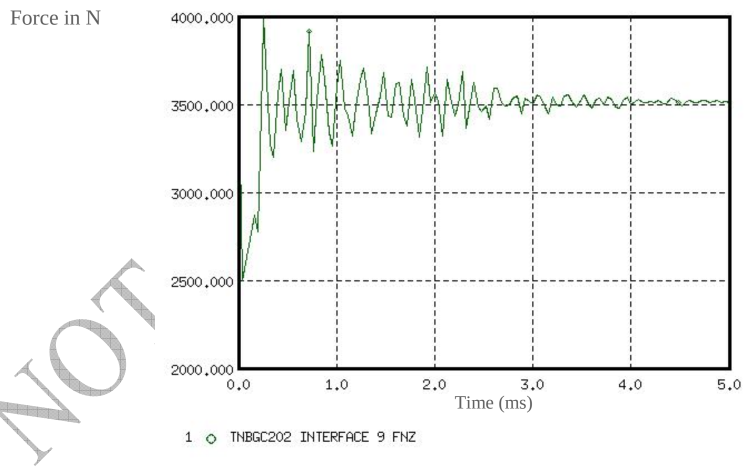


figure 18. *Forces in interface 9 due to the pre-stressing of the Staubli plug*

2.5.6. *Modelling of attachments*

2.5.6.1. Attachment screws for cage tabs

The attachment screws of cage attachment tabs are modelled with 10^5 N/mm stiffness springs for degrees of freedom for stresses and 10^8Nmm/rad for degrees of freedom for moments.

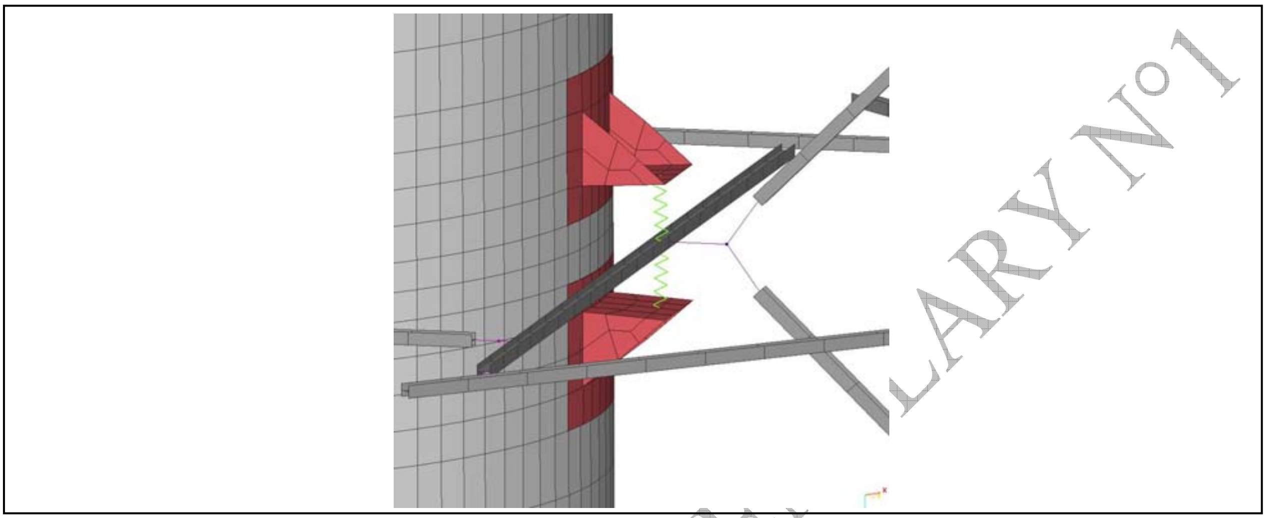


figure 19. Modelling of the cage attachment tab liaison

2.5.6.2. Cover/main section attachments

Cover attachments are modelled as springs (identical to 2.5.6.1), which are connected to the main section and the cover using rigid elements. Stress levels at 20°C and at -40°C are compared to determine the resistance of these attachments.

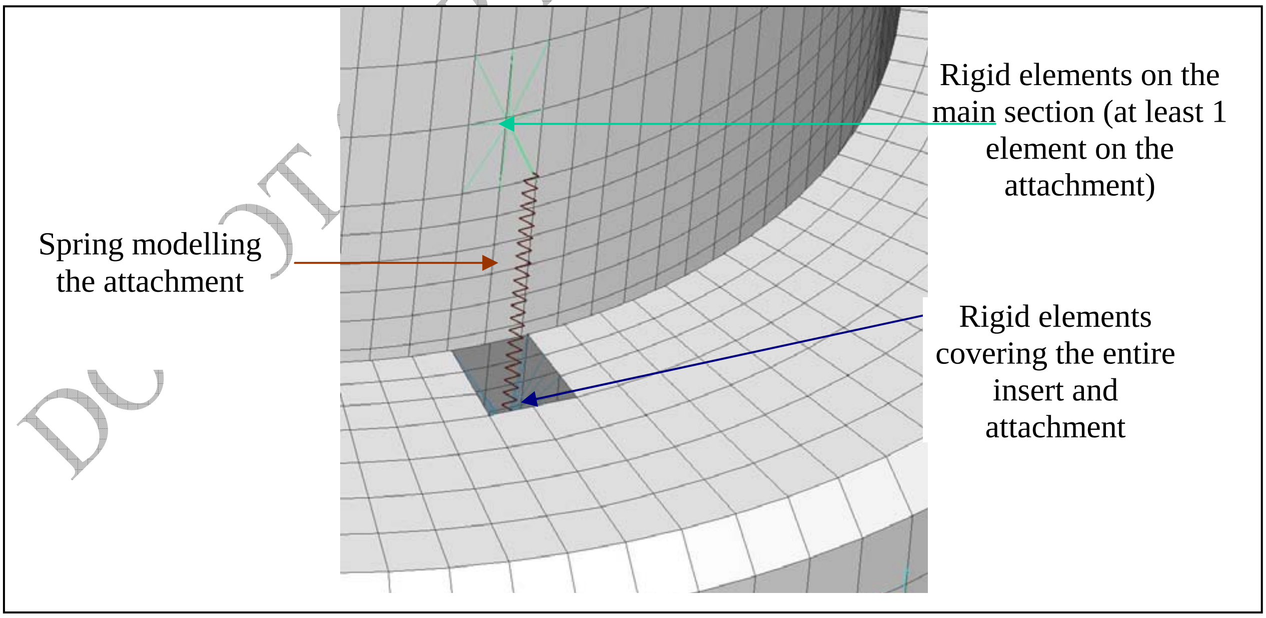


figure 20. Modelling of the cover attachments on the main package section

2.5.7. *Mass report*

	Mass
Cage (structure, corner plates, attachment tabs)	31.6 kg
Cover	40.3 kg
Load	116.1 kg
Plug	27.1 kg
Main package section	183 kg
Total mass	**398.1 kg**

An impact speed of 13.30m/s was obtained for a fall of 9.02 m (test data) and an energy of 35.5 kJ.

3. Results

3.1. Calculation at 20°C and comparison with testing

3.1.1. Energy report

3.1.1.1. Energy report for the package

The first 5 milliseconds are used to prestress the plugs. The package is then "dropped" and gravity applied.

The global energy of the system is maintained during the calculation. This energy is equal to 35.5 kJ.

The initial kinetic energy is transformed into absorbed energy and kinetic rebound energy. The rebound acts when kinetic energy cancels out at 10.08 ms from the start of the simulation (including prestressing of the plugs).

Maximum internal energy is 35.2 kJ.

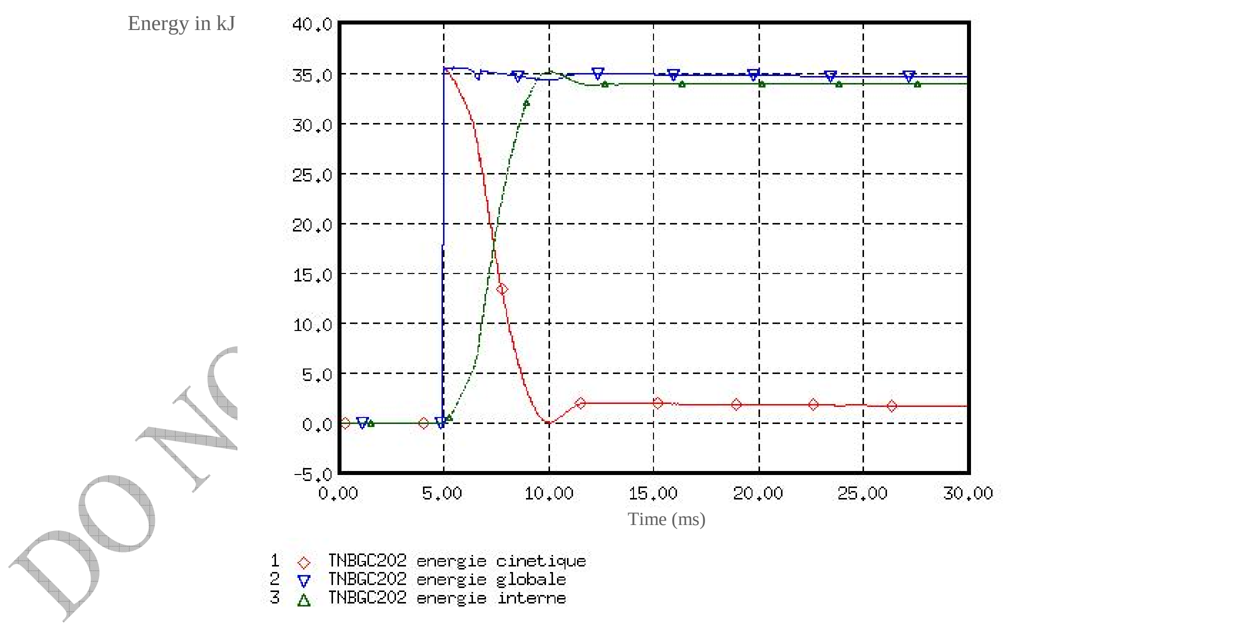


figure 21. Variation in global package energy

Energie cinetique	Kinetic energy
Energie globale	Global energy
Energie interne	Internal energy

3.1.1.2. <u>Distribution in the energy absorbed in sub-assemblies</u>

This distribution enables the display of the sub-assemblies which absorb the most energy at impact.

This includes the cover with 26.4 kJ (75% of global energy absorbed) and the cage with 8.3 kJ (24%). The latter percentage is distributed in the rest of the model.

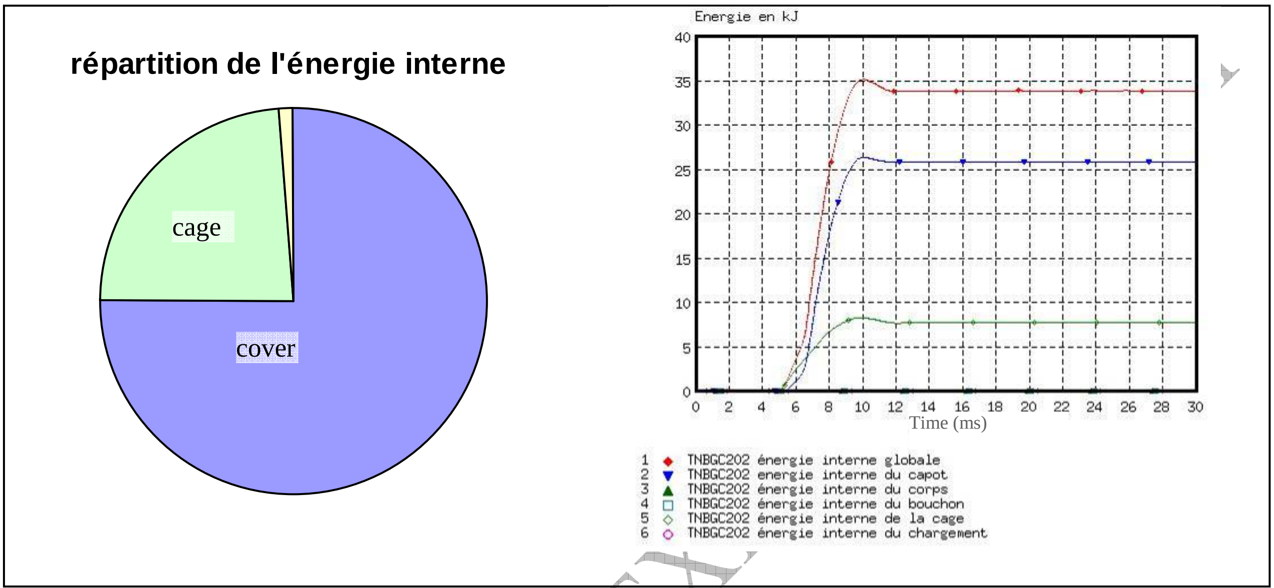


figure 22. *<u>Changes in internal energy per sub-assembly</u>*

Répartition de l'energie interne	Repartition of internal energy
Energie interne globale	Global internal energy
Energie interne du capot	Cover internal energy
Energie interne du corps	Main section internal energy
Energie interne de la cage	Cage internal energy
Energie interne du bouchon	Plug internal energy
Energie interne chargement	Load internal energy

3.1.2. Qualitative results

3.1.2.1. <u>Indentation of the cover</u>

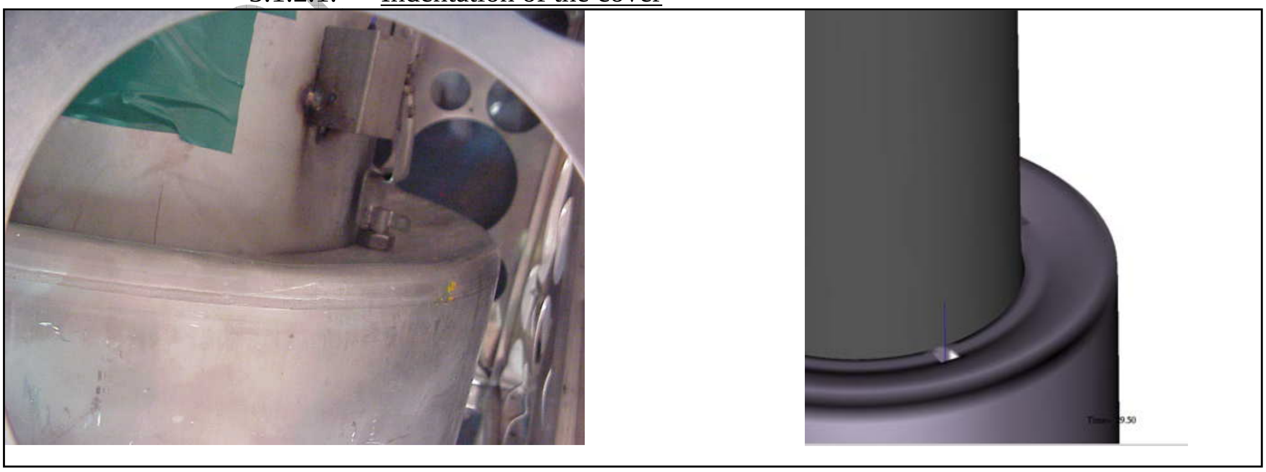


figure 23. *<u>Qualitative comparison of cover indentation between testing and the calculation</u>*

3.1.2.2. Crushing of the cage

As in testing, the cage rotates about its axis (non-symmetry of traverse posts).

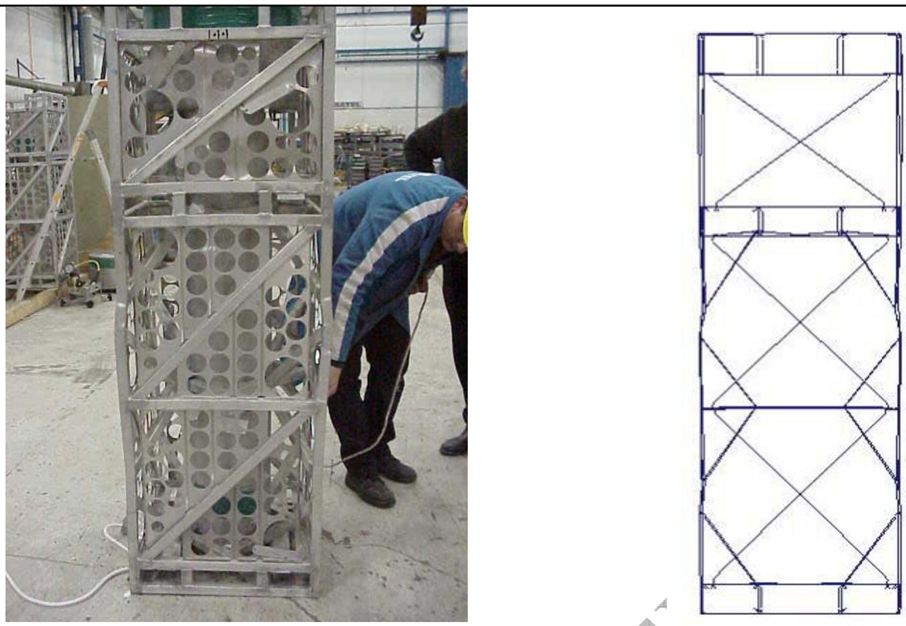


figure 24. Qualitative comparison of the crushing of the cage between testing and the calculation

3.1.2.3. Resistance of cover attachments

The cover remained in position during testing and attachments were closed.

3.1.3. Quantitative results

3.1.3.1. Indentation of the cover

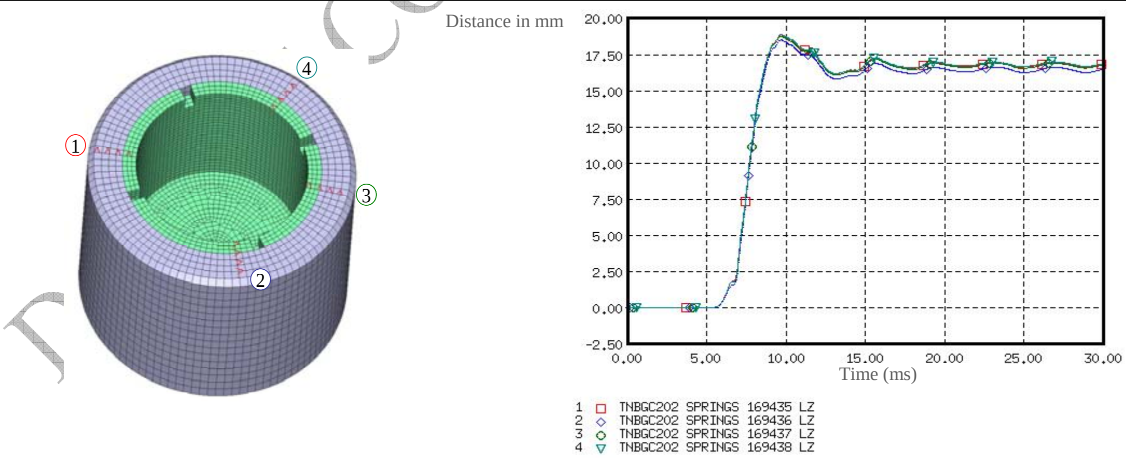


figure 25. Indentation of the cover during calculations at 20°C

The indentation of the cover is measured at four points. These measurements are taken on the cover between the cover edge (outer shell, the lowest point) and the inner part of the cover (inner shell, the lowest point).

The cover indentation measured in testing represents 17 - 19 mm. Residual indentation was calculated as 17 mm.

3.1.3.2. Crushing of the cage

Total residual crushing calculated for the cage is 20 mm (vertically). Testing gave a result of 15 mm.

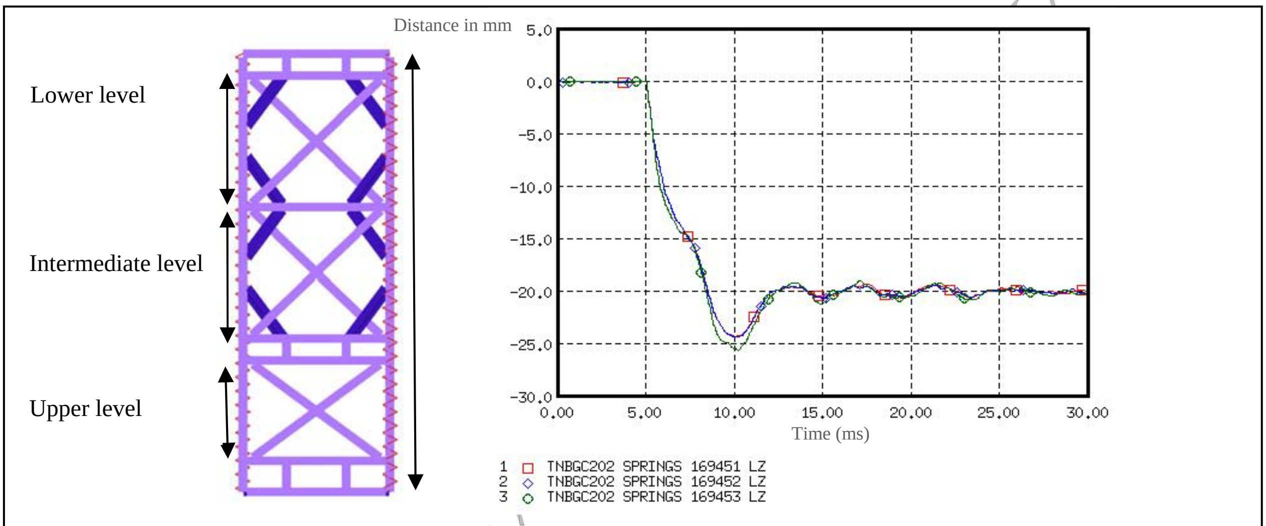


figure 26. Total crushing of the cage in calculations at 20°C

For the purposes of calculations, crushing is taken between the two ends of the beam and strictly vertical.

height	Height before the fall	Test results	Results of calculations at 20°C
Lower cage level (at the top during the fall)	505 mm	508 mm	503 mm
Intermediate level	505 mm	500 - 505 mm	496mm
Upper level (at the bottom during the fall)	380 mm		376 mm
Measurement in the middle of the upper level	380 mm	368 - 370 mm	372 mm

3.1.3.3. Resistance of cover attachments

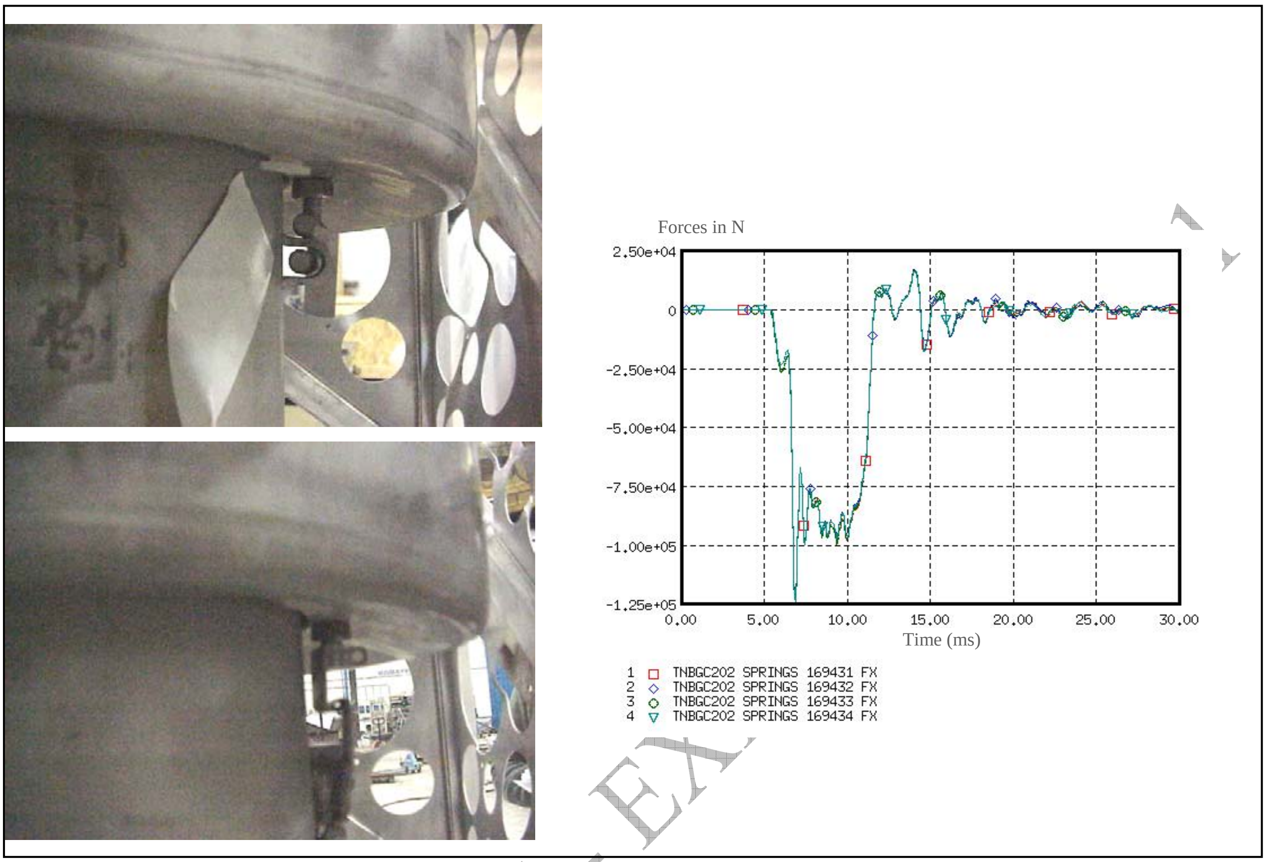


figure 27. *Resistance of cover attachments to testing and forces in attachments for calculations at 20°C*

The stress levels measured in the cover attachments do not open the cover as the attachments remain in position during testing. Forces transmitted in the four attachments are identical. Maximum forces are equivalent to 125 kN.

These values will be used as a reference point for calculations at -40°C. In fact, according to testing, cover attachments remained closed.

3.1.3.4. Attachment screws of the cage on the main section (attachment tabs)

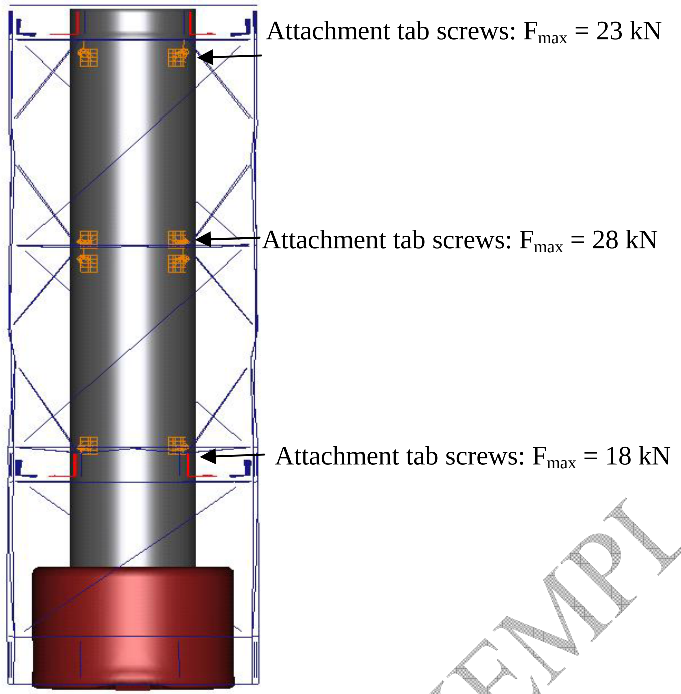


figure 28. Forces in attachment tab screws for calculations at 20°C

3.1.4. Additional results

3.1.4.1. Chronology of impacts in the main section + cover

Deceleration charts indicate the chronology of impacts during the fall.

Acceleration forces are zero up to 5 ms as this period of calculation is used to prestress plugs. The first part to decelerate is the Staubli plug, followed by the plug, the clamp ring and the main section flange, and ending with the load.

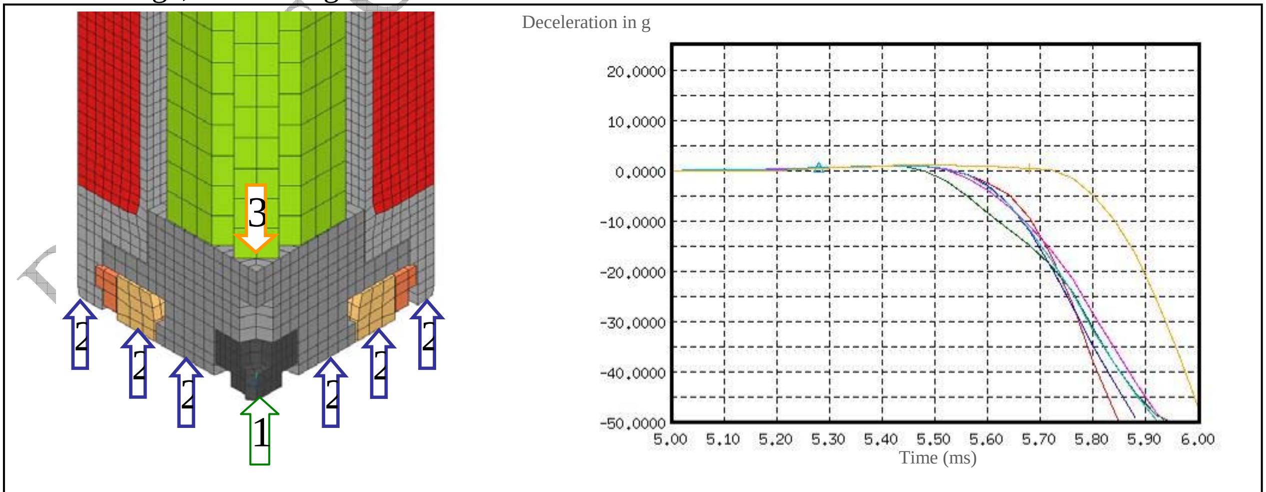
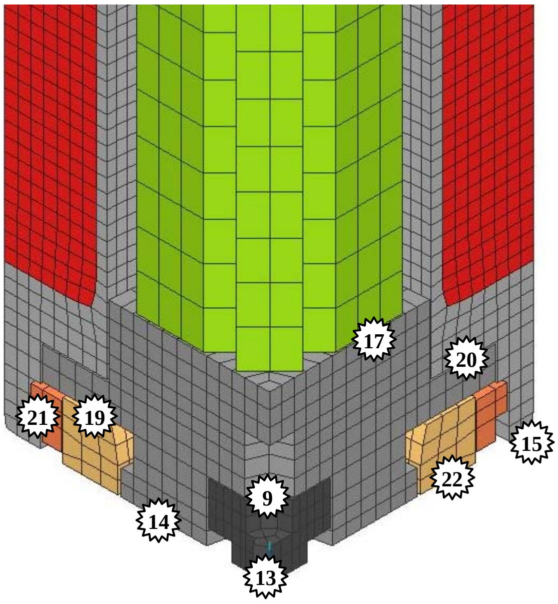


figure 29. Chronology of impacts in the cover for the calculation at 20°C

3.1.4.2. Forces in interfaces

The aim of this study is to validate the seals of the package after the fall, therefore the distribution of forces in the plug interfaces was studied.



Numéro	Pièces concernées par la gestion du contact
9	Bouchon de Staubli /Bouchon
13	Bouchon de staubli/intérieur du capot
14	Bouchon / intérieur du capot
15	Corps/intérieur du capot
17	Bouchon /chargement
19	Bague de serrage/Bouchon
20	Bouchon / corps (appuis des joints)
21	Corps/bague baïonnette
22	Bague de serrage / intérieur du capot

figure 30. Plug interfaces

Numéro	Number
Pièces concernées par la gestion du contact	Parts concerned by contact management
Bouchon de Staubli / Bouchon	Staubli plug/plug
Bouchon de staubli / intérieur du capot	Staubli plug/inside of the cover
Bouchon / intérieur du capot	Plug/inside of the cover
Corps / intérieur du capot	Main section/inside of the cover
Bouchon / chargement	Plug/load
Bague de serrage / Bouchon	Clamp ring/plug
Bouchon / corps	Plug/main section
Corps / bague baïonnette	Main section/bayonet ring
Baugue de serrage / intérieur du capot	Clamp ring/inside of the cover

- for the internal contacts of the cover/plug: at the time of impact, only the Staubli plug and the clamp ring come into contact with the inside of the cover as only interfaces 13 and 22 are activated.

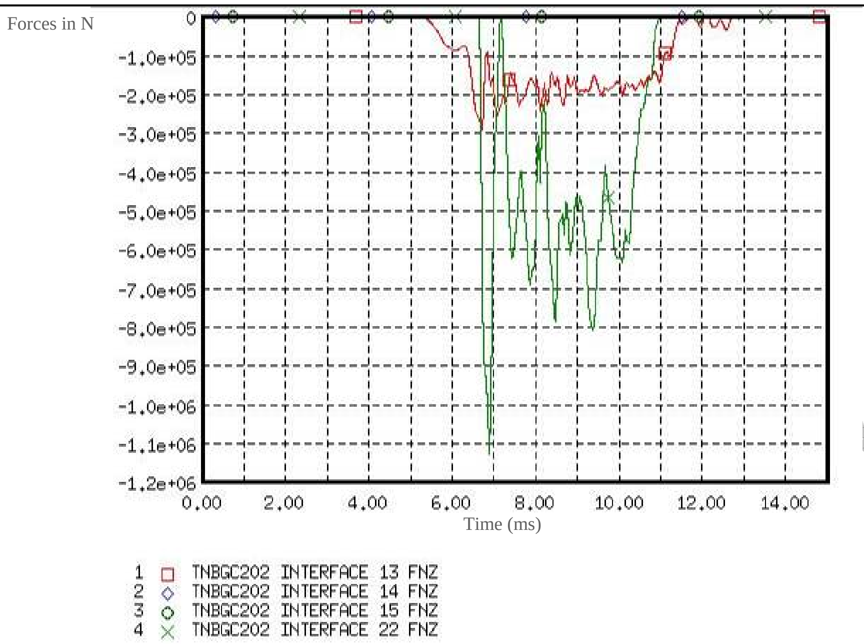


figure 31. *Forces in interfaces between the inside of the cover and the plug (20°C)*

- for plug contacts: contact is constantly maintained between the clamp ring and the plug (19). The interface between the plug and the load (17) discharges the interface between the plug and the main section (20). Loss of contact is therefore caused between the main section and the plug.

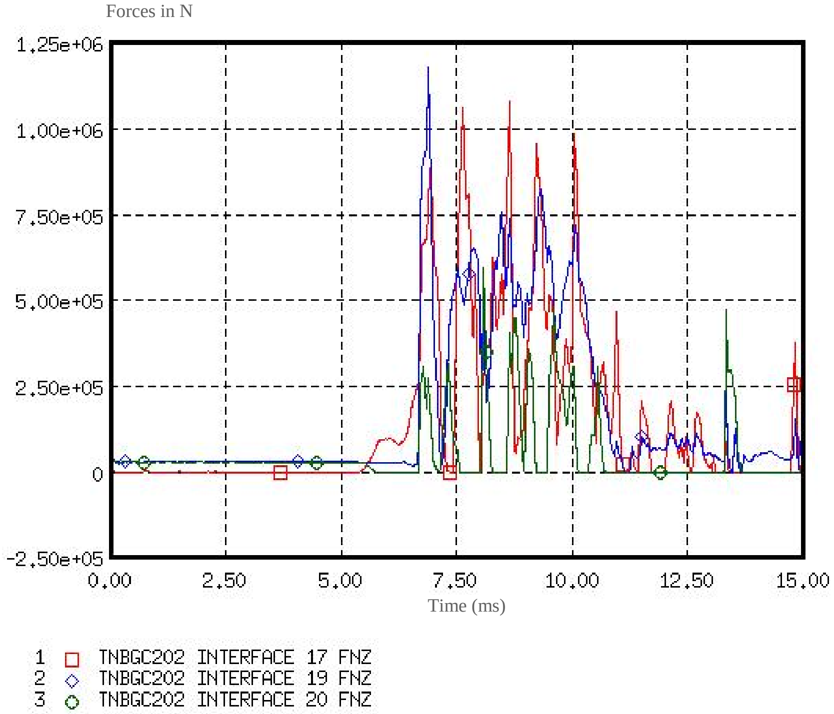


figure 32. Forces on the plug during the fall at 20°C

3.1.4.3. Deceleration levels

Decelerations were filtered with two different filters:

- a Butterworth low-pass filter with a cutout frequency of 400 Hz,
- a Butterworth low-pass filter with a cutout frequency of 600 Hz.

The following values were therefore obtained for the main components of the cover and for the load:

Part	Décélération max en g (filtrage low-pass 400 Hz)	Décélération max en g (filtrage low-pass 600 Hz)
Main section	438	600
Bayonet ring	437	605
Staubli ring	431	487
Plug	423	471
Clamp ring	430	499
Load	454	621

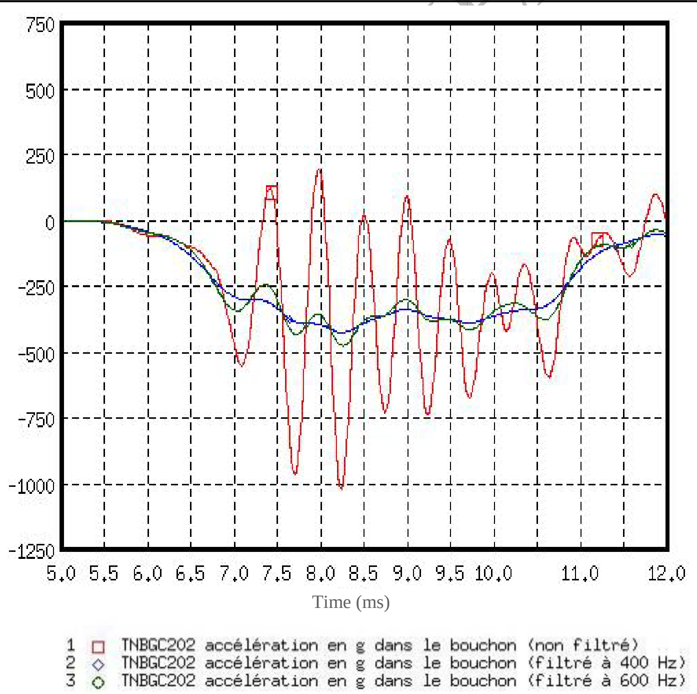


figure 33. *Deceleration of the plug (in g) with different filters (calculation at 20°C)*

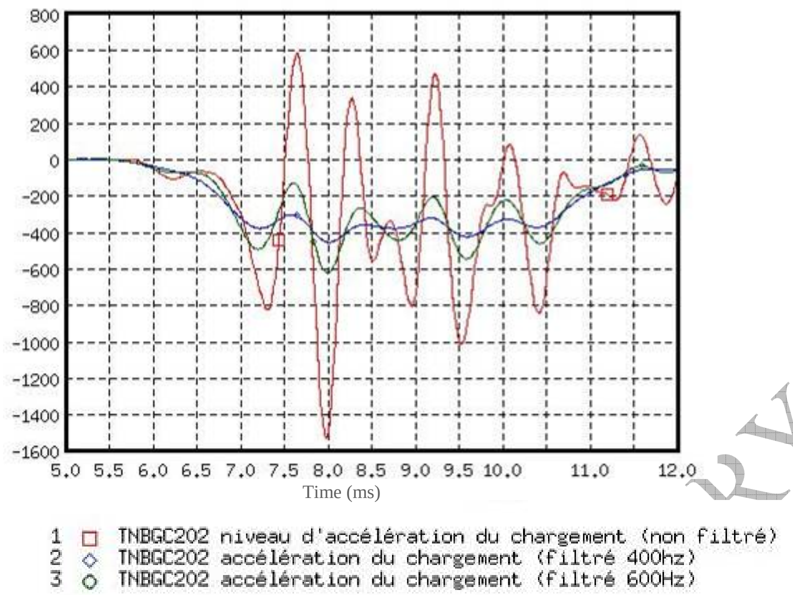
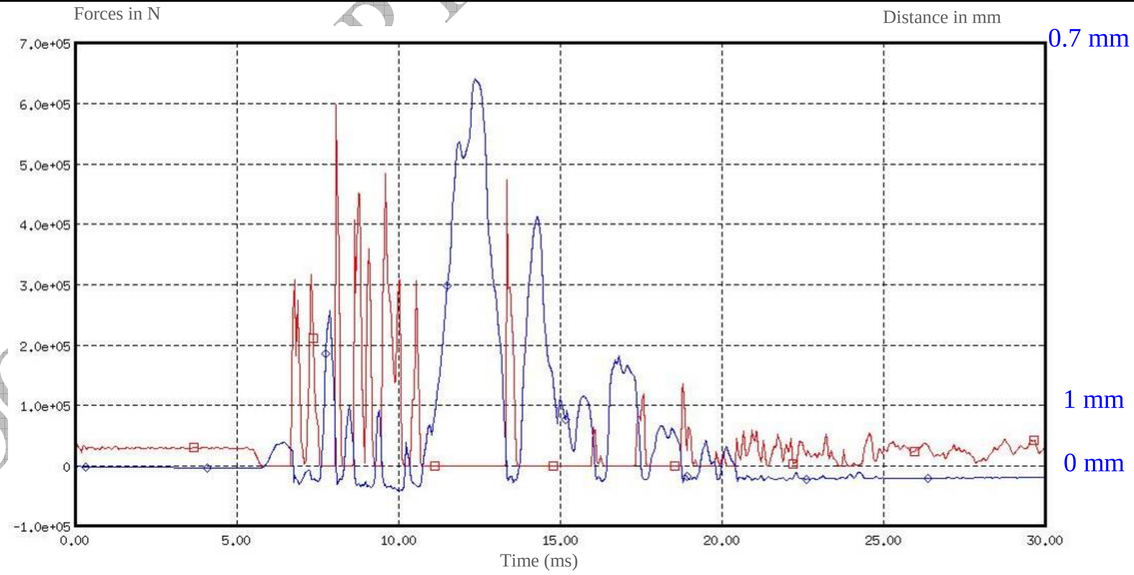


figure 34. Deceleration of the load (in g) with different filters (calculation at 20°C)

3.1.4.4. Detachment on the cover

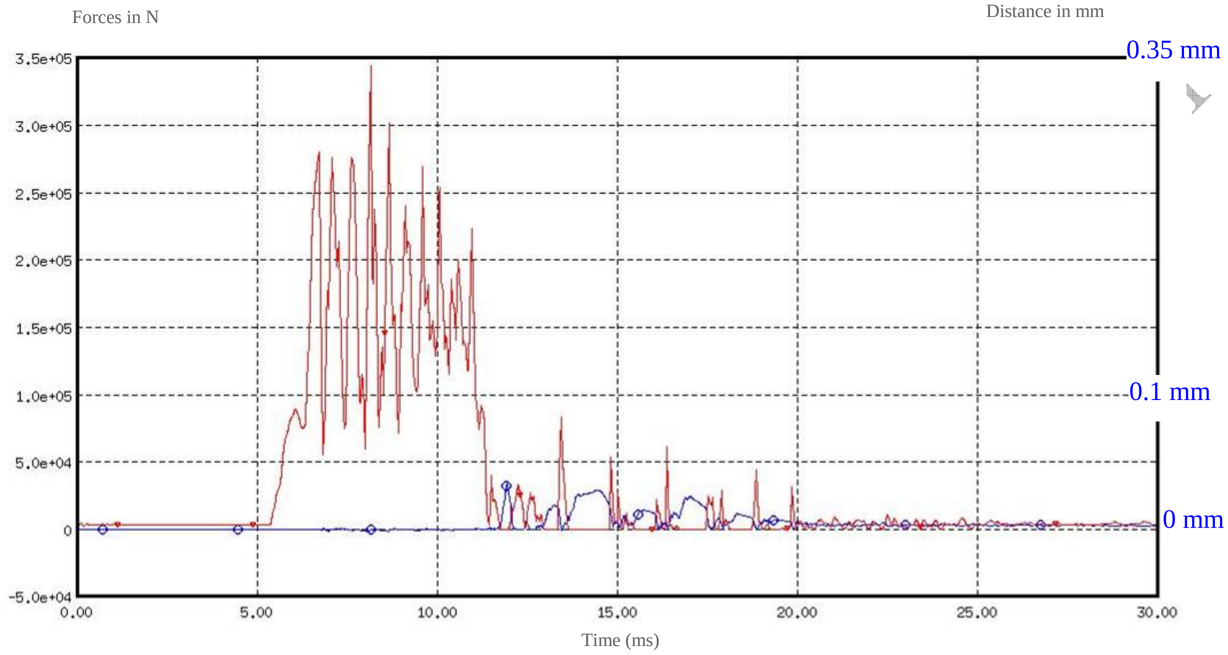
- for the plug: the depth of the weld throat is equal to 4.93 mm and the diameter of the weld is 6.99 mm. Crushing is equal to 30% in normal conditions. With a fall at a temperature of 20°C, cover/flange detachment of 0.64 mm is noted for 3 ms. Crushing is therefore 1-(4.93+0.64)/6.99=20%. This crushing is acceptable and guarantees satisfactory seals as this opening is the largest of all openings (in terms of duration and amplitude).



Forces in the interface 20 and displacement between the plug and the main section at seal contact level
Forces are expressed in N with a maximum of 600 kN
Displacements are expressed in mm with a maximum of 0.64 mm

figure 35. Definition of plug/main section contact for calculations at 20°C

- for the Staubli plug: an opening of 0.03mm was observed during 2ms between the Staubli plug and the blanking plate. Crushing is almost unmodified (seal throats have a height of 2.60 mm). This low variation in crushing guarantees the sealing of the Staubli plug.



Forces in the interface 9 and displacement between the Staubli plug and the plug at seal contact level
Forces are expressed in N with a maximum of 350 kN
Displacements are expressed in mm with a maximum of 0.03 mm

figure 36. *Definition of Staubli plug/blanking plate contact for calculations at 20°C*

In addition, in both cases, the duration of detachment does not exceed 3 ms. This duration is sufficiently low to prevent losses in terms of the sealing of the package.

3.2. Calculation at -40°C

3.2.1. Energy report

3.2.1.1. Energy report for the package

As was the case for calculations at 20°C, the first 5 milliseconds are used to prestress the plugs. The package is then "dropped" and gravity applied.
The global energy of the system is maintained during the calculation.
The initial kinetic energy is transformed into absorbed energy and kinetic rebound energy. The rebound acts when kinetic energy cancels out at 9.32 ms from the start of the simulation (including prestressing of the plugs).
Maximum energy absorbed is equal to 34.7 kJ.

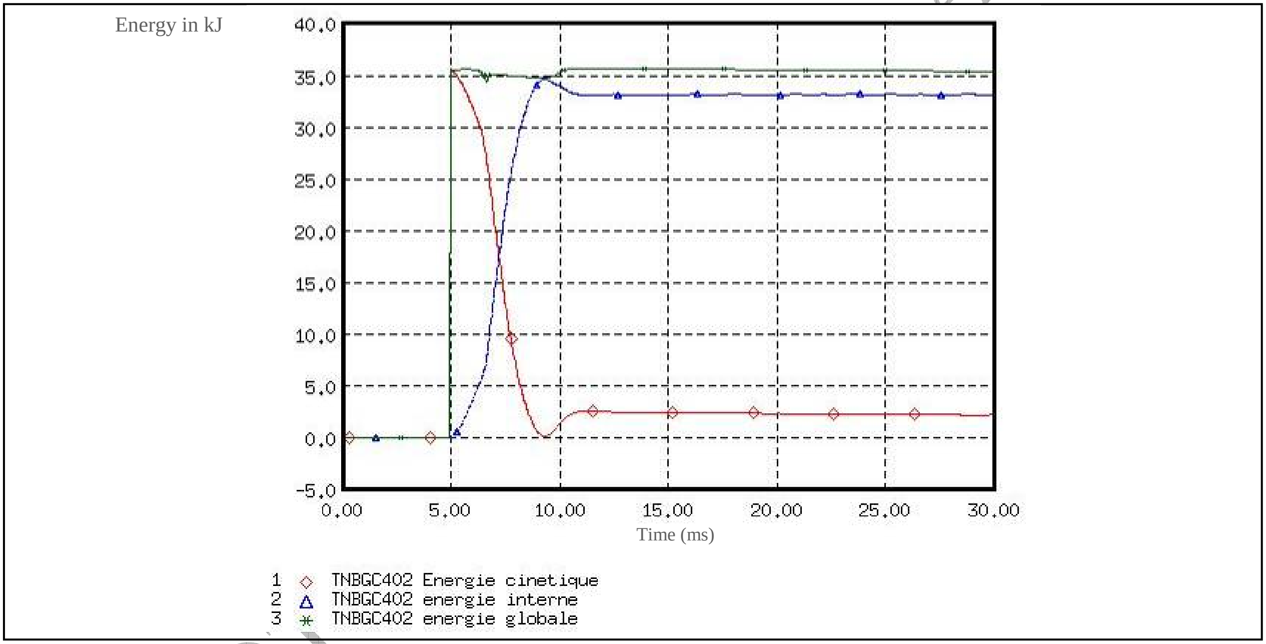


figure 37. Variation in global package energy with modelling at -40°C

Energie cinetique	Kinetic energy
Energie globale	Global energy
Energie interne	Internal energy

3.2.1.2. Distribution in the energy absorbed in sub-assemblies

Part assemblies absorbing the most energy are primarily the cover with 26.7 kJ (i.e. 77% of total internal energy), followed by the cage with 7.28 kJ (i.e. 22%)
The remaining percentage is distributed in the other parts.

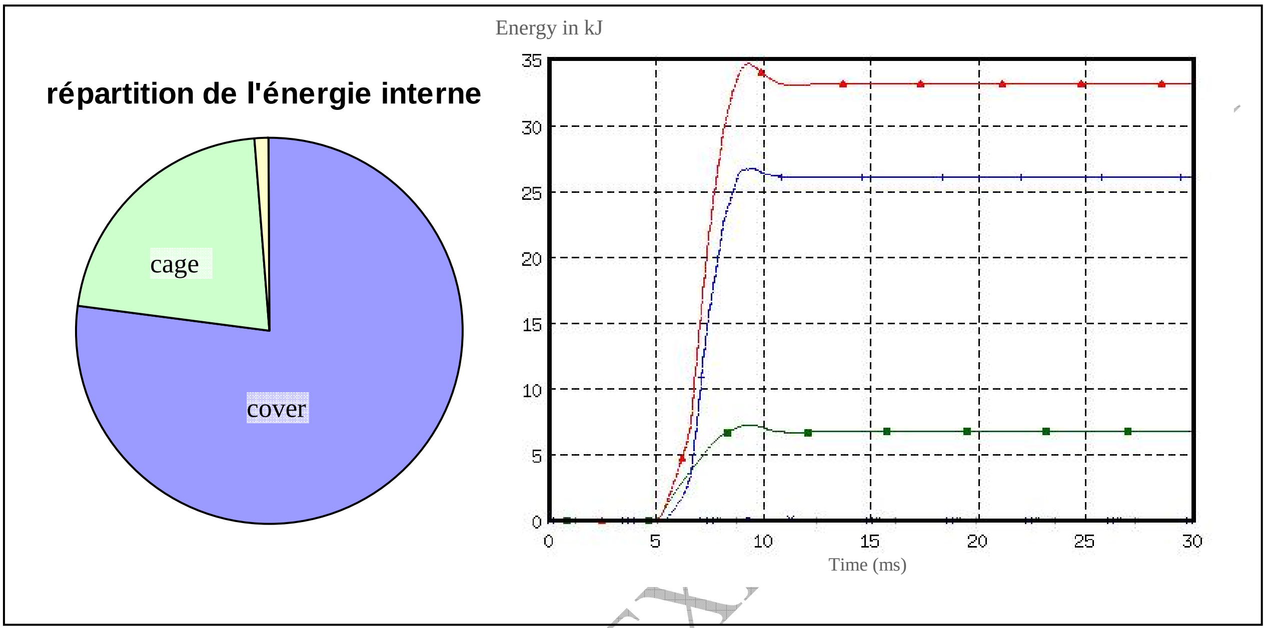


figure 38. Changes in energy absorbed per sub-assembly

Repartition de l'énergie interne	Repartition of internal energy

3.2.2. Qualitative results

3.2.2.1. Indentation of the cover

figure 39. Indentation of the cover during calculations at -40°C

3.2.2.2. Crushing of the cage

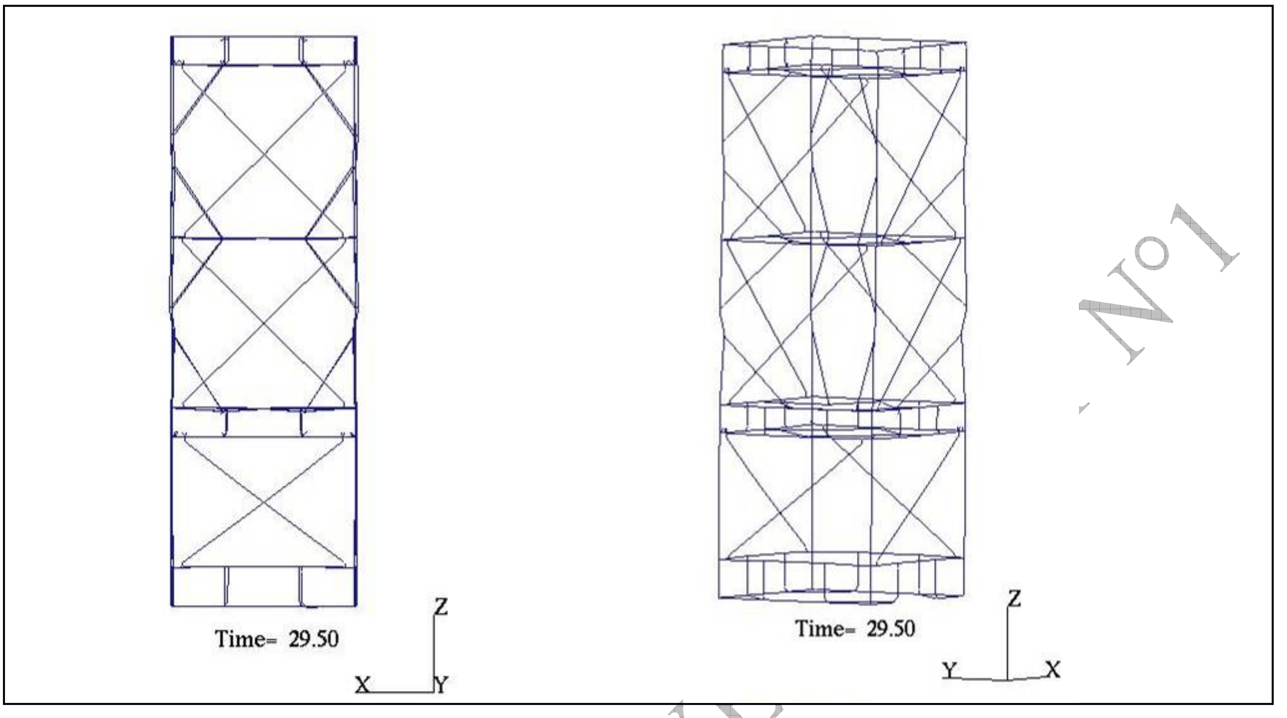


figure 40. Total crushing of the cage in calculations at -40°C

3.2.3. Quantitative results

3.2.3.1. Indentation of the cover

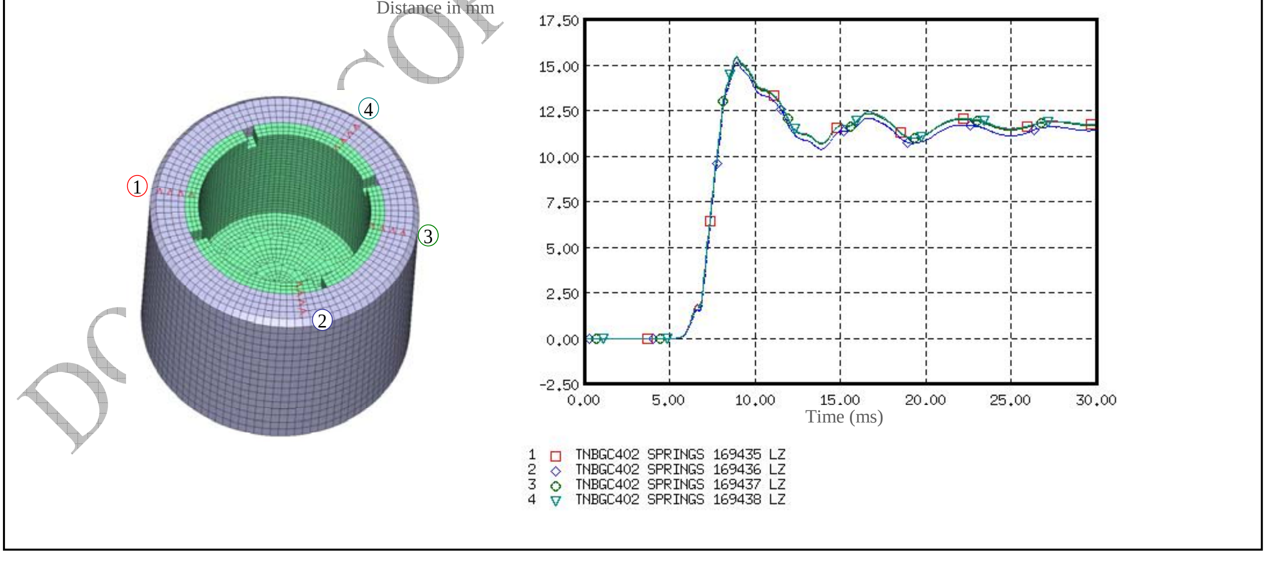
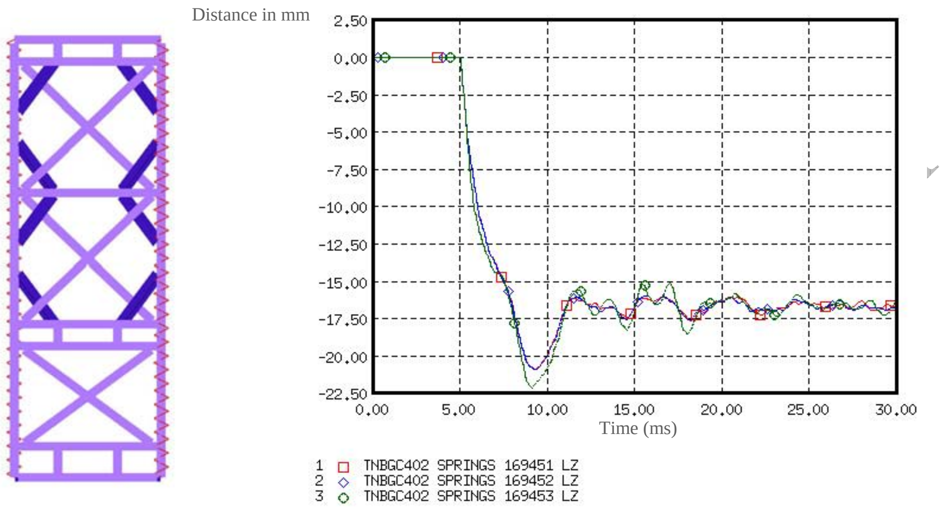


figure 41. Indentation of the cover during calculations at -40°C

The indentation of the cover is measured at four points (identical to modelling at 20°C). Residual indentation is equivalent to 12 mm.

3.2.3.2. Crushing of the cage

Total residual crushing for the cage is 20 mm (vertically).



Measuring of the total crushing of the cage

figure 42. Total crushing of the cage in calculations at -40°C

Crushing is measured between the two ends of the beam and strictly vertical.

height	Height before the fall	Results of calculations at -40°C
Lower cage level (at the top during the fall)	505 mm	504 mm
Intermediate level	505 mm	499 mm
Upper level (at the bottom during the fall)	380 mm	376 mm
Measurement in the middle of the upper level	380 mm	371mm

3.2.3.3. Resistance of cover attachments

Forces in the four attachments of the cover are equivalent. Maximum forces are equivalent to 130 kN.

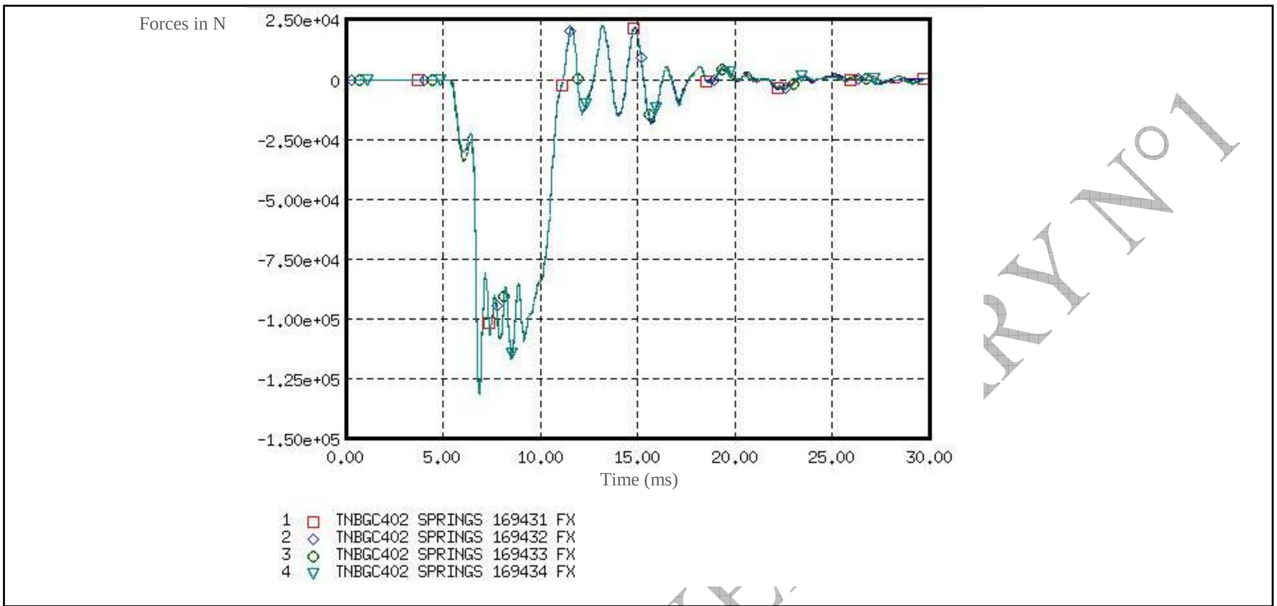


figure 43. Forces in cover attachments during calculations at -40°C

3.2.3.4. Attachment screws of the cage on the main section (attachment tabs)

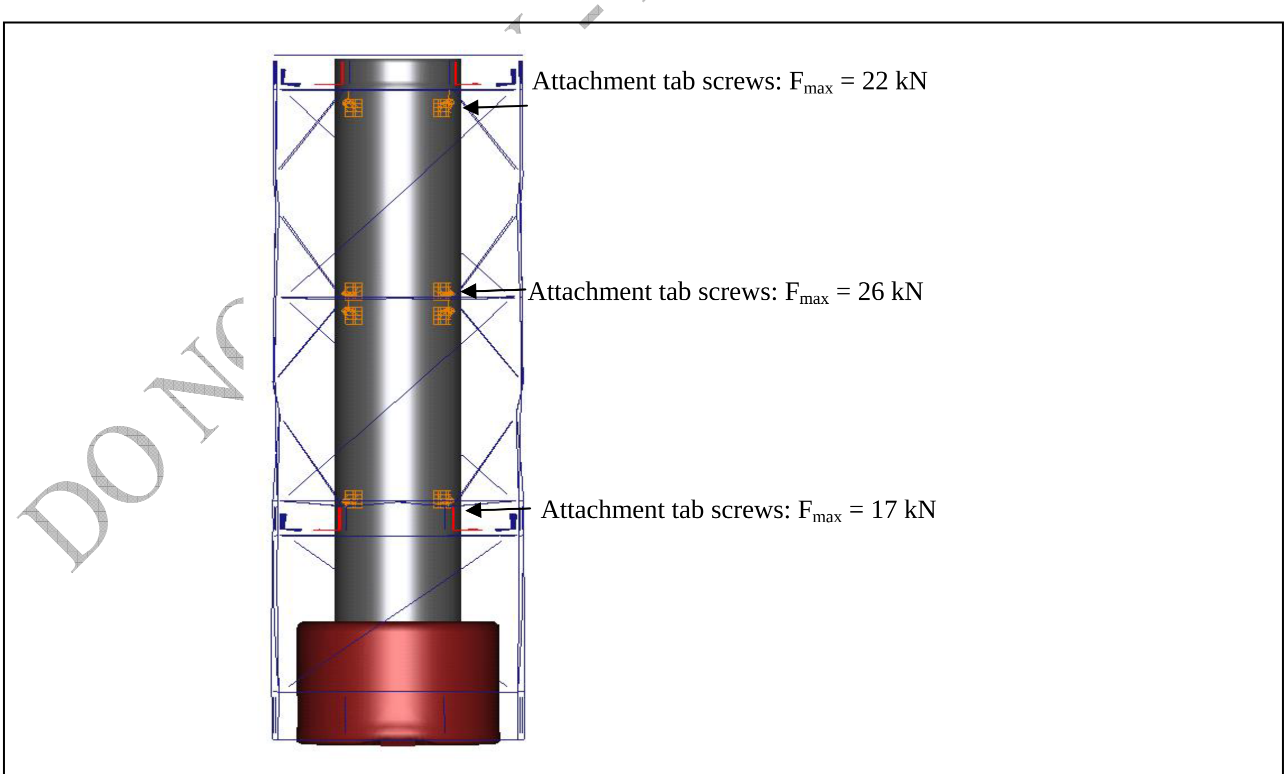


figure 44. Forces in attachment tab screws for calculations at -40°C

3.2.4. Additional results

3.2.4.1. Chronology of impacts in the main section + cover

The chronology of impacts is as follows:

- the Staubli plug,
- the plug, the clamp ring and the main section flange,
- the load.

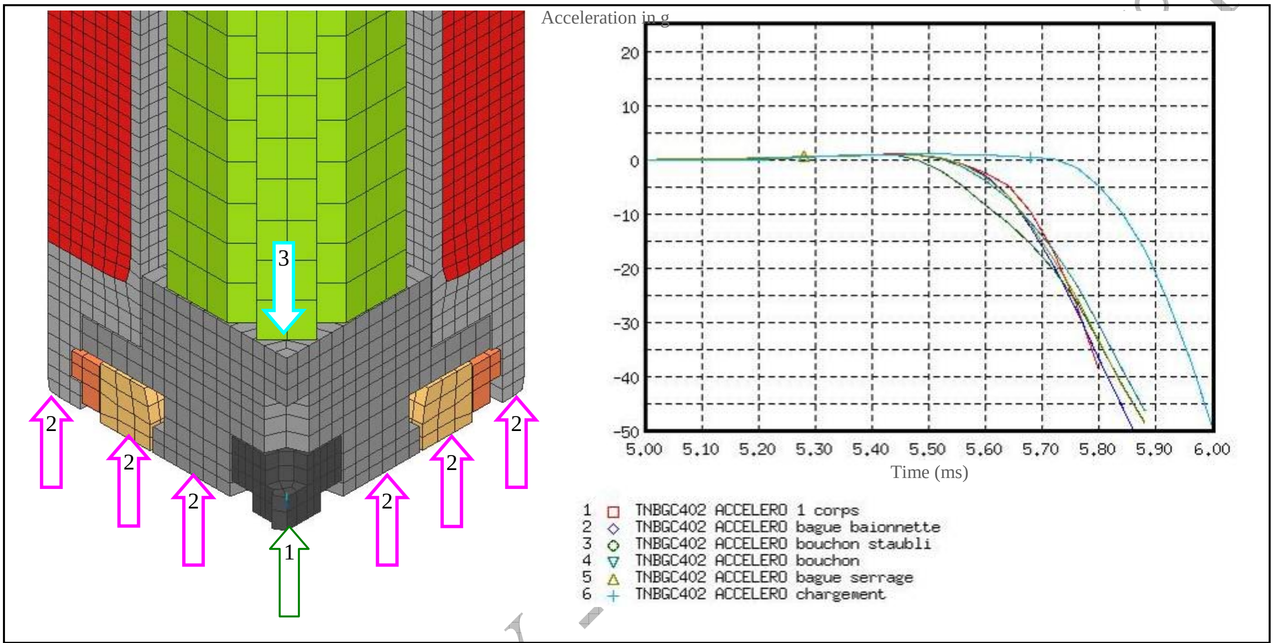


figure 45. Chronology of impacts in the cover for the calculation at -40°C

1 corps	1 main section
bague baïonnette	bayonet ring
bouchon staubli	staubli plug
bouchon	plug
Bague de serrage	Clamp ring
chargement	Load

3.2.4.2. Forces in interfaces

Interface numbers are identical to those used for results at 20°C.

- for the internal contacts of the cover/plug: at the time of impact, only the Staubli plug and the clamp ring come into contact with the inside of the cover as only interfaces 13 and 22 are activated.

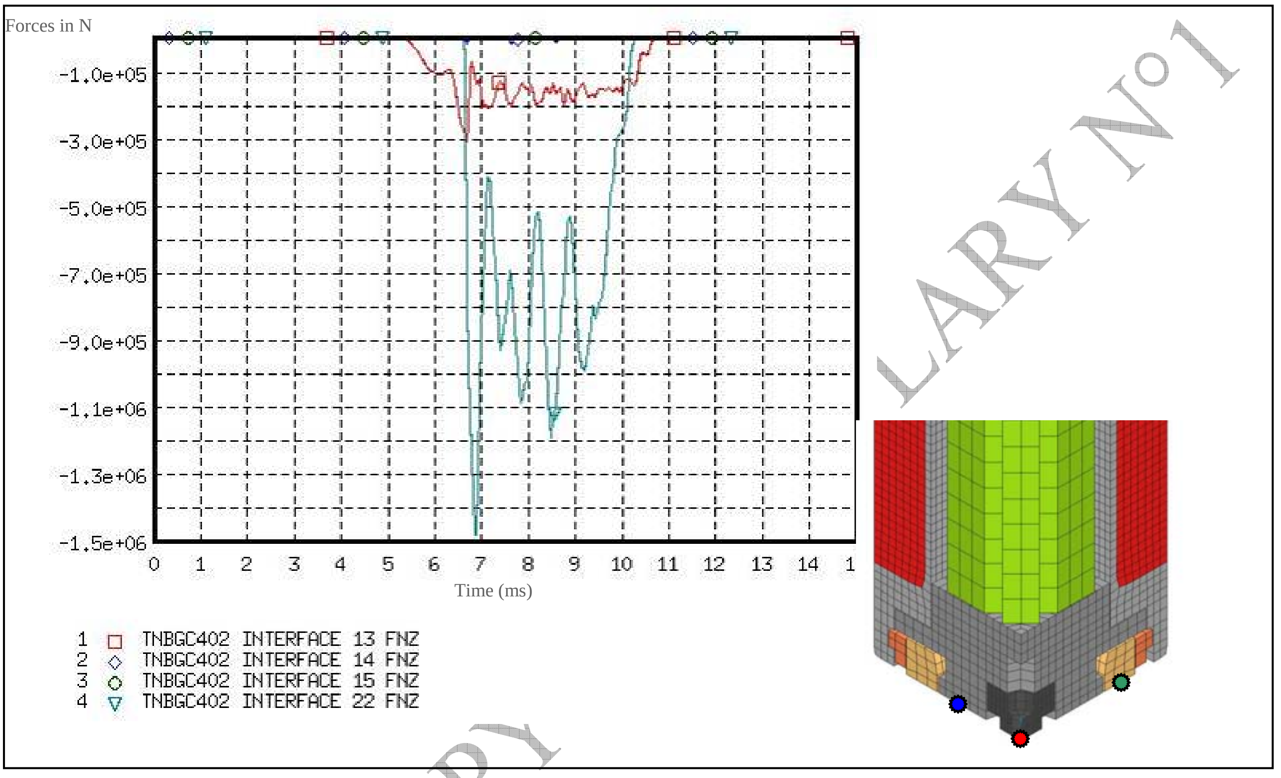


figure 46. Forces in interfaces between the inside of the cover and the plug (-40°C)

- for plug contacts: contact is constantly maintained between the clamp ring and the plug (19). The interface between the plug and the load (17) discharges the interface between the plug and the main section (20). Loss of contact is therefore caused between the main section and the plug.

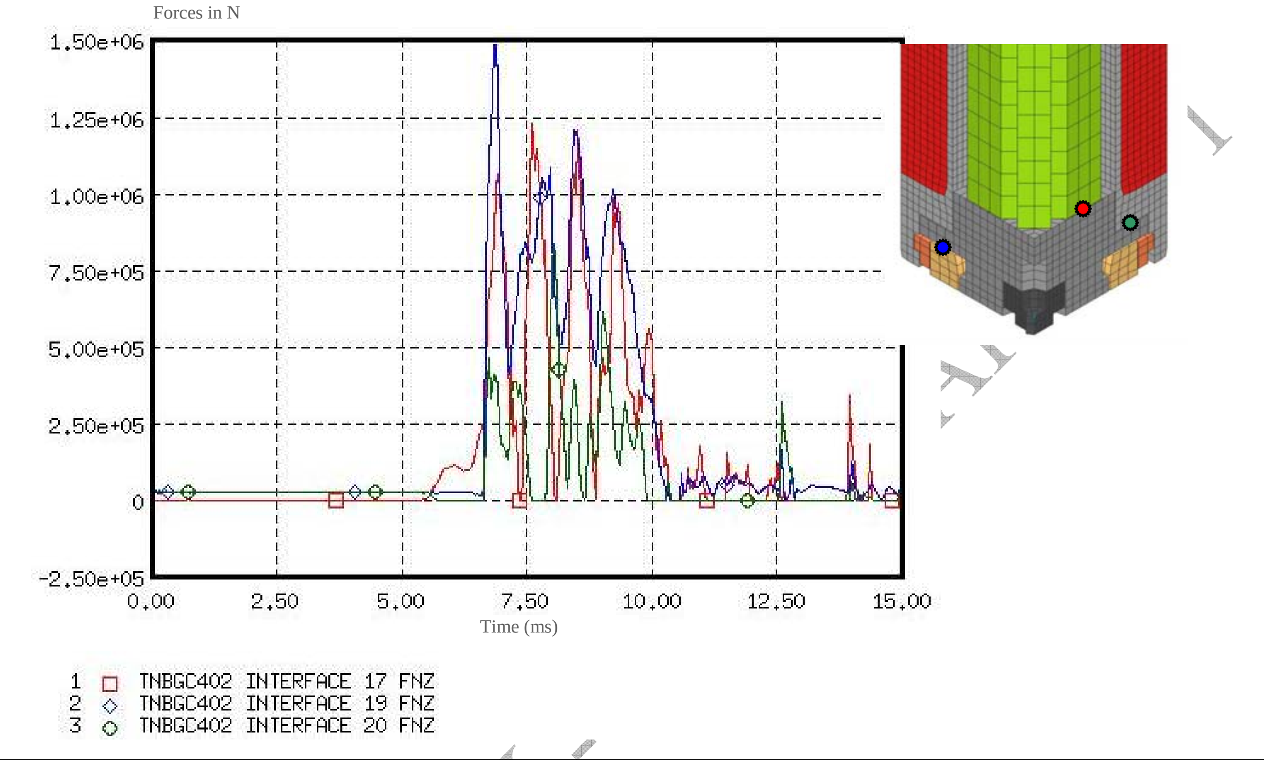


figure 47. Forces on the plug during the fall at -40°C

3.2.4.3. Deceleration levels

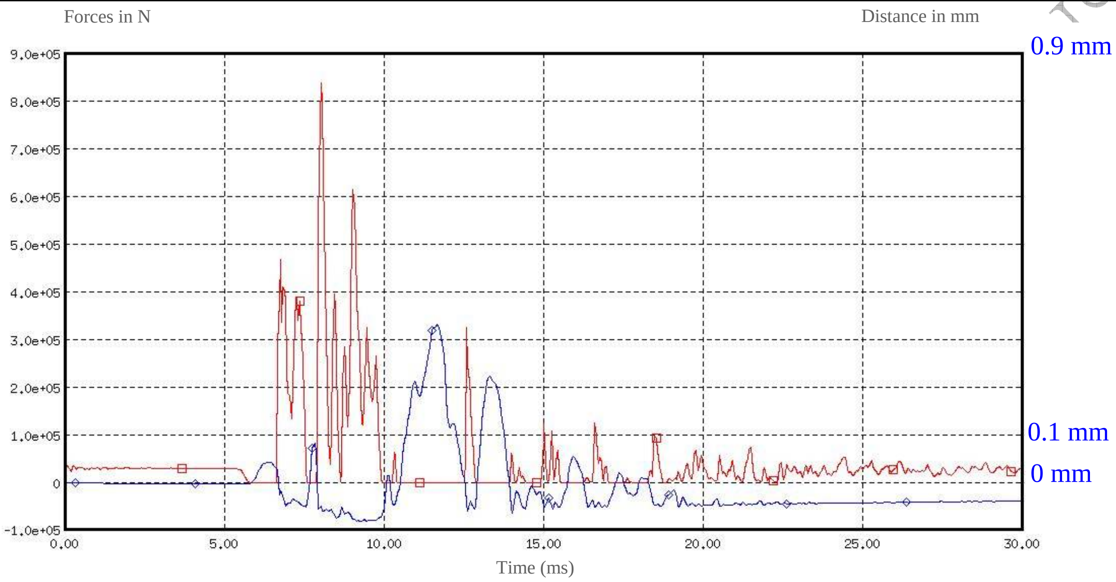
Decelerations were filtered using the two filters used for the analysis of results at 20°C.

The following values were therefore obtained for the main components of the cover and for the load:

Part	Max. deceleration in g (low-pass 400 Hz filter)	Max. deceleration in g (low-pass 600 Hz filter)
Main section	538	697
Bayonet ring	539	703
Staubli plug	519	594
Plug	520	584
Clamp ring	522	624
Load	572	780

3.2.4.4. Detachment on the cover

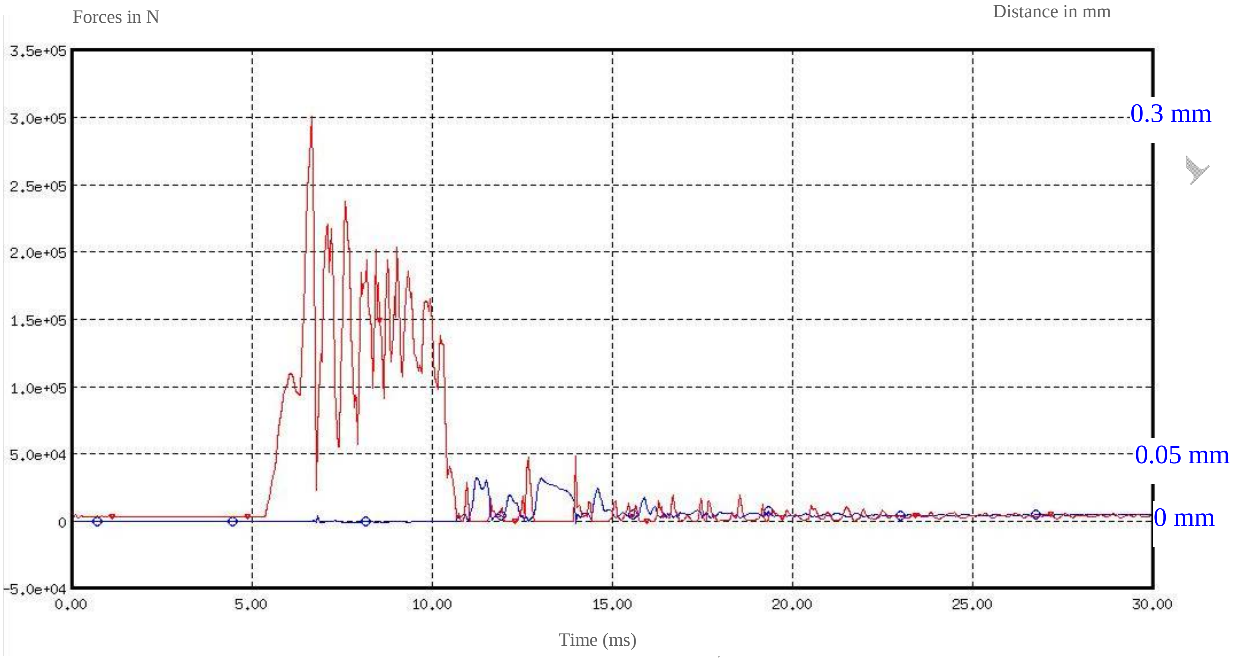
- for the plug: the following chart shows that the interface "opens" on several occasions with a maximum displacement of 0.33 mm for 2 ms. The height of seal throats is equal to 4.93mm and the initial diameter of the seal to 6.99 mm. Minimum crushing represents 24% (1-(4.94+0.33)/6.99). This crushing is adequate to ensure the sealing of the cover.



Forces in the interface 20 and displacement between the plug and the main section at seal contact level
Forces are expressed in N with a maximum of 840 kN

figure 48. Definition of plug/main section contact for calculations at -40°C

- for the Staubli plug: the following graph shows that maximum displacement represents 0.03 mm. As with modelling at 20°C, this low variation in crushing guarantees the sealing of the Staubli plug.



Forces in the interface 9 and displacement between the Staubli plug and the plug at seal contact level
Forces are expressed in N with a maximum of 300 kN
Displacements are expressed in mm with a maximum of 0.03 mm

figure 49. *Definition of Staubli plug/blanking plate contact for calculations at -40°C*

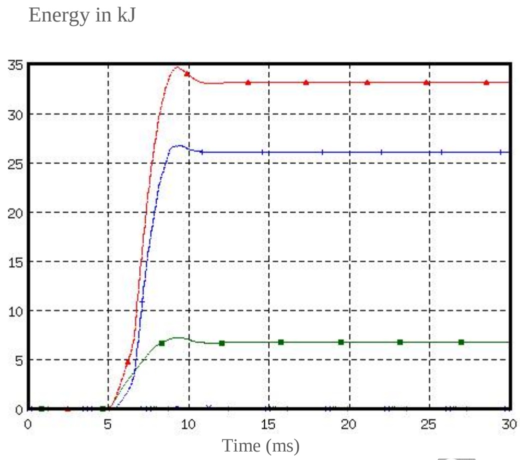
In addition, in both cases, the duration of detachment does not exceed 2 ms. This duration is sufficiently low to prevent losses in terms of the sealing of the package.

4. Overview

The following chapters focus on the influence of the transition to -40°C. Graphs relating to calculations at 20°C will be shown in blue while results at -40°C will be shown in red.

4.1. Influence on energy-absorbing parts

The distribution of the energy absorbed by each part sub-assembly varies little.



Énergie interne	Valeur maximale à -40°C	%	Valeur maximale à 20°C	%
Globale	34,7 kJ à 9,32 ms	100	35,2 kJ à 10,08 ms	100
Capot	26,7 kJ à 9,48 ms	77	26,4 kJ à 10,2 ms	75
Cage	7,28 kJ à 9,40 ms	22	8,3 kJ à 9,8 ms	24
Corps	0,2 kJ à 9,28 ms	0,5	0,2 kJ à 10,2 ms	0,5
Chargement	0,2 kJ	0,4	0,2 kJ	0,4
Bouchon	0,1 kJ	0,1	0,1 kJ	0,1

figure 50. Changes to the distribution of energy absorbed between the calculation at 20°C and at -40°C

Internal energy	Maximum value at -40°	%	Maximum value at 20°C	%
Global	34.7 kJ at 9.32 ms	100	35.2 kJ at 10.08 ms	100
Cover	26.7 kJ at 9.48 ms	77	26.4 kJ at 10.2 ms	75
Cage	7.28kJ at 9.40 ms	22	8.3 kJ at 9.8 ms	24
Main section	0.2 kJ at 9.28 ms	0.5	0.2 kJ at 10.2 ms	0.5
Load	0.2 kJ	0.4	0.2 kJ	0.4
Plug	0.1 kJ	0.1	0.1 kJ	0.1

4.2. Influence on cover indentations

With a fall at -40°C, residual cover indentation is less than 5 mm as compared with indentation for the fall at 20°C.

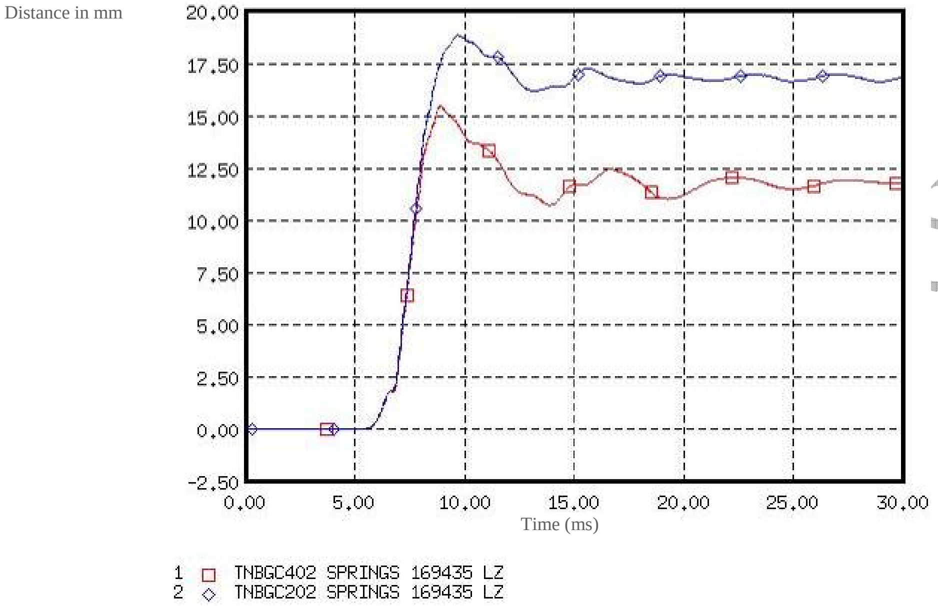


figure 51. *Changes to cover indentation between the calculation at 20°C and at -40°C*

4.2.1.1.

4.3. Influence on the total crushing of the cage

Residual crushing of the cage at -40°C is lower (-3 mm) than crushing at 20°C.

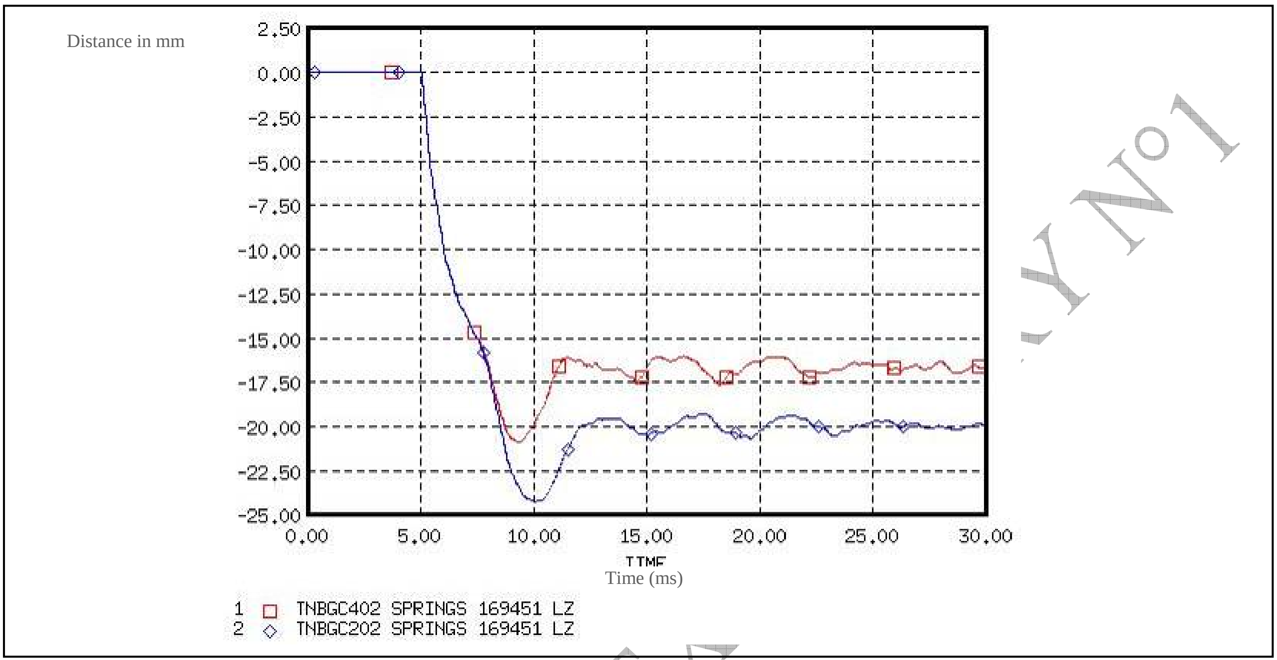


figure 52. Changes to the crushing of the cage between the calculation at 20°C and at -40°C

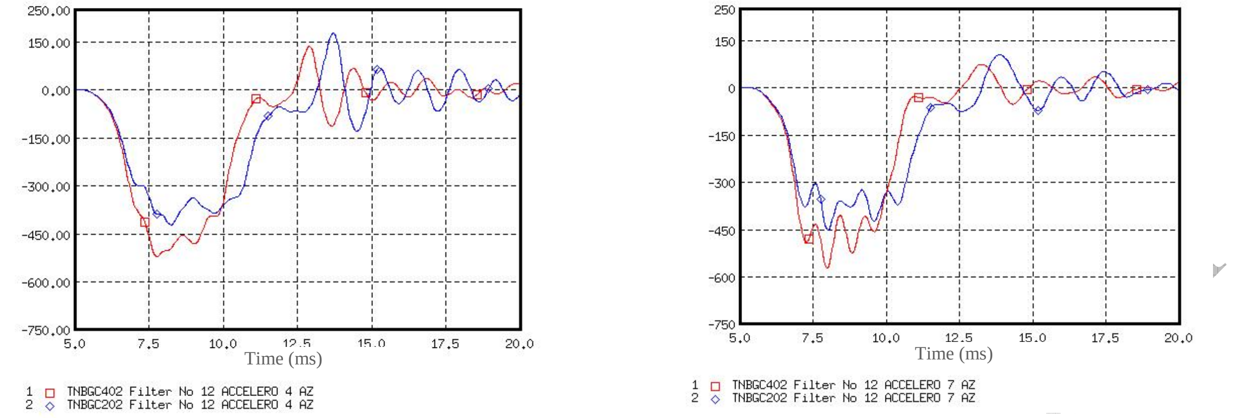
4.4. Influence on deceleration levels

Deceleration is higher at -40°C than at 20°C (approx. 20%) due to the increase in stiffness of wood filler. In fact, the wood is crushed less, therefore deceleration is higher.

Pièce	Décélération en g à 20°C	Augmentation de la décélération due au passage à -40°C
Corps	438	+23% (538)
Bague baïonnette	437	+19% (539)
Bouchon de staubli	431	+17% (519)
Bouchon	423	+19% (520)
Bague de serrage	430	+18% (522)
Chargement	454	+21% (572)

figure 53. Changes to deceleration between the calculation at 20°C and at -40°C

Part	Deceleration in g at 20°C	Increase in deceleration due to the drop to -40°C
Main section	438	+23% (538)
Bayonet ring	437	+19% (539)
Staubli plug	431	+17% (519)
Plug	423	+19% (520)
Clamp ring	430	+18% (522)
Load	454	+21% (572)



Comparison of accelerations in the plug *Comparison of accelerations in loading*

figure 54. *Change in accelerations (in g) in the plug and loading between the 2 temperatures*

4.5. Influence on sealing criteria

4.5.1. For the Staubli plug

The transition from 20°C to -40°C will not cause any substantial modification to sealing for the Staubli plug. In fact, the openings measured remain negligible.

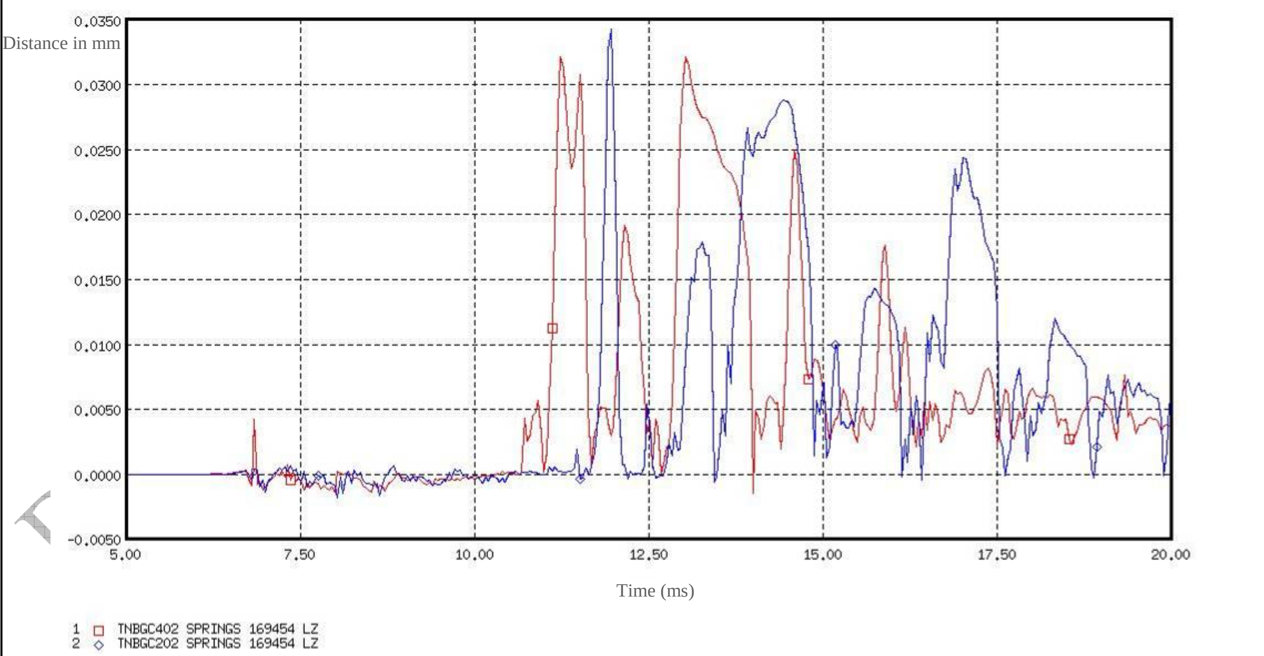


figure 55. *"Opening" of the contact between the Staubli plug and the blocking plate for the two temperatures*

4.5.2. *For the cover plug*

The transition from 20°C to -40°C reduces the amplitude and the duration of the opening of clearance between the plug and the main section. The package remained sealed in a fall at 20°C, and will therefore definitely remain sealed in a fall at -40°C.

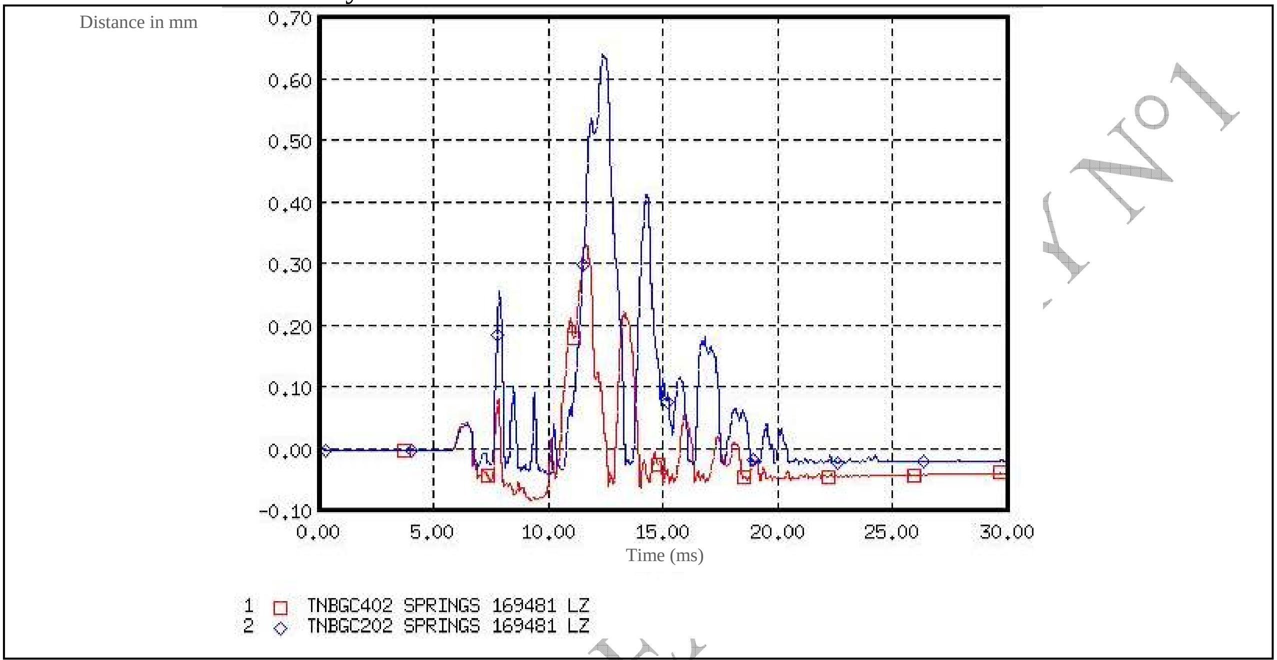


figure 56. *"Opening" of the contact between the plug and the main section for the two temperatures*

4.6. Influence on cover attachments

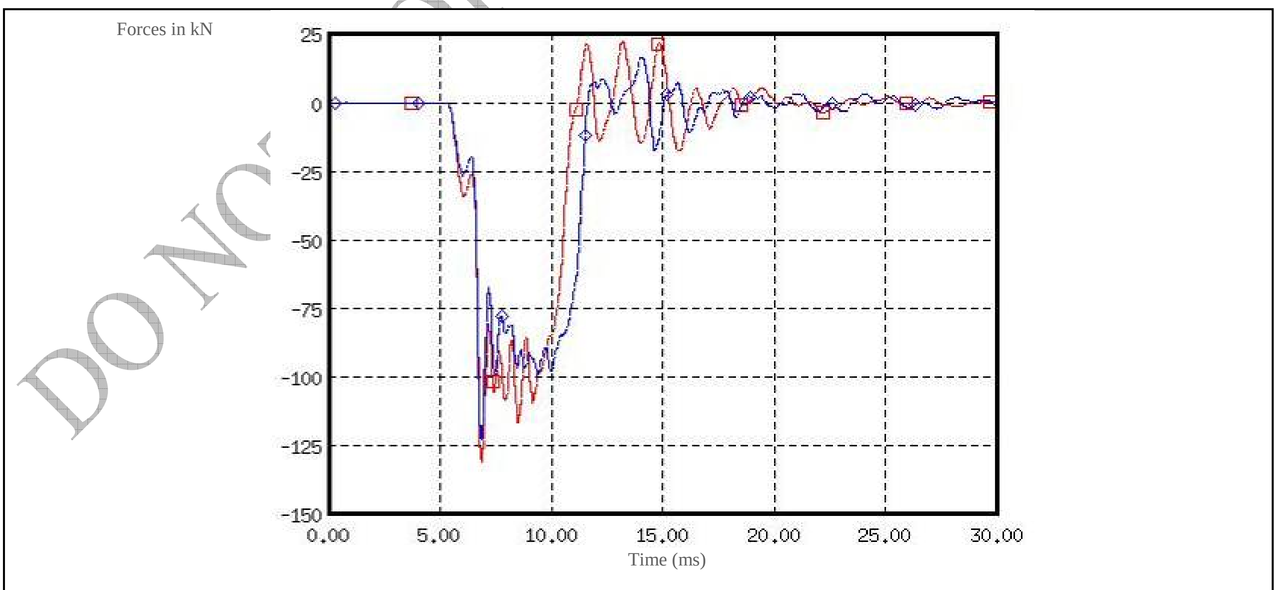


figure 57. *Comparison of forces (in kN) in cover attachments at 20°C and -40°C*

Forces in cover attachments between the fall at 20°C and at -40°C are similar. Temperature therefore has no influence (between -40°C and 20°C) on the resistance of cover attachments.

4.7. Influence on the cage screws

Forces in screws are similar at each attachment level.
Forces crossing attachment screws are similar at both fall temperatures, no additional risk of damage therefore exists according to tests.

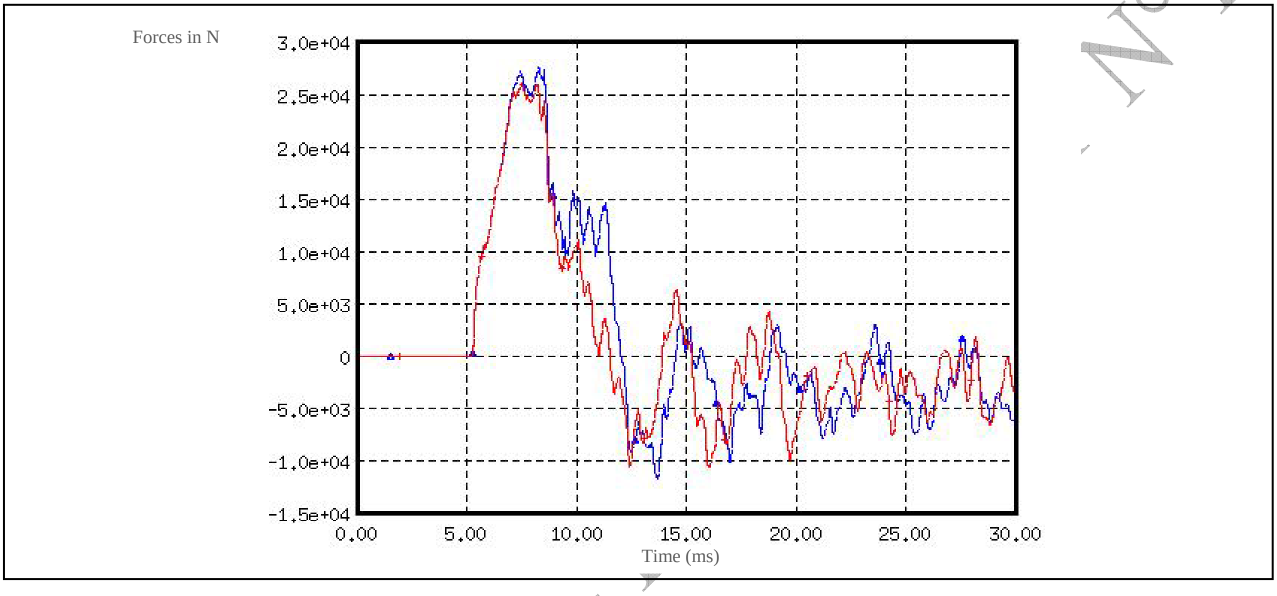


figure 58. *Forces in bottom attachment screws (the furthest area from the impact area)*

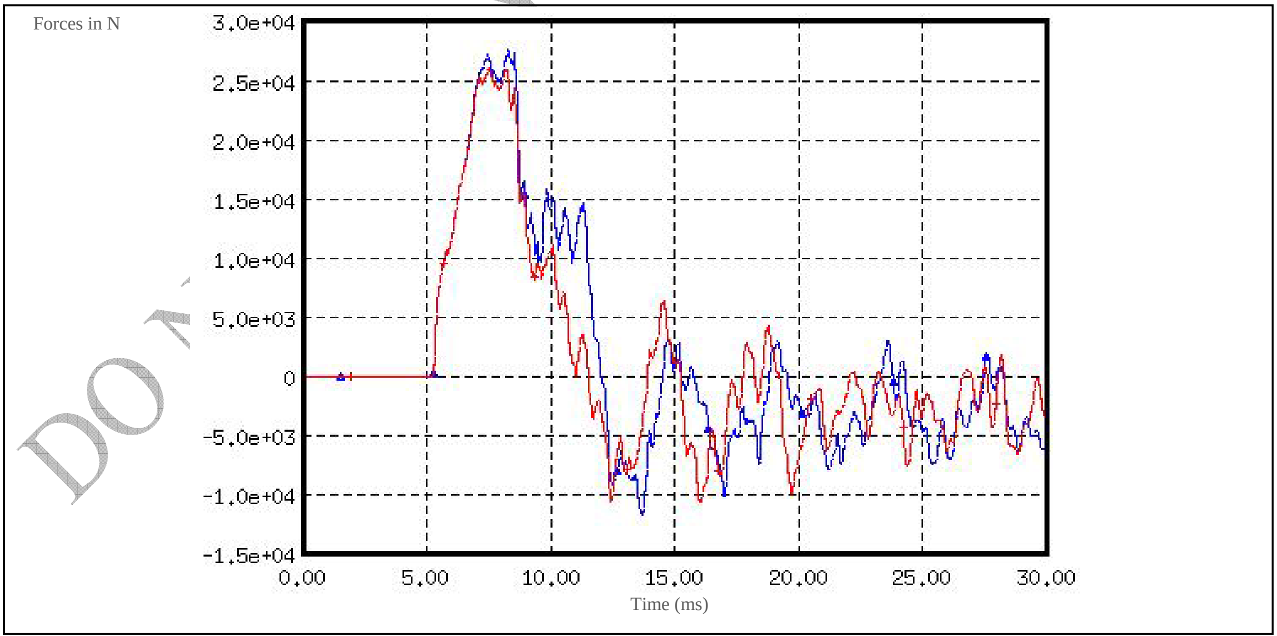


figure 59. *Forces in the attachment screws at intermediate level*

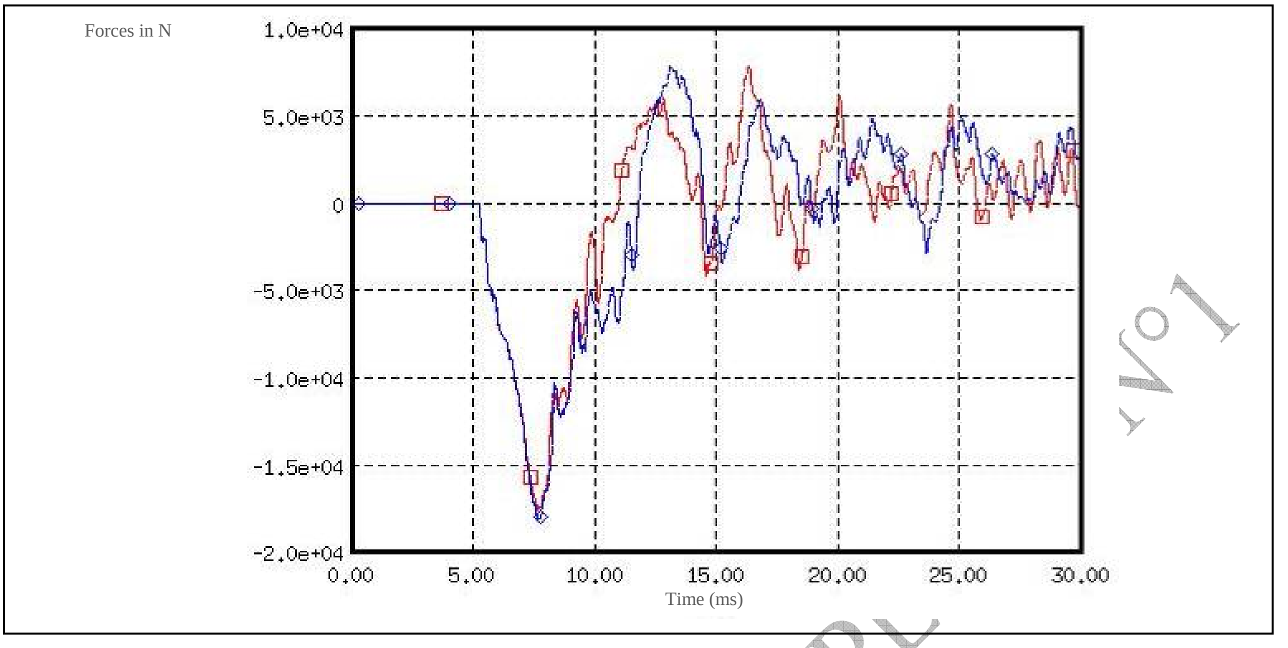


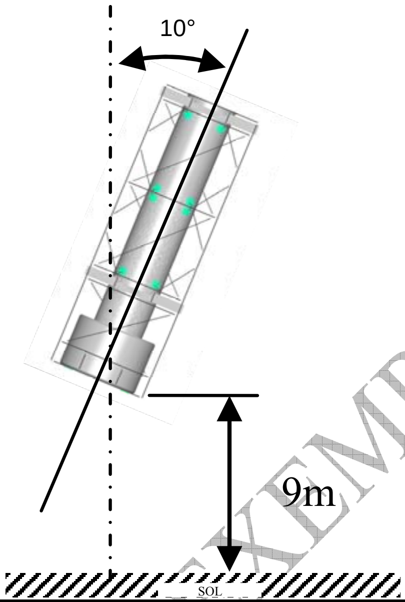
figure 60. *Forces in top attachment screws (the nearest area to the impact area)*

5. Conclusion

This study aimed to check that the TN-BGC1 package remained leakproof following a vertical fall of 9m, at an ambient temperature of -40°C. In view of the results of modelling, the crushing of the cover seals and the Staubli plug remain adequate to guarantee the sealing of the package (minimum 24%). This reduction in crushing only occurs for short periods (maximum of 2ms).

In addition, forces in cover and cage attachments are equivalent at -40°C and 20°C. There is no additional risk compared with testing at 20°C. At -40°C, deformation of the cage and cover is less extensive (-15% and -29% resp.), however, package decelerations are higher (+21% at loading level).

CEA Cadarache centre
DTAP/SET
Study of the continued sealing of package TN-BGC 1 after a fall of 9m from an oblique position (10°)



PROJECT: G03CAL0022A
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Overview of the mechanical study of an oblique drop of 9 metres for the TN-BGC 1 package

Objectives

The aim of this study is to justify the continued sealing of the TN-BGC 1 package after a fall of 9 m from an oblique position, irrespective of the ambient temperature and after the replacement of the lower seal of the plug with a toroid diameter of 6.99 +/- 0.15mm with a seal with a toroid diameter of 6.8 +/- 0.15mm.

The change in the mechanical properties of the wood was integrated based on temperature.

We created a test plan at 20°C to determine the most detrimental fall angle for detachment by varying the fall angle at intervals of 10° from vertical.

Results

The test plan demonstrated that an angle of 10° from vertical represented the most detrimental fall angle configuration in terms of plug detachment. Modelling results at -40°C and 20°C demonstrate that the crushing of the seals of the cover and Staubli plug are identical and remain adequate to seal the package (at least 18.3% for the level of dynamic compression) as the acceptable limit is 15%. This reduction in crushing only occurs for short periods (maximum of 4ms). In addition, after the fall, the level of compression of the seal is close to the initial level of 27.5%.

The reduction of the temperature to -40°C had almost no effect on the results obtained at 20°C. We even noted a decrease in the force of ground/package contact of 36kN and a decrease in deceleration of 10G. At an ambient temperature of -40°C, the mechanical properties of wood stiffen and improve absorption at initial impact. Initial deceleration caused by the crushing of the wood at -40°C is slightly higher, i.e. the main section is slowed down slightly more. Maximum deceleration of the centre of gravity is due to initial deformation of the steel corner of the package when the wood achieves maximum yield in both cases. The results obtained for both temperatures are globally similar to the low wood thickness subjected to stresses during the fall.

The detachment of the plug starts with the contact of the load and subsequently with the bending of the packages in all cases. The position of the load in its housing and rigidity appear to play a key role in the detachment of the plug: we used a detrimental configuration in our simulations:

- as the load is free to move radially within its containment. In addition, we considered the load as a single rigid steel block,

- and the stiffness in the closing system at clamp ring level was underestimated, leading to local detachment and overestimated rotations.

In view of these final remarks, we can conclude that the sealing of TN-BGC 1 packages is guaranteed after falls at an angle.

Table of modifications

Version	History	Pages modified	Date	Revised by	Approved by
1.0			06/03/07	S. Tholance	S. Diet
2.0	Integration of remarks from the first CEA control sheet	All	06/04/07	S. Tholance	S. Diet
3.0	Second correction	All	23/04/07	E. Piskula	S. Diet

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Figures and Tables

1. Presentation of the study and references

1.1. Introduction.

The aim of this study is to justify the continued sealing of the TN-BGC 1 package after a fall of 9 m from an oblique position, irrespective of the ambient temperature and after the replacement of the lower seal of the plug with a toroid diameter of 6.99 +/- 0.15mm with a seal with a toroid diameter of 6.8 +/- 0.15mm.

The change in the mechanical properties of the wood was integrated based on temperature.

We created a test plan to determine the most detrimental fall angle for detachment by varying the fall angle at intervals of 10° from vertical.

We then analysed results for the most detrimental fall at both ambient temperatures (20°C and -40°C)

1.2. References

N°	
[1.1]	Specifications 160 EMBAL PFM CDC 06 001827A
[1.2]	Eurosim report ref.: 2CE3E100
[1.3]	Quote SA/E064503
[1.4]	Technical note on wood compression testing according to temperature 160 EMBAL PFM NOT 04001858 A

2. Modelling and hypotheses

2.1. Presentation of package TN-BGC -1

The TN-BGC1 package consists of:

- a rhomb cage with a structure in aluminium tubes with a 30 x 30 mm square section and a thickness of 2 mm. The cage has a section of 600x600 mm. The overall height of the cage represents 1815 mm. The cage mainly consists of vertical uprights and horizontal bars defining 3 levels. Tubes are placed diagonally to ensure the lateral rigidity of this structure. Holes for fork lift trucks are reinforced with corner plates. A frame system attached to the main section transmits stresses between the main section and the cage. Cut sheets are placed around the periphery of the cage to prevent contact between personnel and the package and to reduce radiation exchange between the main section of the package and the surrounding environment,

- a cylindrical cavity intended to house a TN90-type load with an external diameter of 295 mm. This section consists of an internal stainless steel shell with a working inner diameter of 178 mm, an external shell with a diameter of 295mm, a steel distribution plate, a wooden caisson and resin filler,

- a closing system involving a stainless steel plug, a bronze clamp ring and a stainless steel bayonet ring,

- a damper cover with an external diameter of 466 mm, consisting of two stainless steel caissons. The area around the main section is filled with the same resin as the main package. The inner cover has a diameter of 300 mm. The outer caisson contains poplar and balsa wood and this cover is fitted with two folding handles at the peak. The cover is attached to the main section by two bent rods and two grips,

- loads consist of a TN90-type container with a plug-side diameter of 148 mm and a distribution plate side diameter of 124 mm. Loads are surrounded with two spacers (E1 and E2), both of which are cylindrical. Spacer E1 has an internal diameter of 140 mm and an external diameter of 176 mm. Spacer E2 has an internal diameter of 126 mm and an external diameter of 139 mm.

2.2. Seals

In the previous study, the inner seal of the plug fitted on package TN-BGC 1 had an toroid diameter of 6.99 +/- 0.15mm. This latter switched to a diameter of 6.80 +/- 0.15mm with a seal throat with a height of 4.93mm. Under normal conditions, crushing represents 27.5%. Sealing is considered as non-guaranteed if the level of compression is less than 15%.

2.3. Hypotheses and simplifications

2.3.1. Materials

Materials were separated into two categories:

- metals and resins: elasto-plastic materials,
- wood (balsa and poplar) is an orthotropical material, and close attention was paid to the direction of the wood fibres.

The transition to an ambient temperature of -40°C had no substantial influence on the mechanical properties of the metals used. Young's modulus varied slightly for aluminium down to -80°C (cf.: engineering technique-M438-19). Woods were the most sensitive materials to drops in temperature, only their mechanical properties were modified for the calculation at -40°C.

2.3.2. Simplified modelling

2.3.2.1. <u>Modelling of the cage</u>

The cage is a structure which consists of aluminium tubes with a section of 30x30 and a thickness of 2 mm.

The cage was modelled using columns with no initial forces equivalent to a square section of 30x30 and a length of 20 mm. No strapping was detected in testing at 20°C. The modelling of beams is precise enough to represent tube buckling.

Links between the different tubes (structural nodes) are shown as rigid elements (no consideration of ruptures of welded links).

Cut sheets do not add substantial rigidity to the structure and are not modelled.

2.3.2.2. <u>Modelling of screws and attachments for the cover/main section</u>

Screws and attachments are modelled using stiff springs and with no consideration of rupture. This enables the measurement of stress levels during the two calculations.

2.3.2.3. <u>Modelling of the load</u>

The load may come into contact with the plug in case of impact. It is therefore important to consider load. The internal unit and the system of spacers are modelled as a cylinder with an equivalent mass and identical contact surface to the plug.

2.3.2.4. The floor

The floor is assumed to be infinitely rigid. The energy of the impact is therefore entirely transformed into energy absorbed by the package or kinetic rebound energy.

2.3.3. Efforts due to the tightening of plugs

The tightening of the package cover is shown by connecting the clamp ring and the bayonet ring. Pre-stressing is equivalent to 30 kN and is considered to be uniformly distributed over the contact surface. Local resistance provided by the rubber seal is not taken into account as the impact stresses act perpendicularly to this contact surface.

In the same way, pre-stressing in the Staubli plug is shown by linking the Staubli plug and the blocking plate. Pre-stressing is equivalent to 3520 N. This corresponds to the minimum effort transmitted by the plug clamp torque (50 Nm).

2.4. Output criteria

2.4.1. Deformation of the package assembly

We will focus our analysis on deformation during the fall from different points of view:

- global view: cage + package,
- section view of the cage/package assembly,
- close-up of the closing system.

2.4.2. Global criteria: speeds and deceleration

We will mainly focus on decelerations and speeds, both of the load and the centre of gravity.

2.4.3. Local criteria: level of compression and contact forces

Changes in the distance between the two cover/flange contact parts and contact stresses at the two temperatures are measured. This measurement enables the quantification of any detachment of the cover. Two types of detachment were selected and will provide:

- a level of dynamic compression, i.e. a minimum level of compression obtained during the entire fall,
- a level of residual compression, i.e. a level of compression obtained at the end of the fall.

We will also analyse forces in the Staubli plug and plug closing systems

2.5. Modelling

2.5.1. Unit system

The unit system used for this study is:

- Mass in grams **[g]**,
- Distance in millimetres **[mm],**
- Time in milliseconds **[ms]**,
- Density in grams per millimetre cubed **[g/mm3],**
- Speed in millimetres per millisecond **[mm/ms]**,
- Stresses in Mega Pascals **[MPa].**

2.5.2. Meshing

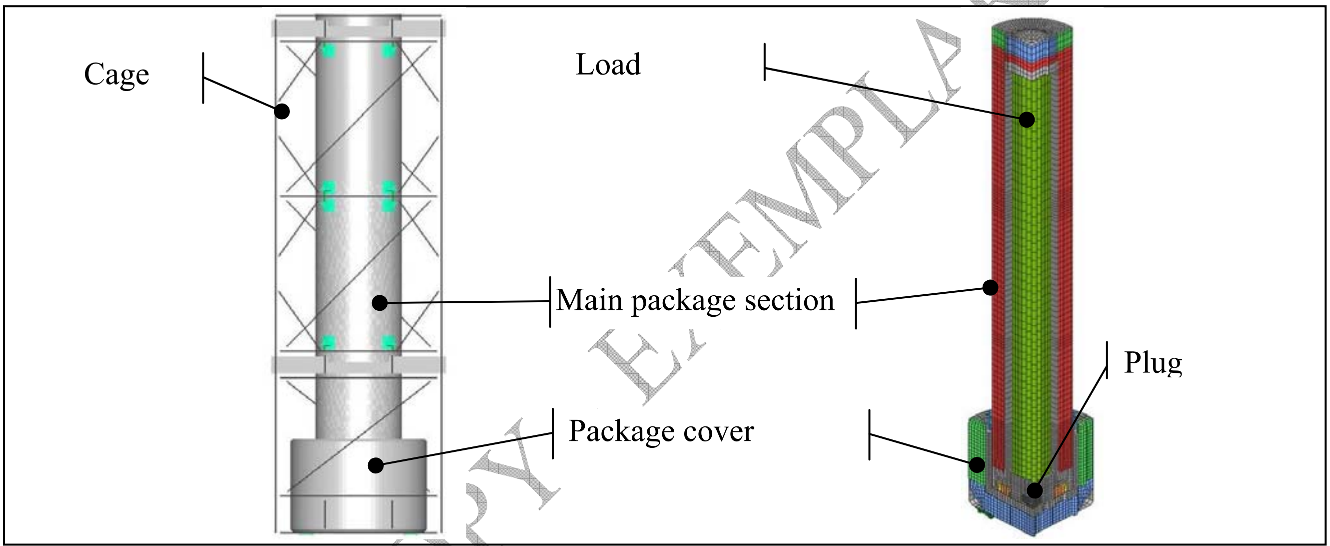


Figure 1 -Sub-assemblies of the model

2.5.2.1. <u>TN BGC1 package cage:</u>

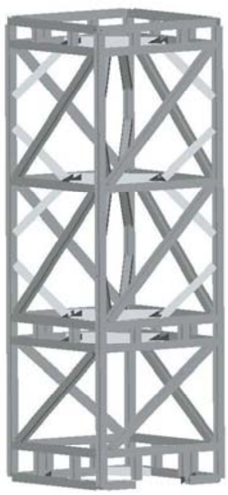


Figure 2 -Modelling of the package cage

Part number	Part name	Property	Number of elements	Size of elements (mean)	Material
3	Structure of the cage	column	2222	20 mm	Aluminium 6082
3f, 3g, 3h	Flat and corner plates	hull	1560	10 - 20 mm	Aluminium 6060

Welds were modelled using rigid elements.

2.5.2.2. <u>Package cover</u>

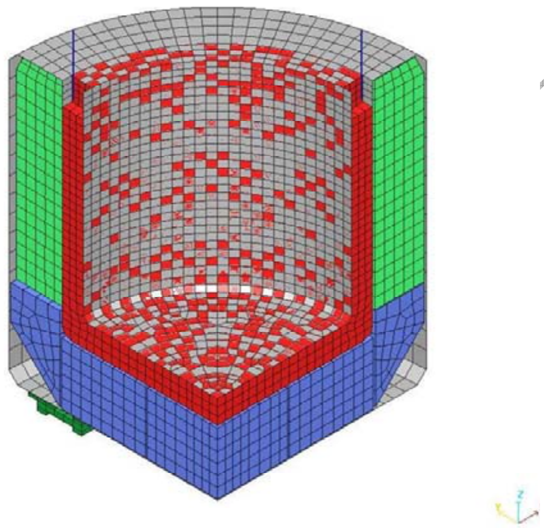


Figure 3 -Modelling of the package cover

Part number	Part name	Property	Number of elements	Size of elements	material
	Base and shell	Hulls (4 mm, 1.5 mm, etc.)	12308	6 - 20 mm	Z2 CN 18.10
4e1	Wood filler (poplar)	Volume	11970	10 mm	Poplar
4e2	Wood filler (balsa)	Volume	7548	6 - 20 mm	Balsa
4j	Resin filler	Volume	12744	6 - 20 mm	Resin
4f	Folding handles	Volume	88	3 - 10	Stainless

				mm	steel 304
	Cover attachments	Spring	4		

The shells and the cover base have been modelled using hulls due to their low thickness (e < 5 mm). Cover attachments are shown as springs.

The resin was modelled in terms of volume with three elements in the thickness. The resin is linked to the shells via common nodes.

Wood/shell and wood/wood clearance has been accounted for.

The direction of wood fibres has been modelled, giving the following radial models for fibres in the central sections of the balsa and the poplar (red arrow):

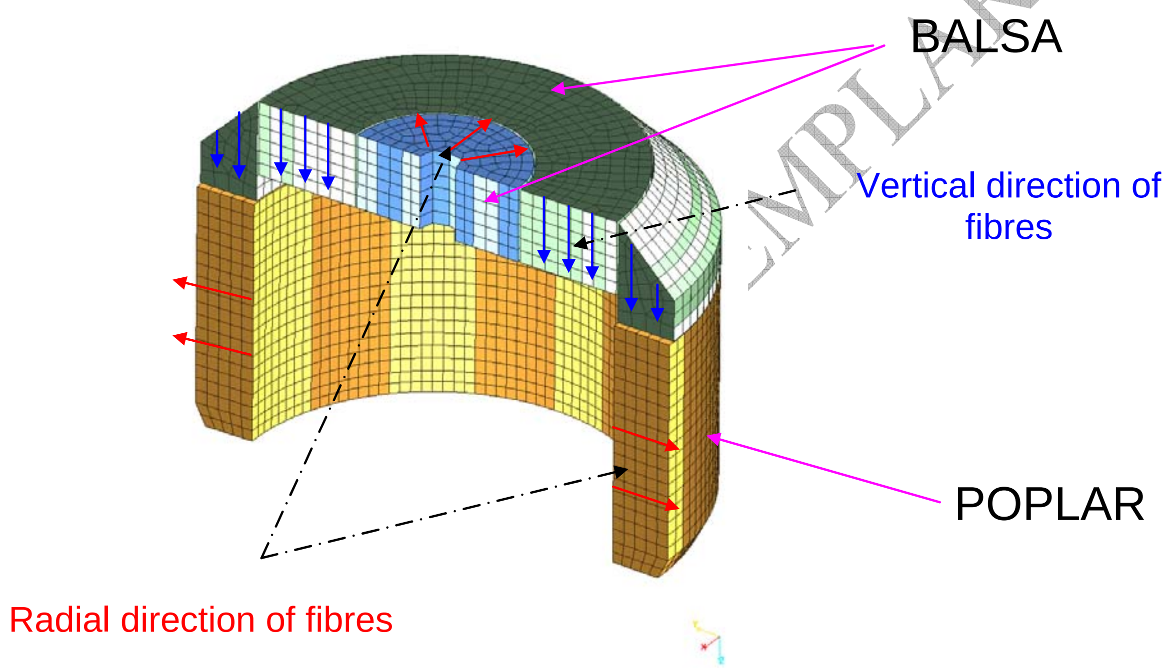


Figure 4 -Modelling of the direction of wood fibres in the package cover

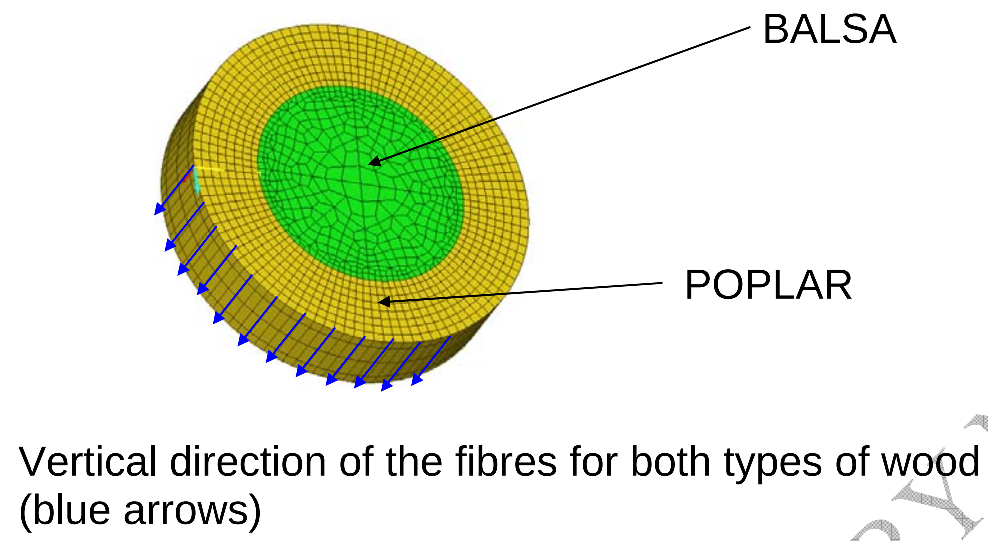


Figure 5 -Modelling of the direction of wood fibres in the package base

2.5.2.3. TN-BGC1 package plug

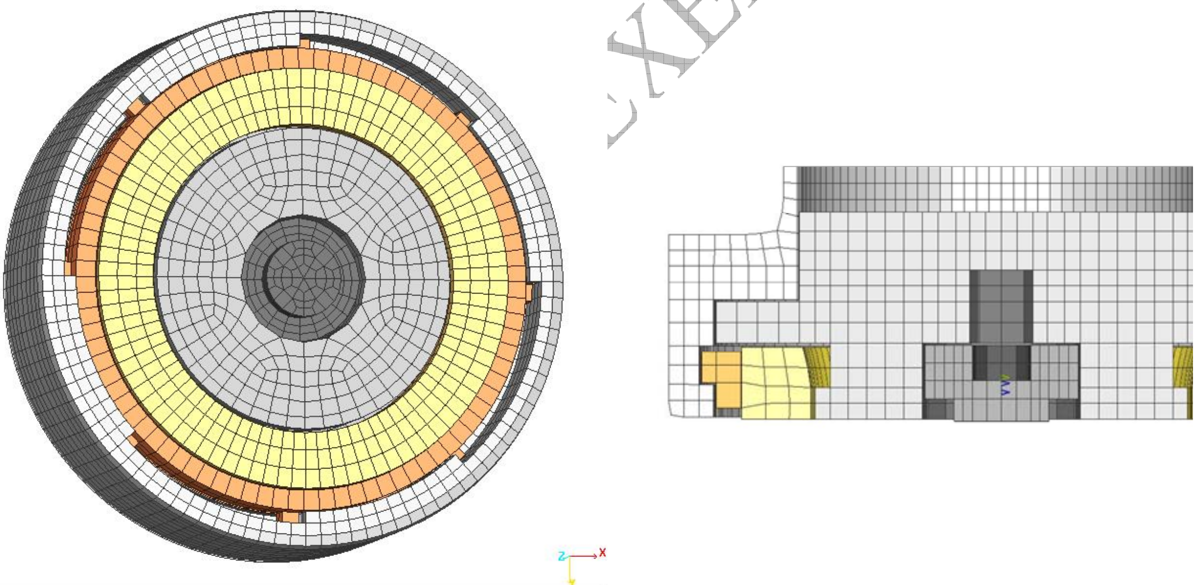


Figure 6 -Modelling of the package plug

Part number	Part name	Property	Number of elements	Size of elements	material
2	Plug	volume	3868	6 - 12 mm	Z2 CN 18.10
5	Bayonet	volume	360	6 - 10 mm	Z2 CN 18.10

	ring				
6	Clamp ring	volume	1056	6 - 10 mm	CuA19Ni5Fe5Y20
7	Staubli plug	volume	328	3 - 8 mm	Z2 CN 18.10
1	Flange	volume	5296	5 - 10 mm	Z2 CN 18.10

Clearance and support between the different parts were modelled. Seals are not shown, but were identified.

2.5.2.4. TN BGC1 main package section

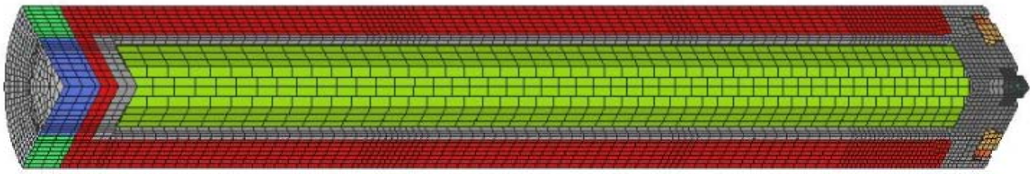


Figure 7 -Modelling of the main package section

Part number	Part name	Property	Number of elements	Size of elements	material
1	Outer shell	Hull	13504	7 - 20 mm	Z2 CN 18.10
	Internal shell (containment) and flange	volume	10800	7 - 20 mm	Z2 CN 18.10
1d	Distribution plate	volume			
1g	Resin filler	volume	74656	7 - 20 mm	Resin
1h1	Wood filler	volume	3328	10 - 20 mm	Poplar
1h2	Wood filler	volume	1840	10 - 25 mm	Balsa
1m	Cage attachment tab	3 mm hull	736	4 - 10 mm	Stainless steel 304
	Load	volume	5200	20 - 30 mm	Fictitious material

Modelling of the distribution plate has been simplified by integrating the component in the internal shell base. This simplification has no impact on the study given the distance from the impact zone.

2.5.2.5. Load

The internal unit and system of spacers are modelled as one single part. Modelling using a cylinder with an equivalent mass and identical contact surface is adequate to validate leaktightness. The material used for the calculation has the same mechanical properties as the steel and a density ensuring that the global mass corresponds to the mass of container TN90 and spacers E1 and E2. Radial clearance between the spacers and the cavity is shown. However, longitudinal clearance (top-bottom) is almost non-existent (<0.001 mm): it may therefore be considered as zero.

2.5.3. Materials

2.5.3.1. Balsa and poplar

Wood is an orthogonal material: this means that mechanical properties depend on the direction of the wood fibre, or the different directions of the glued-laminated layers. Properties are also significantly affected by humidity and temperature. The input data required for the modelling of wood using a honeycomb type law is difficult to find.
The direction of fibres is integrated based on a local marker. The same material is used for all parts in wood, only the direction of the local marker will change.
The direction of the fibre is 1, therefore E11, Young's modulus is in the same direction as the fibre.

- The elastic part is described using the traction and shear modules Eii and Gij. (i.e. 6 values if we consider that the Gij are symmetric).
- The simplified plastic section is described for each stress ij using a graph as shown below:

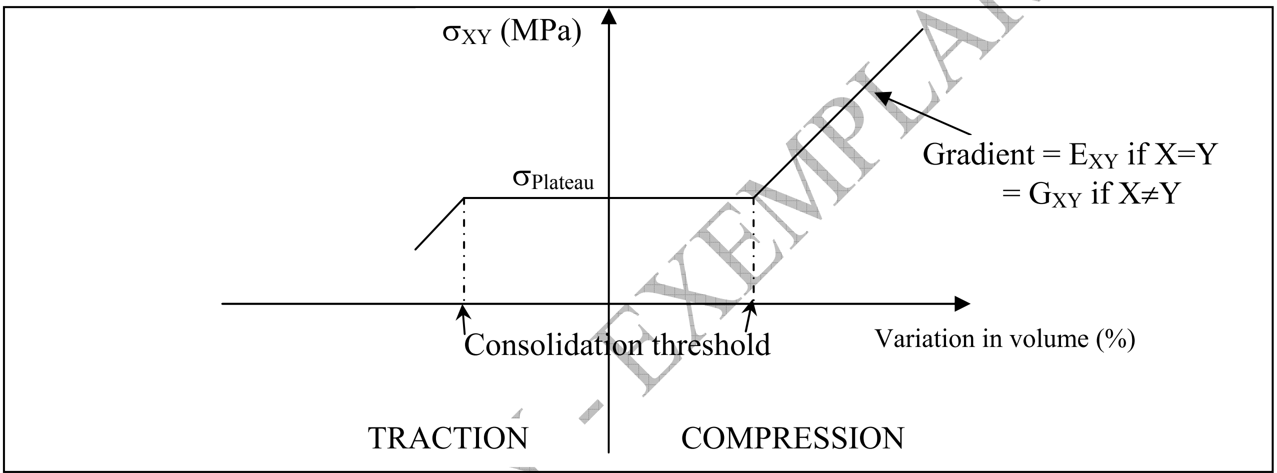


Figure 8 - Stress chart depending on variation in volume

The Plateau is also the elastic limit. Stresses are considered as constant (ideal plastic properties): Plateau is also the plastic stress value.
It is assumed that traction and compression properties are identical (and for other stress directions). Wood hardens from a certain extent of crushing: when the consolidation threshold is reached. The gradient was equal to that of the corresponding Young's modulus by default.

The compression consolidation threshold is crushing of over 60% for balsa and of over 45% for poplar.The values of wood properties based on temperature have been specified based on results obtained in compression testing carried out by the CEA (cf. data [1.4]).

type de bois		PEUPLIER						BALSA					
Température		20°C			-40°C			20°C			-40°C		
origines des donnees		Etude initiale [1.2]	CEA_DOC [1.4]	Valeurs Etude	Etude initiale [1.2]	CEA_DOC [1.4]	Valeurs Etude	Etude initiale [1.2]	CEA_DOC [1.4]	Valeurs Etude	Etude initiale [1.2]	CEA_DOC [1.4]	Valeurs Etude
Densité (kg / m³)		390	425	**360**	390	416	**360**	150	108,3	**110**	150	109,3	**110**
Partie Elastique	E_{11} (en MPa)	3500,00	3693,00	**3500,00**	3500,00	4397,00	**4167,21**	2300,00	600,00	**2300,00**	2300,00	650,00	**2491,67**
	E_{22} (en MPa)	350,00	242,00	**350,00**	350,00	300,00	**433,88**	460,00	23,00	**460,00**	460,00	24,00	**480,00**
	E_{33} (en MPa)	350,00	242,00	**350,00**	350,00	300,00	**433,88**	460,00	23,00	**460,00**	460,00	24,00	**480,00**
	G_{12} (en MPa)	700,00	738,60	**700,00**	700,00	879,40	**833,44**	120,00	31,30	**120,00**	120,00	33,91	**130,00**
	G_{23} (en MPa)	140,00	147,72	**140,00**	140,00	175,88	**166,69**	120,00	31,30	**120,00**	120,00	33,91	**130,00**
	G_{31} (en MPa)	700,00	738,60	**700,00**	700,00	879,40	**833,44**	120,00	31,30	**120,00**	120,00	33,91	**130,00**
Partie Plastique	σ_{11} (plateau) (en MPa)	35,00	43,90	**35,00**	70,00	57,30	**45,68**	12,00	8,80	**8,80**	13,30	10,50	**10,50**
	σ_{22}(plateau) (en MPa)	3,50	4,30	**3,50**	14,00	6,20	**5,05**	2,40	0,48	**0,48**	2,80	0,65	**0,65**
	σ_{33}(plateau) (en MPa)	3,50	4,30	**3,50**	14,00	6,20	**5,05**	2,40	0,48	**0,48**	2,80	0,65	**0,65**
	σ_{12}(plateau) (en MPa)	8,00	NC	**8,00**	25,20	NC	**10,44**	3,00	NC	**2,01**	4,20	NC	**2,40**
	σ_{23}(plateau) (en MPa)	5,00	NC	**5,00**	14,00	NC	**6,53**	0,60	NC	**1,26**	0,84	NC	**1,50**
	σ_{31}(plateau) (en MPa)	8,00	NC	**8,00**	25,20	NC	**10,44**	3,00	NC	**2,01**	4,20	NC	**2,40**
	Seuil de consolidation (%)	45,00	NC	**45,00**	45,00	NC	**45,00**	60,00	NC	**60,00**	60,00	NC	**60,00**

type de bois	wood type
PEUPLIER	POPLAR
BALSA	BALSA
Température	Temperature
Origines des données	Source of data
Etude initiale	Initial study
CEA_DOC	CEA_DOC
Valeurs Etude	Study values
Densité (kg / m³)	Density (kg / m³)
Partie Elastique	Elastic part
Partie Plastique	Plastic part
E11 (en MPa)	E11 (in MPa)
E22 (en MPa)	E22 (in MPa)
E 33 (en MPa)	E 33 (in MPa)
G12 (en MPa)	G12 (in MPa)
G23 (en MPa)	G23 (in MPa)
G31 (en MPa)	G31 (in MPa)
Ó 11 (plateau) (en MPa)	Ó 11 (plateau) (in MPa)
Ó 22 (plateau) (en MPa)	Ó 22 (plateau) (in MPa)
Ó 33 (plateau) (en MPa)	Ó 33 (plateau) (in MPa)
Ó 12 (plateau) (en MPa)	Ó 12 (plateau) (in MPa)
Ó 23 (plateau) (en MPa)	Ó 23 (plateau) (in MPa)
Ó 31 (plateau) (en MPa)	Ó 31 (plateau) (in MPa)
Seuil de consolidation (%)	Consolidation threshold (%)

Should testing not have been conducted, data at traditional ambient temperature (20°C) can be found fairly easily in texts for the main wood species, i.e. generally:

- density with humidity of 12%,
- the Young's modulus longitudinally (E11),
- the Young's modulus transversally (E22 or E33),
- an elastic limit or a Plateau longitudinally (11),
- an elastic limit or a Plateau transversally (22 or 33),

I.e. a total of 5 values. However, at least 14 parameters must be selected for the law applied (cf. 1 column in the above table). In the context of the note [1.2], missing values were calculated based on a minor bibliographical analysis and the following assumptions were made:

- for poplar:
  - E22=E33=E11/10,
  - G12=G21=G31=G13=E11/5,
  - G23=G32=G12/5,
  - σ22=σ33=σ11/10,
  - σ12=σ21=σ31=σ13=σ11/4,
  - σ23=σ32=σ11/7,
  - Density and maximum yield in compression were indicated in the safety file for the initial DGD,
- for balsa:
  - E22=E33=E11/5,
  - G12=G21=G31=G13=G23=G32=E11/5,
  - σ22=σ33=σ11/5,
  - σ12=σ21=σ31=σ13=σ11/4,
  - σ23=σ32=σ12/5,
  - Density and maximum yield in compression were indicated in the safety file for the reference DGD G03CAL009B-5-Ind 1.0.

The influence of temperature on these materials is difficult to find in texts. CEA note [1.4] indicates trends for changes in density for E11, 11 and 22 or 33 between 20°C and -40°C and between 20°C and +80°C. It was not possible to determine change gradients in MPa / degrees Celsius for these parameters. However, testing of specimens did not enable other values to be determined for the law. The ratios used in study [1.2] were therefore applied between each variable.

2.5.3.2. Aluminium 6082 and 6060:

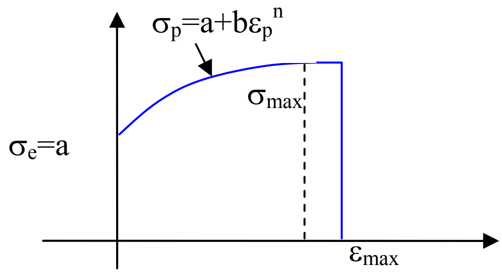
The general mechanical properties of aluminium 6082 and 6060 are as follows:

Young's modulus = 70,000 MPa
Poisson's ratio = 0.33
Density = 0.0027 g/mm3

The plastic section of aluminium is defined by a Johnson-Cook's law as follows:

$_p=a+b\varepsilon_p^n$

Where a = 260
b = 158
n = 0,5
where σ_{max} = 310
ε_{max} = 10%



2.5.3.3. Z2Cn18-10 or 304L or X2CrNi1911 or 1.4306

The general mechanical properties of Z2C18-10 are:

Young's modulus = 200,000 MPa
Poisson's ratio = 0.29
Density = 0.0079 g/mm3

This steel is defined by a Johnson-Cook's law as follows:
$\sigma_p = a + b\varepsilon_p^n$
Where a = 220
b = 448
n = 0,5
where σ_{max} = 520
ε_{max} = 45%

2.5.3.4. Cu A19Ni5Fe5Y20: Bronze

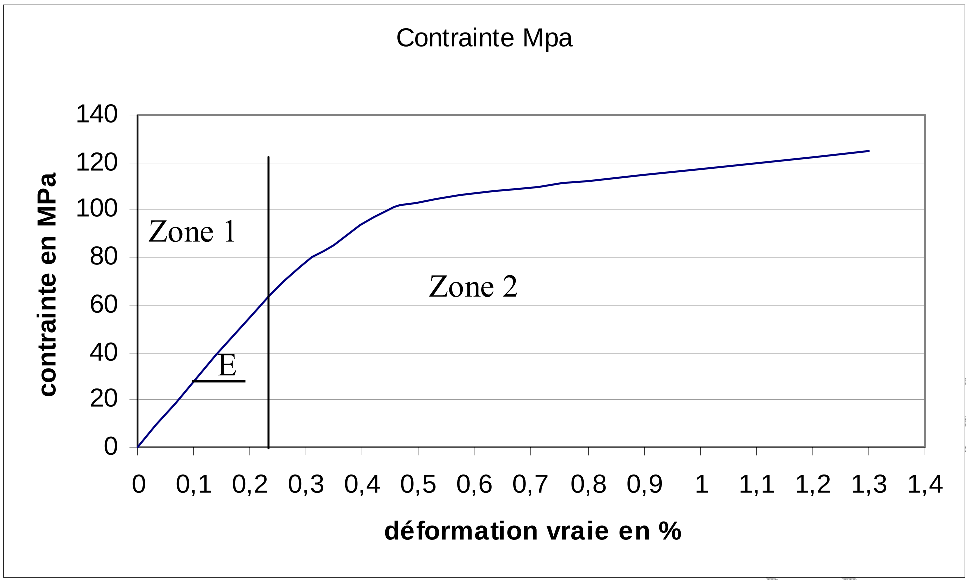
The general mechanical properties of bronze are:

Young's modulus = 115,000 MPa
Poisson's ratio = 0.33
Density = 0.0076 g/mm3

This material is defined by a Johnson-Cook's law as follows:
$\sigma_p = a + b\varepsilon_p^n$
Where a = 250
b = 1107
n = 0.5

2.5.3.5. Resin

Young's modulus:
26 000 MPa Poisson's ratio: 0.33
Density: 0.0016 g/mm^3
Resin is defined by a user-type law based on the specimen traction test chart:



Contrainte Mpa Contrainte en Mpa Zone 1 Zone 2 Déformation vraie en %	Stress MPa Stress in MPa Zone 1 Zone 2 Actual deformation in %

The elastic part (1) is described by the Young's modulus and the plastic part (2) is described by the chart in zone 2.

2.5.4. Contact management

Contacts are managed via a digital RADIOSS tool known as an interface. Several types of interfaces exist depending on the type of contact between the parts. "Adhesive" interfaces force the parts in contact to move in an identical manner. General interfaces prevent two parts from interlinking during impact. Repulsion, proportional to the rigidity of the parts, is generated by contact surfaces from a minimum gap between the two parts.

2.5.4.1. Using kinematic adhesive interfaces

The only parts concerned by this modelling are the main section and the attachment tabs.

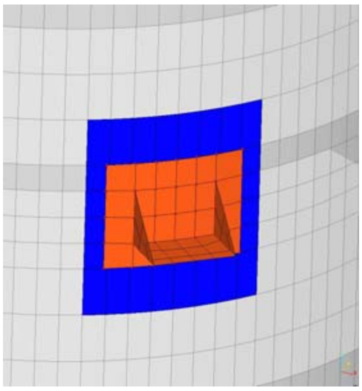


Figure 9 -Kinematic adhesive interface

2.5.4.2. Using contact interfaces

In our studies, these interfaces are used to manage contact between parts in the package liable to move on impact.
This type of modelling also enables the identification of forces on surfaces in contact. It can be used, for example, between the bayonet ring and the main section flange, or between the floor and the package.

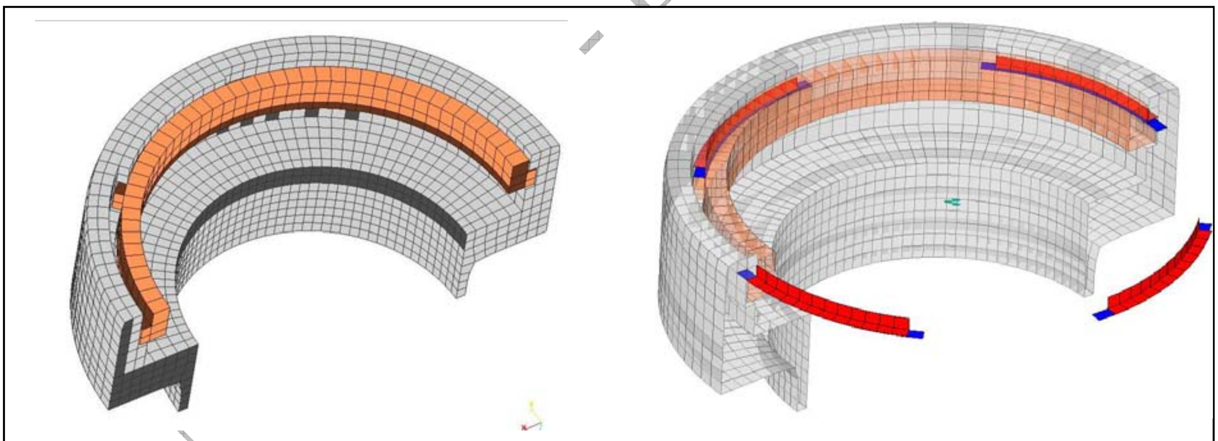


Figure 10 -Contact management interface

2.5.5. Modelling of pre-stresses in plugs

Modelling accounts for pre-stresses due to cover grips and the Staubli plug. Clamp spring stiffnesses do not represent the reality as we have no data on stiffness for clamp ring screw pitches.

In all cases, the following stiffnesses were identified for springs modelling the staubli and clamp ring threads:

- Stiffness with compression-traction: 5 N/mm, i.e. 10 tons managed per mm stretched.(F=Kx),

- Stiffness with shear: 10^5 N/mm ,
- Stiffness with twisting Rt: ^{6} Nmm/rad Mt=$GI_O\theta$ (θ in rad/m) and Mt=Rt x (rotation of node 2 – rotation of node 1), i.e. Rt=GIO/radius of the screw,
- Stiffness with bending Rf: 10^6 Nmm/rad Mf=EIGZ y ‘’ (y’’ rad/m) in the same way Rf= EIGZ/Lu.

These stiffnesses were measured conservatively as the actual stiffnesses of these two parts were unknown (traction testing would be required or an analytical calculation to estimate thread resistance). These stiffnesses are underestimated and detachment is therefore overestimated. To give an example, a steel screw with a diameter of 10mm gripping a part with a height of 10mm has a stiffness K=ES/Lu where E = Young's modulus, S = screw section and Lu = clamped or working length.
K= 210 000 x PIx10²/4/10= 16.5 10 5N/mm
Rotation stiffness for the same screw:
Twisting GI0 where G = Shear module =E/2(1+μ), μ = Poisson's ratio = 0.3 and I0 = quadratic twisting moment = ΠxD4/32,
Rt= 15.9 10^6 Nmm/rad,
EIG bending Z = where E = Young's modulus and IGZ = quadratique twisting moment = PIxD4/64,
Rt= 10.3 1066 Nmm/rad,

Not only is the diameter of the clamp ring far larger, but the possibility for the ring to rotate in the closing system is much lower as compared with a screwed assembly.

2.5.5.1. Pre-stresses in the cover

A rigid element links all of the nodes of the clamp ring threads. Another rigid element links all of the nodes of the bayonet ring threads. A compressed spring is placed between these two rigid elements. This spring will attempt to return to its rest position, i.e. extend. It pushes the bayonet ring against the flange and the clamp ring against the plug. This modelling may be used thanks to the symmetry of the main section and cover.

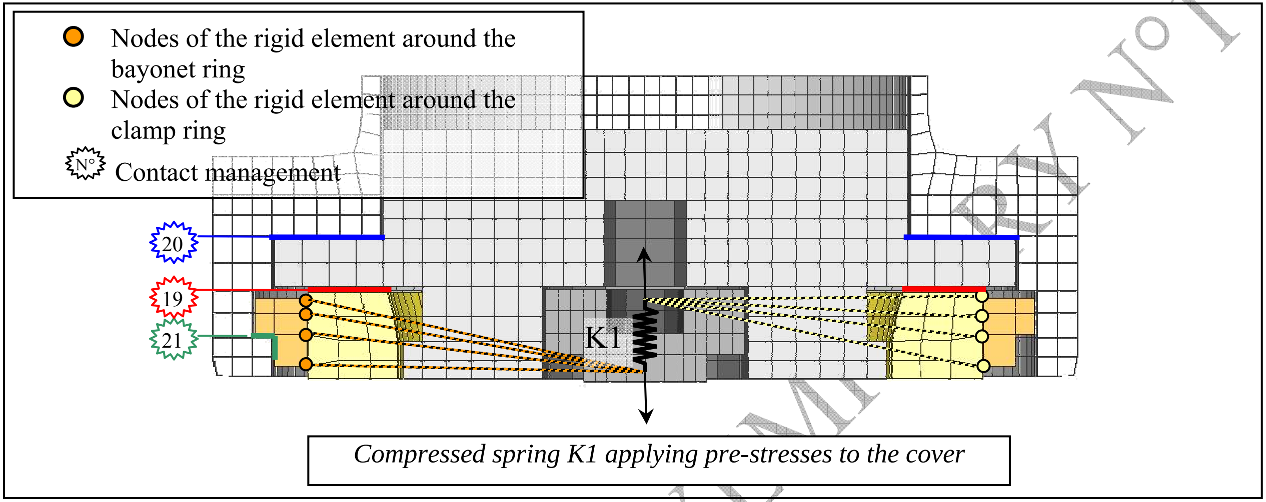


Figure 11 -Modelling of pre-stresses in the cover

Spring K1 is defined as follows:

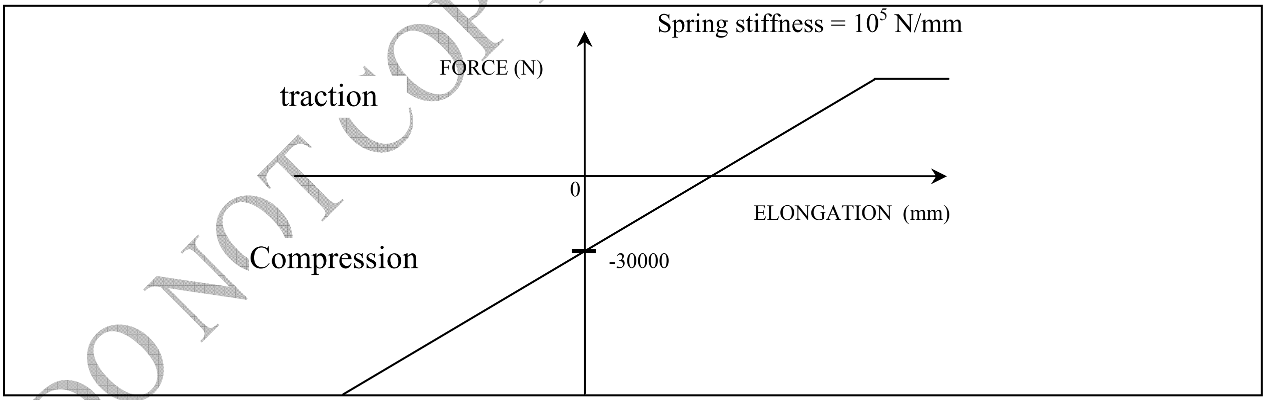


Figure 12 -Cover pre-stresses definition chart for spring K1

The first part of the calculation involves loading the plug and waiting until the spring force balances the forces on the contact surfaces. Oscillations are controlled by a damper.

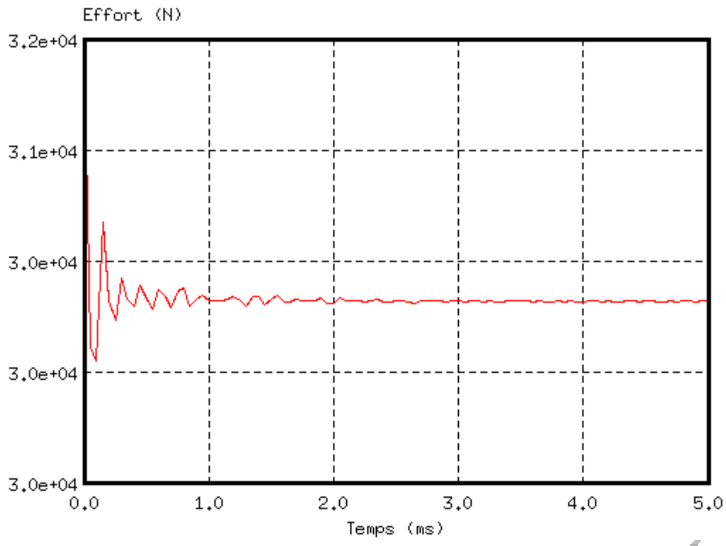


Figure 13 - Force in spring K1 over time

It must then be checked that forces are correctly distributed over the different contact surfaces. The following interfaces are affected by the loading of the cover:

- the interface between the main section flange and the bayonet ring (interface 21),
- the interface between the clamp flange and the plug (interface 20),
- the interface between the plug and the main section (interface 19),

The forces applied by the spring are also transmitted to these interfaces, therefore the pre-stressing of 30 kN is transferred between the plug and the main section.

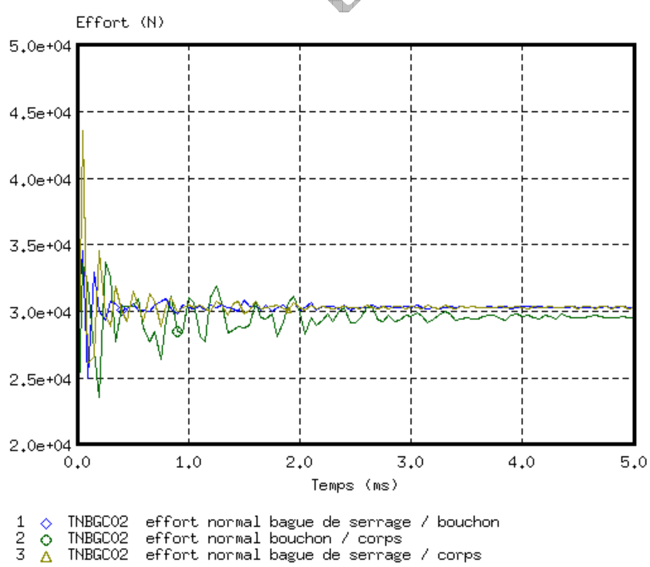


Figure 14 -Forces on interfaces 19, 20 and 21 due to pre-stressing in the plug

Effort (N) Temps (ms)	Forces (N) Time (ms)
Effort (N) effort normal bague de serrage/bouchon effort normal bouchon/corps effort normal bague de serrage/corps	Forces (N) plug/clamp ring normal stress main section/plug normal stress main section/clamp ring normal stress

2.5.5.2. Pre-stresses in the Staubli plug

In the same way as for the pre-stressing in the cover, the pre-stressing of the Staubli plug is modelled using two rigid elements and a spring. One of the rigid elements links the nodes of the Staubli plug threaded surface. The second rigid elements links the nodes of the plug threaded surface. A compressed spring links the two nodes for the rigid elements.
Torque of 50 Nm is applied and minimum pre-stresses for the total surface area is 3520N.

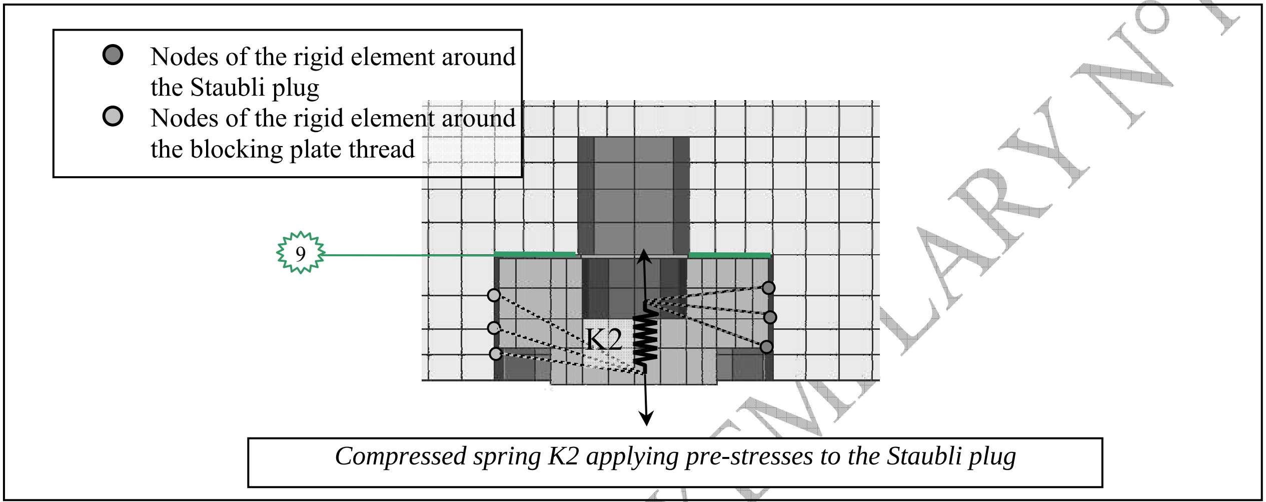


Figure 15 -Modelling of pre-stresses in the Staubli plug

Spring K2 is defined as follows:

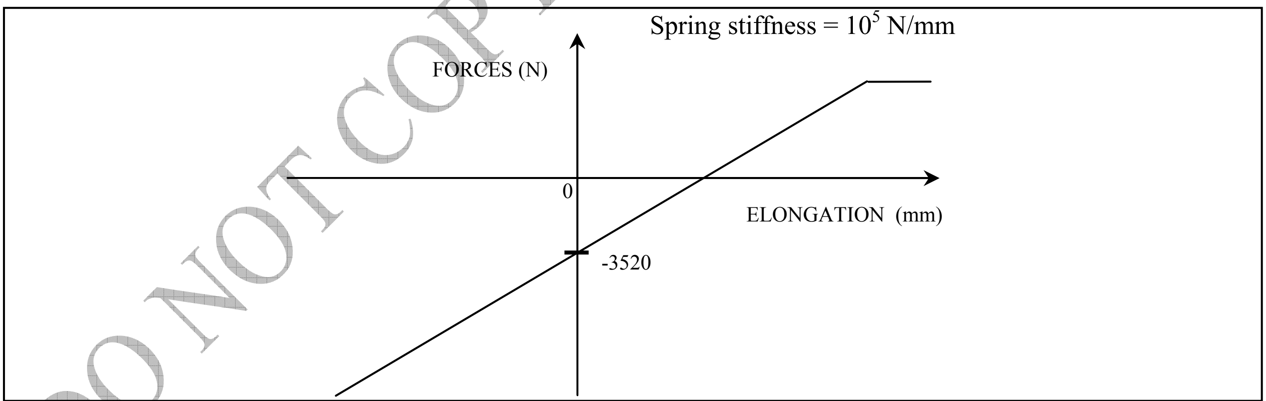


Figure 16 -Cover pre-stresses definition chart for spring K2

The first part of the calculation involves loading the plug and waiting until the forces balance.

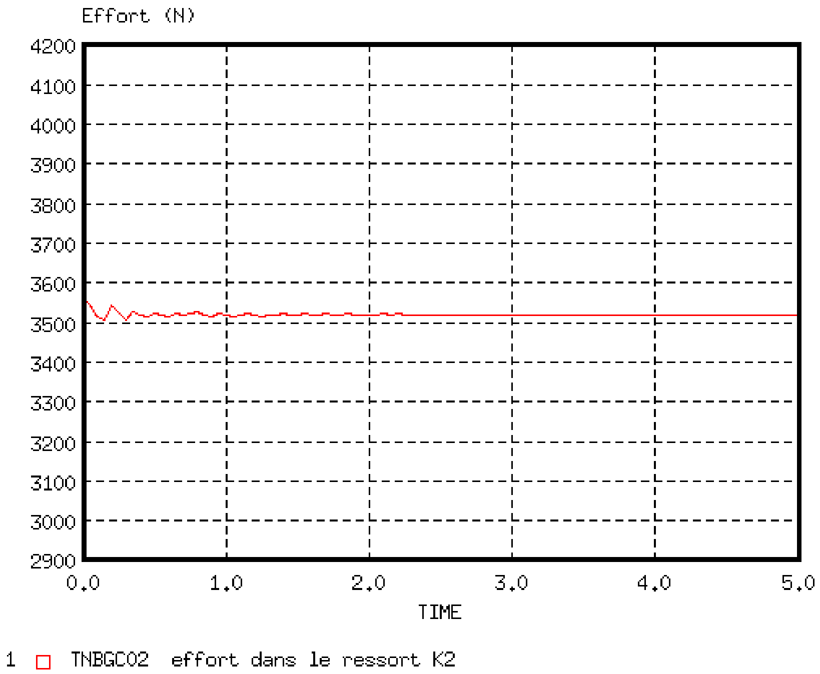


Figure 17 - Force in spring K2 over time

In the same way, the forces applied by the spring are integrally transmitted to the interface (9).

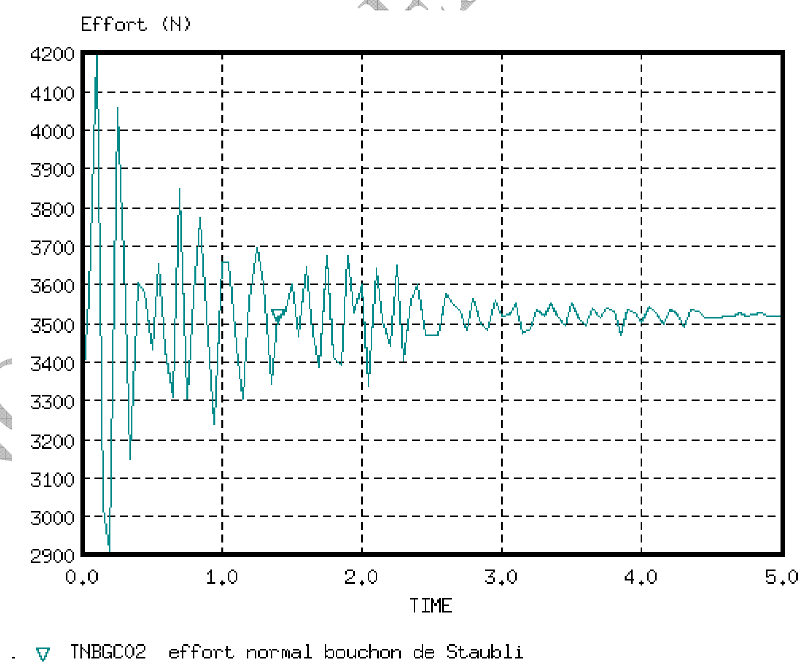


Figure 18 -Forces in interface 9 due to the pre-stressing of the Staubli plug

Effort (N) effort dans le ressort K2 Effort (N) effort normal bouchon de Staubli	Forces (N) forces in spring K2 Forces (N) normal force in Staubli plug

2.5.6. Modelling of attachments

2.5.6.1. <u>Attachment screws for cage tabs</u>

The attachment screws of cage attachment tabs are modelled with 1055 N/mm stiffness springs for degrees of freedom for stresses and 108Nmm/rad for degrees of freedom for moments.

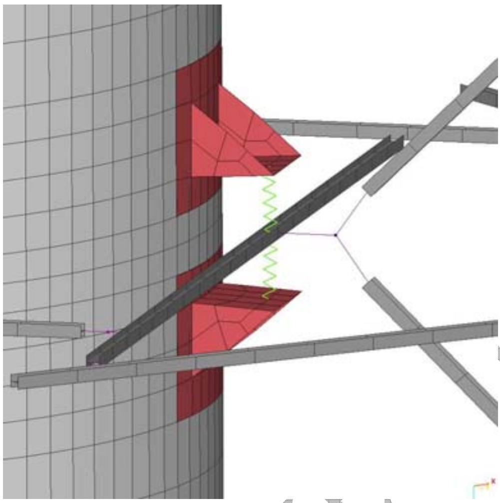


Figure 19 -Modelling of the cage attachment tab liaison

2.5.6.2. <u>Cover/main section attachments</u>

Cover attachments are modelled as springs (identical to 2.5.6.1), which are connected to the main section and the cover using rigid elements. Stress levels at 20°C and at -40°C are compared to determine the resistance of these attachments.

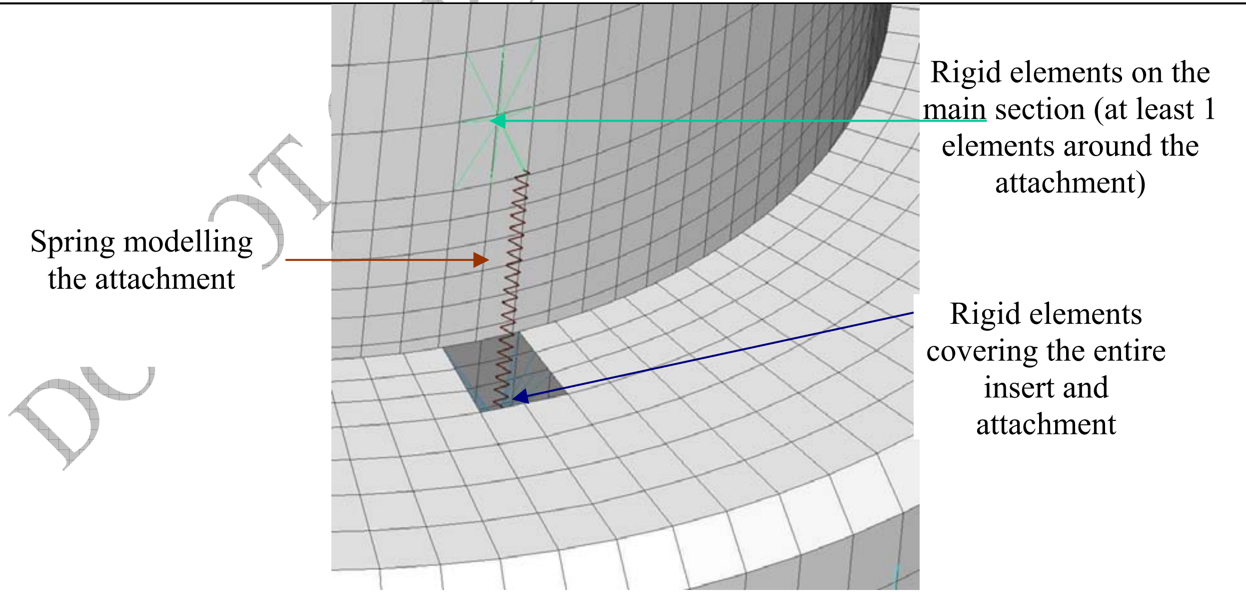


Figure 20 -Modelling of the cover attachments on the main package section

Mass report

	Mass
Cage (structure, corner plates, attachment tabs)	31.6 kg
Cover	40.3 kg
Load	116.1 kg
Plug	27.1 kg
Main package section	183 kg
Total mass	**398.1 kg**

An impact speed of 13.28m/s was obtained for a fall of 9.00 m and an energy of 35.1 kJ.

3. Modelling results

3.1. Fall configuration

3.1.1. Determination of the critical fall position

The TN-BGC 1 package is fitted with a TN90-type unit and a blocking system. The theoretical height of the fall is 9m (between the lowest point of the package and the floor). We applied 4 iterations by varying the fall angle by 10° to determine the most detrimental case.

We noted deceleration and the level of compression of the seal per zone for each fall configuration.

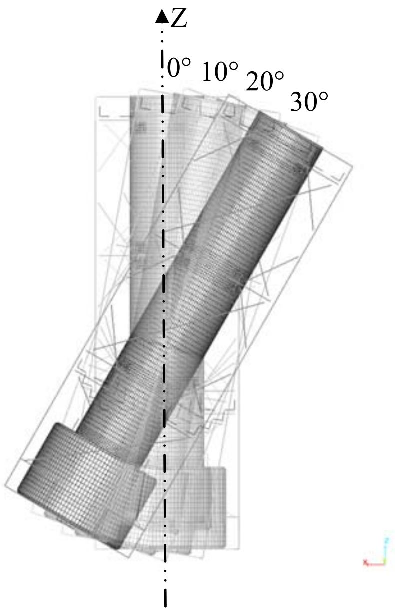


Figure 21 -Fall angles

The level of compression was measured in 4 zones of the seal (cf. figure below): measurements were taken at 3 points in each zone.

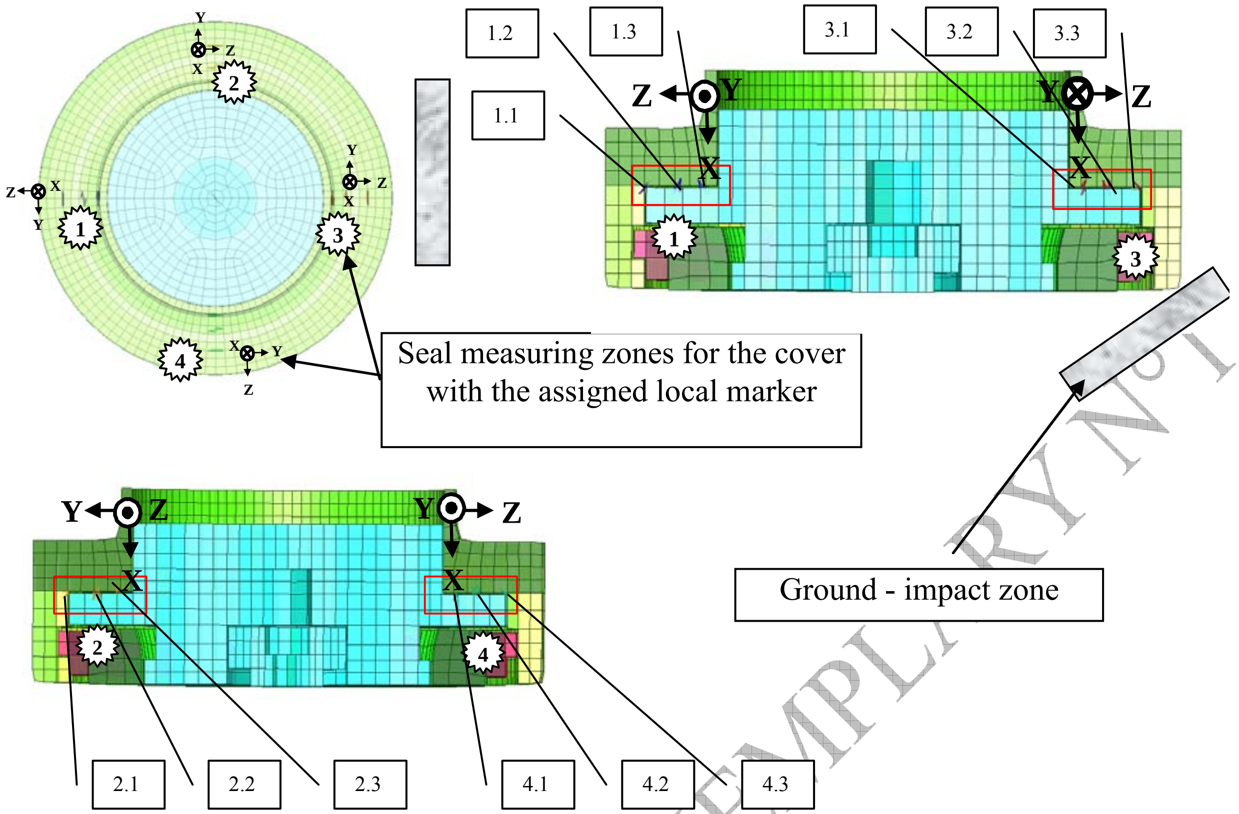


Figure 22 -View of the closing system with seal measurement zones

The following results show residual compression obtained for all fall angles:

Temperature ambiante (°C)	20	20	20	20
angle-chute par rapport l'axe Z (°)	0	10	20	30
taux de compression residuel - zone4-3	27,6%	27,8%	27,6%	27,6%
taux de compression residuel - zone4-2	27,5%	27,5%	27,5%	27,5%
taux de compression residuel - zone4-1	27,5%	27,4%	27,6%	27,5%
taux de compression residuel - zone3-3	27,6%	29,3%	27,4%	27,7%
taux de compression residuel - zone3-2	27,5%	27,9%	27,7%	27,6%
taux de compression residuel - zone3-1	27,5%	27,3%	27,9%	27,4%
taux de compression residuel - zone1-1	27,5%	27,7%	27,7%	27,6%
taux de compression residuel - zone1-2	27,5%	27,5%	27,5%	27,5%
taux de compression residuel - zone1-3	27,5%	27,5%	27,4%	27,5%
taux de compression residuel - zone2-3	27,5%	27,3%	27,4%	27,5%
taux de compression residuel - zone2-1	27,6%	27,9%	27,5%	27,6%
taux de compression residuel - zone2-2	27,5%	27,5%	27,4%	27,5%
taux de compression residuel - mini	27,5%	27,3%	27,4%	27,4%

Figure 23 -Residual compression in the seal determined in the test plan

Température ambiante	Ambient temperature
angle-chute par rapport l'axe Z (°)	fall angle from the z axis (°)
taux de compression residuel - zone 4-3	level of residual compression - zone 4-3
taux de compression residuel - zone 4-2	level of residual compression - zone 4-2
taux de compression residuel - zone 4-1	level of residual compression - zone 4-1
taux de compression residuel - zone 3-3	level of residual compression - zone 3-3
taux de compression residuel - zone 3-2	level of residual compression - zone 3-2
taux de compression residuel - zone 3-1	level of residual compression - zone 3-1
taux de compression residuel - zone 1-1	level of residual compression - zone 1-1
taux de compression residuel - zone 1-2	level of residual compression - zone 1-2
taux de compression residuel - zone 1-3	level of residual compression - zone 1-3
taux de compression residuel - zone 2-3	level of residual compression - zone 2-3
taux de compression residuel - zone 2-1	level of residual compression - zone 2-1
taux de compression residuel - zone 2-2	level of residual compression - zone 2-2
taux de compression residuel - mini	level of residual compression - min.

The above table shows that sealing is maintained at the end of the fall for all fall angles.

The following table indicates minimum dynamic compression for the seal during the fall:

Temperature ambiante (°C)	20	20	20	20
angle-chute par rapport l'axe Z (°)	0	10	20	30
taux de compression du joint d'etanchéité_zone4-3	22,9%	21,3%	23,2%	24,5%
taux de compression du joint d'etanchéité_zone4-2	22,1%	21,2%	23,0%	24,4%
taux de compression du joint d'etanchéité_zone4-1	21,8%	21,2%	23,0%	24,3%
taux de compression du joint d'etanchéité_zone3-3	22,8%	18,3%	20,5%	23,0%
taux de compression du joint d'etanchéité_zone3-2	22,0%	18,7%	20,8%	23,2%
taux de compression du joint d'etanchéité_zone3-1	21,8%	18,9%	20,9%	23,4%
taux de compression du joint d'etanchéité_zone1-1	22,7%	20,3%	24,0%	21,9%
taux de compression du joint d'etanchéité_zone1-2	21,9%	20,8%	24,1%	22,3%
taux de compression du joint d'etanchéité_zone1-3	21,8%	20,9%	24,1%	22,4%
taux de compression du joint d'etanchéité_zone2-3	21,7%	21,2%	22,5%	24,2%
taux de compression du joint d'etanchéité_zone2-1	22,8%	21,3%	22,6%	23,9%
taux de compression du joint d'etanchéité_zone2-2	21,9%	21,2%	22,5%	24,1%
taux de compression dynamique(minimum)	21,7%	18,3%	20,5%	21,9%
taux de compression dynamique moyen	22,2%	20,4%	22,6%	23,5%

Figure 24 -Residual compression in the seal determined in the test plan

Température ambiante	Ambient temperature
angle-chute par rapport l'axe Z (°)	fall angle from the z axis (°)
taux de compression du joint - zone 4-3	level of seal compression - zone 4-3
taux de compression du joint - zone 4-2	level of seal compression - zone 4-2
taux de compression du joint - zone 4-1	level of seal compression - zone 4-1
taux de compression du joint - zone 3-3	level of seal compression - zone 3-3
taux de compression du joint - zone 3-2	level of seal compression - zone 3-2
taux de compression du joint - zone 3-1	level of seal compression - zone 3-1

taux de compression du joint - zone 1-1	level of seal compression - zone 1-1
taux de compression du joint - zone 1-2	level of seal compression - zone 1-2
taux de compression du joint - zone 1-3	level of seal compression - zone 1-3
taux de compression du joint - zone 2-3	level of seal compression - zone 2-3
taux de compression du joint - zone 2-1	level of seal compression - zone 2-1
taux de compression du joint - zone 2-2	level of seal compression - zone 2-2
taux de compression dynamique (minimum)	level of dynamic compression (min.)
taux de compression dynamique moyen	level of mean dynamic compression

The above table demonstrates that the level of compression of the seal remains in excess of 15%: sealing is therefore guaranteed for all oblique falls. The most detrimental configuration in terms of detachment would appear to be a fall at an angle of 10° from vertical. We note that the zone of the plug most subject to stresses is located on the side of the impact.

We propose the future study of falls at an angle of 10° and an ambient temperature of -40°C, which could downgrade results.

3.1.2. Global mass of the system

The global mass of the package and its load is theoretically 396 kg.

3.1.3. Impact speed and energy

The principle of the conservation of mechanical energy applies as follows between the point where the package is dropped (no initial speed) and the point of impact:

$$\frac{1}{2}m{v_f}^2 = mgh_i$$

I.e.

Where m is the mass of the loaded package, vf the speed at impact and hi the fall height.

Impact energy represents Echoc=mghi

3.1.4. The most detrimental configuration

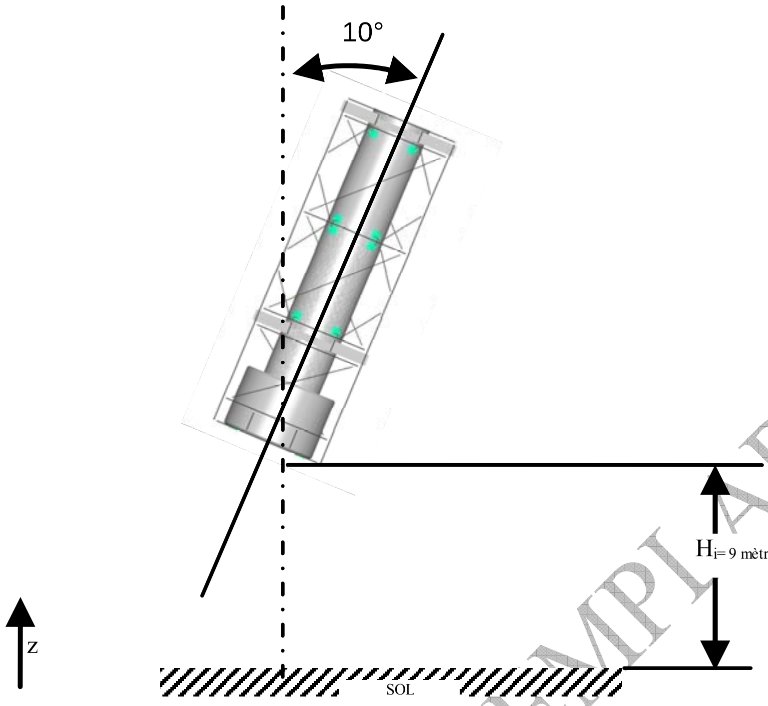


Figure 25 -Most detrimental fall configuration - oblique fall at an angle of 10° from vertical

3.2. Configuration N°1: fall at an angle of 10 degrees and an ambient temperature of 20°C

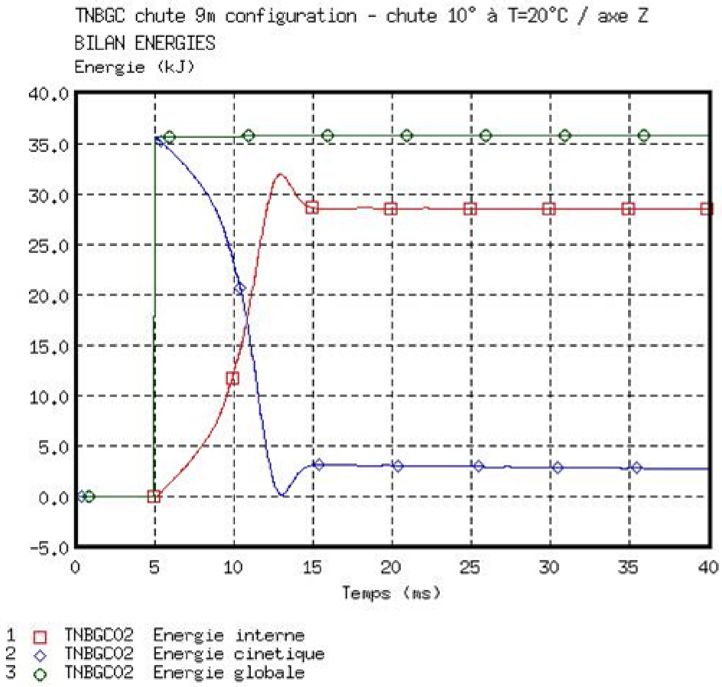
3.2.1. Energy report

The first 5 milliseconds are used to prestress the plugs. The package is then "dropped" and gravity applied.

The global energy of the system is maintained during the calculation. This energy is equal to 35.1 kJ.

The initial kinetic energy is transformed into absorbed energy and kinetic rebound energy. The rebound acts when kinetic energy cancels out at 13 ms from the start of the simulation (including prestressing of the plugs).

Maximum internal energy is 31.96 kJ.



TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z BILAN ENERGIES Energy (kJ) Temps (ms) Energie interne Energie cinetique Energie globale	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis ENERGY REPORT Energy (kJ) Time (ms) Internal energy Kinetic energy Global energy

Figure 26 -Global report on fall energies

3.2.2. *Changes to global deformation over time*

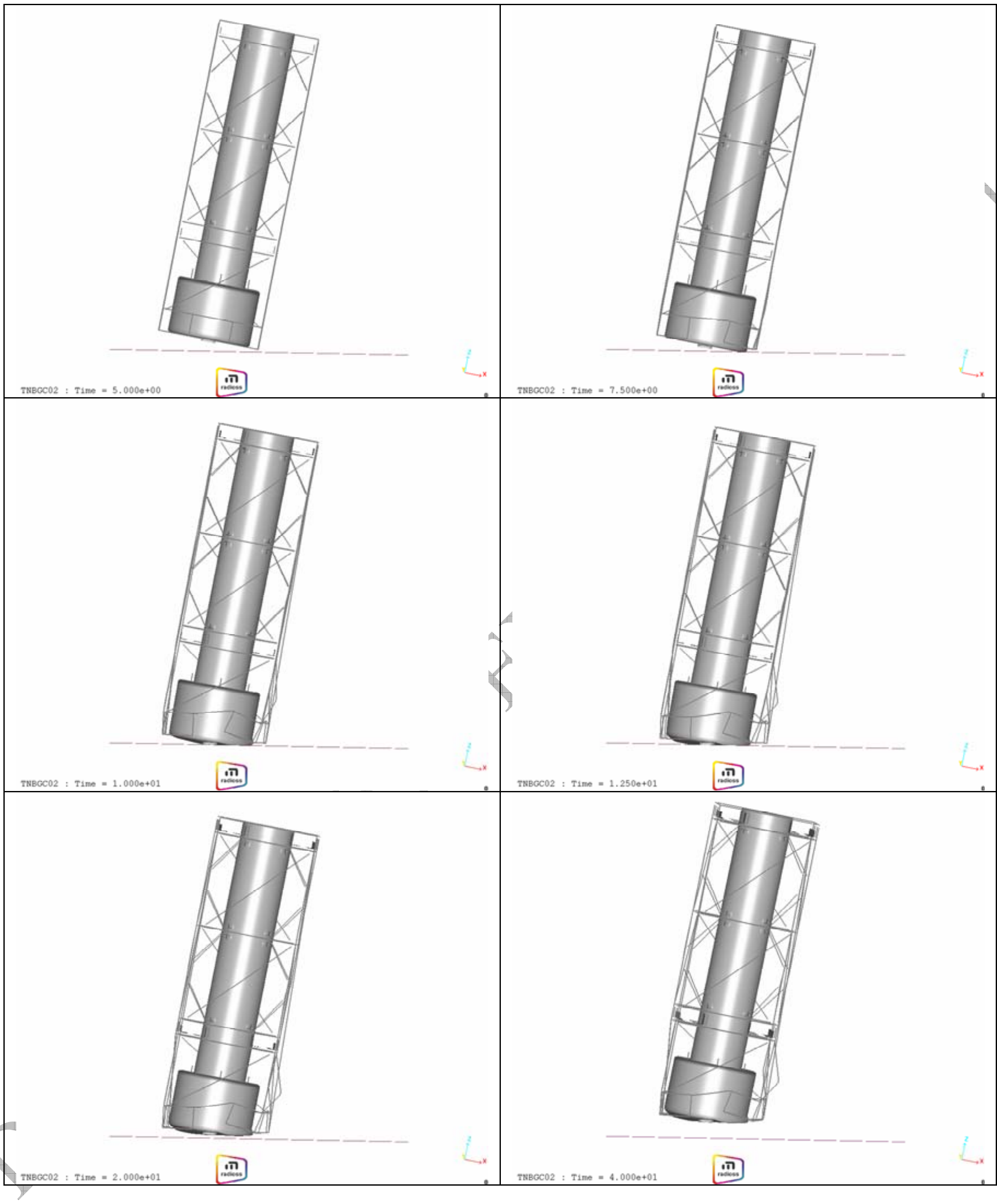


Figure 27 -Global deformation of package TN-BGC 1 from 0 to 40ms at 20°C

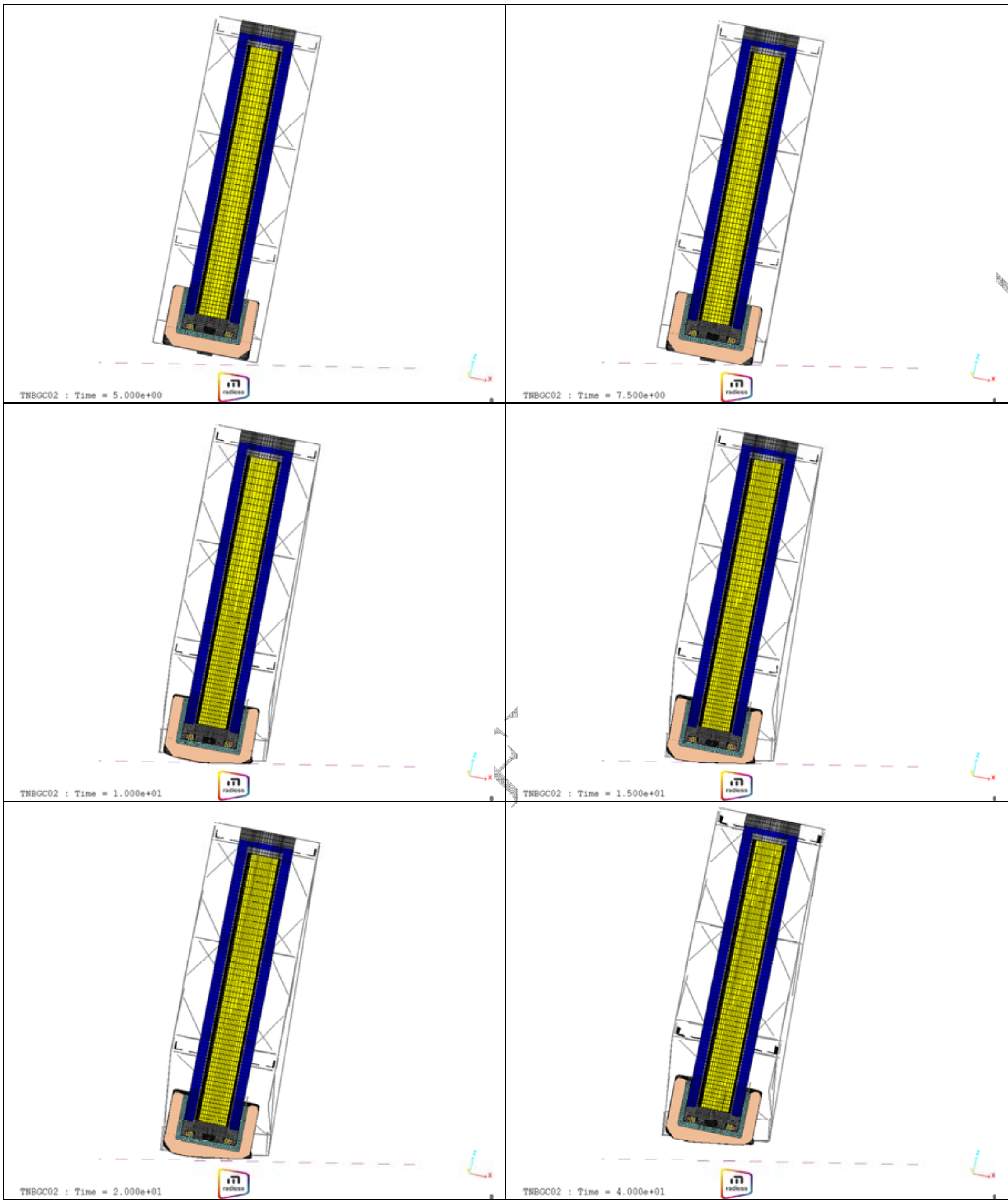


Figure 28 -Section view of the global deformation of package TN-BGC 1 from 0 to 40ms at 20°C

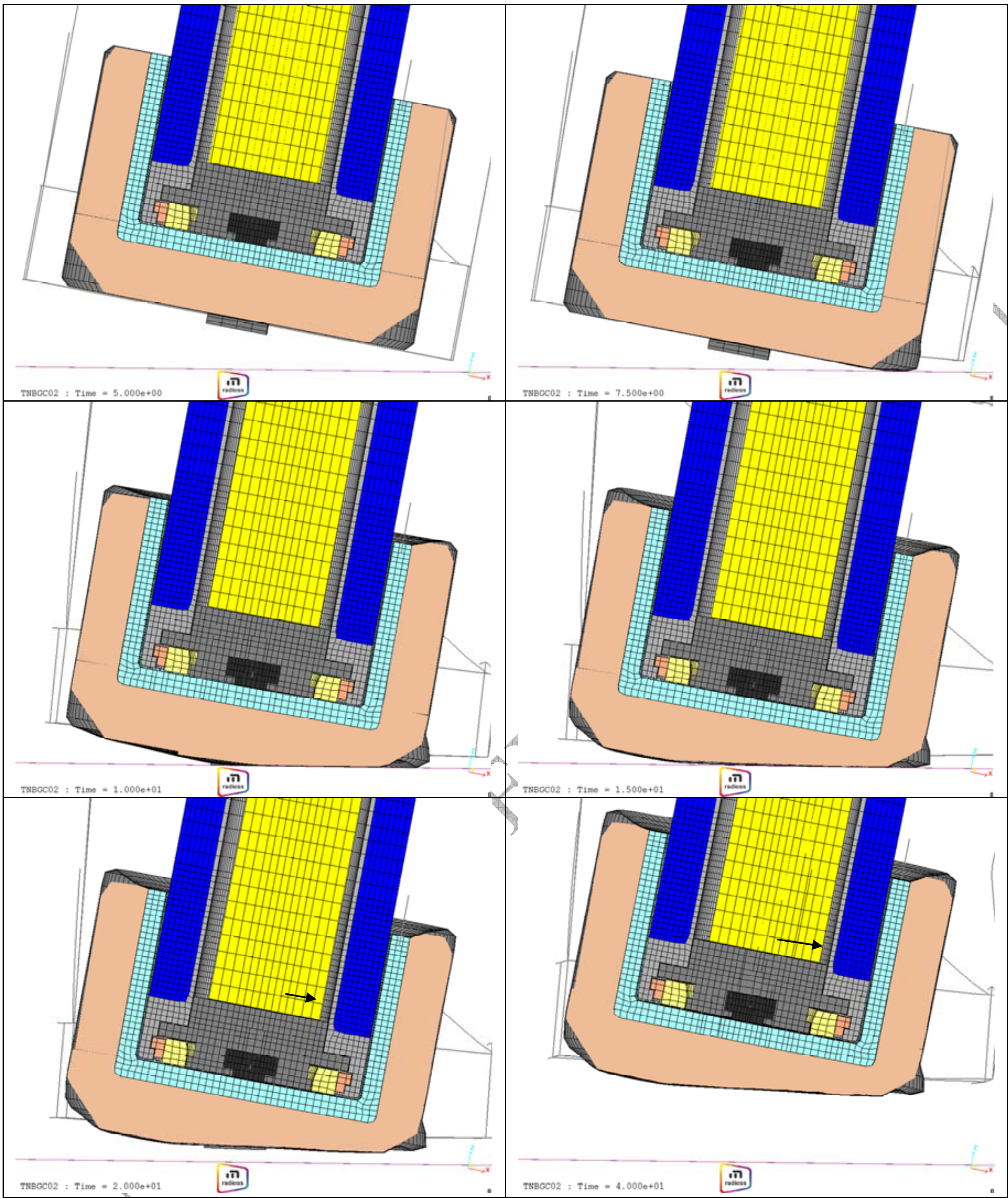


Figure 29 -Section view of the global deformation of the cover of package TN-BGC 1 from 0 to 40ms at 20°C

The above views show that the cage is subjected to stresses in the impact zone and that deformation is globally minor. The plug is compressed at two points: the zone in contact with the ground and the floor. Displacement of the load in the containment liable to open the plug locally was recorded.

3.2.3. Main deformation of the package after the initial impact

Figure 30 -Main deformation of the package at 20°C

We noted that deformation was local at the end of the fall: only the upper section of the cage and plug had plastic deformation.

3.2.4. Quantitative results

3.2.4.1. <u>Speeds and displacement</u>

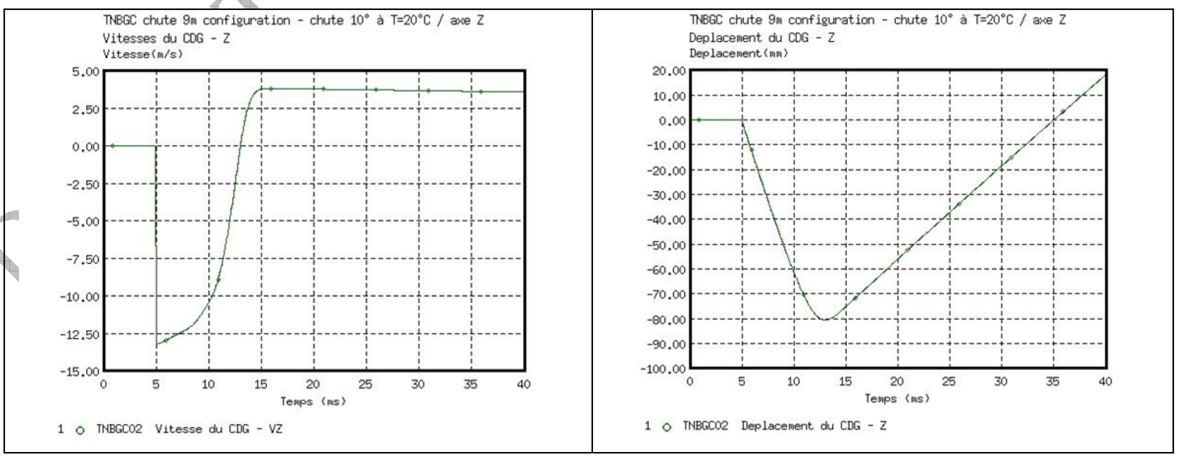


Figure 31 -Speed and displacement of the centre of gravity of the package on vertical axis Z (20°C)

The above graphs show that package TN-BGC 1 rebounds at T=13ms.

3.2.4.2. <u>Deceleration</u>

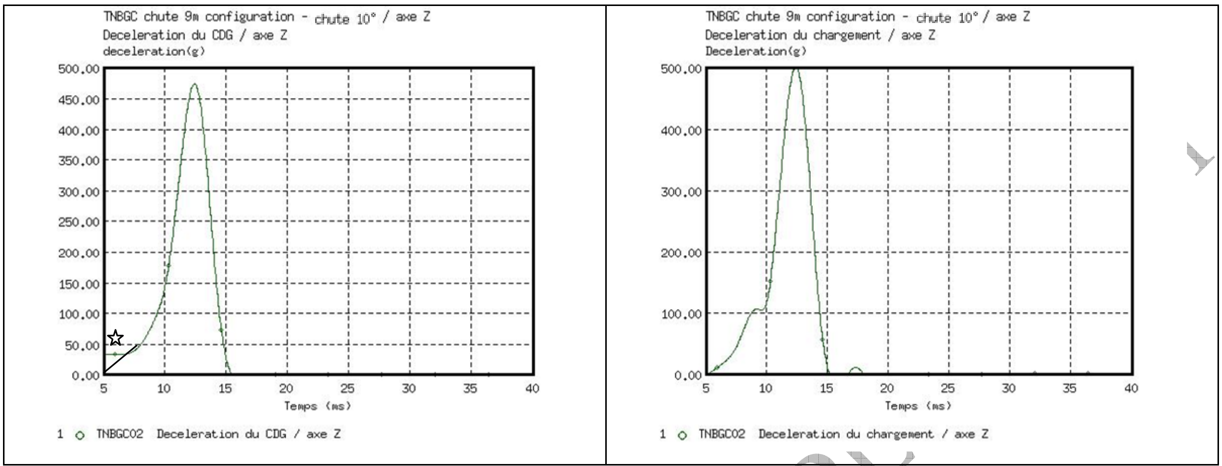


Figure 32 -Deceleration of the centre of gravity of the package and load with an oblique fall at an angle of 10° (ambient temperature of 20°C)

[figures 31 and 32]

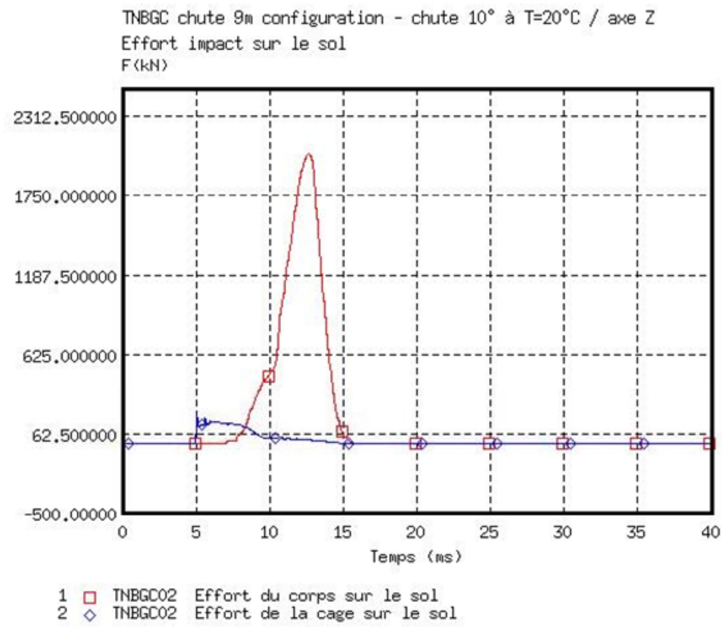
TNBGC chute 9m configuration - chute 10° / axe Z Décélération du chargement / axe Z Décélération du chargement / axe Z Temps (ms)	TNBGC 9m fall configuration - 10° fall / z axis Decelération of the load / z axis Decelération of the load / z axis Time (ms)

TNBGC chute 9m configuration - chute 10° / axe Z Décélération du CDG / axe Z décélération (g) Temps (ms) Décélération du CDG / axe Z	TNBGC 9m fall configuration - 10° fall / z axis Decelération of the CoG / z axis deceleration (g) Time (ms) Decelération of the CoG / z axis

Maximum deceleration of the centre of gravity reached with a fall at 10° equals 475g as compared with 504g for the load. This difference is due to the fact that the load can move in the containment.

N.B.: With the deceleration of the centre of gravity, we noted digital offset due to the initial acceleration of the model and the derivative of the speed.

3.2.4.3. <u>Ground forces</u>

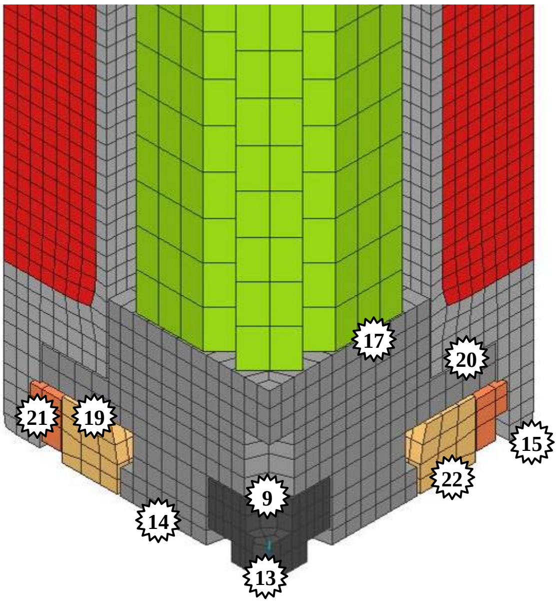


TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Effort impact sur le sol F (kN) Effet du corps sur le sol Effet de la cage sur le sol	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Ground impact force F (kN) Ground main section force Ground cage force

Figure 33 -Ground forces of the cage and main section (20°C)

Maximum force recorded for ground contact = 2046kN for the package.

3.2.4.4. Plug forces



Numéro	Pièces concernées par la gestion du contact
9	Bouchon de Staubli /Bouchon
13	Bouchon de staubli/intérieur du capot
14	Bouchon / intérieur du capot
15	Corps/intérieur du capot
17	Bouchon /chargement
19	Bague de serrage/Bouchon
20	Bouchon / corps (appuis des joints)
21	Corps/bague baïonnette
22	Bague de serrage / intérieur du capot

Figure 34 -Plug interfaces

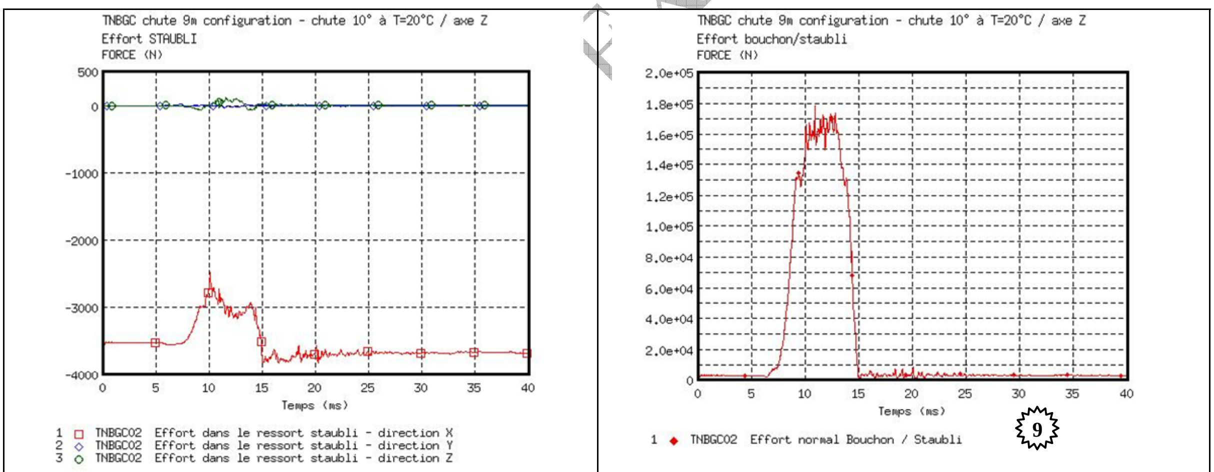


Figure 35 -Forces in the interfaces between the plug and the Staubli plug (20°C)

Numéro	Number
Pièces concernées par la gestion du contact	Parts concerned by contact management
Bouchon de Staubli / Bouchon	Staubli plug/plug
Bouchon de staubli / intérieur du capot	Staubli plug/inside of the cover
Corps / intérieur du capot	Main section/inside of the cover
Bouchon /chargement	Plug/load
Baugue de serrage / Bouchon	Clamp ring/plug
Bouchon / corps	Plug/main section
Corps / bague baïonnette	Main section/bayonet ring
Baugue de serrage / intérieur du capot	Clamp ring/inside of the cover
TNBGC chute 9m configuration - chute 10° / axe	TNBGC 9m fall configuration - 10° fall

Z Effet STAUBLI FORCE (N) Temps (ms) Effort dans le ressort staubli - direction X Effort dans le ressort staubli - direction Y Effort dans le ressort staubli - direction Z	/ z axis STAUBLI force FORCE (N) Time (ms) Force in the staubli spring - direction X Force in the staubli spring - direction Y Force in the staubli spring - direction Z

TNBGC chute 9m configuration - chute 10° / axe Z Effet bouchon / staubli FORCE (N) Temps (ms) Effort normal Bouchon / Staubli	TNBGC 9m fall configuration - 10° fall / z axis Staubli/plug force FORCE (N) Time (ms) Normal Plug/Staubli force

The above figure shows that the initial force between the plug and the Staubli plug is maintained after the impact. The interface force between the plug and the Staubli plug reaches a maximum of 178kN: this peak is transferred to the Staubli plug via the ground contact.

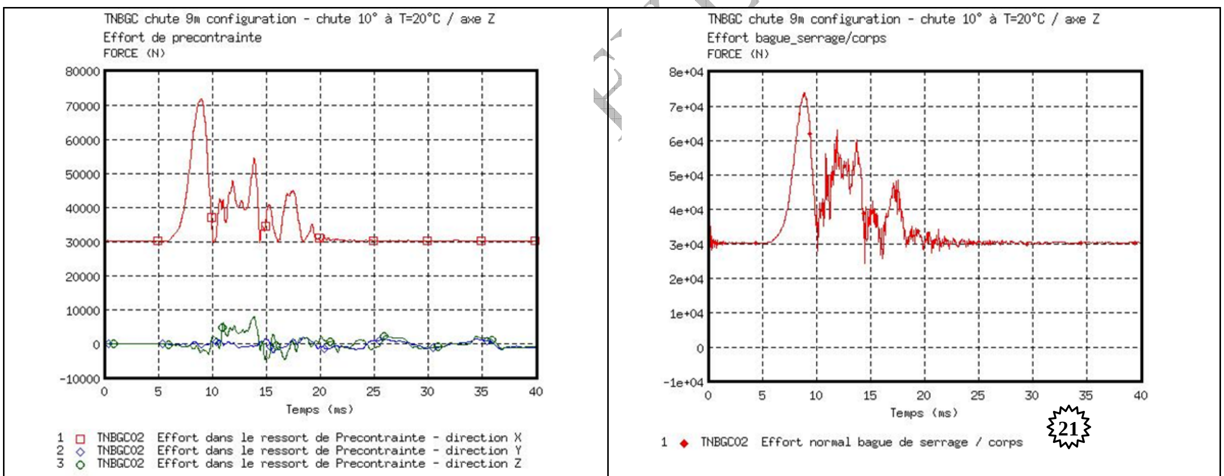


Figure 36 -Forces in interfaces between the inside of the cover and the plug (20°C)

TNBGC chute 9m configuration - chute 10° / axe Z Effort precontrainte FORCE (N) Temps (ms) Effort dans le ressort de Precontrainte - direction X Effort dans le ressort de Precontrainte - direction Y Effort dans le ressort de Precontrainte - direction Z	TNBGC 9m fall configuration - 10° fall / z axis Pre-stressing forces FORCE (N) Time (ms) Force in the pre-stressing spring - direction X Force in the pre-stressing spring - direction Y Force in the pre-stressing spring - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Effort bagues serrage /corps FORCE (N) Temps (ms) Effort normal bague de serrage	Clamp ring/main section force FORCE (N) Time (ms) Normal clamp ring force

Zones de mesures d'étanchéité du couvercles avec le repère local associé Zone d'impact - Sol	Seal measuring zones for covers with the assigned local marker Ground- impact zone

Charts demonstrate a maximum peak at 9ms originating at the contact of the plug with the ground. The plug is locally compressed at this point. After impact, pre-stressing remains constant at 30 000N corresponding to the pre-clamp force.

3.2.4.5. Detachment on the cover

For the plug: the depth of the weld throat is equal to 4.93 mm and the diameter of the weld is 6.8 mm. Crushing is equal to 27.5% when closing the package. We have broken the closing system down into 4 zones, each including 3 measurement points distributed radially, to assist in locating any deterioration of sealing.

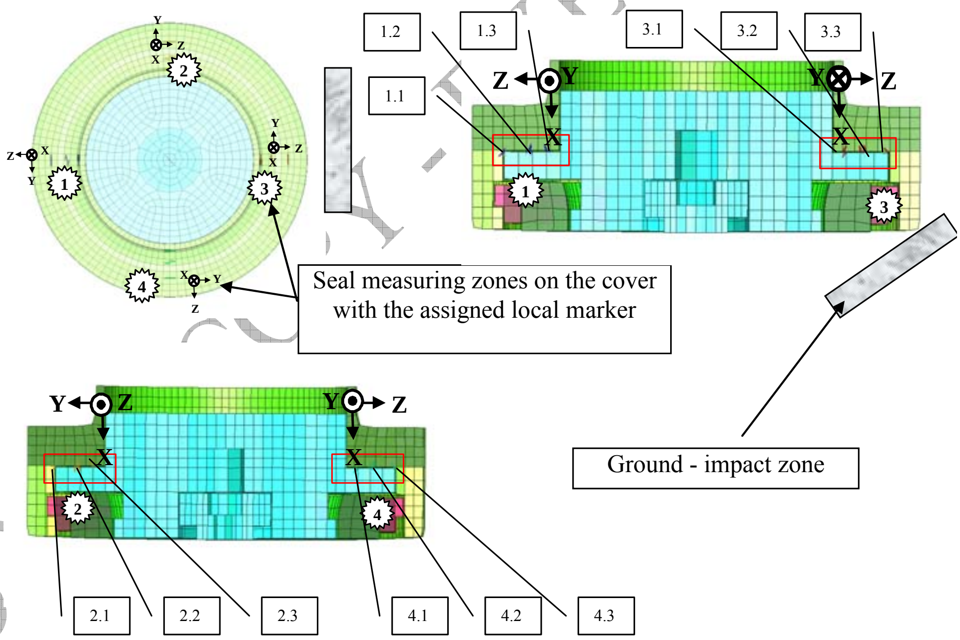
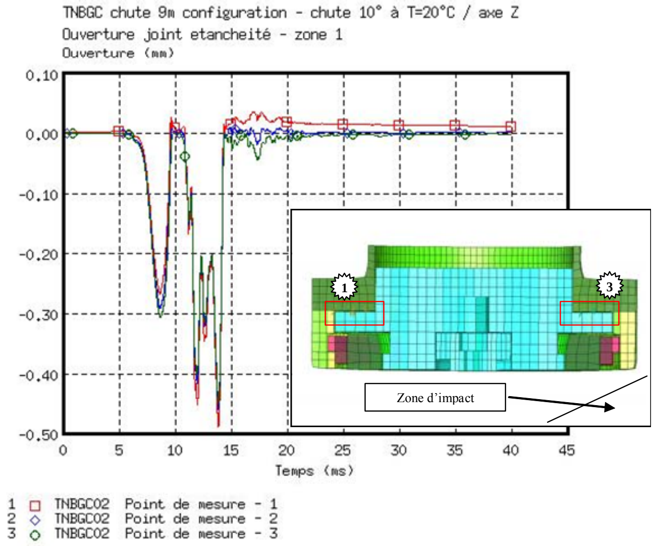
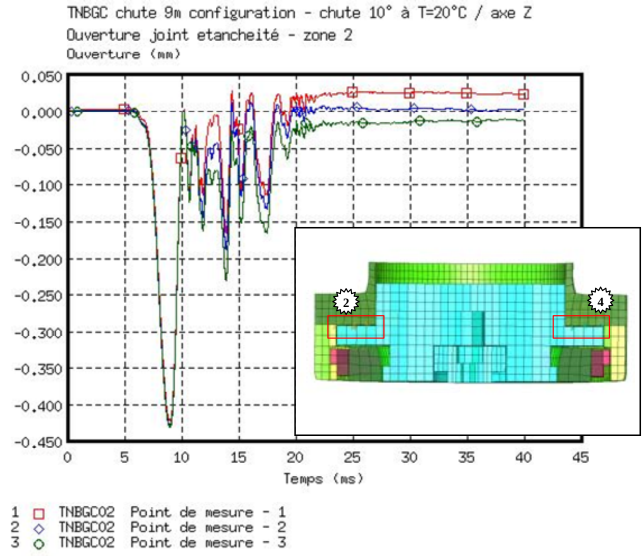


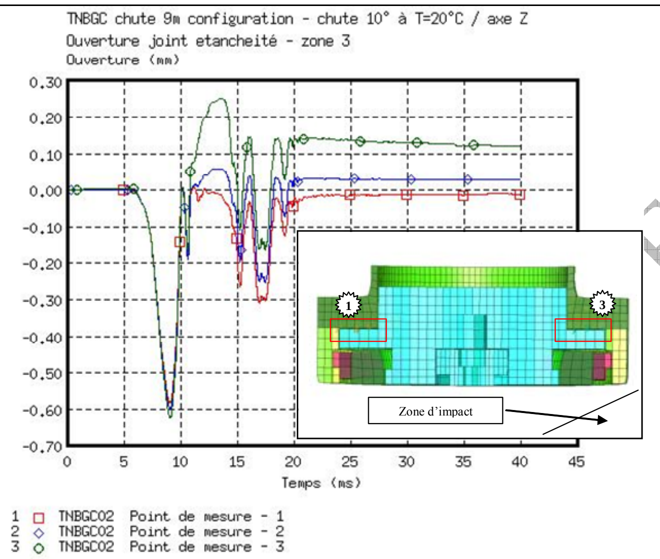
Figure 37 -Plug closing system with seal measurement zones



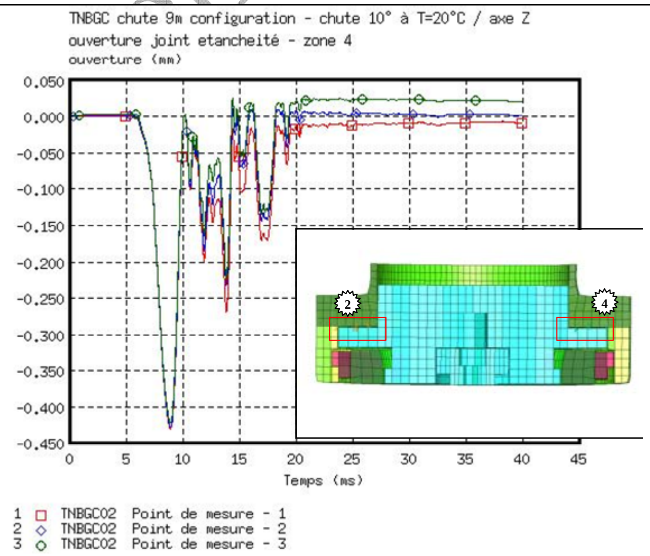
Sealing measurement zone N°1



Sealing measurement zone N°2



Sealing measurement zone N°3



Sealing measurement zone N°4

Figure 38 -Detachment of the seal (20°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 1 Ouverture (mm) Zone d'impact Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 1 Opening (mm) Impact zone Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Ouverture joint étanchéité - zone 2 Ouverture (mm) Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	Opening of the seal - zone 2 Opening (mm) Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 3 Ouverture (mm) Zone d'impact Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 3 Opening (mm) Impact zone Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 4 Ouverture (mm) Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 4 Opening (mm) Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3

N.B.: Measuring points are directed, requiring a negative sign

Temperature ambiante (°C)	20
angle-chute par rapport l'axe Z (°)	10
décélération (norme) du chargement (g)	503,6
taux de compression du joint d'etanchéité_zone4-3	21,3%
taux de compression du joint d'etanchéité_zone4-2	21,2%
taux de compression du joint d'etanchéité_zone4-1	21,2%
taux de compression du joint d'etanchéité_zone3-3	18,3%
taux de compression du joint d'etanchéité_zone3-2	18,7%
taux de compression du joint d'etanchéité_zone3-1	18,9%
taux de compression du joint d'etanchéité_zone1-1	20,3%
taux de compression du joint d'etanchéité_zone1-2	20,8%
taux de compression du joint d'etanchéité_zone1-3	20,9%
taux de compression du joint d'etanchéité_zone2-3	21,2%
taux de compression du joint d'etanchéité_zone2-1	21,3%
taux de compression du joint d'etanchéité_zone2-2	21,2%
taux de compression dynamique(minimum)	18,3%
taux de compression dynamique moyen	20,4%

Temperature ambiante (°C)	20
angle-chute par rapport l'axe Z (°)	10
taux de compression residuel - zone4-3	27,8%
taux de compression residuel - zone4-2	27,5%
taux de compression residuel - zone4-1	27,4%
taux de compression residuel - zone3-3	29,3%
taux de compression residuel - zone3-2	27,9%
taux de compression residuel - zone3-1	27,3%
taux de compression residuel - zone1-1	27,7%
taux de compression residuel - zone1-2	27,5%
taux de compression residuel - zone1-3	27,5%
taux de compression residuel - zone2-3	27,3%
taux de compression residuel - zone2-1	27,9%
taux de compression residuel - zone2-2	27,5%
taux de compression residuel - mini	27,3%

Figure 39 -Overviews of compression of the seal per measurement zone

Température ambiante (°C) angle-chute par rapport l'axe Z décélération (norme) du chargement (g) taux de compression du joint d'étanchéité_zone 4-3 taux de compression du joint d'étanchéité_zone 4-2 taux de compression du joint d'étanchéité_zone 4-1 taux de compression du joint d'étanchéité_zone 3-3 taux de compression du joint d'étanchéité_zone 3-2 taux de compression du joint d'étanchéité_zone 3-1 taux de compression du joint d'étanchéité_zone 1-1 taux de compression du joint d'étanchéité_zone 1-2 taux de compression du joint d'étanchéité_zone 1-3 taux de compression du joint d'étanchéité_zone 2-3 taux de compression du joint d'étanchéité_zone 2-1 taux de compression du joint d'étanchéité_zone 2-2 taux de compression dynamique (minimum) taux de compressions dynamique moyen	Ambient temperature (°C) fall angle from the z axis deceleration (standard) of the load (g) level of compression of the seal - zone 4-3 level of compression of the seal - zone 4-2 level of compression of the seal - zone 4-1 level of compression of the seal - zone 3-3 level of compression of the seal - zone 3-2 level of compression of the seal - zone 3-1 level of compression of the seal - zone 1-1 level of compression of the seal - zone 1-2 level of compression of the seal - zone 1-3 level of compression of the seal - zone 2-3 level of compression of the seal - zone 2-1 level of compression of the seal - zone 2-2 level of dynamic compression (min.) level of mean dynamic compression
Température ambiante (°C) angle-chute par rapport l'axe Z taux de compression residuel - zone 4-3 taux de compression residuel - zone 4-2 taux de compression residuel - zone 4-1 taux de compression residuel - zone 3-3 taux de compression residuel - zone 3-2 taux de compression residuel - zone 3-1 taux de compression residuel - zone 1-1 taux de compression residuel - zone 1-2 taux de compression residuel - zone 1-3 taux de compression residuel - zone 2-3 taux de compression residuel - zone 2-1 taux de compression residuel - zone 2-2 taux de compression residuel - mini	Ambient temperature (°C) fall angle from the z axis level of residual compression - zone 4-3 level of residual compression - zone 4-2 level of residual compression - zone 4-1 level of residual compression - zone 3-3 level of residual compression - zone 3-2 level of residual compression - zone 3-1 level of residual compression - zone 1-1 level of residual compression - zone 1-2 level of residual compression - zone 1-3 level of residual compression - zone 2-3 level of residual compression - zone 2-1 level of residual compression - zone 2-2 level of residual compression - min.

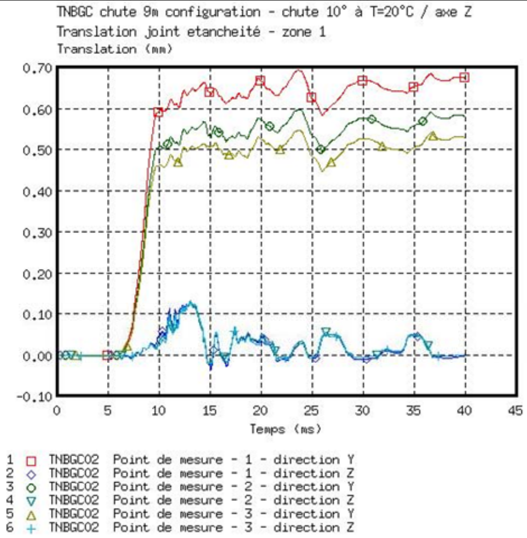
The above tables demonstrate that the levels of both dynamic and residual compression are adequate to guarantee plug seals.

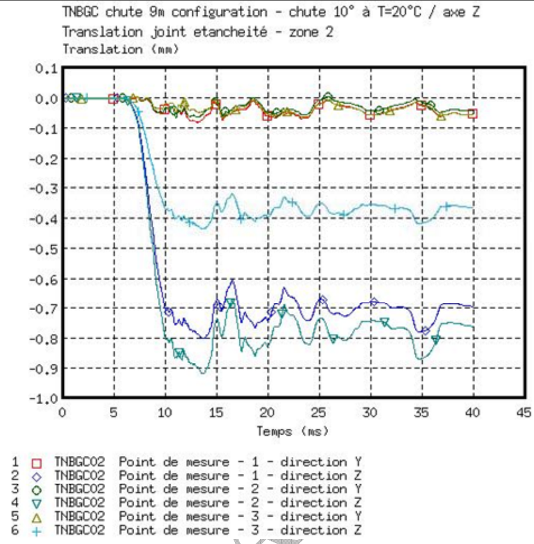
We detected that the zone of the seal most subjected to stresses is in zone n°3, i.e. the zone suffering direct impact. Compression is minimal when the load comes into contact with the plug for an extremely short period. This phenomenon was recorded in almost all zones, with the exception of zone 1, at the opposite end from ground contact. Maximum plug detachment in zone N°1 originated with the package rebound. We detected that the load slipped towards the impact zone in its containment. Slight bending of the package would explain the detachment of the plug in this zone.

Residual compression was higher than before the fall in zone 3-3. In addition, the lowest level of dynamic compression was recorded in this zone. This is due to:

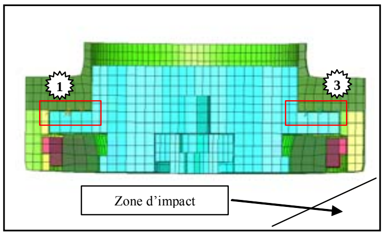
- the load initially pushes on the plug and encourages detachment,
- the wooden section in this zone is then completely crushed. The plug moves nearer to the main section and the seal is therefore subjected to higher levels of compression.

3.2.4.6. Translation of the seal on the cover

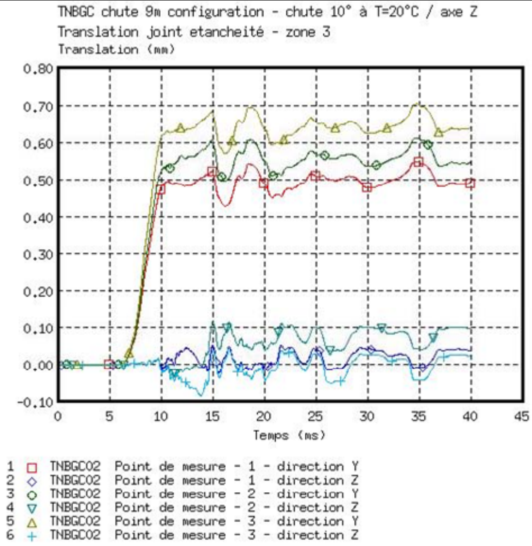


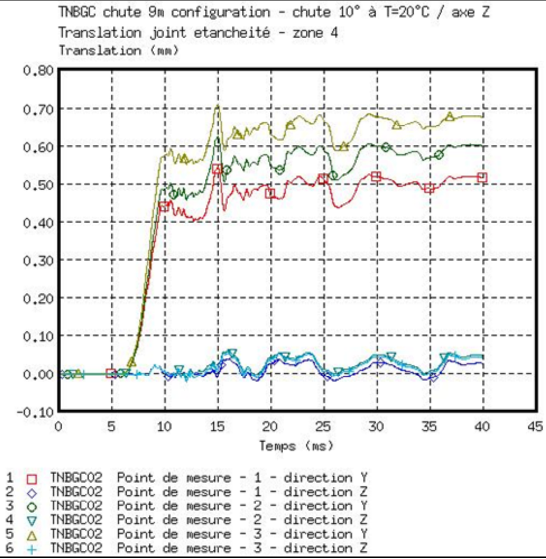


Sealing measurement zone N°1

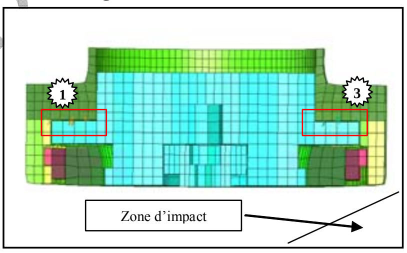


Sealing measurement zone N°2





Sealing measurement zone N°3



Sealing measurement zone N°4

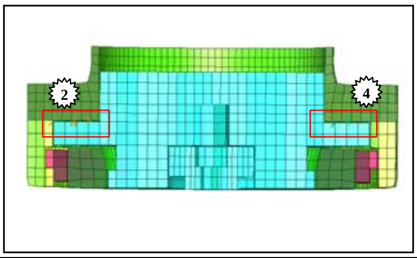
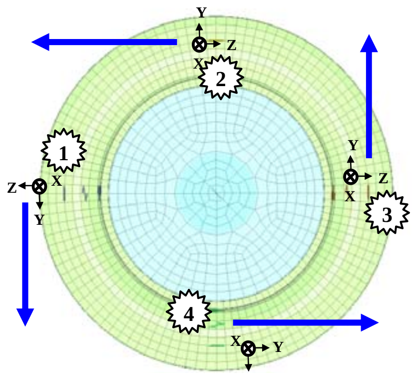


Figure 40 -Transversal displacement of the seal (20°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Translation joint étanchéité - zone 1 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	Translation of the seal - zone 1 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 2 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 2 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
Zone d'impact	Impact zone
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 3 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 3 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 4 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 4 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
Zone d'impact	Impact zone



The above measurements revealed that the plug rotated anti-clockwise slightly, which would have no effect on sealing (cf. above figure). These rotations are initiated due to the underestimation of the stiffness of springs. They do not therefore actually exist in reality.

3.3. Configuration N°2: fall at an angle of 10 degrees and an ambient temperature of -40°C

3.3.1. Energy report

The first 5 milliseconds are used to prestress the plugs. The package is then "dropped" and gravity applied.

The global energy of the system is maintained during the calculation. This energy is equal to 35.1 kJ.

The initial kinetic energy is transformed into absorbed energy and kinetic rebound energy. The rebound acts when kinetic energy cancels out at 13 ms from the start of the simulation (including prestressing of the plugs).

Maximum internal energy is 32.1 kJ.

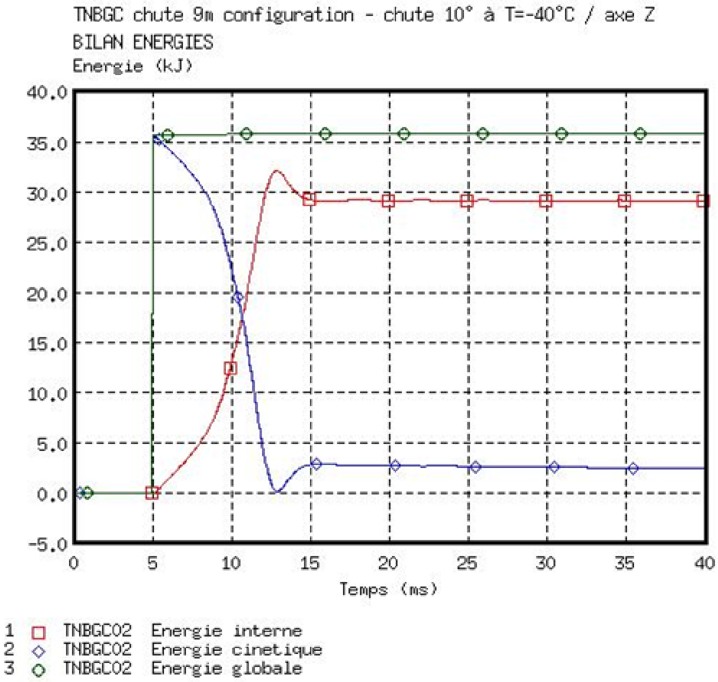
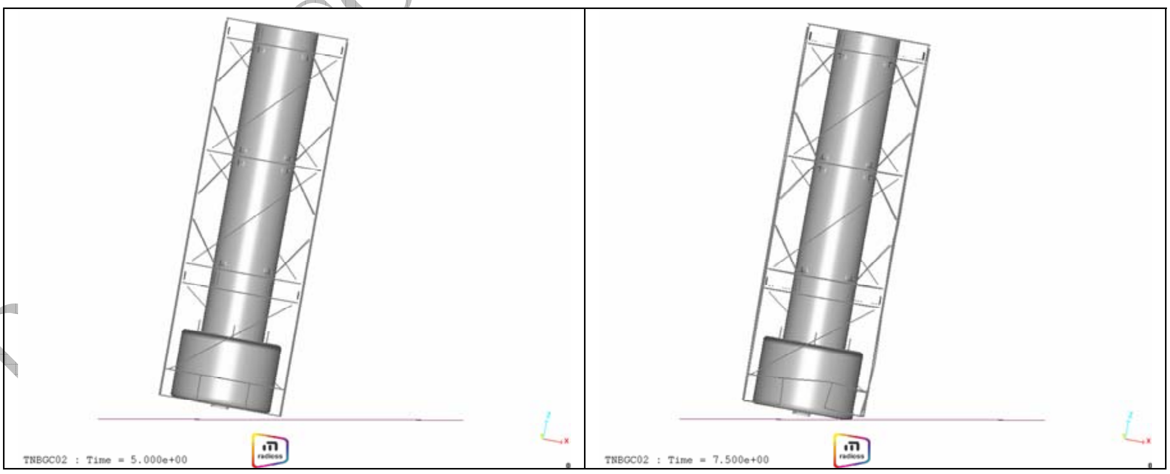


Figure 41 -Global report on fall energies at -40°C

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z BILAN ENERGIES Energie (kJ) Energie interne Energie cinetique Energie globale	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis ENERGY REPORT Energy (kJ) Internal energy Kinetic energy Global energy

3.3.2. Changes to global deformation over time



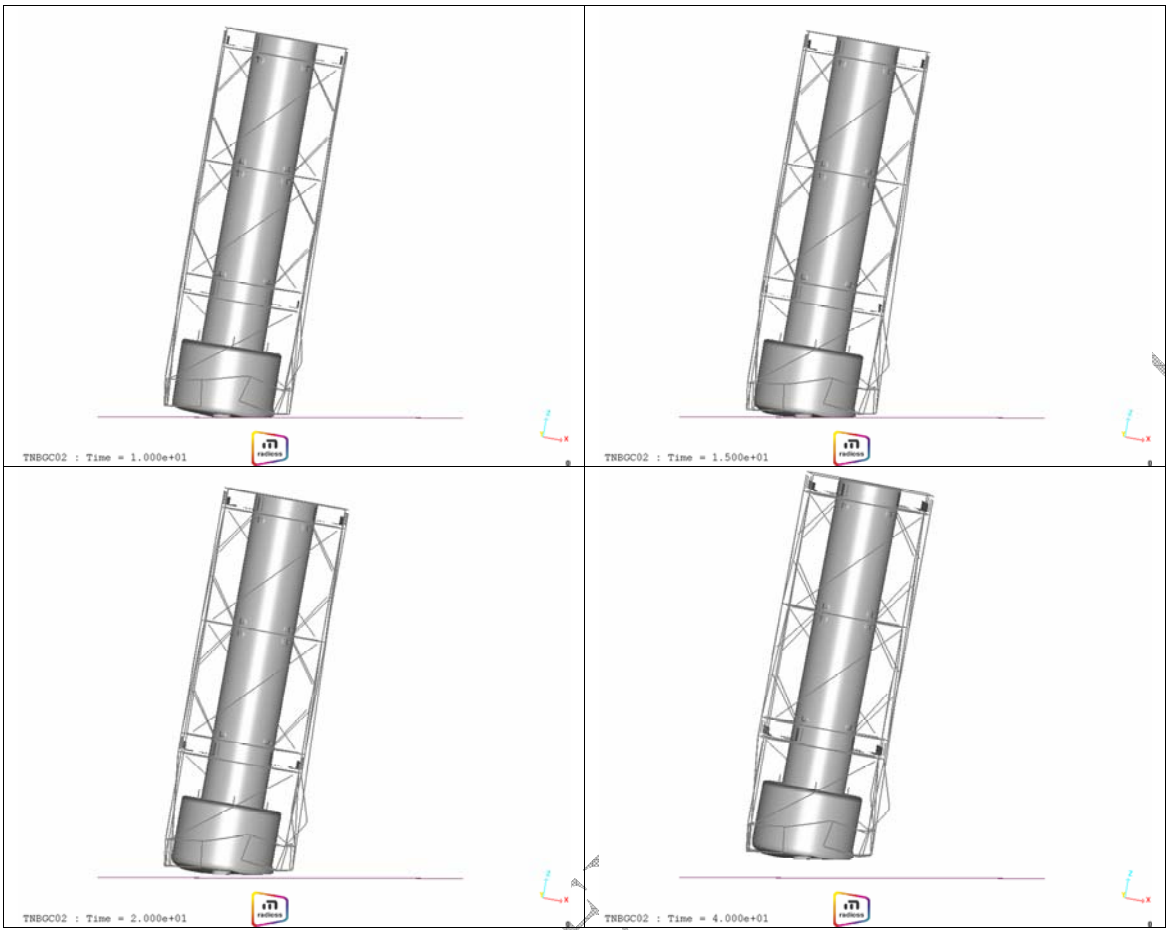


Figure 42 -Global deformation of package TN-BGC 1 from 0 to 40ms at -40°C

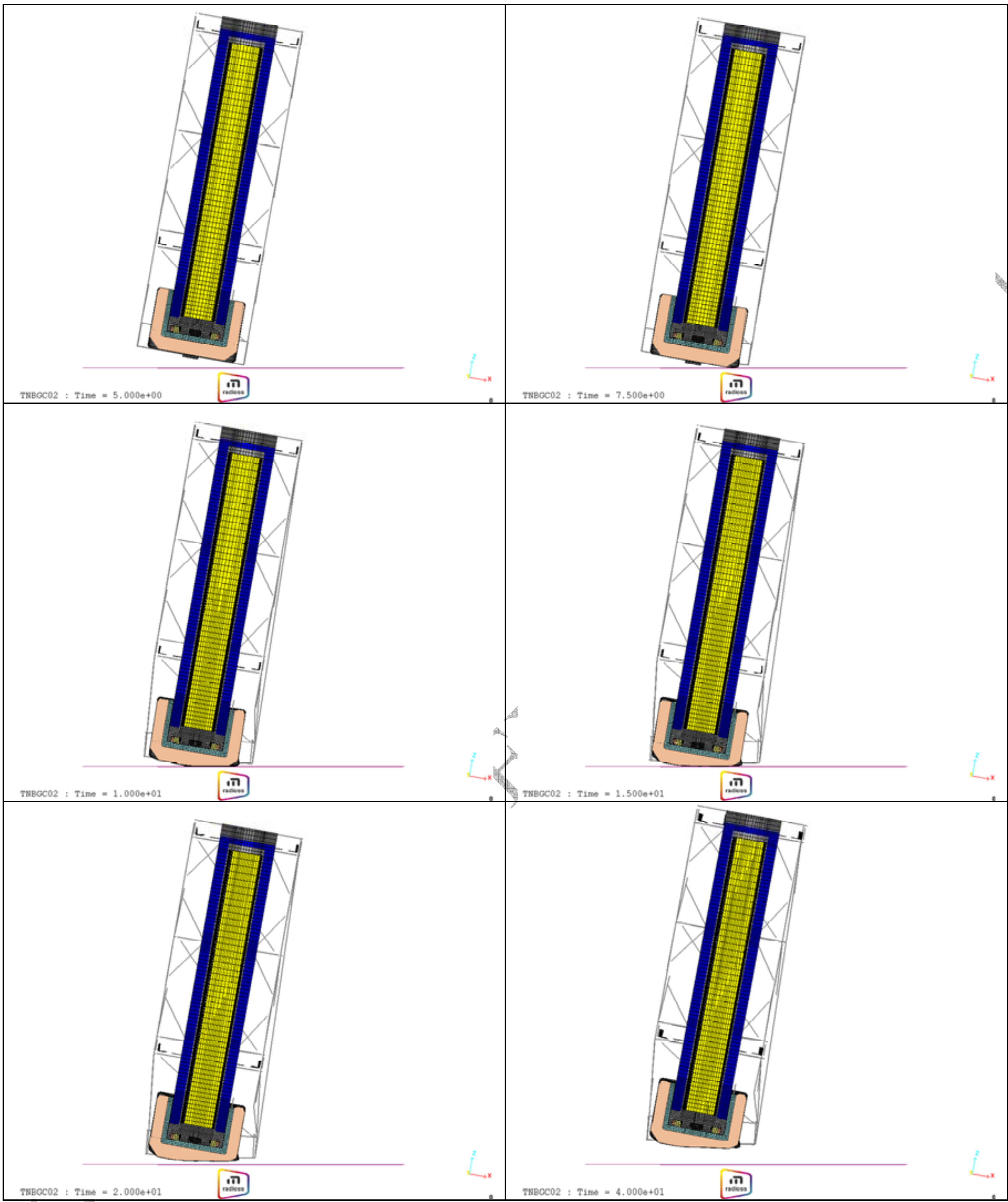


Figure 43 -Section view of the global deformation of package TN-BGC 1 from 0 to 40ms at -40°C

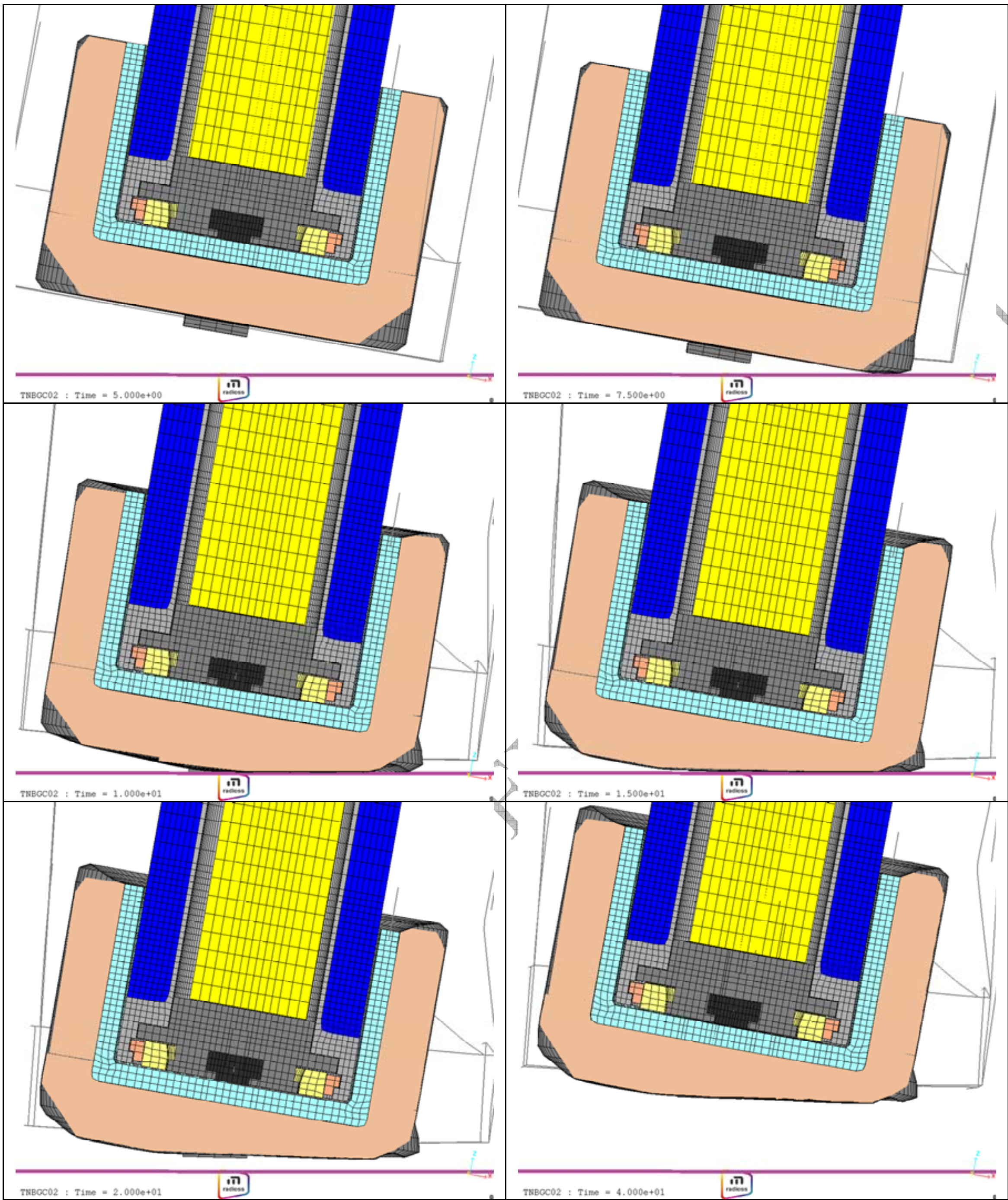


Figure 44 -Section view of the deformation of the cover of package TN-BGC 1 from 0 to 20ms at -40°C

The drop in ambient temperature from 20°C to -40°C will not involve major modifications in terms of deformation.

3.3.3. Main deformation of the package after the initial impact

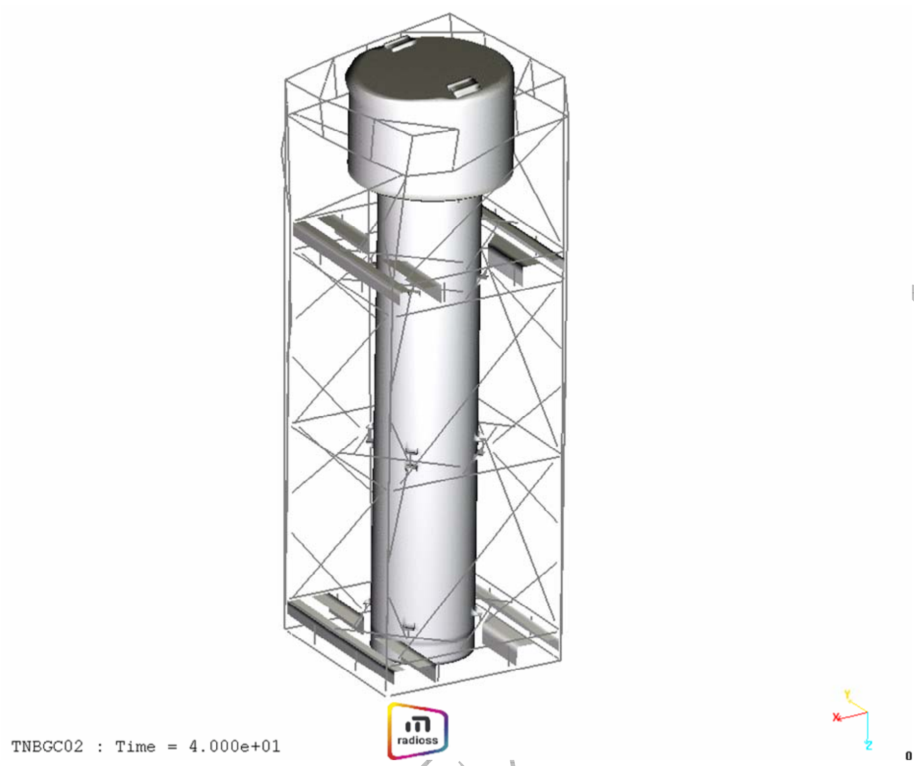


Figure 45 -Main deformation of the package at -40°C

Deformation is local and centred on the upper section of the cage and plug, as was the case for fall configuration at 20°C.

3.3.4. Quantitative results

3.3.4.1. Speeds and displacement

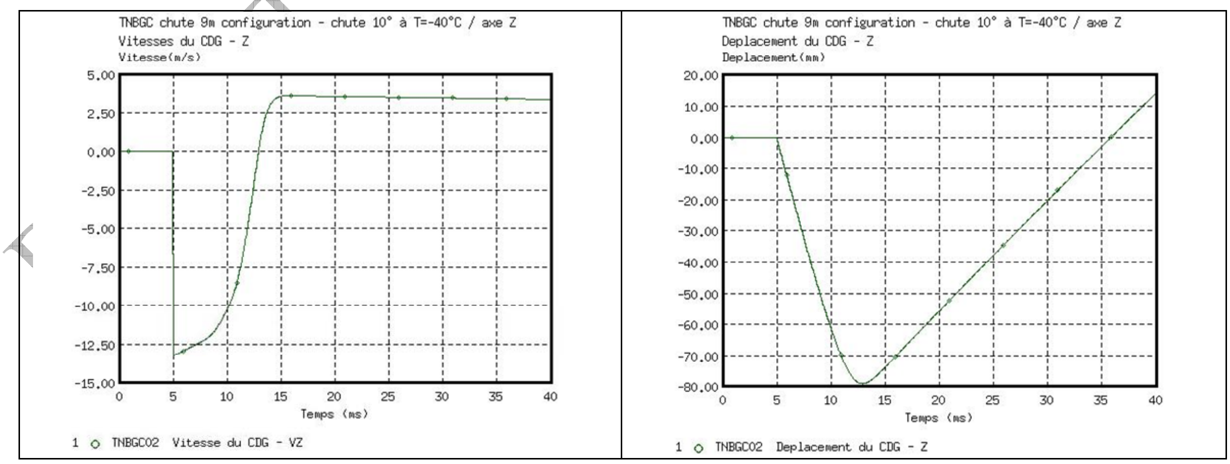


Figure 46 -Speed and displacement of the centre of gravity of the package on vertical axis Z (-40°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Vitesses du CDG - Z Vitesse (m/s) Temps (ms) Vitesse du CDG - VZ	Speed of the CoG - Z Speed (m/s) Time (ms) Speed of the CoG - VZ
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Deplacement du CDG - Z Deplacement (mm) Temps (ms) Deplacement du CDG - VZ	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Displacement of the CoG - Z Displacement (mm) Time (ms) Displacement of the CoG - VZ

The above graphs show that package TN-BGC 1 rebounds after 8 ms (T=13ms)

3.3.4.2. Deceleration

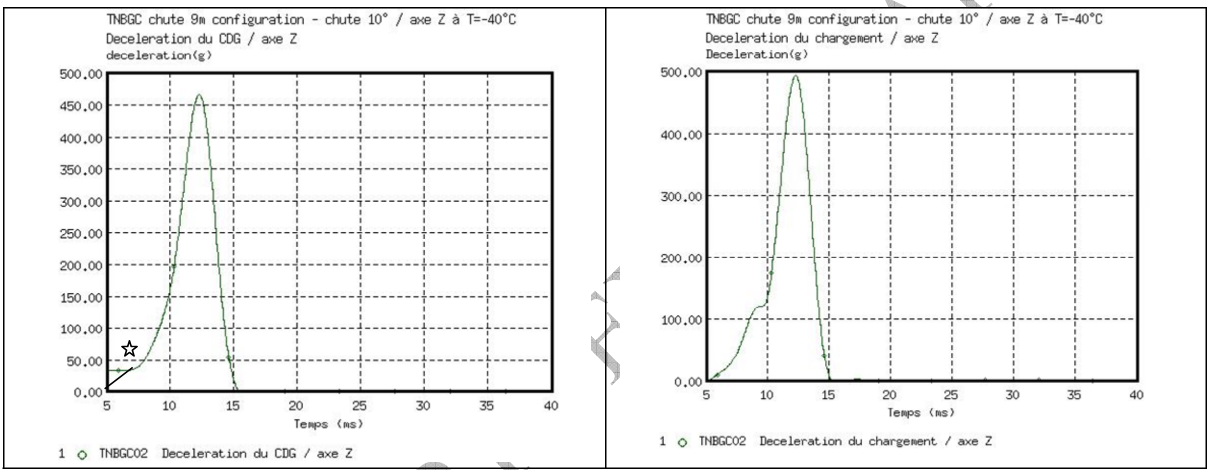


Figure 47 -Deceleration of the centre of gravity of the package and load (-40°C)

Maximum deceleration of the centre of gravity reached with a fall at 10° equals 467g as compared with 495g for the load. This difference is due to the fact that the load can move in the containment.

N.B.: With the deceleration of the centre of gravity, we noted offset due to the initial acceleration of the model and the derivative of the speed.

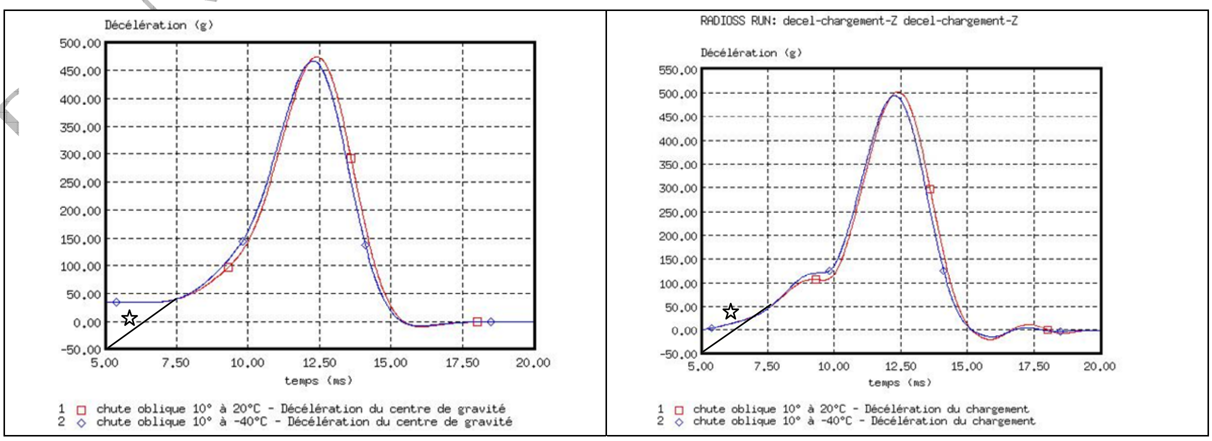


Figure 48 -Comparison of deceleration of the centre of gravity of the package and load at different temperatures (-40°C and 20°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Décélération du CDG décélération (g) Temps (ms) Décélération du CDG / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Deceleration of the CoG deceleration (g) Time (ms) Decelération of the CoG / z axis
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Décélération du chargement décélération (g) Temps (ms) Décélération du chargement / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Deceleration of the load deceleration (g) Time (ms) Decelération of the load / z axis
Décélération (g) Temps (ms) chute oblique à 20°C - Décélération du centre de gravité chute oblique à - 40°C - Décélération du centre de gravité	Deceleration (g) Time (ms) oblique fall at 20°C - Deceleration of the centre of gravity oblique fall at - 40°C - Deceleration of the centre of gravity
RADIOSS RUN: décél - chargement - Z - décél - chargement - Z Décélération (g) Temps (ms) chute oblique à 20°C - Décélération du centre de gravité chute oblique à - 40°C - Décélération du centre de gravité	RADIOSS RUN: decel - load - Z - decel - load - Z Deceleration (g) Time (ms) oblique fall at 20°C - Deceleration of the centre of gravity oblique fall at - 40°C - Deceleration of the centre of gravity

At an ambient temperature of -40°C, the mechanical properties of wood stiffen and improve absorption at initial impact. Initial deceleration caused by the crushing of the wood at -40°C is slightly higher, i.e. the main section is slowed down slightly more. Maximum deceleration of the centre of gravity is due to initial deformation of the steel corner of the package when the wood achieves maximum yield in both cases. The results obtained for both temperatures are globally similar to the low wood thickness subjected to stresses during the fall.

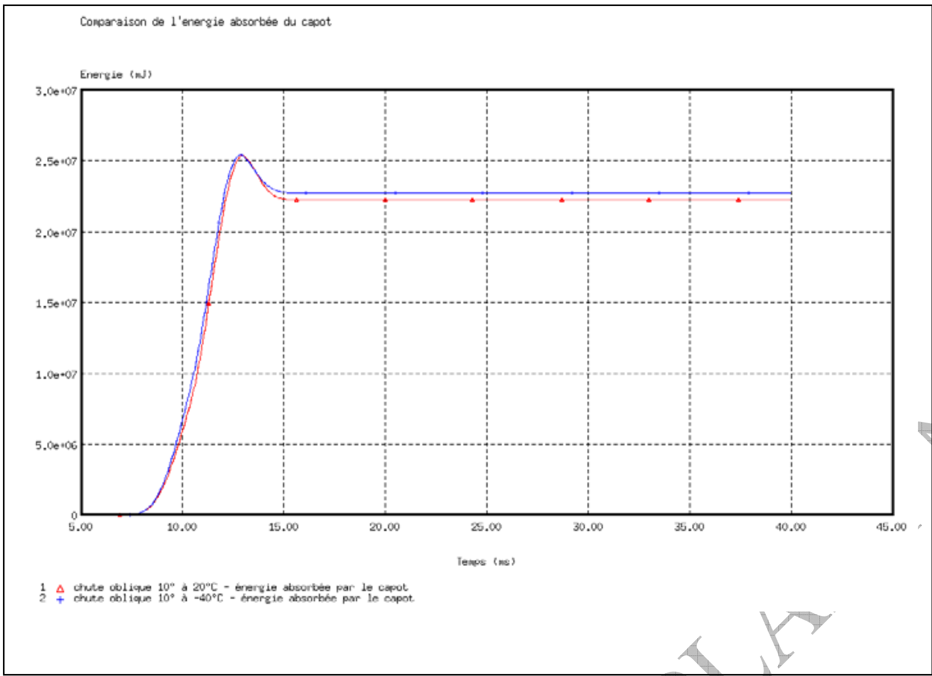


Figure 49 -Comparison of energy absorbed for the cover at different temperatures (-40°C and 20°C)

The above figure shows that, at -40°C, the cover absorbs more energy in the initial phase of impact. Maximum energy absorbed is almost identical, however, at the end of the fall, the level of energy absorbed at -40°C remains slightly higher than at 20°C.

3.3.4.3. Ground forces

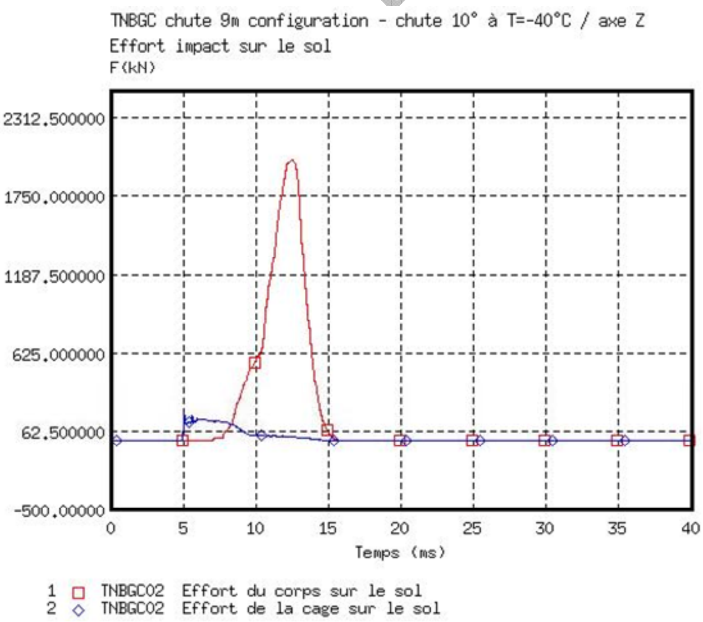


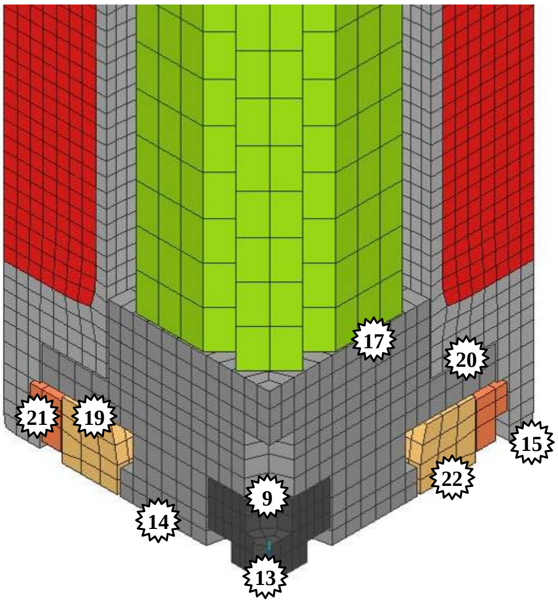
Figure 50 -Forces in interfaces between the inside of the cover and the plug (-40°C)

Maximum force recorded for ground contact = 2,010kN for the package.

Comparaison de l'énergie absorbée du capot Energie (aJ) Temps (ms)	Comparison of the energy absorbed from the cover Energy (mJ)

chute oblique 10° à 20°C - énergie absorbée par le capot chute oblique 10° à -40°C - énergie absorbée par le capot	Time (ms) oblique fall at 10° & 20°C - energy absorbed by the cover oblique fall at 10° & -40°C - energy absorbed by the cover
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Effort impact sur le sol F (kN) Temps (ms) Effort du corps sur le goal Effort de la cage sur le sol	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Ground impact force F (kN) Time (ms) Main section force on the ground Cage force on the ground

3.3.4.4. Plug forces



Numéro	Pièces concernées par la gestion du contact
9	Bouchon de Staubli /Bouchon
13	Bouchon de staubli/intérieur du capot
14	Bouchon / intérieur du capot
15	Corps/intérieur du capot
17	Bouchon /chargement
19	Bague de serrage/Bouchon
20	Bouchon / corps (appuis des joints)
21	Corps/bague baïonnette
22	Bague de serrage / intérieur du capot

Figure 51 -Plug interfaces

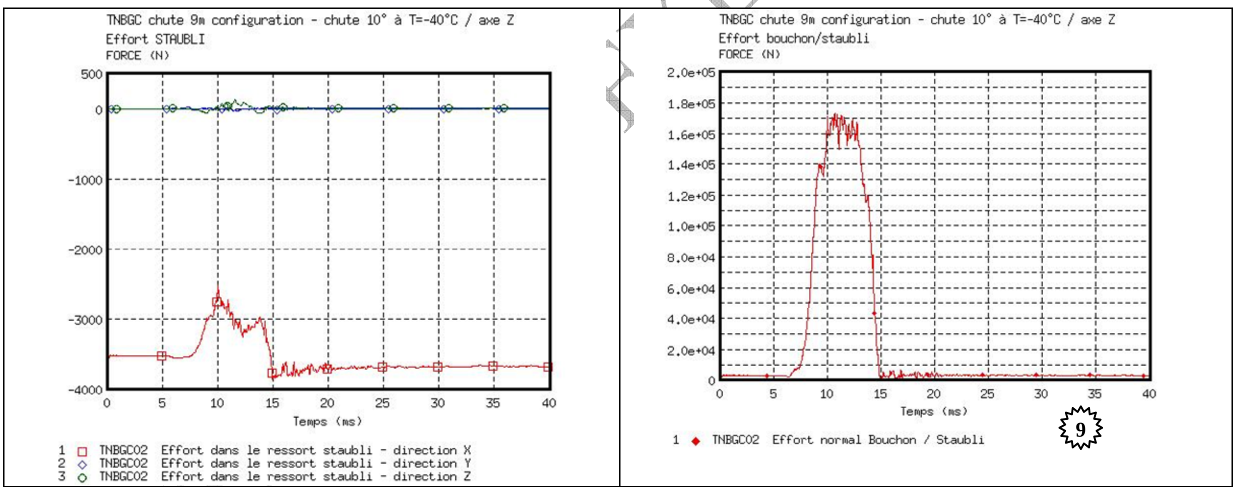


Figure 52 -Forces in interfaces between the inside of the cover and the plug (-40°C)

Numéro	Number
Pièces concernées par la gestion du contact	Parts concerned by contact management
Bouchon de Staubli / Bouchon	Staubli plug/plug
Bouchon de staubli / intérieur du capot	Staubli plug/inside of the cover
Bouchon / intérieur du capot	Plug/inside of the cover
Corps / intérieur du capot	Main section/inside of the cover
Bouchon / chargement	Plug/load
Bague de serrage / Bouchon	Clamp ring/plug
Bouchon / corps	Plug/main section
Corps / bague baïonnette	Main section/bayonet ring
Baugue de serrage / intérieur du capot	Clamp ring/inside of the cover

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Effort STAUBLI FORCE (N) Temps (ms) Effort dans le ressort staubli - direction X Effort dans le ressort staubli - direction Y Effort dans le ressort staubli - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis STAUBLI force FORCE (N) Time (ms) Force in the staubli spring - direction X Force in the staubli spring - direction Y Force in the staubli spring - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Effort bouchon / staubli FORCE (N) Effort normal Bouchon / Staubli	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Staubli/plug force FORCE (N) Normal Plug/Staubli force

The above figure shows that the initial force between the plug and the Staubli plug is maintained after the impact. The interface force between the plug and the Staubli plug reaches a maximum of 172kN: this peak is transferred to the Staubli plug via the ground contact.

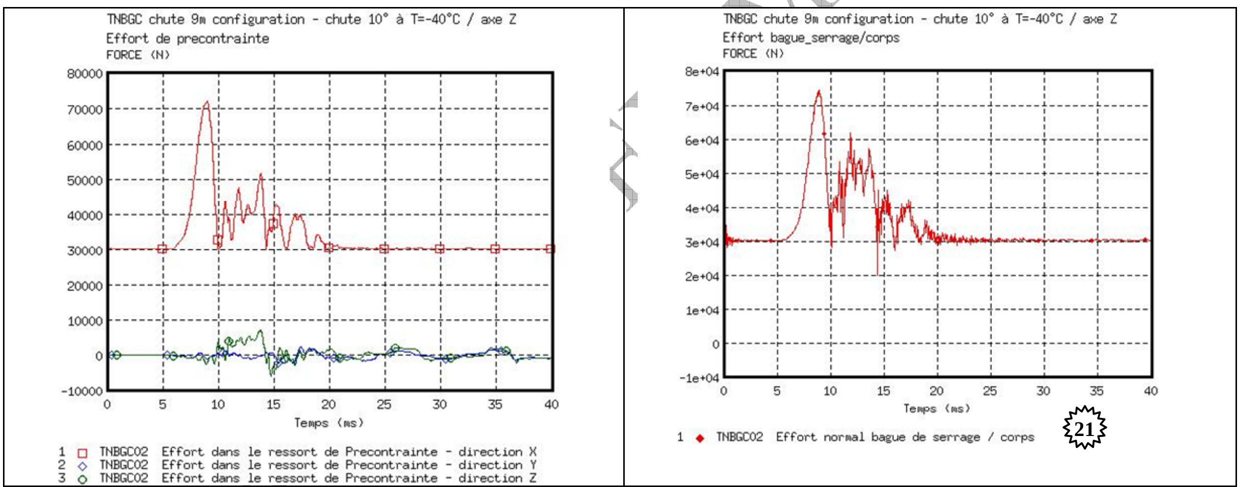


Figure 53 -Forces in interfaces between the inside of the cover and the plug (-40°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Effort de précontrainte FORCE (N) Temps (ms) Effort dans le ressort Precontrainte - direction X Effort dans le ressort Precontrainte - direction Y Effort dans le ressort Precontrainte - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Pre-stressing forces FORCE (N) Time (ms) Force in the pre-stressing spring - direction X Force in the pre-stressing spring - direction Y Force in the pre-stressing spring - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Effort bague-serrage / corps FORCE (N) Temps (ms) Effort normal bague de serrage / corps	Clamp ring/main section force FORCE (N) Time (ms) Normal clamp ring/main section force

Charts demonstrate a maximum peak at 9ms originating at the contact of the plug with the ground. The plug is locally compressed at this point. After impact, pre-stressing remains constant at 30 000N corresponding to the pre-clamp force.

3.3.4.5. Detachment on the cover

For the plug: the depth of the weld throat is equal to 4.93 mm and the diameter of the weld is 6.8 mm. Crushing is equal to 27.5% when closing the package. We have broken the closing system down into 4 zones, each including 3 measurement points distributed radially, to assist in locating any deterioration of sealing.

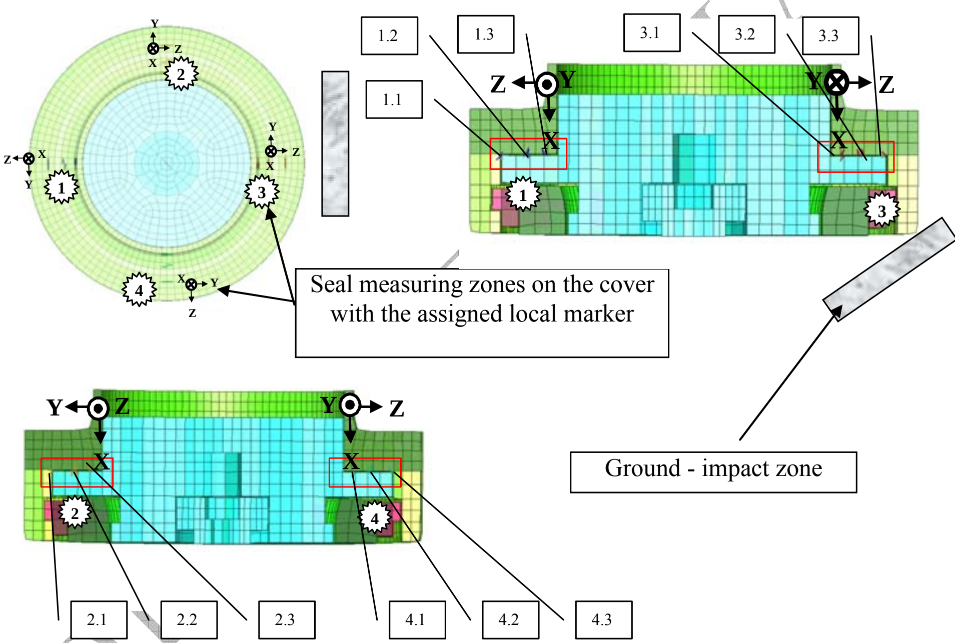
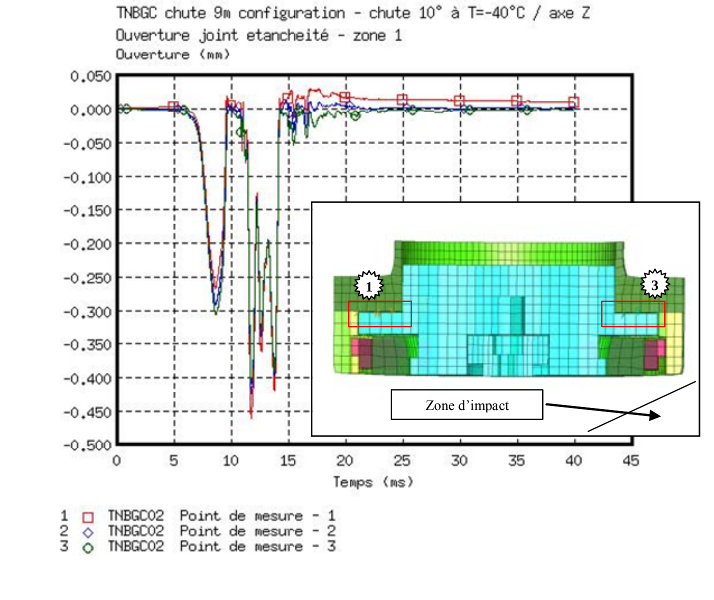
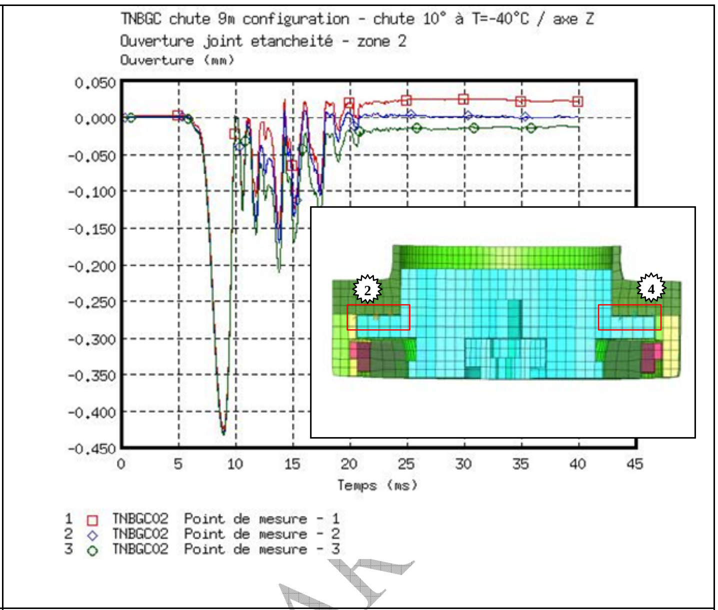


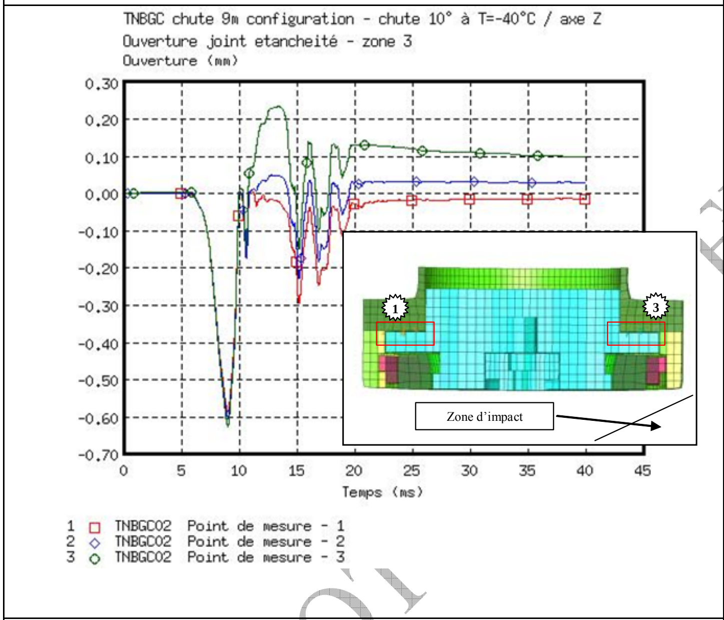
Figure 54 -Plug closing system with seal measurement zones



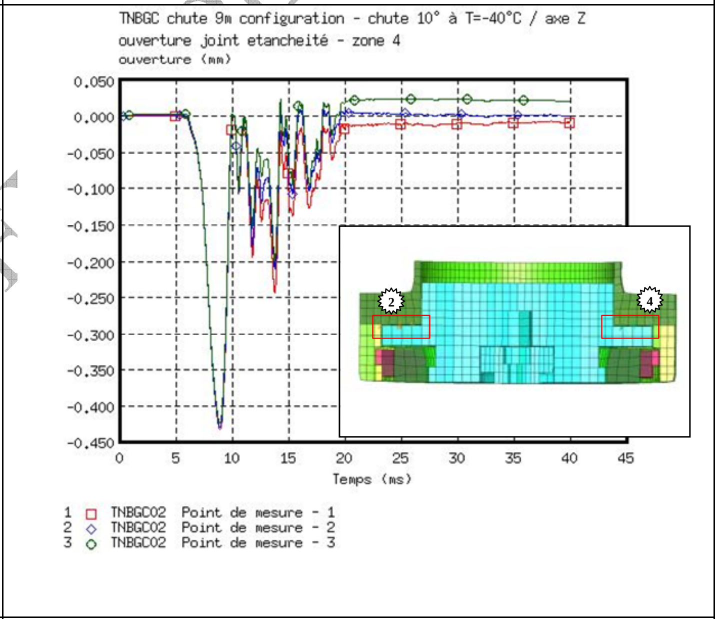
Sealing measurement zone N°1



Sealing measurement zone N°2



Sealing measurement zone N°3



Sealing measurement zone N°4

Figure 55 -Detachment of the seal (-40°C)

TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 1 Ouverture (mm) Temps (ms) Zone d'impact Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 1 Opening (mm) Time (ms) Impact zone Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis

Ouverture joint étanchéité - zone 2 Ouverture (mm) Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	Opening of the seal - zone 2 Opening (mm) Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 3 Ouverture (mm) Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 3 Opening (mm) Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Ouverture joint étanchéité - zone 4 Ouverture (mm) Zone d'impact Temps (ms) Point de mesure - 1 Point de mesure - 2 Point de mesure - 3	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Opening of the seal - zone 4 Opening (mm) Impact zone Time (ms) Measuring point - 1 Measuring point - 2 Measuring point - 3

Temperature ambiante (°C)	20	-40
angle-chute par rapport l'axe Z (°)	10	10
décélération (norme) du chargement (g)	503,6	494,9
taux de compression du joint d'etanchéité_zone4-3	21,3%	21,3%
taux de compression du joint d'etanchéité_zone4-2	21,2%	21,2%
taux de compression du joint d'etanchéité_zone4-1	21,2%	21,2%
taux de compression du joint d'etanchéité_zone3-3	18,3%	18,3%
taux de compression du joint d'etanchéité_zone3-2	18,7%	18,6%
taux de compression du joint d'etanchéité_zone3-1	18,9%	18,9%
taux de compression du joint d'etanchéité_zone1-1	20,3%	20,7%
taux de compression du joint d'etanchéité_zone1-2	20,8%	21,3%
taux de compression du joint d'etanchéité_zone1-3	20,9%	21,5%
taux de compression du joint d'etanchéité_zone2-3	21,2%	21,1%
taux de compression du joint d'etanchéité_zone2-1	21,3%	21,3%
taux de compression du joint d'etanchéité_zone2-2	21,2%	21,2%
taux de compression dynamique(minimum)	18,3%	18,3%
taux de compression dynamique moyen	20,4%	20,5%

Temperature ambiante (°C)	20	20
angle-chute par rapport l'axe Z (°)	10	30
taux de compression residuel - zone4-3	27,8%	27,8%
taux de compression residuel - zone4-2	27,5%	27,5%
taux de compression residuel - zone4-1	27,4%	27,4%
taux de compression residuel - zone3-3	29,3%	28,9%
taux de compression residuel - zone3-2	27,9%	27,9%
taux de compression residuel - zone3-1	27,3%	27,3%
taux de compression residuel - zone1-1	27,7%	27,7%
taux de compression residuel - zone1-2	27,5%	27,5%
taux de compression residuel - zone1-3	27,5%	27,5%
taux de compression residuel - zone2-3	27,3%	27,3%
taux de compression residuel - zone2-1	27,9%	27,8%
taux de compression residuel - zone2-2	27,5%	27,5%
taux de compression residuel - mini	27,3%	27,3%

Figure 56 -Overviews of compression of the seal per measurement zone and comparison with results obtained at T = -40°C

Température ambiante (°C)	Ambient temperature (°C)
angle-chute par rapport l'axe Z	fall angle from the z axis
décélération (norme) du chargement (g)	deceleration (standard) of the load (g)
taux de compression du joint d'étanchéité_zone 4-3	level of compression of the seal - zone 4-3
taux de compression du joint d'étanchéité_zone 4-2	level of compression of the seal - zone 4-2
taux de compression du joint d'étanchéité_zone 4-1	level of compression of the seal - zone 4-1
taux de compression du joint d'étanchéité_zone 3-3	level of compression of the seal - zone 3-3
taux de compression du joint d'étanchéité_zone 3-2	level of compression of the seal - zone 3-2
taux de compression du joint d'étanchéité_zone 3-1	level of compression of the seal - zone 3-1
taux de compression du joint d'étanchéité_zone 1-1	level of compression of the seal - zone 1-1
taux de compression du joint d'étanchéité_zone 1-2	level of compression of the seal - zone 1-2
taux de compression du joint d'étanchéité_zone 1-3	level of compression of the seal - zone 1-3
taux de compression du joint d'étanchéité_zone 2-3	level of compression of the seal - zone 2-3
taux de compression du joint d'étanchéité_zone 2-1	level of compression of the seal - zone 2-1
taux de compression du joint d'étanchéité_zone 2-2	level of compression of the seal - zone 2-2
taux de compression dynamique (minimum)	level of dynamic compression (min.)
taux de compressions dynamique moyen	level of mean dynamic compression

Température ambiante (°C)	Ambient temperature (°C)
angle-chute par rapport l'axe Z	fall angle from the z axis
taux de compression residuel - zone 4-3	level of residual compression - zone 4-3
taux de compression residuel - zone 4-2	level of residual compression - zone 4-2
taux de compression residuel - zone 4-1	level of residual compression - zone 4-1
taux de compression residuel - zone 3-3	level of residual compression - zone 3-3
taux de compression residuel - zone 3-2	level of residual compression - zone 3-2
taux de compression residuel - zone 3-1	level of residual compression - zone 3-1
taux de compression residuel - zone 1-1	level of residual compression - zone 1-1
taux de compression residuel - zone 1-2	level of residual compression - zone 1-2
taux de compression residuel - zone 1-3	level of residual compression - zone 1-3
taux de compression residuel - zone 2-3	level of residual compression - zone 2-3
taux de compression residuel - zone 2-1	level of residual compression - zone 2-1
taux de compression residuel - zone 2-2	level of residual compression - zone 2-2
taux de compression residuel - mini	level of residual compression - min.

The above tables demonstrate that the levels of both dynamic and residual compression are adequate to guarantee plug seals and are almost identical to compression at 20°C.

The same applies to the zones subjected to the most stresses.

3.3.4.6. Translation of the seal on the cover

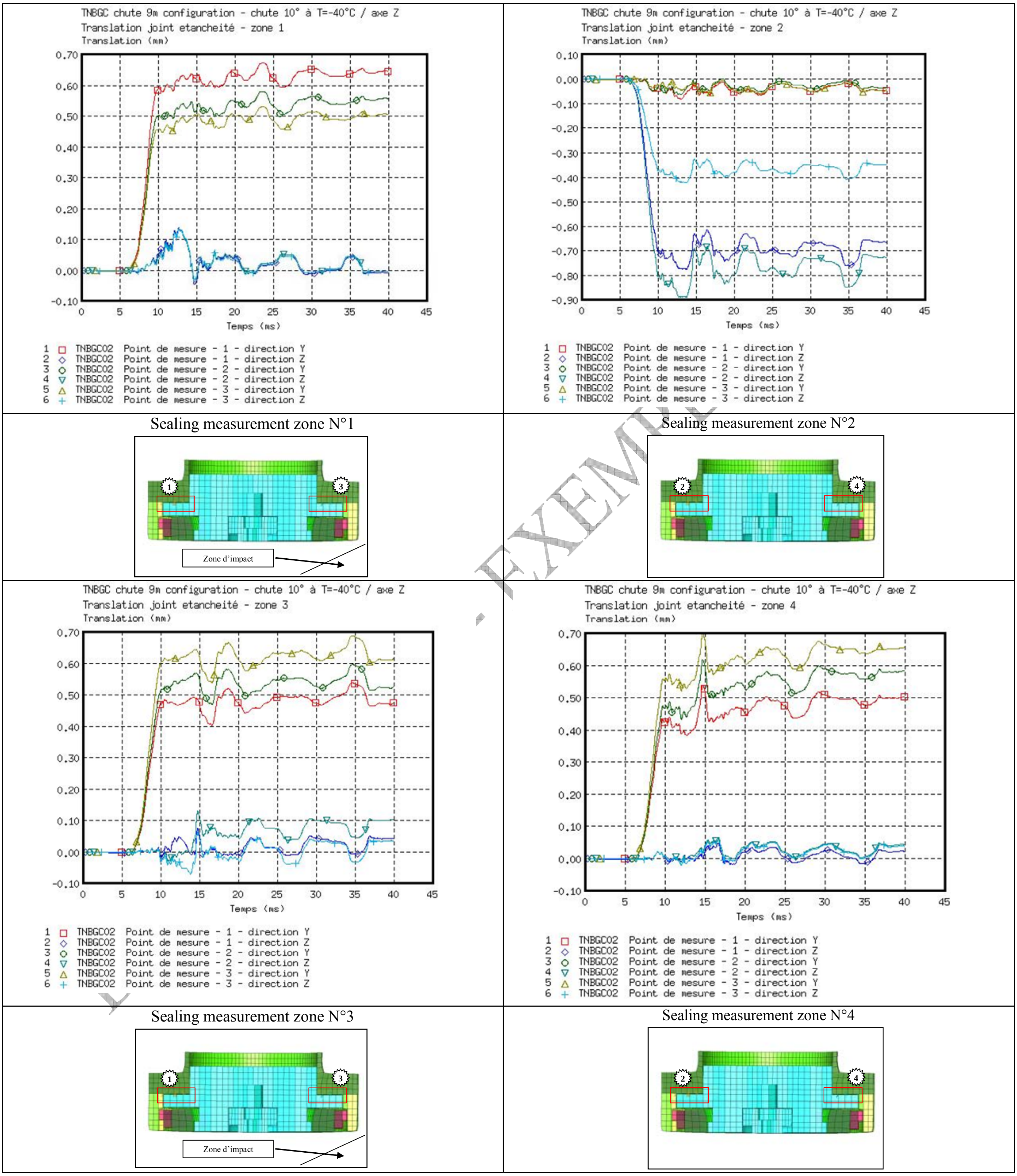
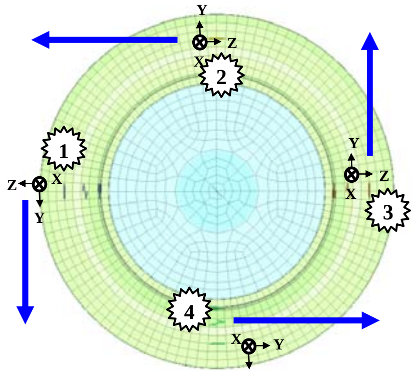


Figure 57 -Transversal displacement of the seal (-40°C)



TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 1 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 1 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 2 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 2 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
Zone d'impact	Impact zone
TNBGC chute 9m configuration - chute 10° à T=20°C / axe Z Translation joint étanchéité - zone 3 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	TNBGC 9m fall configuration - 10° fall at T=20°C / z axis Translation of the seal - zone 3 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
TNBGC chute 9m configuration - chute 10° à	TNBGC 9m fall configuration - 10° fall

T=20°C / axe Z Translation joint étanchéité - zone 4 Translation (mm) Temps (ms) Point de mesure -1 - direction Y Point de mesure -1 - direction Z Point de mesure -2 - direction Y Point de mesure -2 - direction Z Point de mesure -3 - direction Y Point de mesure -3 - direction Z	at T=20°C / z axis Translation of the seal - zone 4 Translation (mm) Time (ms) Measuring point - 1 - direction Y Measuring point - 1 - direction Z Measuring point - 2 - direction Y Measuring point - 2 - direction Z Measuring point - 3 - direction Y Measuring point - 3 - direction Z
Zone d'impact	Impact zone

The above measurements revealed that the plug rotated anti-clockwise slightly, which would have no effect on sealing (cf. above figure). These rotations are initiated due to the underestimation of the stiffness of springs. They do not therefore actually exist in reality.

4. Conclusion

The test plan demonstrated that an angle of 10° from vertical represented the most detrimental fall angle configuration in terms of plug detachment. Modelling results at -40°C and 20°C demonstrate that the crushing of the seals of the cover and Staubli plug are identical and remain adequate to seal the package (at least 18.3% for the level of dynamic compression) as the acceptable limit is 15%. This reduction in crushing only occurs for short periods (maximum of 4ms). In addition, after the fall, the level of compression of the seal is close to the initial level of 27.5%

The reduction of the temperature to -40°C had almost no effect on the results obtained at 20°C. We even noted a decrease in the force of ground/package contact of 36kN and a decrease in deceleration of 10G. At an ambient temperature of -40°C, the mechanical properties of wood stiffen and improve absorption at initial impact. Initial deceleration caused by the crushing of the wood at -40°C is slightly higher, i.e. the main section is slowed down slightly more. Maximum deceleration of the centre of gravity is due to initial deformation of the steel corner of the package when the wood achieves maximum yield in both cases. The results obtained for both temperatures are globally similar to the low wood thickness subjected to stresses during the fall.

The detachment of the plug starts with the contact of the load and subsequently with the bending of the packages in all cases. The position of the load in its housing and rigidity appear to play a key role in the detachment of the plug: we used a detrimental configuration in our simulations:

- as the load is free to move radially within its containment. In addition, we considered the load as a single rigid steel block,
- and the stiffness in the closing system at clamp ring level was underestimated, leading to local detachment and overestimated rotations.

In view of these final remarks, we can conclude that the sealing of TN-BGC 1 packages is guaranteed after falls at an angle.

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CONTENTS

1 INTRODUCTION

The aim of the study is to check the mechanical resistance of package TN-BGC 1 to external pressure of 2 MPa.

2 calculations are carried out:

- an analytical calculation verifying the behaviour of the inner shell of the TN-BGC 1 in case of buckling,
- a digital calculation using a model of the cover and its connections to verify the containment of the radioactive material (cover seal) if external pressure is applied.

2 ASSUMPTIONS AND DATA

2.1 MATERIALS

The following table summarises the data used for package materials.

Material		Young's modulus	Poisson's ratio	Density
	symbol	E	ν	ρ
	Unit	Pa		Kg/m^3
Steels 304L and 30 CD 4		1.80E+11	0.3	7900
Aluminium		6.95E+10	0.33	2700
Neutron-absorbing resin		2.20E+10	0.3	1600
Balsa wood		2.30E+09	0.2	150
Poplar wood		1.20E+10	0.3	450
Neoprene rubber		2.00E+06	0.3	1000

The properties of the stainless steel 304L used for the container are shown below.

Stainless steel Z2 CN 18.10 (304L) Property	Symbol	Unit	**TEMPERATURE**			
			0°C	20°C	100°C	200°C
Density	ρ	Kg/m^3		**7930**		
Elasticity module	E	103 MPa	198.5	**197**	191.5	184
Poisson's ratio	ν	-		**0.3**		
Min. elastic limit	$R_{0,2\%}$	Mpa		**180**	145	118
Elastic limit at 1 lo	$R_{p,}$	Mpa		**215**	180	145
Min. limit at rupture	Rm	Mpa		**483**	450	404

The properties of the aluminium alloy 6082 T6 used for the cage are shown below.

Aluminium alloy 6082 T6 property	Symbol	Unit	**TEMPERATURE**					
			0°C	20°C	100°C	150°C	204°C	250°C
Density	ρ	Kg/m^3		2700				

Elasticity module	E	103 MPa		69.5				
Poisson's ratio	v	-		0.33				
Elastic limit	$R_{0,2\%}$	Mpa		280	265	240	105	
Min. limit at rupture	Rm	Mpa		315	300	220	130	

2.2 ACCEPTANCE CRITERIA

The stresses calculated are acceptable if the value is less than the elastic limit of the material. A welding coefficient of 0.7 is applied to weld zones.

Reference temperature is equal to 150°C, and for steel 304L, the elastic limit is equal to 1132.5 MPa (linear interpolation). The study is carried out using CODAP Chapter C4.1.

3 ANALYSIS OF RESISTANCE TO PRESSURE

Pressure of 2 MPa (20 bar) is applied to the container. The following calculations enable the buckling resistance of the inner shell to be checked together with the mechanical resistance of the cover.

3.1 BUCKLING OF THE INNER SHELL

This study is carried out using CODAP C4.1. Only the study of the inner wall is carried out to establish a tolerance interval for mechanical resistance.

The shell is defined on the basis of the following data:

e: acceptable thickness of the cylindrical containment = 6 mm,

De: external diameter = 192 mm,

L: length of the cylinder to which the buckling forces apply = 1487 mm.

Nomographs are used and input data is defined on the basis of the following values:

L/De=7.74,

De/e = 32.

Coefficient A is determined on the basis of these two values: A = 0.0014.

Coefficient B is determined on the basis of A for the material used (stainless steel 304L) and the operating

temperature. Maximum temperature is equal to 150°C (Cf. chapter 3.6).

I.e. B = 54.

The acceptable external pressure in MPa (or internal reduction in pressure) is determined using the formula

$$Pa = 4BK/3 \times De/e$$

K is a coefficient equal to 1.35 in exceptional operating conditions.

I.e. Pa = 3 MPa

Maximum acceptable external pressure as per CODAP (3 MPa) is higher than the external pressure of 2 MPa.

CODAP buckling criteria are satisfied in exceptional operating conditions.

3.2 COVER WITH EXTERNAL PRESSURE

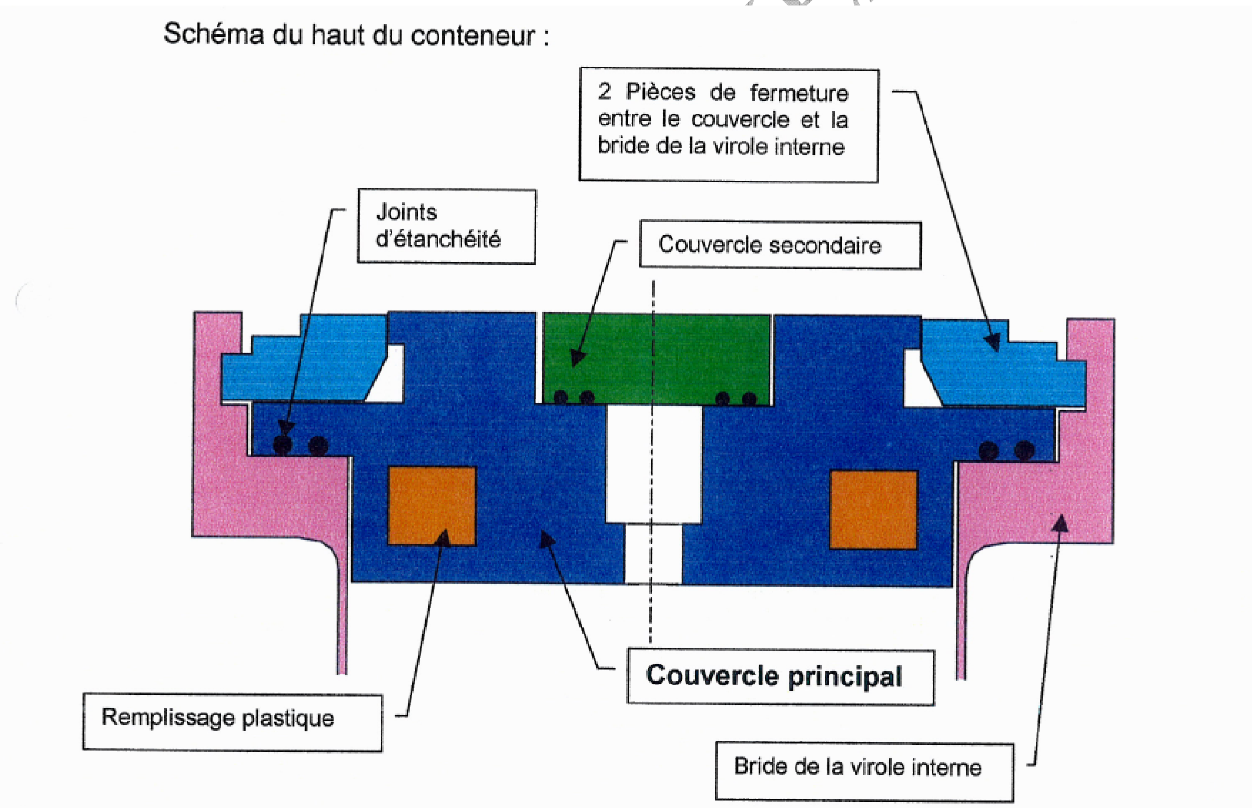


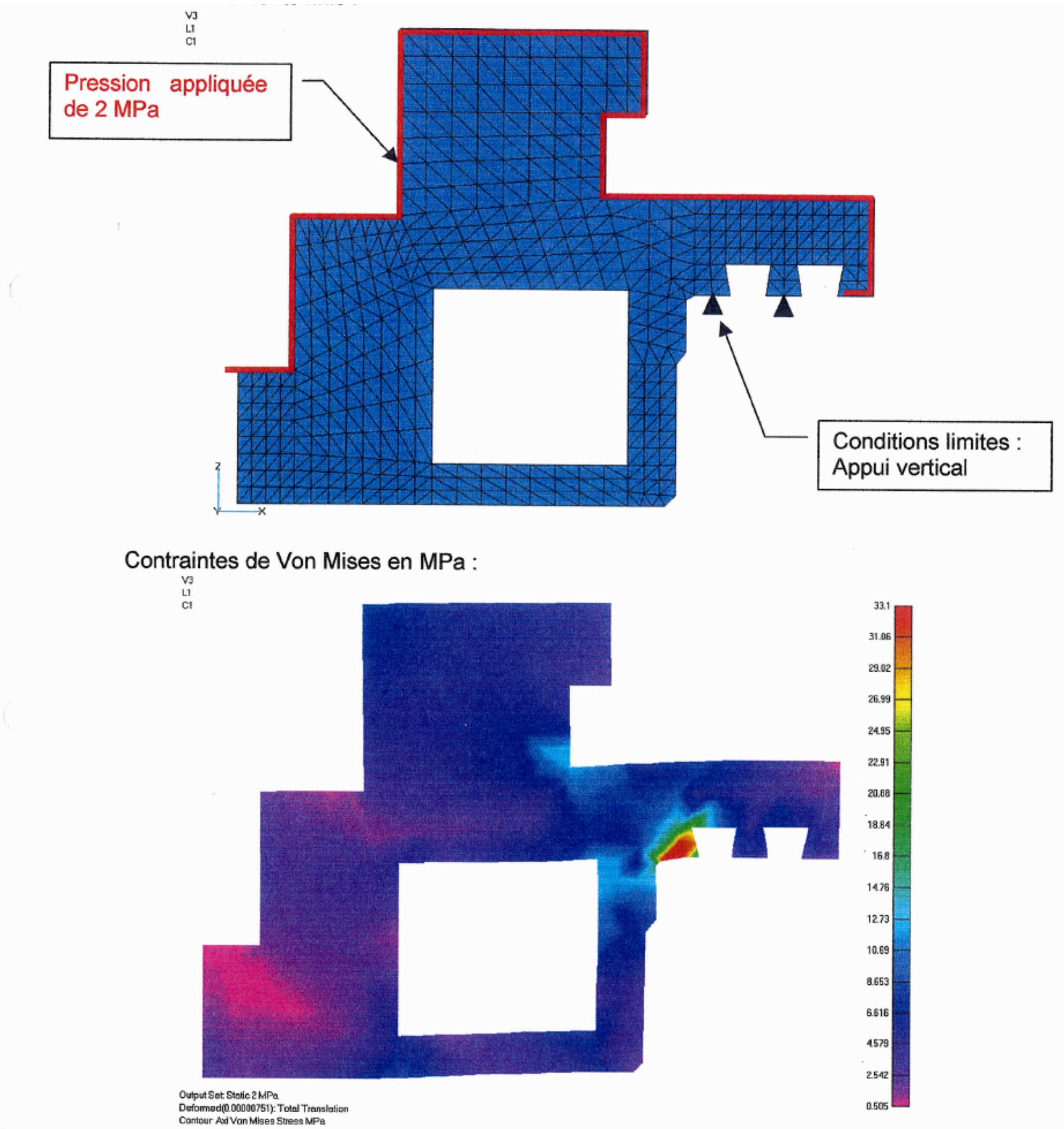
Schéma du haut du conteneur	Diagram of the container top
2. Pièces de fermeture entre le couvercle et la bride de la virole interne	2 closing parts between the cover and the flange of the internal shell
Joints d'étanchéité	Seals
Couvercle secondaire	Secondary cover
Couvercle principal	Main cover
Remplissage plastique	Plastic filling
Bride de la virole interne	Flange of the internal shell

The external pressure is applied until the seal only applies forces to the main cover. The secondary cover has far less surface area and is subjected to low loads. The 2 closing parts are subjected to hydrostatic pressure covering the entire external surface and therefore applying zero stresses on the cover. The inner shell was studied previously. For modelling, only the main cover is shown as an axisymmetric component.

With regard sealing, external pressure tends to compress the seals, improving the sealing of the package.

The following figures show the modelling and results for an external pressure of 2 MPa.

Model of the finished components



Pression appliquée de 2 MPa Conditions limites : Appui vertical Constraintes de Von Mises en MPa	Pressure of 2 MPa applied Limits: vertical pressure Von Mises stresses in MPa

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Maximum shear stress (33 MPa) is less than the elastic limit of the 304L stainless steel at 150°C (132.5 MPa), which corresponds to a safety coefficient of 4.

4 CONCLUSION

Mechanical resistance of package TN-BGC 1 during regulatory immersion to a depth of 200m is therefore guaranteed.

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Attachment 3.1-7: resistance of handling devices

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This chapter demonstrates the resistance of handling devices for package TN-BGC 1

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LIST OF FIGURES

1 INTRODUCTION

This note aims to analyse the resistance of package components during handling.

The calculations carried out mainly concern the attachment points between the main section of the cage and handling points.

2 DESCRIPTION OF THE PACKAGE

The description of the cage, attachment points of the main section on the cage and handling points on the cage are included in chapter 2.

Figures 3.1-7.1 and 3.1.7.2 show block diagrams of the overall unit.

2.1 MASSES

The total mass of the package when loaded will be conservatively assumed as a maximum of 400 kg distributed as follows:

- main section + content and cover: 370 kg
- the cage: 30 kg

The centre of gravity of the package is located approximately 1020 mm from the bottom of the cage if the package is vertical and 300 mm if the package is horizontal.

2.2 MATERIALS

The mechanical properties of the materials of the main section and cage are indicated in chapter 2.

Comment:

The structural components of the cage are welded together, therefore, the aluminium will lose part of its mechanical properties in welding. Welding sections are determined to maintain mechanical resistance equivalent to that of the tube for tube junctions.

However, the elastic limit applied for tube junctions near to the weld is identical to the limit for the corresponding aluminium when annealed to ensure conservative results.

3 STRESSES

The package is designed to be handled vertically or horizontally.

If the package is vertical, handling is possible (figure 3.1-7.3):

- either using four-strand slings, at an angle equal to or less than 45° from vertical,
- or using a forklift truck able to handle the package via the cage at one of two levels.

If the package is horizontal, handling is possible using straps around the cage.

4 RESISTANCE DURING HANDLING

Handling of the package either horizontally and vertically is considered in this paragraph.

Stresses obtained for the different points on the package (main section and cage) in this note, are determined for accelerations of 2g in handling conditions.

This acceleration of 2g corresponds to an envelope of values indicated in reference rules [3]. For the calculation of lifting frames, these rules recommend a maximum safety coefficient of 1.5 for the elastic limit and a dynamic amplification coefficient of 1.3 for overhead cranes and standard gantry cranes. The combination of these two factors will therefore give 1.3 x 1.5 = 1.95 rounded up to 2.

If the package is horizontal, straps are passed around the cage.

In this case, cage-main section liaison stresses are covered by a study corresponding to transport conditions (attachment n°3.1-8).

This paragraph describes the resistance of the cage during handling.

4.1 LIFTING USING SLINGS

If the package is vertical, handling is possible using a four-strand sling.

Attachment points correspond to the four oblique horizontal bars in the upper frame. The total load applied is F = 3 924 N corresponding to the total mass of the package (m = 400 kg).

We assume that the total load is supported by two of the four slings.

This load is therefore distributed to the two sling attachment points. Sling angle remains equal to or lower than 45°.

The force applied by each sling is equal to:

$$P = \frac{F\sqrt{2}}{2} = 2\,774{,}8\,N$$

4.1.1 Modelling method

Modelling of cages constructed on the basis of option 1 (see plan in appendix 9990-118 attached with chapter 2) is carried out using a calculation program enabling the consideration of 2D or 3D beam structures.

This program is known as TEDEL and is a structural calculation program integrated in the CASTEM [1] system developed by CEA-DEMT.

For cages constructed as per option 2, maximum stresses were proved to be less than those calculated for option 1.

Meshing representing the structures studied is conducted by the program, integrating the geometry of the structure defined on the basis of its nodes and elements, application points for loads and the sections of the tubes in the structure.

The program will perform calculations integrating the values of active forces, transversal inertia moments (Iy & Iz), twisting moment (Io) and Young's modulus (E), Coulomb' modulus (G) and Poisson's ratio () for the material in question.

The results obtained are given for each component within the structure defined based on nodes and the coordinates of the orthnormal local marker for each tube.

The x axis is assigned to the longitudinal axis of the tube for each local marker of each tube.

The y and z axes are perpendicular to the x axis.

The following results were obtained in addition to displacement and for each local marker:

- the final bending moments for each structural element (My, Mz),
- the twisting moment (Io),
- compression forces along the longitudinal axis of the beam (SB),
- cutting forces (T_y and T_z),
- mean shear stresses (y and z).

The program clearly indicates displacements for each node in the structure.

All tubes are 30 x 30 x 2 and have a section S = 224 mm².

Transversal inertia moments for the local marker are Iy=Iz=29415 mm^4.

Twisting inertia moment is Io = 58 830 mm

Bending inertia modules are therefore:

$$\frac{I_y}{v} = \frac{I_z}{v} = 1961\,mm^3$$

4.1.2 Results

The force applied P is broken down on the basis of three components running parallel to the main orthonormal axes used for the geometrical definition of the structure, i.e.:

$$Px = Py = \frac{P}{2} = 1387{,}4\,N \text{ and } Pz = \frac{F}{2} = 1962\,N$$

1) <u>The sides of the frame</u>

A) The highest forces in the side tubes are located at the junctions with the oblique sling tubes.

The intensity of the maximum final stress is 114 MPa.

With cages constructed as per option 2, the addition of two vertical tubes under the sides of the frame, connected to a second horizontal tube, will increase the rigidity of the sides of the frame, which can only reduce stresses at junctions with sling tubes.

B) The intensity of the highest stress in terms of welding is located at the junction of the sides of the frame and remains less than 31 MPa.

With cages constructed as per option 2, handling forces, which tend to affect the angles between the frame sides (diagonal deformation), are transferred to two horizontal tubes per frame side instead of one. Stresses in welds are therefore less than those calculated for cage option 1.

2) <u>Oblique sling tubes</u>

The highest forces on oblique sling tubes are located at sling attachment points.

The intensity of the stress at this point is less than 111 MPa.

With cages constructed as per option 2, frame sides are more rigid and stresses at sling attachment points are hence reduced.

4.2 HANDLING USING A FORKLIFT TRUCK

If the package is vertical, handling is possible using a forklift truck (figure 3.1-7.5).
The cage is equipped with two handling levels (lower and intermediate), which may be used by a forklift truck.

The most detrimental configuration involves the cage constructed as per option 1, which is integrated in calculations.

4.2.1 Lower lifting corners

The most detrimental configuration for fork insert corners arises if the cage tilts sideways during handling using the

lower level, as the entire load will be applied to one single corner.

The load applied to the corner is the total load, F = 3 924 N.

A) The corner will be subject to bending forces.

The corner is assumed to be embedded at the two ends on the sides corresponding to the frame and the load distributed over the entire length.

With embedding, the corner is welded to both the frame and uprights. The overall inertia in this location is sufficient to ensure that bending stresses are insignificant)

The bending moment at the centre of the corner is equal to:

$$M_f = \frac{F.L}{24} = \frac{3924.540}{24} = 88\,290\,mm.N$$

The inertia module of a corner of 40 x 40 x 4 =

$$\frac{I}{v} = 1616\,mm^3$$

Bending stresses are equal to:

$$\sigma_1 = \frac{88\,290}{1616} = 54{,}7\,MPa$$

B) The horizontal section of the corners to which the loads are applied are subjected to bending forces. Each horizontal section is assumed to be embedded in the vertical section.

It is assumed that the force is applied to the end of the horizontal section for corners with a width of 60 mm to ensure conservative results.

The bending moment per unit for embedding is equal to:

$$M_f = \frac{F}{L}.\frac{1}{2} = \frac{3924.56}{540.2} = 203{,}4\,mm.N/mm$$

The inertia module per corresponding unit is equal to:

$$\frac{I}{v} = \frac{1.4^2}{6} = 2{,}66\,mm^3$$

Bending stresses are equal to:

$$\sigma_2 = \frac{203{,}4}{2{,}66} = 76{,}5\,MPa$$

4.2.2 Lifting frames

The load is assumed to be punctual and applied to the two inner corners, to ensure conservative results.

The corresponding sides of the frame will be subject to bending forces.

The load on each point of the crossbeam is equal to:

$$P = \frac{F}{4} = \frac{3924}{4} = 981\,N$$

The two ends of crossbeams are assumed to be embedded.

Maximum bending moment for embedding is equal to:

$$M_f = P\left\{\left(\frac{l_1 . l_2^{\,2}}{L^2}\right) + \left(\frac{l_1^{\,2} . l_2}{L^2}\right)\right\}$$

$$M_f = 981 . \left\{\left(\frac{100.440^2}{540^2}\right) + \left(\frac{100^2 .440}{540^2}\right)\right\}$$

Mf = 79 934 mm.N

Inertia module for the tube $\frac{I}{v} = 1916\,mm^3$

Bending stresses for welds are equal to:

$$\sigma_f = \frac{79934}{1961} = 40{,}8\,MPa$$

4.3 HORIZONTAL HANDLING

The calculation situation studied determines the resistance of the cage during horizontal handling. Two straps are passed around the cage and the package mass is supported by four slings. No location is reserved for the passage of the straps. In a worst case scenario, each strap can be placed against the centre of a beam for the cage.

In view of the structure of the cage, the most detrimental load and highest stresses are obtained by assuming:

- a beam with a length of l = 535 mm with simple supports (detrimental assumption),
- the load (1/4 of total mass) is applied to the centre of the beam,
- the beam is an aluminium upright of the cage with a section of 30 x 30 x 2.
- slings are located transversally in the vertical plane.

The weight applied to the centre of the beam is:

$$P = \frac{400}{4} . 9{,}81 = 981\,N$$

The inertia of a tube is $I = \frac{30^4 - 26^4}{12} = 29\,410\, mm^4$

The maximum bending moment at the centre of the beam is:

$$M_f = \frac{Pl}{4}$$

Mf = 131,210 mm.N

Maximum stresses are equal to:

$$\sigma = \frac{M}{I/15} = \frac{131210.15}{29\,410} = 67\,\text{MPa}$$

4.4 VERTICAL PACKAGE, ATTACHMENT SCREWS FOR MAIN SECTION ON THE CAGE

We assume that the main section is suspended on the four supports located in the middle of the main section to obtain conservative results (figure 3.1-7.6)

The load applied corresponds to the mass of the main section loaded and equipped with the upper cover (without the mass of the cage) i.e.:

F' = 370 x 9.81 = 3 630 N

4.4.1 Oblique vertical bars

The main section is suspended on four supports from the centre and the following traction load is applied to each oblique vertical bar:

$$P_t = \frac{F'\sqrt{2}}{4} = \frac{3630.\sqrt{2}}{4} = 1284\, N$$

The section of the S tube = 224 mm2.

Traction stresses are equal to:

$$\sigma_t = \frac{P_t}{S} = \frac{1284}{224} = 5{,}8\, MPa$$

4.4.2 Vertical uprights

Each vertical upright is subjected to bending loads due to the horizontal component (H).

The load applied is equal to:

$$H = \frac{F'}{4} = \frac{3630}{4} = 908\,N$$

Both ends of the upright are assumed to be embedded (at frame level).

Maximum bending moment for welds is equal to:

$$M_f = H.\frac{l_1.l_2{}^2}{L^2} = \frac{908.236.299^2}{535^2}$$

Mf = 66,932 mm.N

Inertia module for the tube diagonal:

$$\frac{I'}{v} = 1697\,mm^3$$

Bending stresses are equal to:

$$\sigma_f = \frac{66932}{1697} = 39{,}5\,MPa$$

In parallel, compression is applied to part of the upright due to the vertical component:

$$V = \frac{F'}{4} = 908\,N$$

The section of the S tube = 224 mm2.

Compression stresses are equal to:

$$\sigma_c = \frac{908}{224} = 4{,}1\,\text{MPa}$$

The intensity of stresses are equal to:

I = f + c = 39.5 + 4.1 = 43.6 MPa

4.4.3 Main section attachment supports

Attachment supports in the form of a flat "U" with a thickness e = 3 mm, forming a support base with two uprights. The supports are welded to distribution plates of the same thickness.

The main section is assumed to be maintained exclusively by the four centre supports.

The load applied P is equal to V = 908 N.

The "U" support base for dimensions, length a = 30 mm and width b = 20 mm.

The base is subjected to a bending load and is assumed to be embedded on three sides with the load distributed over the entire surface.

Table 26, table l0a of [2], includes formula for the calculation of stress.

Maximum stresses are equal to:

$$\sigma_b = \frac{B_1 q b^2}{e^2}$$

with unit load q = $\frac{908}{30 \, x \, 20} = 1{,}52 \, \text{MPa}$

and coefficient B1 = 0.727 (for

$$\sigma_b = \frac{0{,}727 \text{ x } 1{,}52 \text{ x } 20^2}{3^2} = 49{,}2 \text{ MPa}$$

The base is maintained by the two uprights of the "U".

The load applied is equal to:

$$V' = \frac{V}{2} = \frac{908}{2} = 454 \ N$$

The uprights of the "U" are in triangle format with width 1 = 20 mm, height = 20 mm, thickness = 3 mm and are subjected to bending loads.

One end of uprights are assumed to be embedded with distribution of the load.

The bending moment is equal to:

$$M_f = \frac{V.1}{2} = \frac{454.20}{2} = 4540 \text{ mmN}$$

The corresponding inertia module is equal to:

$$\frac{I}{v} = \frac{3.20^2}{6} = 200 \, mm^3$$

Bending stresses are equal to:

$$\sigma_f = \frac{4540}{200} = 22{,}7 \, MPa$$

5 CONCLUSIONS

The stresses calculated at the different points on the package (main section and cage) remain less than the elastic limit for accelerations of 2g in handling conditions. The resistance of the package has therefore been demonstrated.

6 REFERENCES

[1] : CASTEM system - TEDEL program - User manual, August 1980.

[2] : Formulas for stress and strain - ROARK and YOUNG - 5e edition 1975.

[3] : Rules for the calculation of lifting devices - Fédération Européenne de la manutention (Europeanhandling federation) - Section I - Heavy lifting and handling devices 2nd edition - December 70 and later amendments.

FIGURE 3.1-7.: PACKAGE - STRAIGHT SECTION

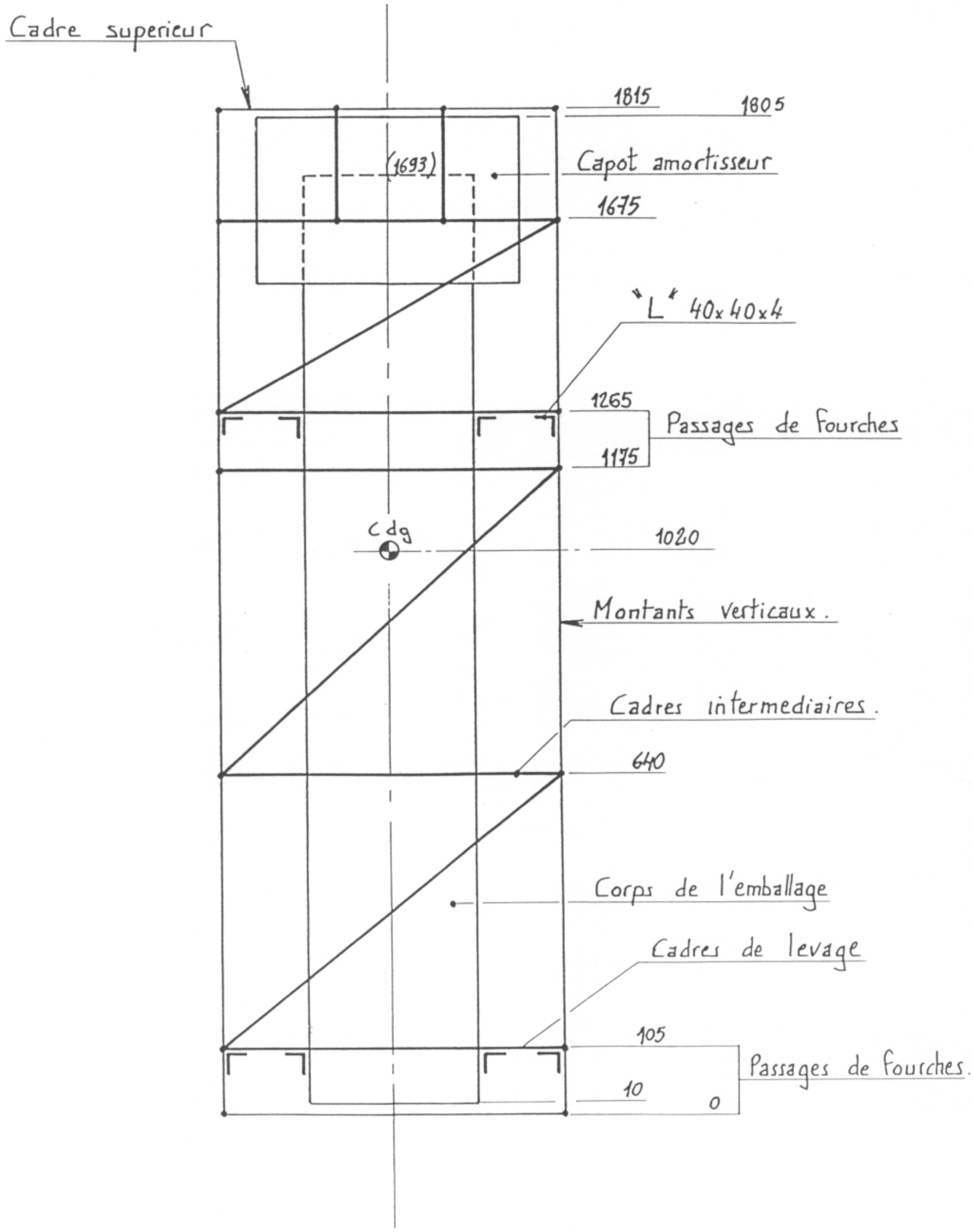


FIGURE 3.1-7.1: PACKAGE - DIAGONAL SECTION

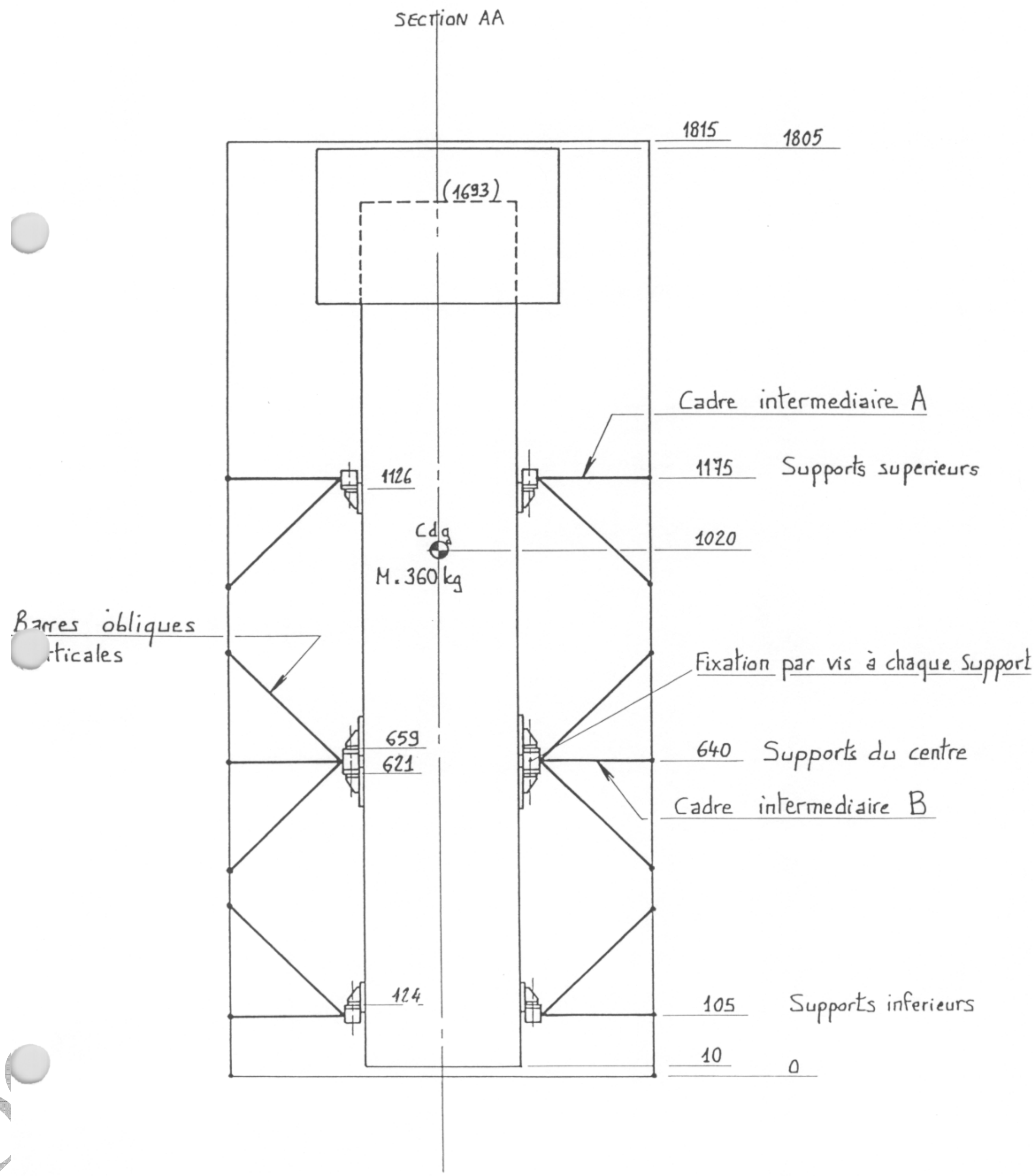
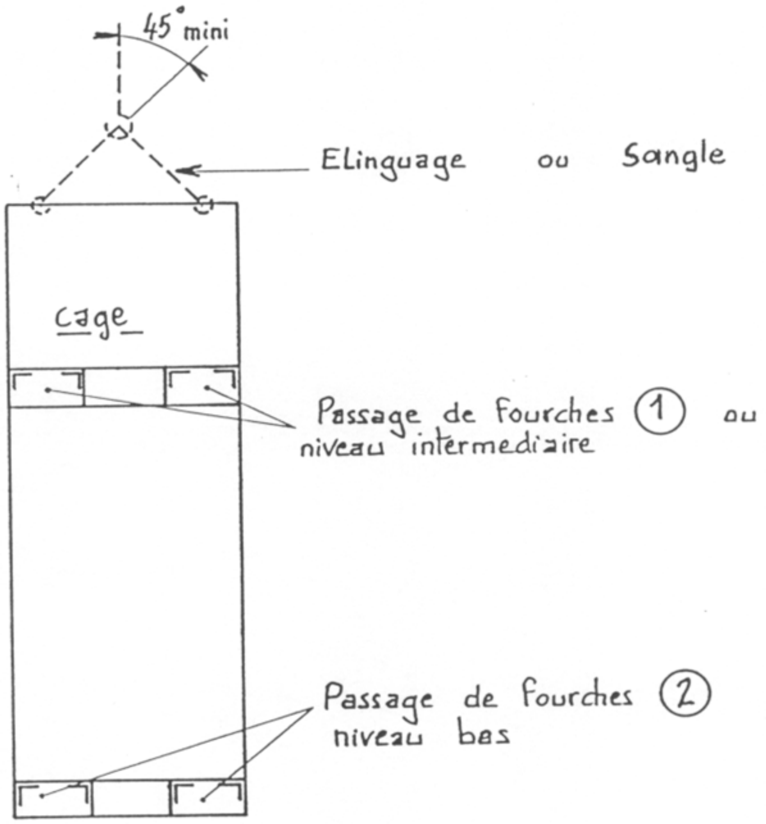


FIGURE 3.1-7.2: HANDLING - VERTICAL PACKAGE



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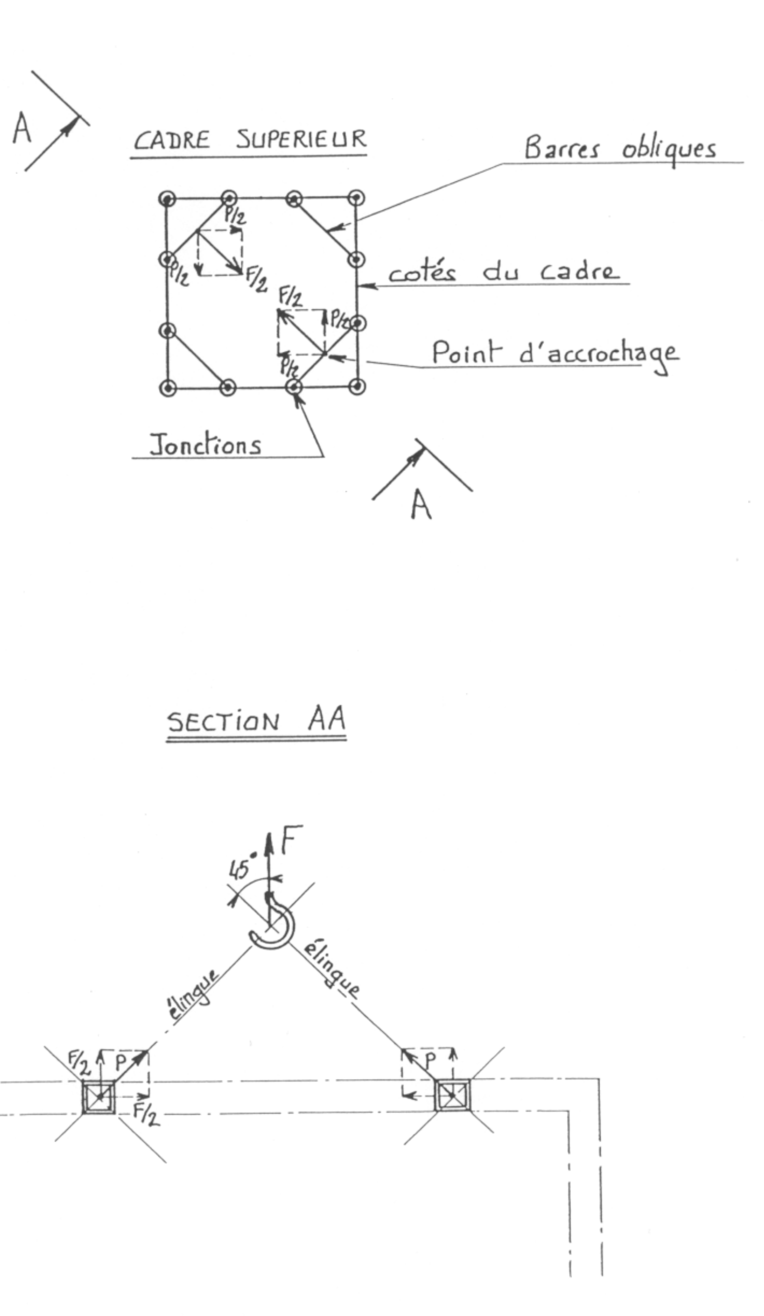
Department of Installations and Packaging projects
CEA Transport package service

FIGURE 3.1-7.3: SLING HANDLING - VERTICAL PACKAGE



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Industrial and commercial public service
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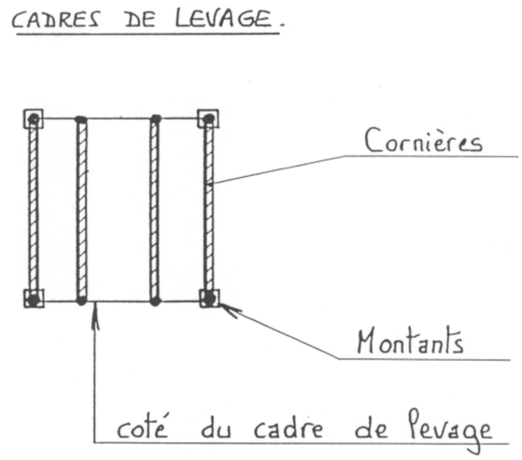
FIGURE 3.1-7.4: FORKLIFT TRUCK HANDLING - VERTICAL PACKAGE



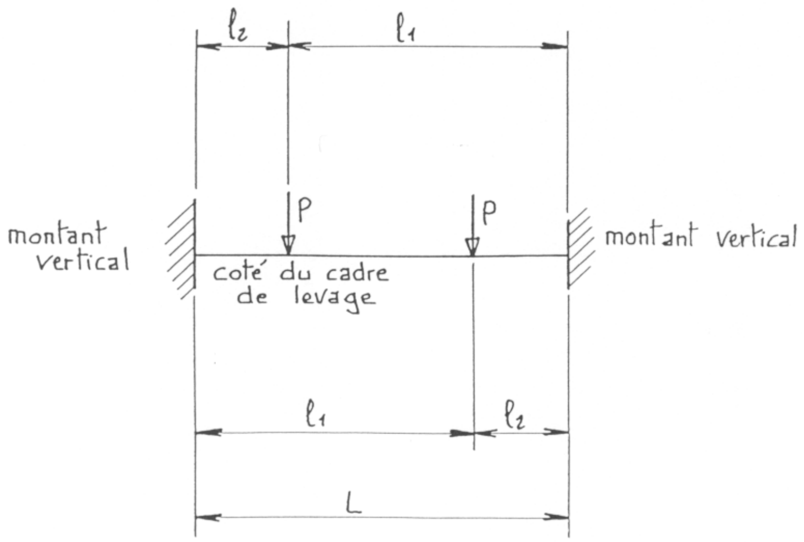
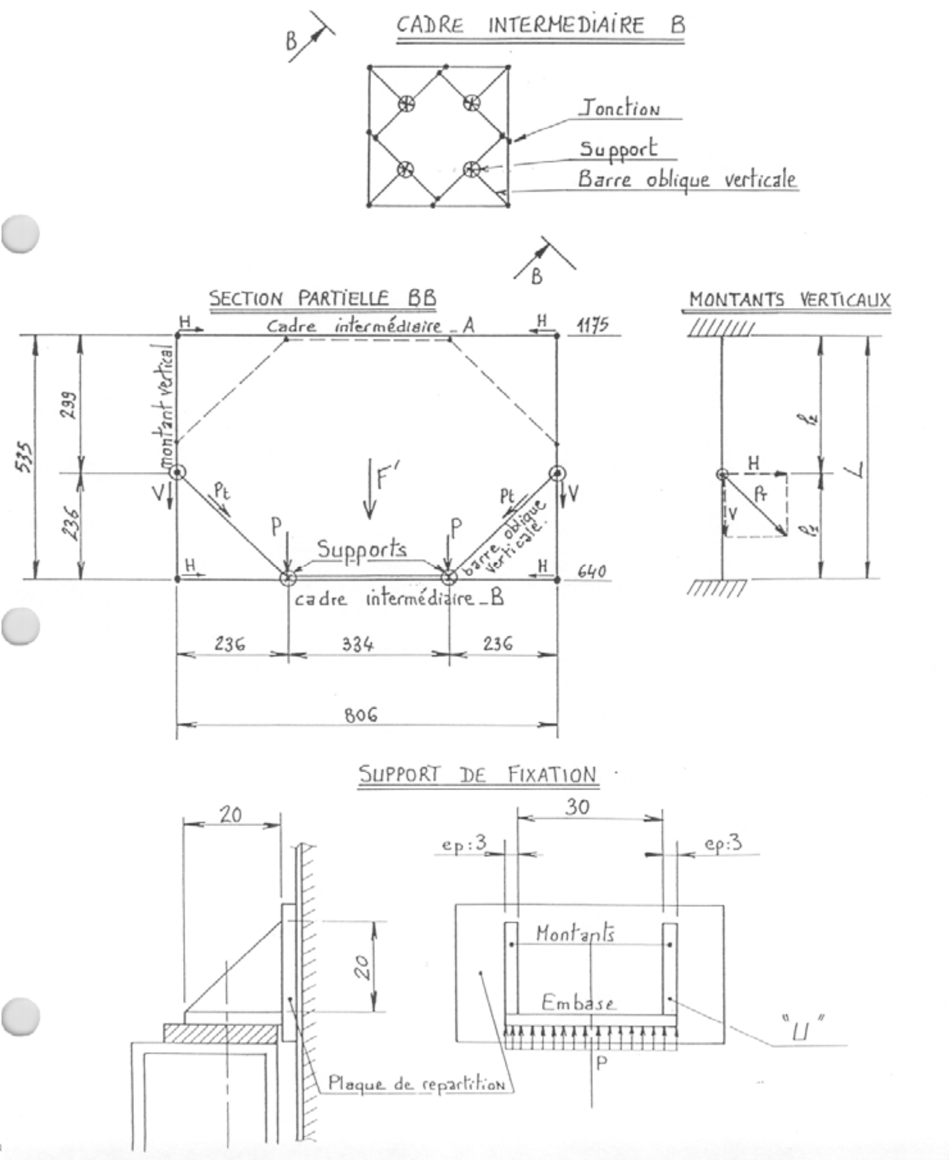


FIGURE 3.1-7.5: SUSPENSION OF THE MAIN SECTION IN THE CAGE - VERTICAL PACKAGE



[images] :

Page 14	Page 14
Cadre supérieur	Upper frame
Capot amortisseur	Damper cover
Passages de fourches	Fork inserts
Montants verticaux	Vertical uprights
Cadres intermédiaires	Intermediate frames

Corps de l'emballage Cadres de levage Passages de fourches	Main package section Lifting frames Fork inserts
Page 15 Section AA Barres obliques verticales Cdg Cadre intermédiaire A Supports supérieurs Fixation par vis à chaque support Supports du centre Cadre intermédiaire B Supports inférieurs	Page 15 Section AA Oblique vertical bars CoG Intermediate frame A Upper supports Screw attachment to each support Central supports Intermediate frame B Lower supports
Page 16 45° mini Cage Elinguage ou sangle Passage de fourches ou niveau intermédiaire Passage de fourches niveau bas	Page 16 min. 45° Cage Sling or strap Fork inserts or intermediate level Low-level fork inserts
Page 17 Cadre supérieur Barres obliques cotés du cadre Point d'accrochage Jonctions Section AA élingue élingue	Page 17 Upper frame Oblique bars frame sides Attachment points Junctions Section AA sling sling
Page 18 Cadres de levage Cornières Montants coté du cadre de levage montant vertical coté du cadre de levage montant vertical	Page 18 Lifting frames Corners Uprights lifting frame side vertical upright lifting frame side vertical upright
Page 19 Cadre intermédiaire Jonction support Barre oblique verticale Montants verticaux Section partielle BB Cadre intermédiaire A montant vertical Supports cadre intermédiaire B barre oblique verticale Support de fixation	Page 19 Intermediate frame Support junction Oblique vertical bar Vertical uprights Partial section BB Intermediate frame A vertical upright Supports intermediate frame B oblique vertical bar Attachment support

Montants Embase Plaque de répartition	Uprights Base Distribution plate

Reference: 299E05W03
17 August 2005

CEA CADARACHE

MECHANICAL STUDIES OF THE SECURING OF PACKAGE TN/BGC1 - COMBINED ACCELERATIONS

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Title:. Mechanical studies of the package TN/BGC1 - Combined accelerations

Customer	CEA CADARACHE
For the attention of	Mr. Vincent PAUTROT
DEMA reference	299E05W03 ind A
Author	Pascal VERNAY

Summary:

Five securing studies with acceleration combinations and four types of transport as per ref. {2} were carried out:

	Satisfied acceptance criteria				
Configuration n°	Road transport	Rail transport	Maritime transport	Air transport with net	Air transport without net
N°1: 1 vertical package	yes	no	yes	yes	
N°2: 2 vertical packages	yes	no	yes		
N°3: 4 vertical packages	no	no	no		
N°4: 3 horizontal packages	yes	yes			no
N°5: 1 horizontal package			yes	YES	yes

For configuration 1 (1 vertical package), acceptance criteria are satisfied for road and maritime transport (air transport not studied). Criteria are not satisfied for rail transport, but only for 2 MPa on fixation axes.

For configuration 2 (2 vertical packages), acceptance criteria are satisfied for road and maritime transport (air transport not studied). Criteria are not satisfied for rail transport.

For configuration 3 (4 vertical packages), acceptance criteria are not satisfied for road, rail and maritime transport (air transport not studied).

For configuration 4 (3 horizontal packages), acceptance criteria are satisfied for air transport with a protection net and criteria are not satisfied for air transport without a protection net (3 other types of transport not studied).

For configuration 5 (1 horizontal package), acceptance criteria are satisfied for all types of transport (road, rail, maritime and air transport with or without a net).

Calculations were conducted using the following software per finished element: MSC NASTRAN 2003 (FEMAP 8.2)

	Name	Date	Signature
Emitted by:	Pascal VERNAY	05/09/05	[signature]
Checked by:	Yves BRUN	06/09/05	[signature]

TABLE OF CONTENTS

I. PURPOSE OF THE CALCULATION MEMO.

The aim of the study is to check the resistance of the securing of the package TN-BGC 1 in several configurations for 4 types of transports (road, rail, maritime and air).

Sizing is analysed in compliance with the requirements of the IAEA in references {2} and {3}. Regulatory accelerations are combined in particular.

Results enable the appraisal of stresses in netting bars, stresses in the netting-container ties, stresses in M6 connecting screws and forces in straps.

II. ASSUMPTIONS AND DATA *11.1. Materials*

The following table summarises the data used for package materials.

Material		Young's modulus	Poisson's ratio	Density
	symbol	E	v	p
	Unit	Pa		Kg/m3
Steels 304L and 30 CD 4		1.80E+11	0.3	7900
Aluminium		6.95E+10	0.33	2700
Neutron-absorbing		2.20E+10	0.3	1600
Balsa wood		2.30E+09	0.2	150
Poplar wood		1.20E+10	0.3	450
Neoprene rubber		2.00E+06	0.3	1000

Source for the first 5 materials: CEA specifications TN/BGC 1
Source for rubber: MatWeb

The properties of the stainless steel 304L used for the container are shown below.

Steel Z2CN 18.10 (304L) Property	Symbol	Unit	Source	TEMPERATURE			
				0°C	**20°C**	100°C	200°C
Density Elasticity modulus Poisson's ratio Min. elastic limit Elastic limit at 1% Limit at min. rupture	p	Kg/m3			**7930**		
	E	• 103 MPa	1	198.5	**197**	191.5	184
	v	-			**0.3**		
	R0.2%	Mpa	2		**180**	145	118
	Rpi	Mpa	2		**215**	180	145
	Rm	Mpa	1		**483**	450	404

1 RCC-M ZI
2 Standard NF 100-88-3

The properties of the aluminium alloy 6082 in state T6 used for the t below. cage

Aluminium alloy 6082 state T6 Property	Symbol	Unit	Source	TEMPERATURE		
				0°c	**20°C**	100°C
Density	P	Kg/m3	1		**2700**	
Elasticity modulus	E	103 MPa	1		**69.5**	
Poisson's ratio	v	**-**	1		**0.33**	
Elastic limit L	^0,2%	Mpa	2		**260**	245
imit at rupture	Rm	Mpa	2		**310**	295

1 CEA specifications TN-BGC 1
2 NFEN 485-2

Comment: temperature properties for aluminium are determined on the basis of variations between 20°C and 100°C, using ALCAN data (PECHINEY).

11.2. Acceptance criteria

The stresses calculated are acceptable if the value is less than the elastic limit of the material. A welding coefficient of 0.7 is applied to weld zones. Weld beads are technically complex to create. We opted for a minimum coefficient of 0.7 plus an envelope for austenitic and ferritic materials only.

Reference temperature was taken as 80°C (temperature envelope in NDT). For aluminium alloy 6082, the elastic limit is equal to **249 MPa** (linear interpolation) in non-welded zones and **174 MPa** in welded zones. For steel 304L, the elastic limit is equal to **189 MPa** (linear interpolation from Rp1).

Attachment axes M6 at bracket level are selected from class A5-80 (elastic limit: 600 MPa), and are mainly subjected to shear stresses. Maximum shear stresses for axes must therefore be less than 360 MPa (0.6x640 MPa).

Straps are in polyester. The maximum tension calculated for the straps in the different configurations will be indicated in intermediate conclusions.

11.3. Initial data

The mass of the package with cage and cover is equal to 280 kg. The maximum total mass of the loaded package (with cage, cover and content) integrated in securing calculations is equal to 396 kg.

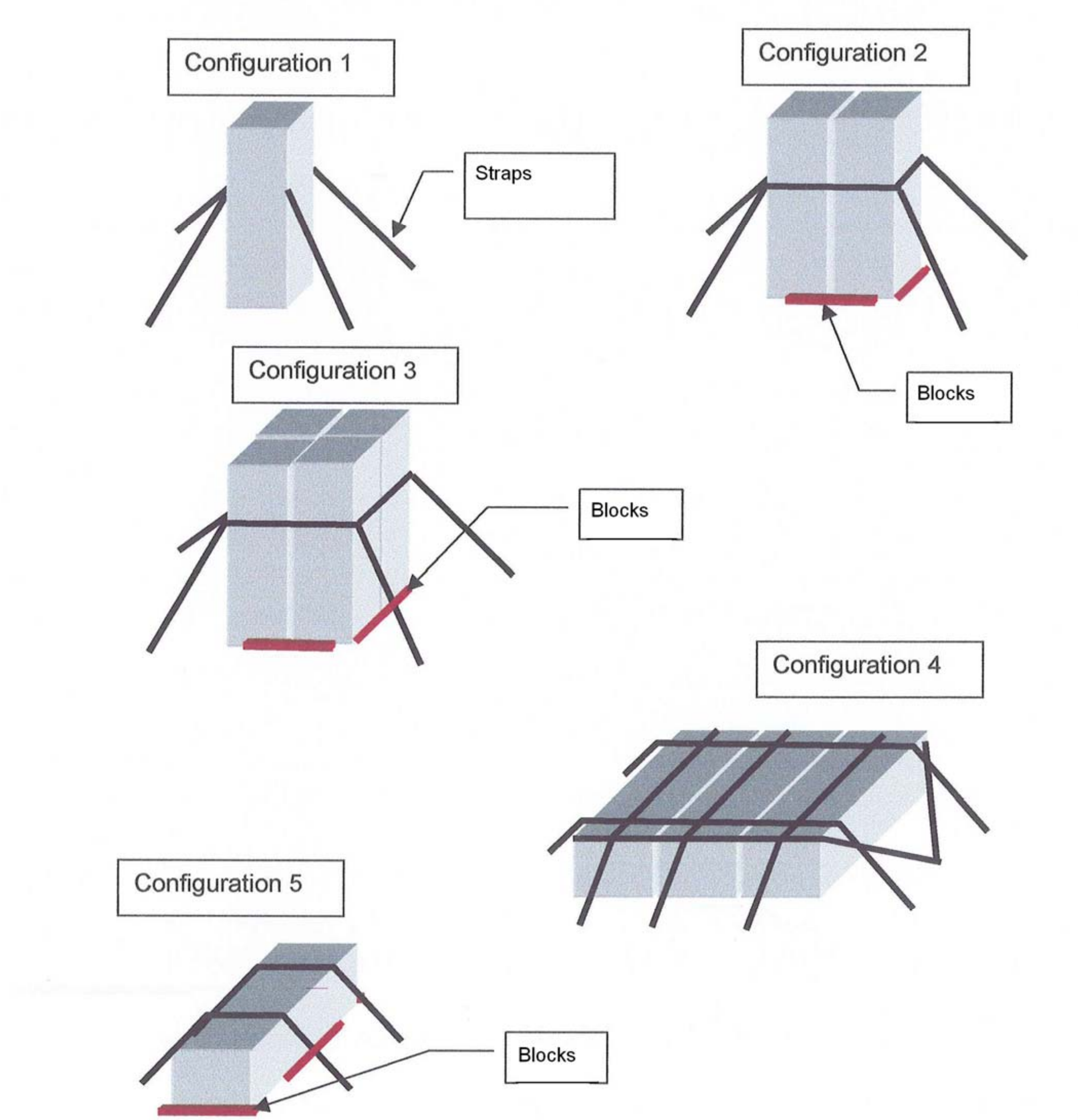
With securing models, the longitudinal axis is the x axis, the transversal axis is the y axis and the vertical axis is the z axis.

Packages are held in place using straps with a pre-tension of 100 daN.

No friction is integrated in the mechanical resistance envelope.

11.4. Configurations

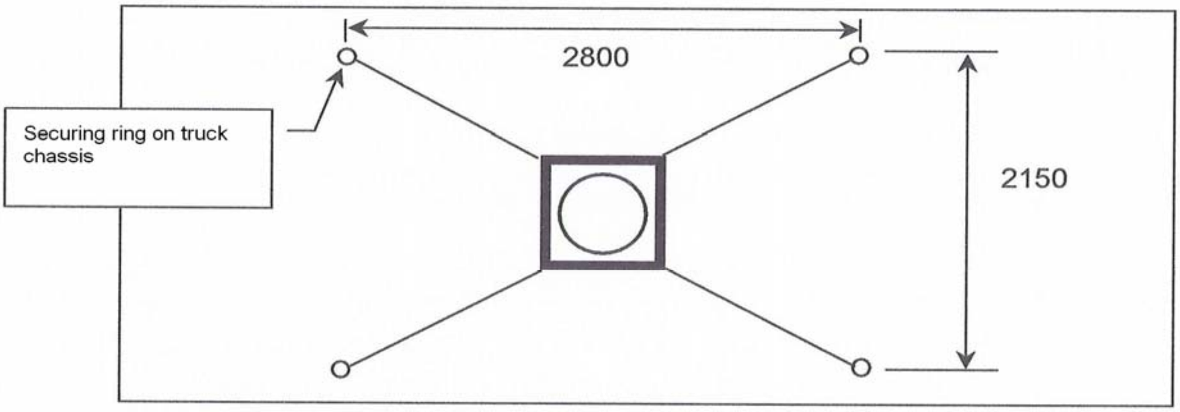
The following 5 configurations were studied. Not all types of transport are proposed for each configuration.



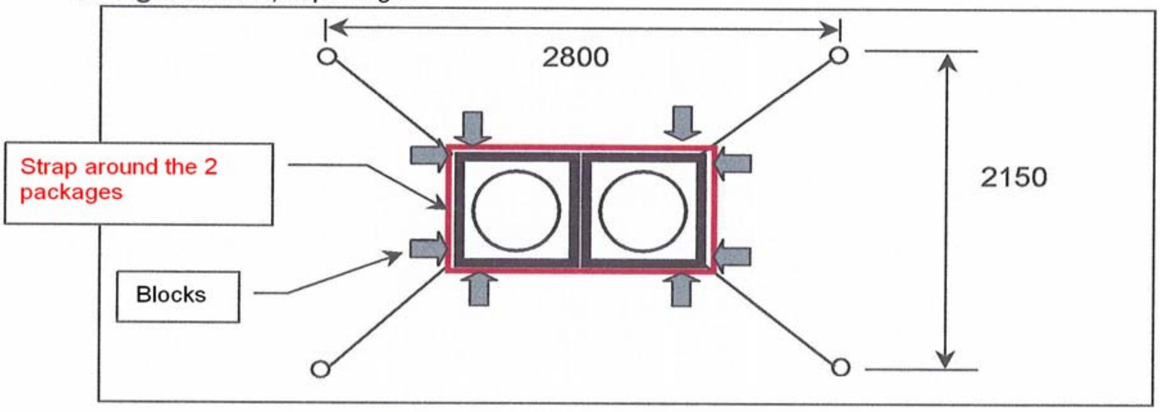
The positions of the straps in vertical configurations are indicated for road transport on truck deck securing positions.

Direction of transport →

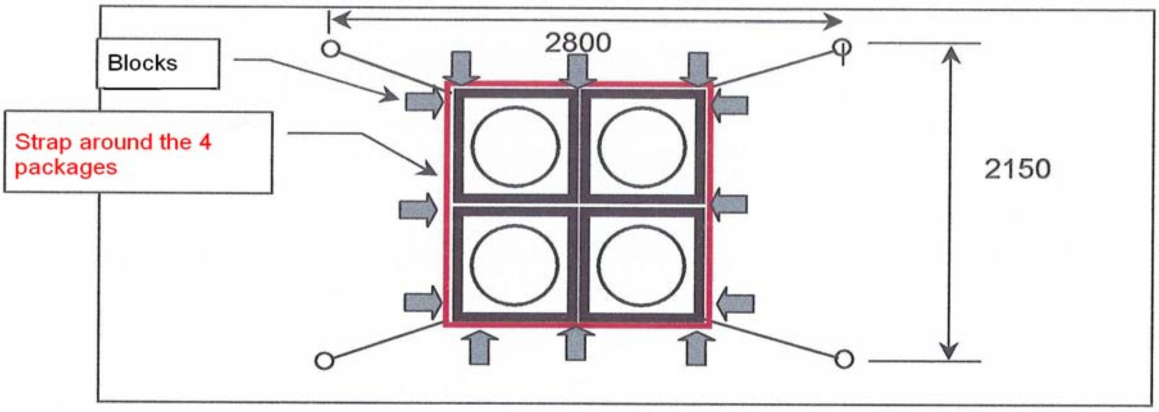
configuration 1, 1 package :



configuration 2, 2 packages:



configuration 3, 4 packages :



11.5. Loads

Maximum accelerations for the 4 types of transport (road, air, rail and maritime) are as follows:

Transport	Accelerations		
	Vertical	Longitudinal	Transversal
Road	3g (lower) 2g (upper)	±2g	±1g
Rail	±2g	±5g	±2g
Maritime	±2g	±2g	±2g
Air	6g (lower) 2g (upper)	1.5g (9g forwards)	1.5g

Accelerations are combined in sets of three for calculations. Only 2 (or 4 for air transport) combinations are immediately obvious due to symmetry and the position of the centre of gravity centred on the package supports.

Combination 1: + longitudinal, + transversal and -vertical
Combination 2: + longitudinal, + transversal and +vertical
For air transport, 2 additional combinations with 9g instead of +1.5g longitudinally. Acceleration of 9g must be taken into consideration if no protection net is used.

Comment: If zero acceleration is included in stress combinations, 27 combinations are possible.

11.6. Calculations completed

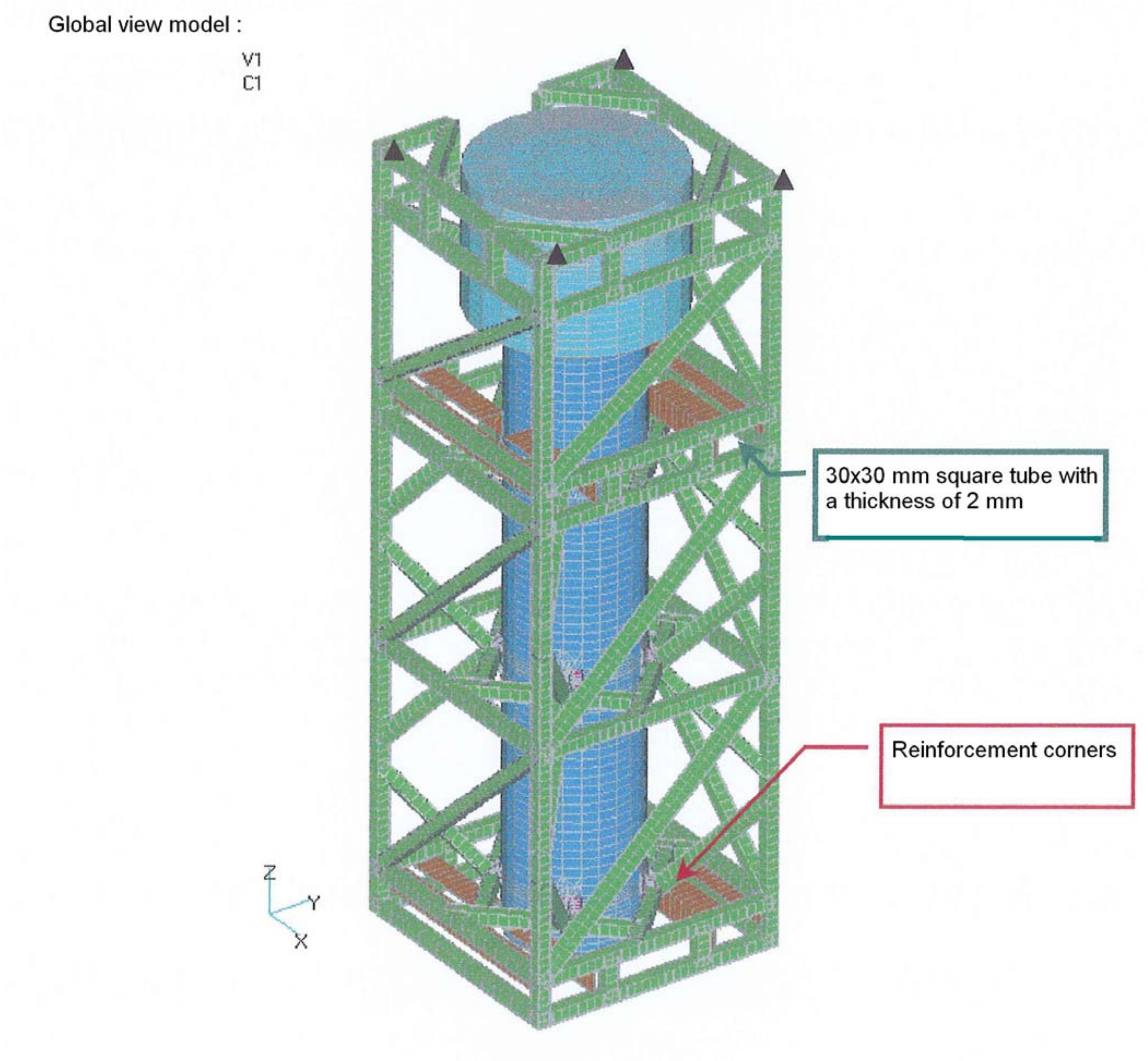
We assume that the vertical transport of the package (configurations N°1, 2 & 3) is not possible in air transport. We also assume that configuration 4 is not possible in road, rail or maritime transport due to dimensions.

Configuration	**Road**	**Rail**	**Maritime**	**Air**	**Total**
N°1	**2**	**2**	**2**	**0**	**6**
N°2	**2**	**2**	**2**	**0**	**6**
N°3	**2**	**2**	**2**	**0**	**6**
N°4	**0**	**0**	**0**	**4**	4
N°5	**2**	**2**	**2**	**4**	**10**

For the 5 study configurations, if we combine accelerations for the selected modes of transport (not all), 32 calculations must be carried out with non-linear contact.

III. PRESENTATION OF THE MODEL OF THE CAGE AND PACKAGE

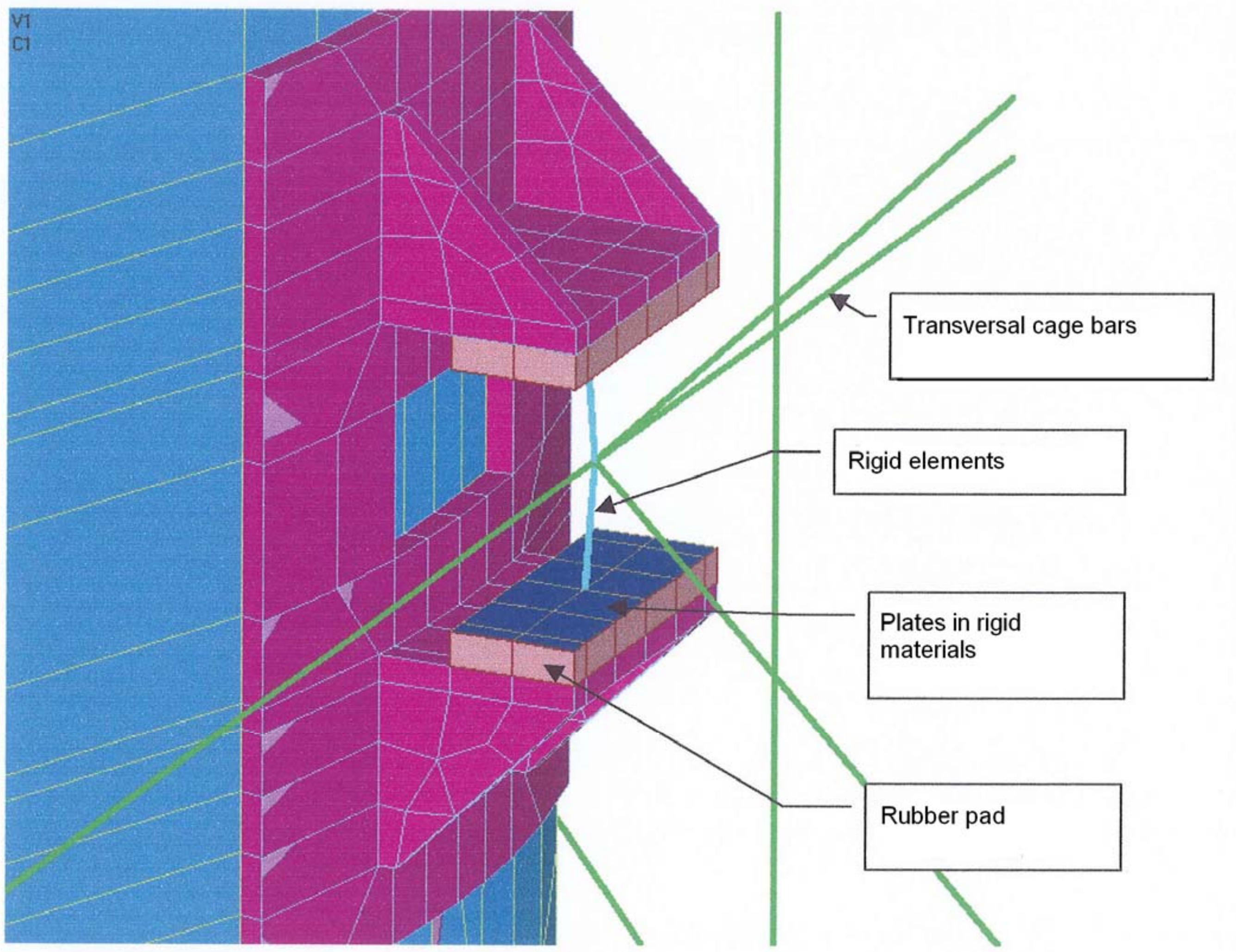
The complete 3D model was created based on drawings ref. {1}. The cut sheets in the cage were not considered as they do not contribute to mechanical resistance.



Calculations enable the definition of stresses in netting and forces in straps.

Rubber pads are modelled as solid elements and plate elements with a rigid material (E = 2e13MPa) rigidifying the inner surface of pads supported by the rubber. Rigid elements bind the centre of the pads (inner surface) with the transversal bars of the cage. Other rigid elements enable radial blocking between the cage brackets and bars to model the attachment axis (M6).

Model, main section/cage liaison details:
Bars are shown as lines to simplify the understanding of the model.



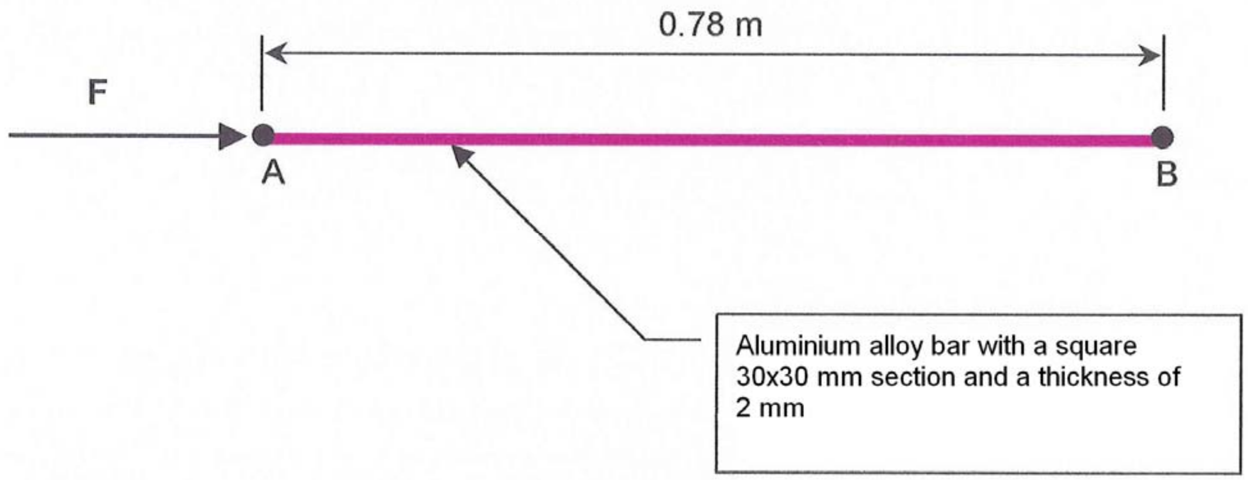
Forces in rigid elements modelling attachments axes are determined and processed using Excel to obtain shear stresses in M6 screws (these axes are subjected to low traction-compression forces).

IV. CALCULATIONS

IV. 1. Verification of the buckling of cage bars

Netting elements may be subjected to compression with risk of buckling. This prior study, conducted in the most detrimental geometric configuration, enables the determination of the stress threshold for instability due to buckling.

A simple model was created, with a 30x30 square tube with a thickness of 2 in aluminium alloy with a length corresponding to the longest of the free lengths of the cage (0.78 m on the upper diagonal) and was subjected to compression.



Point B is embedded (modelling connections welded to cage nodes). Axial translation is left unrestrained at point A (to ensure that the bar is subjected to compression while guided radially).

Compression force F is applied to the free end of the beam.

Calculations were carried out for buckling and finished elements determining that the buckling threshold corresponds to a force of 1.26 105 N. The corresponding stress of 564 MPa is substantially higher than the elastic limit of the aluminium alloy selected as an acceptance criterion.

In view of the acceptance criteria selected for linear analysis, **netting bars will not buckle.**

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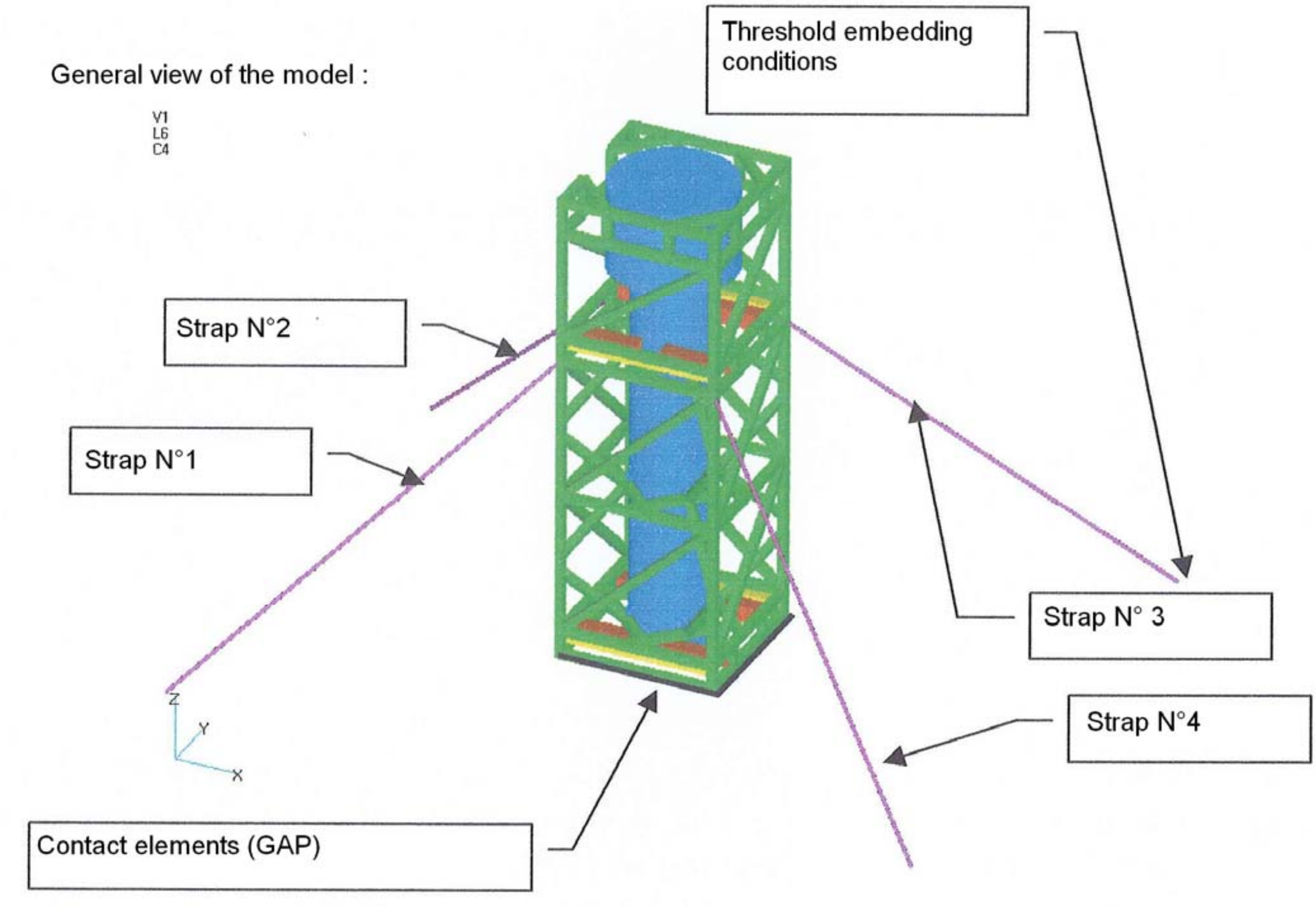
IV.2. Configuration 1: 1 vertical package IV.2.1. Model



The cage is supported by the truck chassis via contact elements (GAP) to prevent any sliding or the detachment of the package.

Threshold embedding conditions apply for each strap end.

Straps are modelled with bars which only transfer traction (non-linear material). Pre-tension of 100 daN is applied (entirely feasible value) to each strap.

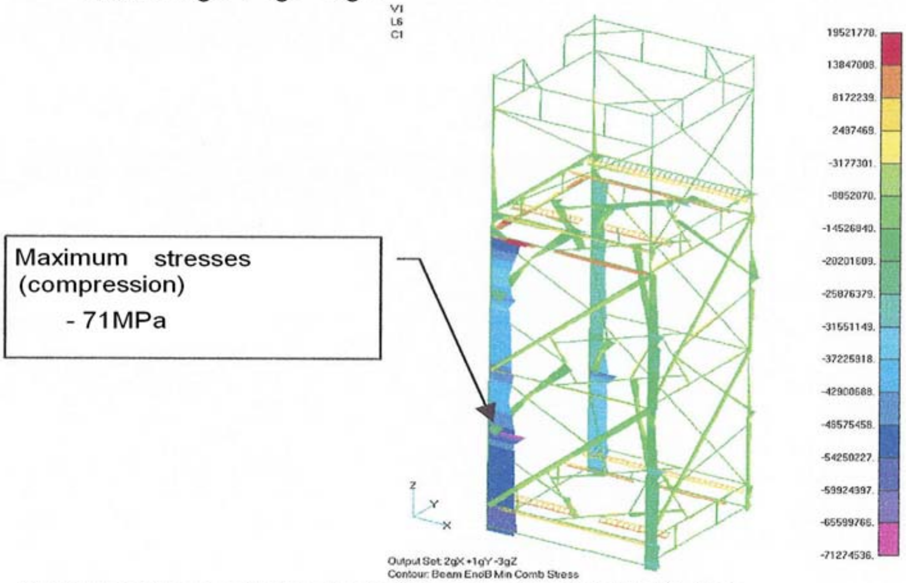
Strap N°1 absorbs forces along the longitudinal axis (X) and the transversal axis (Y) (strap subjected to the most stresses). Strap N°2 absorbs forces along the longitudinal axis (X) (together with strap N°1). Straps N°3 and N°4 are defined on the basis of the direction of rotation of the numbering of the first 2 straps.

IV.2.2. Road transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

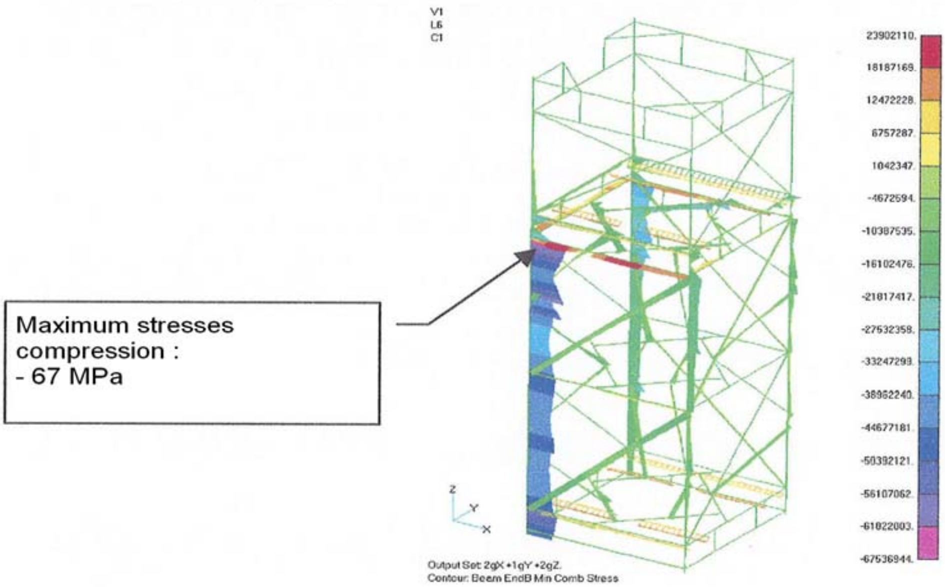
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 2gX + 1gY - 3gZ:



Maximum stresses in the aluminium cage are equal to 71 MPa.

Load of 2gX + 1gY + 2gZ :

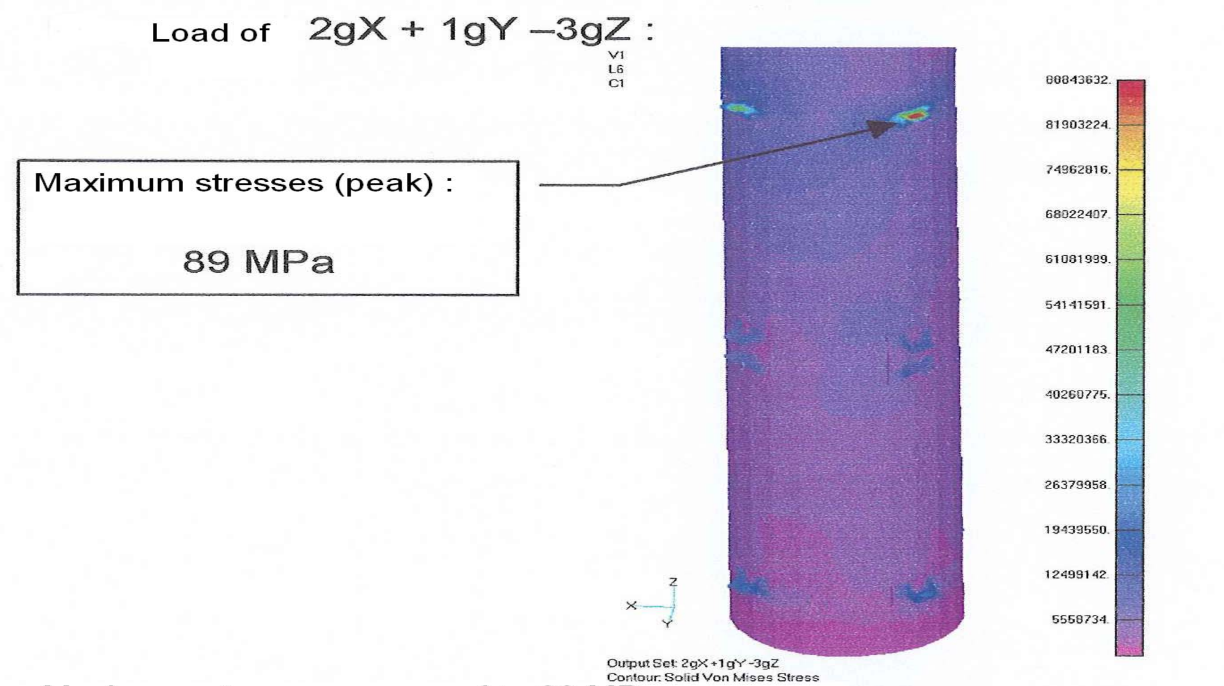


Maximum stresses in the aluminium cage are equal to 67 MPa.

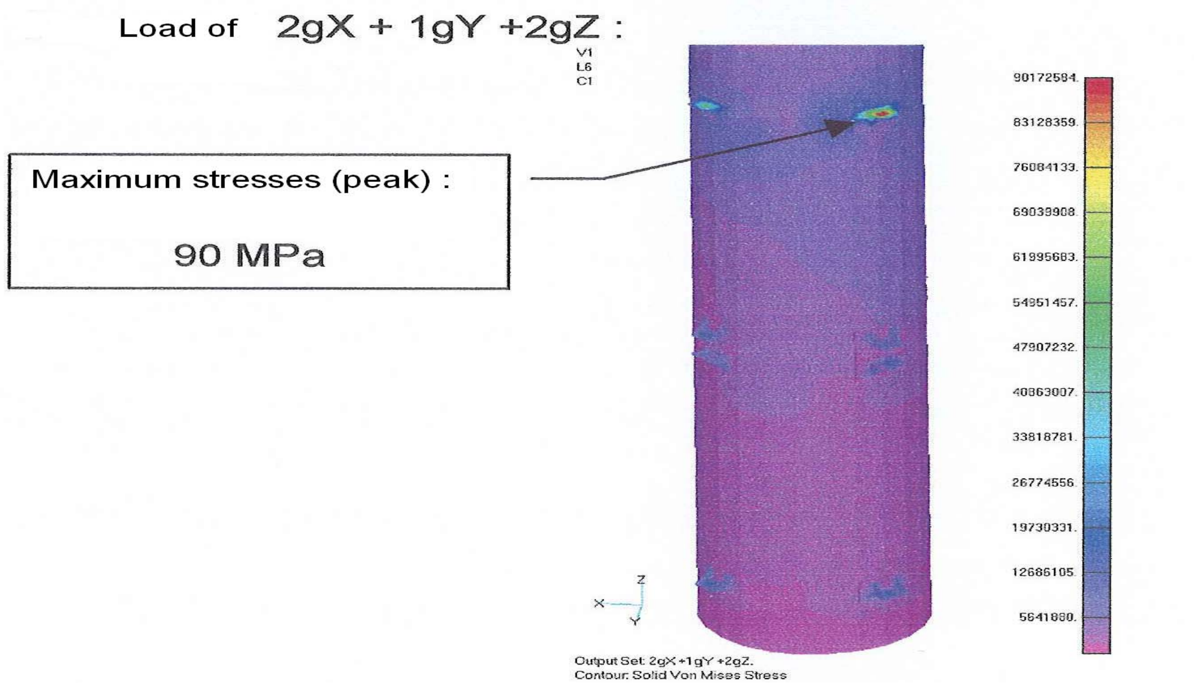
Maximum stresses in the aluminium cage, for both loads, are equal to 71 MPa in a

welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.



Maximum stresses are equal to 89 MPa.



Maximum stresses are equal to 90 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 90 MPa near to attachment brackets.

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The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 1			00 daN
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Road	+2gX+1gY-3gZ	1075	630	0	445
	+2gX+1gY+2gZ	1315	868	238	682

Maximum tension is equal to 1315 **daN.**

For M6 screws, maximum shear force is equal to 3240 N, and maximum shear stress is therefore 161 MPa.

CONFIGURATION 1; 1 VERTICAL PACKAGE - ROAD TRANSPORT

Maximum tension in straps is equal to 1315 daN.

Maximum shear stress in M6 screws (161 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 2.2.

Maximum shear stress in the steel structure (90 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 2.1.

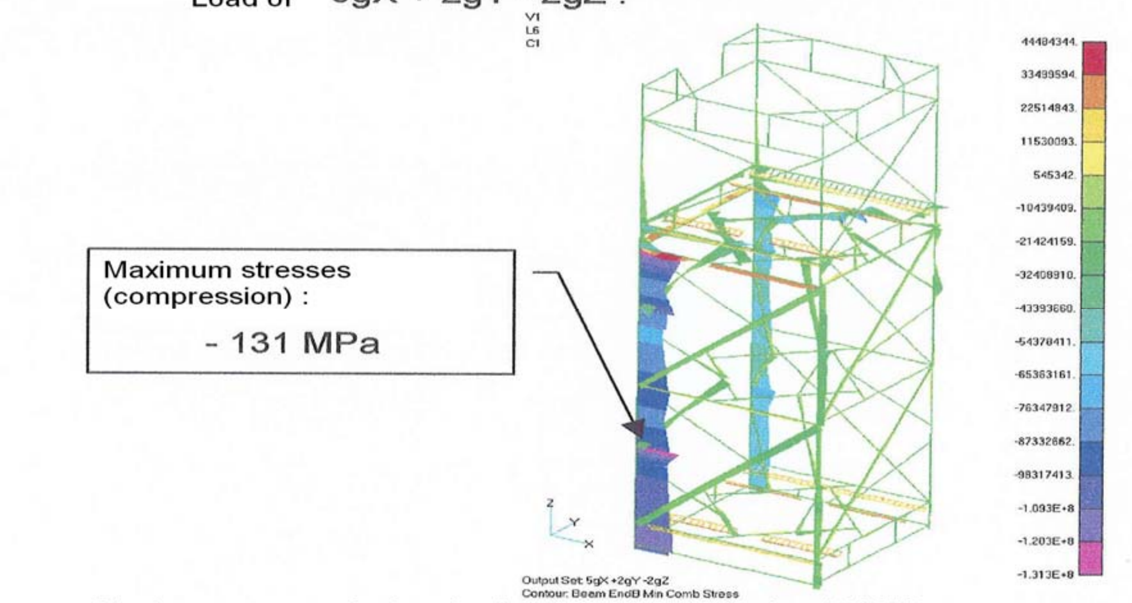
Maximum shear stress in the bars (71 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa), which corresponds to a safety coefficient of 2.45.

IV.2.3. Rail transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

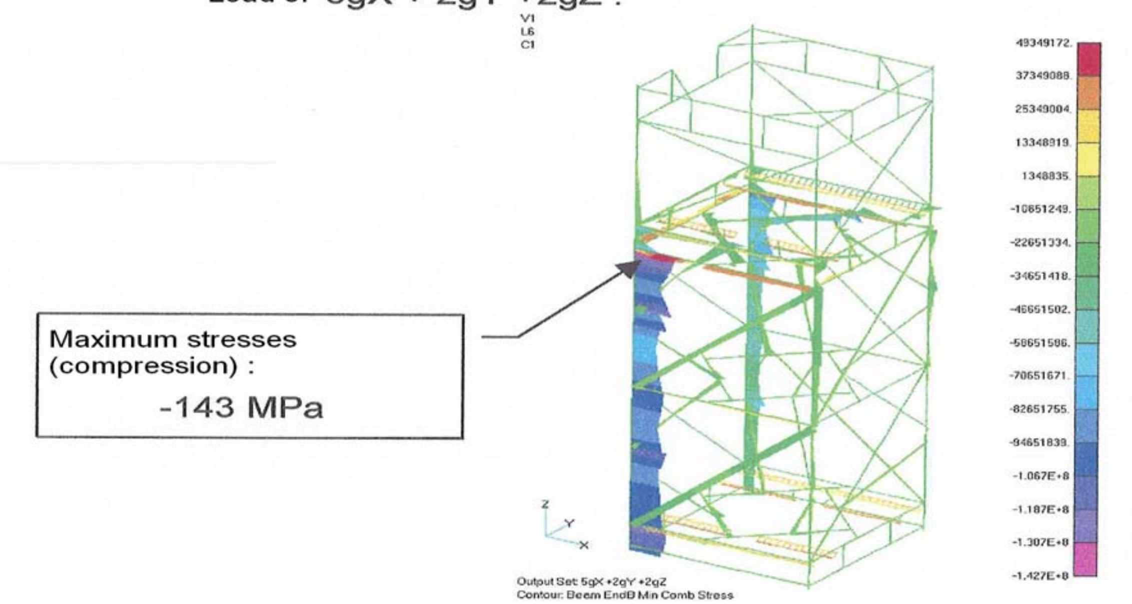
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 5gX + 2gY −2gZ :



Maximum stresses in the aluminium cage are equal to 131 MPa

Load of 5gX + 2gY +2gZ :

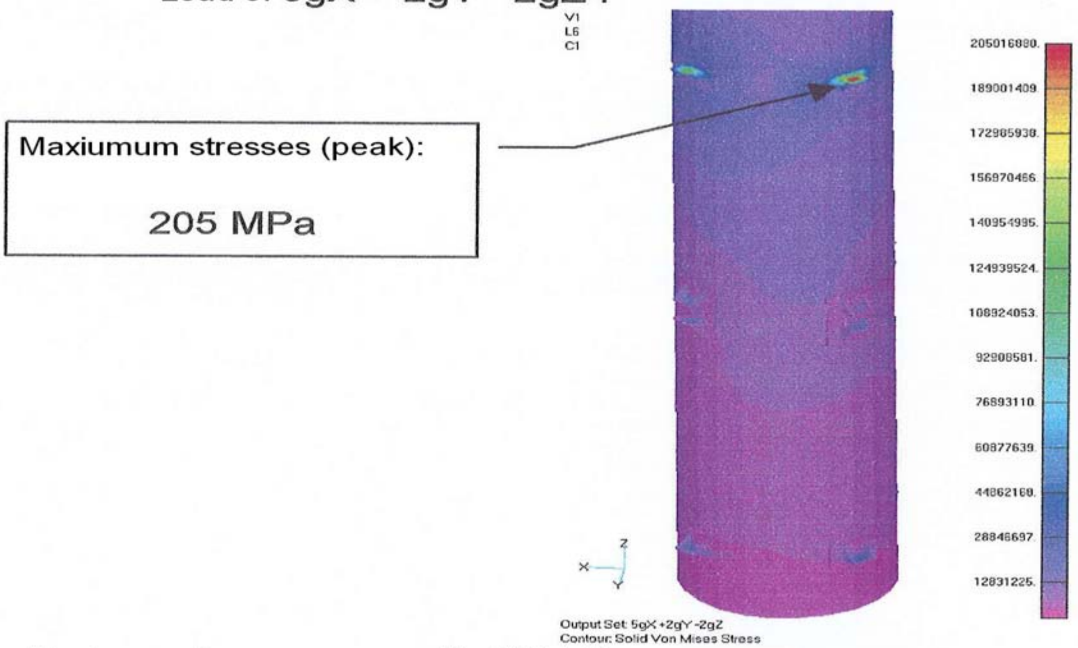


Maximum stresses in the aluminium cage are equal to 143 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 143 MPa in a welded zone.

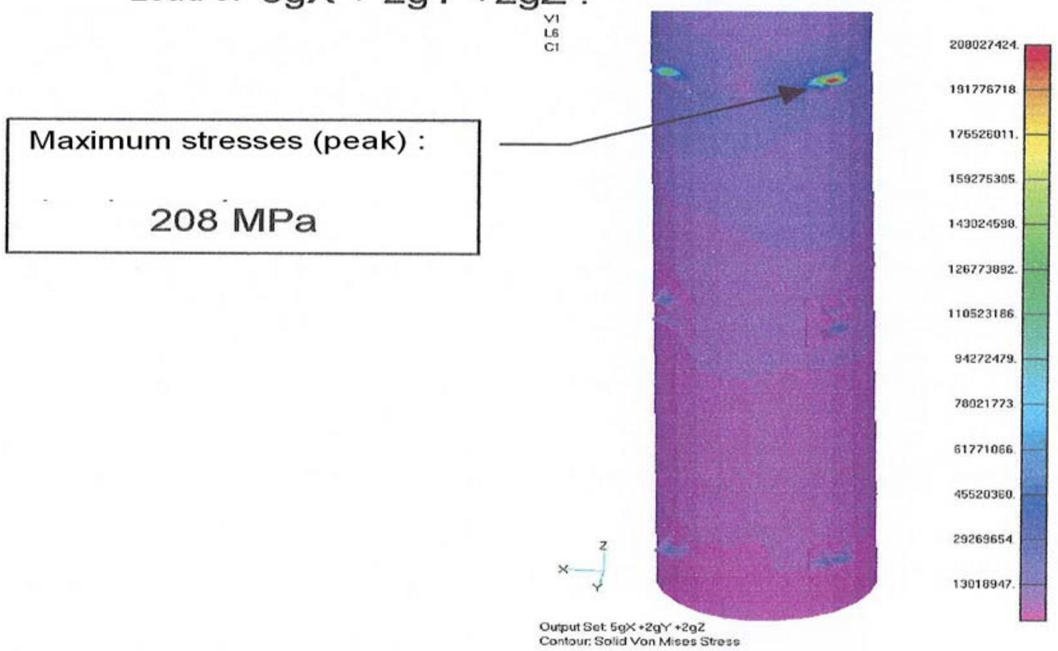
The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.

Load of 5gX + 2gY –2gZ :



Maximum stresses are equal to 205 MPa.

Load of 5gX + 2gY +2gZ :



Maximum stresses are equal to 208 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to

208 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Rail	+5gX +2gY -2gZ	2465	1575	0	889
	+5gX +2gY +2gZ	2725	1835	260	1149

Maximum tension is equal to 2725 **daN.**

For M6 screws, maximum shear force is equal to 7,276 N, and maximum shear stress is therefore 362 MPa.

CONFIGURATION 1: 1 VERTICAL PACKAGE - RAIL TRANSPORT

Maximum tension in straps is equal to 2725 daN.

Maximum shear stress in M6 screws (362 MPa) is very slightly higher than the maximum acceptable stress of 360 MPa.

Maximum shear stress in the steel structure (208 MPa) is slightly higher than the elastic limit of the 304L steel at 80°C (189 MPa). However, this refers to peak stresses in a local area, and the rest of the steel structure is not subjected to significant stresses.

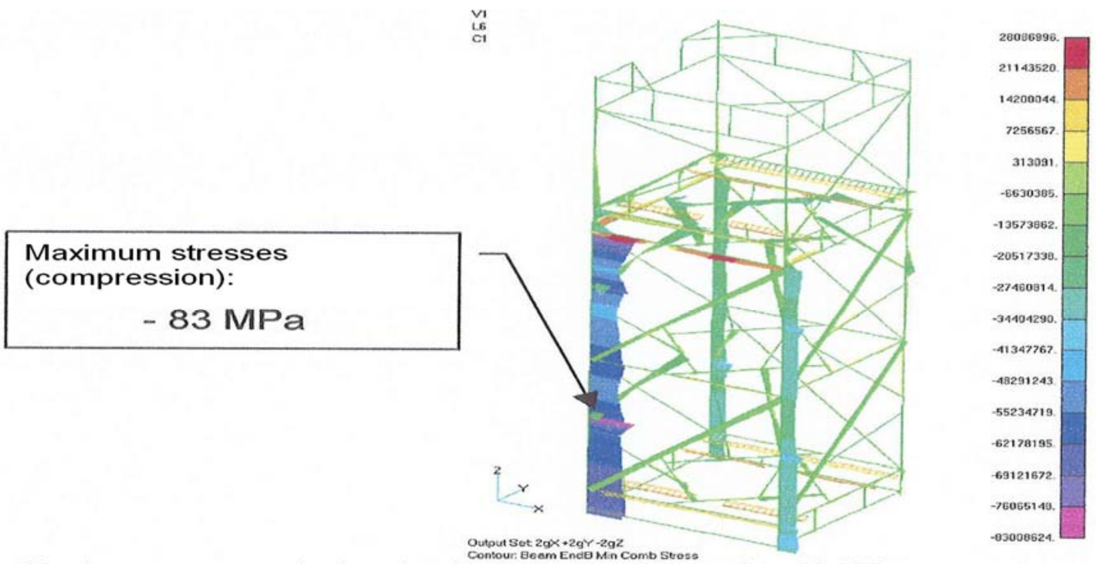
Maximum shear stress in the bars (143 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa), which corresponds to a safety coefficient of 1.2.

IV.2.4. Maritime transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

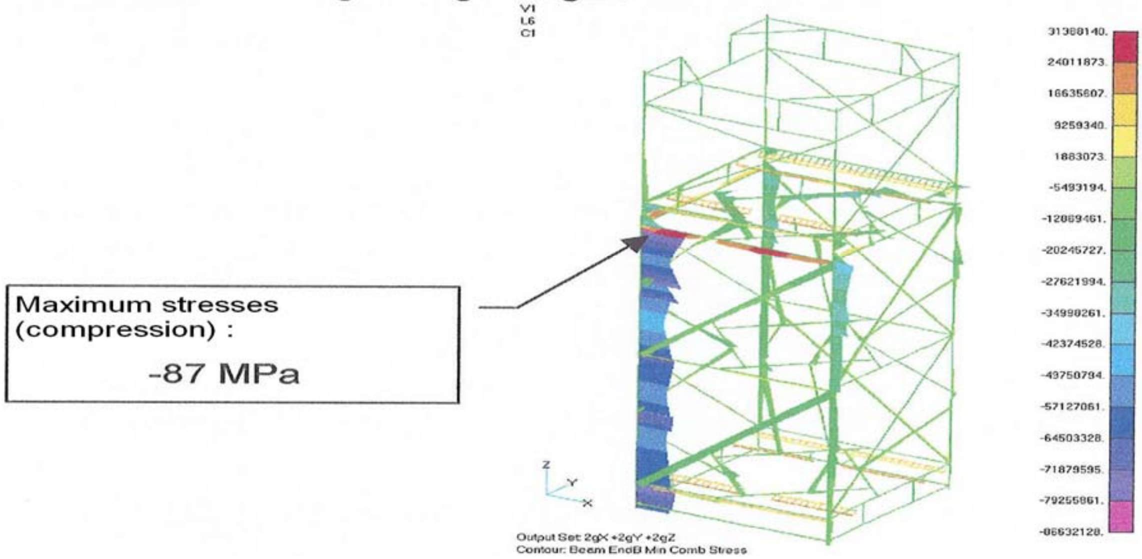
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 2gX + 2gY -2gZ:



Maximum stresses in the aluminium cage are equal to 83 MPa.

Load of 2gX + 2gY +2gZ :

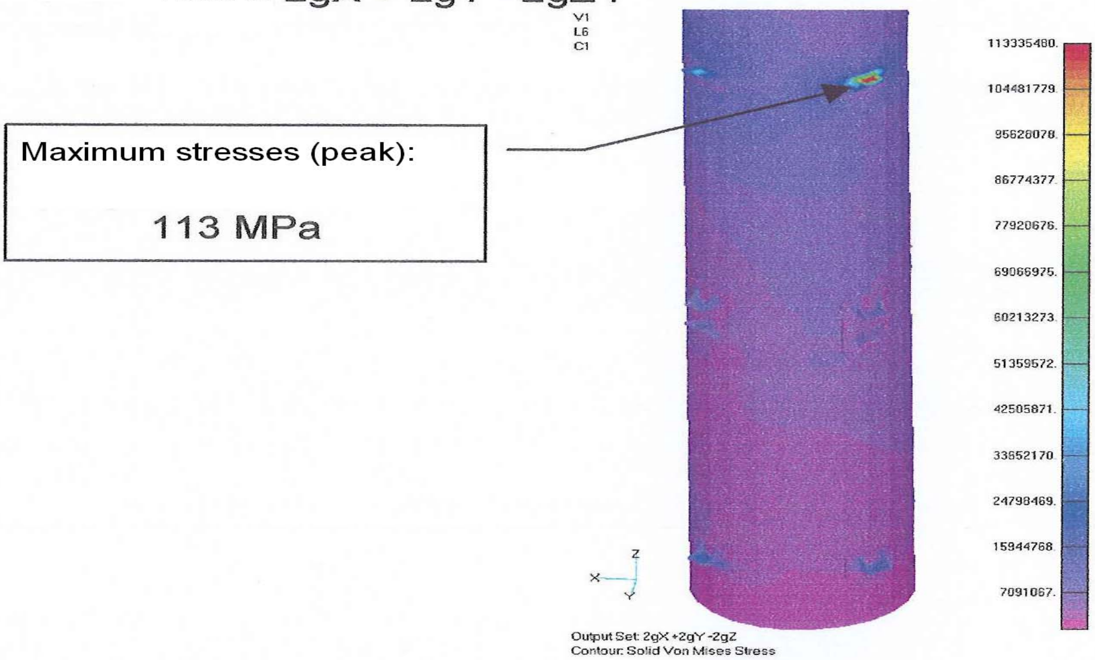


Maximum stresses in the aluminium cage are equal to 87 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 87 MPa in a welded zone.

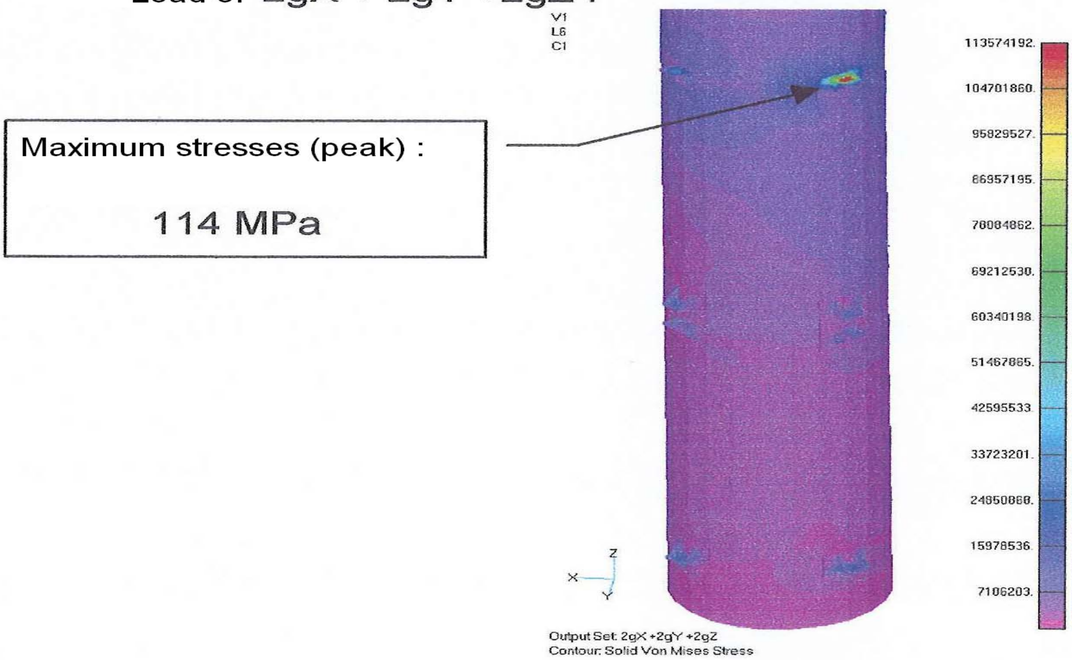
The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.

Load of 2gX + 2gY –2gZ :



Maximum stresses are equal to 113 MPa.

Load of 2gX + 2gY +2gZ :



Maximum stresses are equal to 114 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to

114 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Maritime	+2gX +2gY -2gZ	1520	630	0	889
	+2gX +2gY +2gZ	1664	775	145	1034

Maximum tension is equal to 1664 daN.

For M6 screws, maximum shear force is equal to 4,214 N, and maximum shear stress is therefore 210 MPa.

CONFIGURATION 1: 1 VERTICAL PACKAGE - MARITIME TRANSPORT

Maximum tension in straps is equal to 1664 daN.

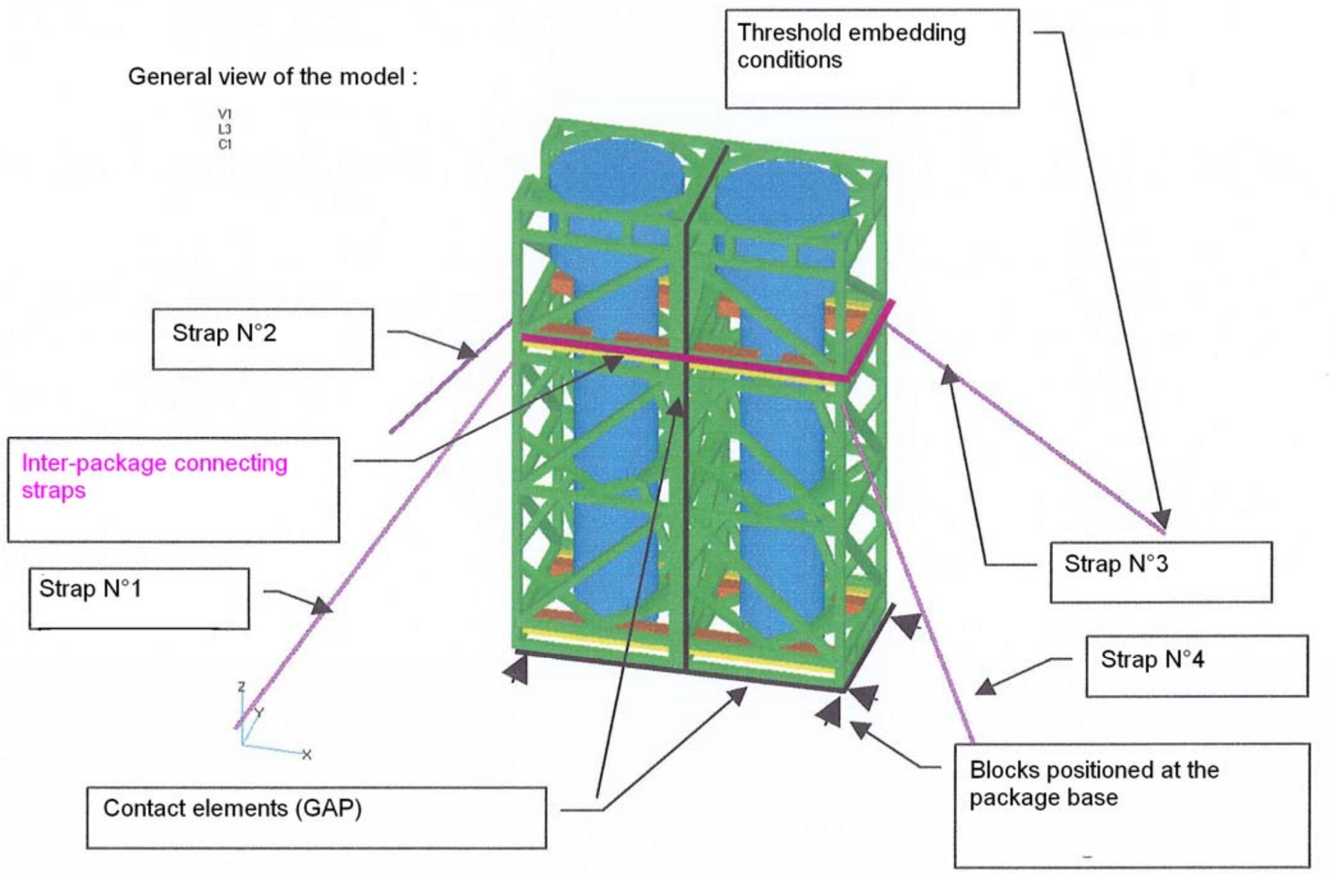
Maximum shear stress in M6 screws (210 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 1.7.

Maximum shear stress in the steel structure (114 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 1.6.

Maximum shear stress in the bars (87 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa), which corresponds to a safety coefficient of 2.

IV. 3. Configuration 2: 2 vertical packages

IV.3.1. Model



The cages mutually support each other and are also supported by the truck chassis via contact elements (GAP) to prevent any sliding or the detachment of the packages.

Threshold embedding conditions apply for each strap end.

Straps are modelled with bars which only transfer traction (non-linear material). Pre-tension of 100 daN is applied to each strap.

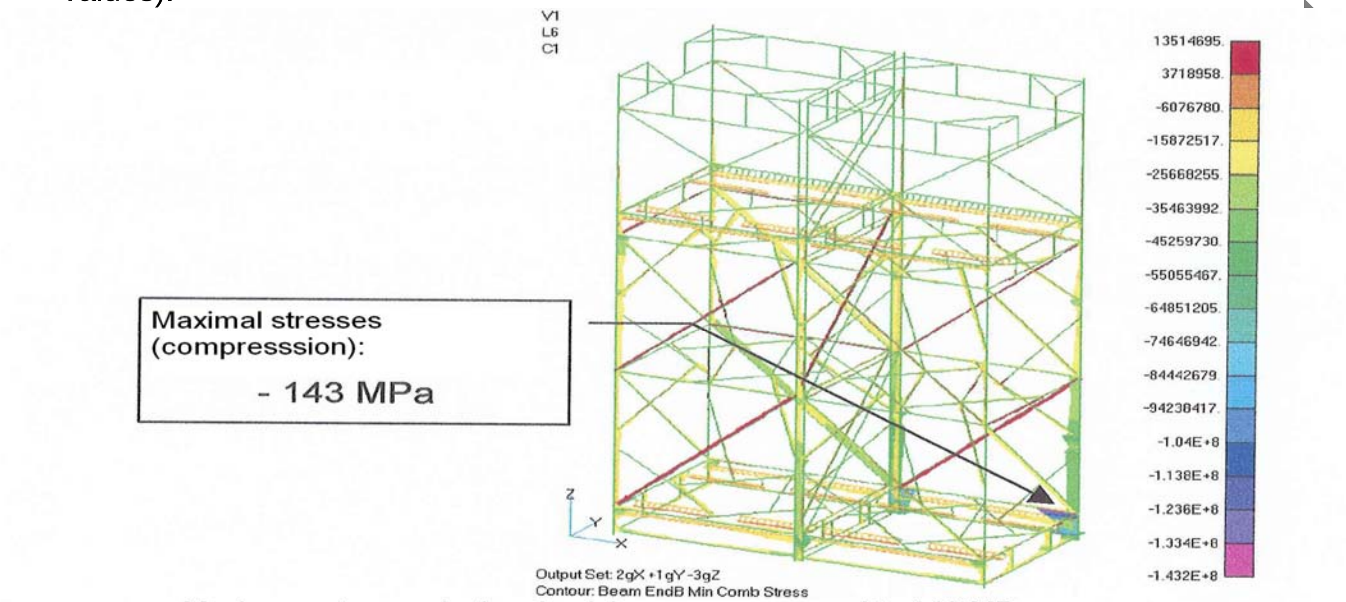
Strap N°1 absorbs forces along the longitudinal axis (X) and the transversal axis (Y) (strap subjected to the most stresses). Strap N°2 absorbs forces along the longitudinal axis (X) (together with strap N°1). Straps N°3 and N°4 are defined on the basis of the direction of rotation of the numbering of the first 2 straps.

Blocks are added at the base of the packages and connected to the truck.

IV.3.2. Road transport

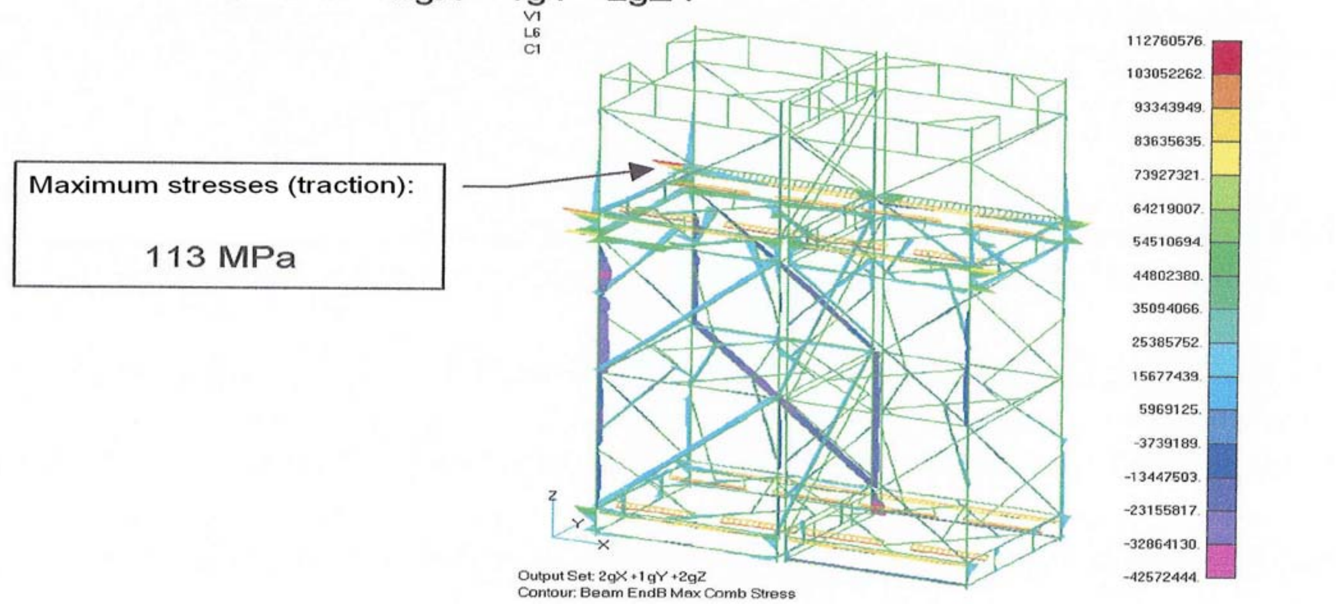
The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

Important: maximum stresses may be in red or magenta (compression or traction values).



Maximum stresses in the aluminium cage are equal to 143 MPa. t de 143 MPa.

Load of 2gX + 1gY +2gZ :

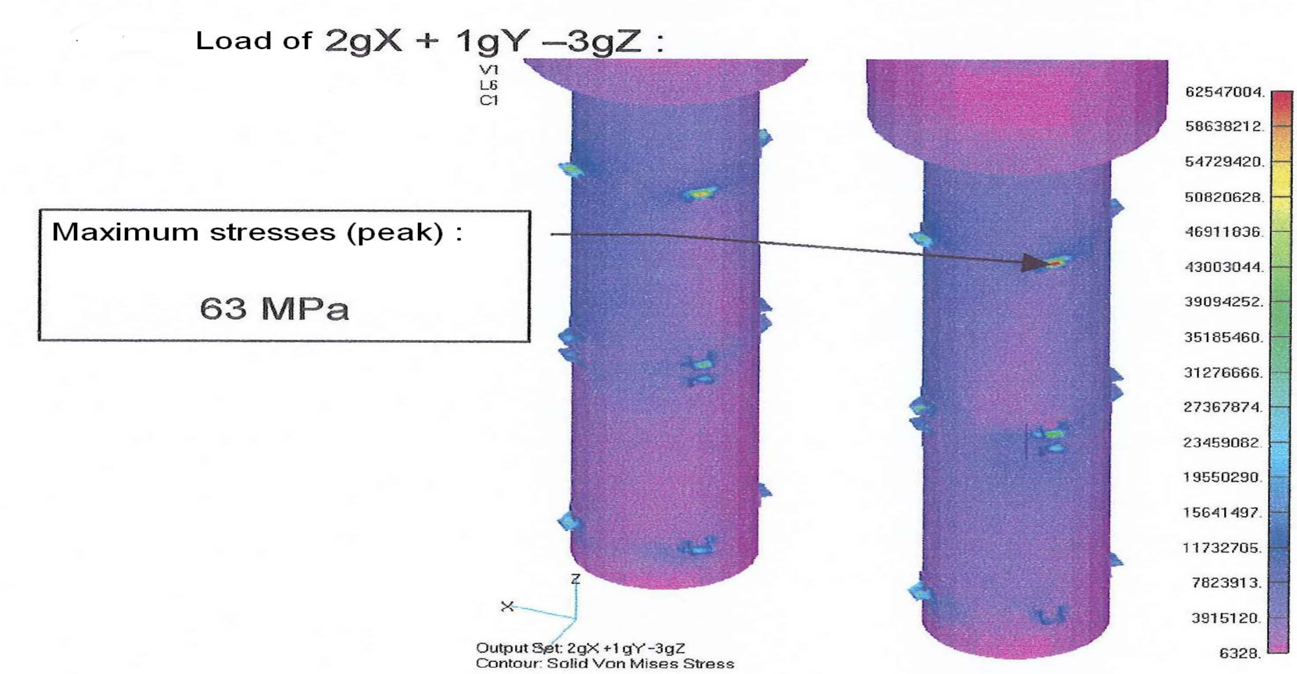


Maximum stresses in the aluminium cage are equal to 113 MPa.

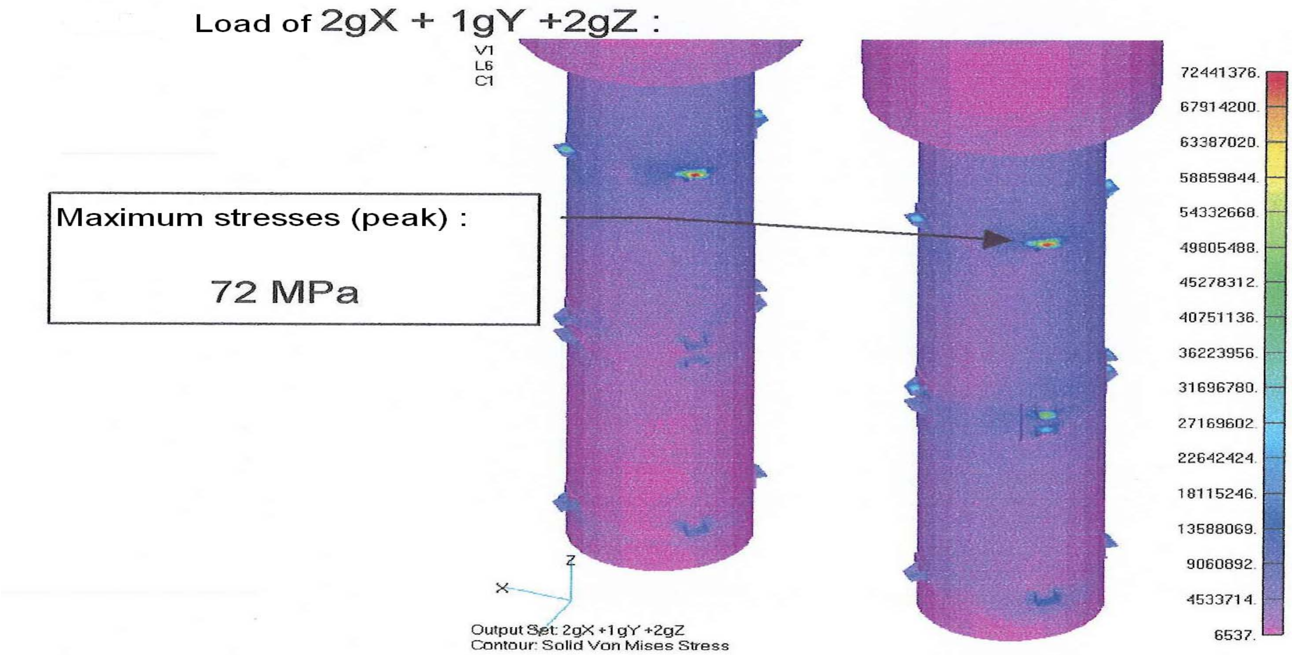
Maximum stresses in the aluminium cage, for both loads, are equal to 143 MPa in a

welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.



Maximum stresses are equal to 63 MPa.



Maximum stresses are equal to 72 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to

72 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Road	+2gX+1gY-3gZ	583	356	0	59
	+2gX+1gY+2gZ	1438	1215	283	793

Maximum tension is equal to 1438 daN.

For M6 screws, maximum shear force is equal to 2,576 N, and maximum shear stress is therefore 128 MPa.

CONFIGURATION 2: 2 VERTICAL PACKAGES - ROAD TRANSPORT

Maximum tension in straps is equal to 1438 daN.

Maximum shear stress in M6 screws (128 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 2.8.

Maximum shear stress in the steel structure (72 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 2.6.

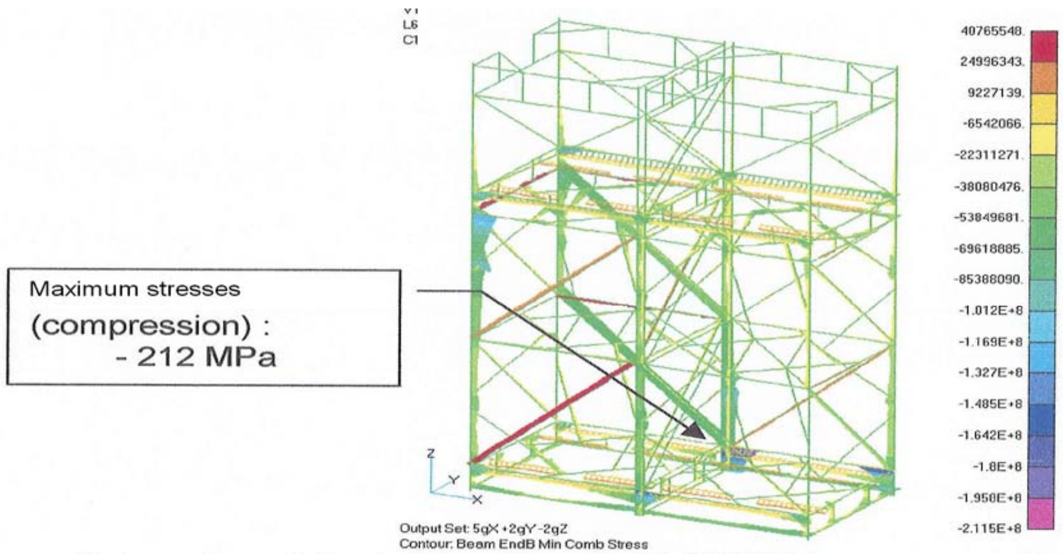
Maximum shear stress in the bars (143 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa), which corresponds to a safety coefficient of 1.2.

IV.3.3. Rail transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

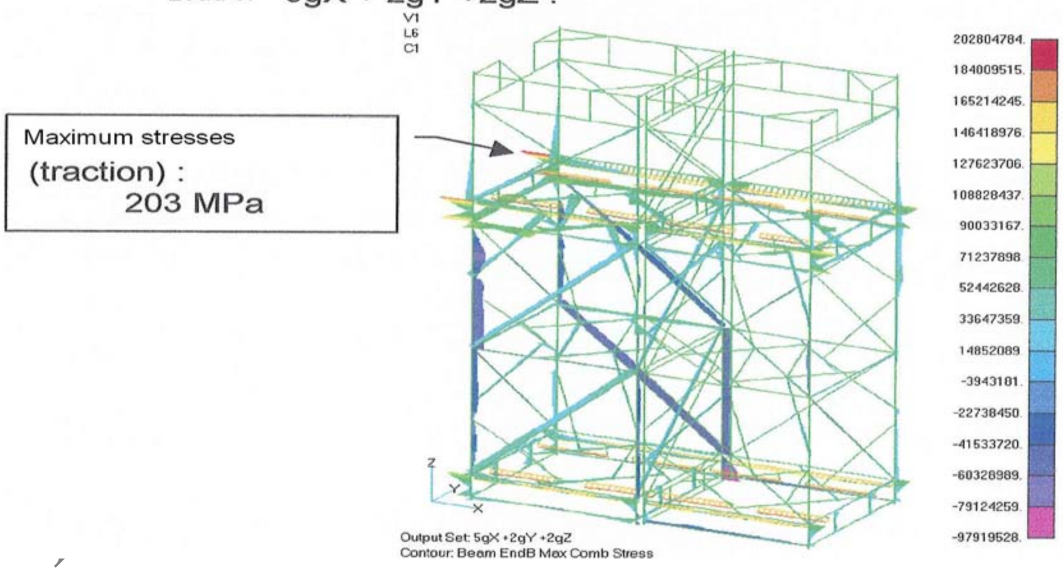
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 5gX + 2gY -2gZ:



Maximum stresses in the aluminium cage are equal to 212 MPa.

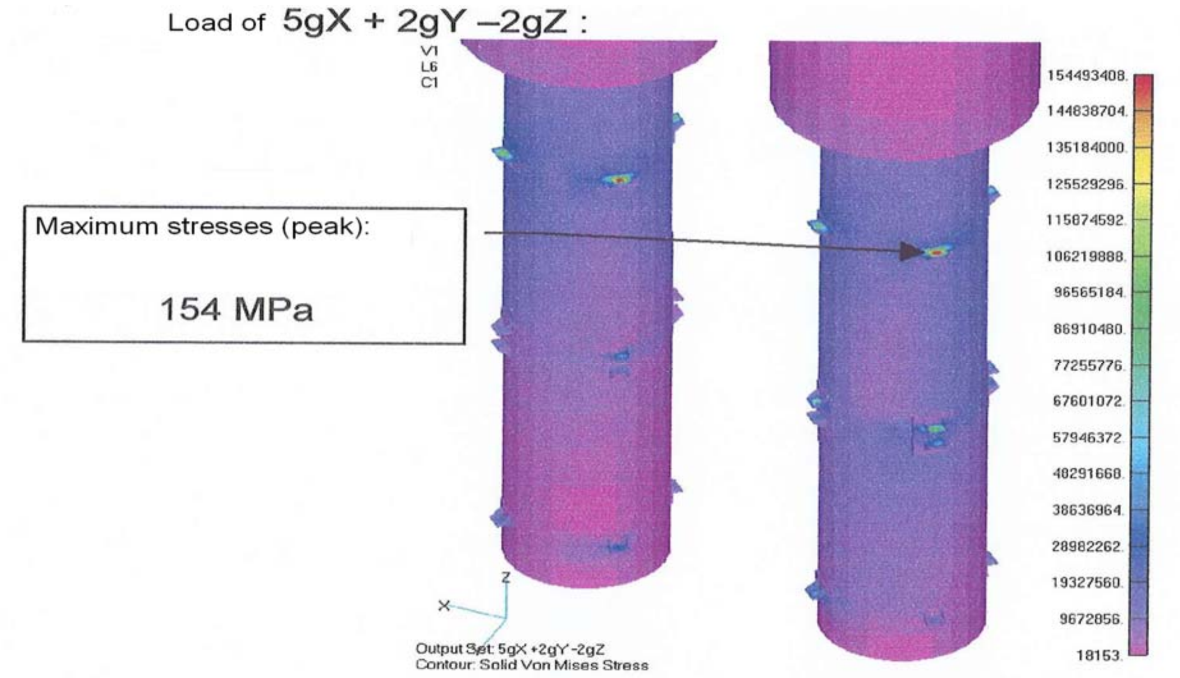
Load of 5gX + 2gY +2gZ :



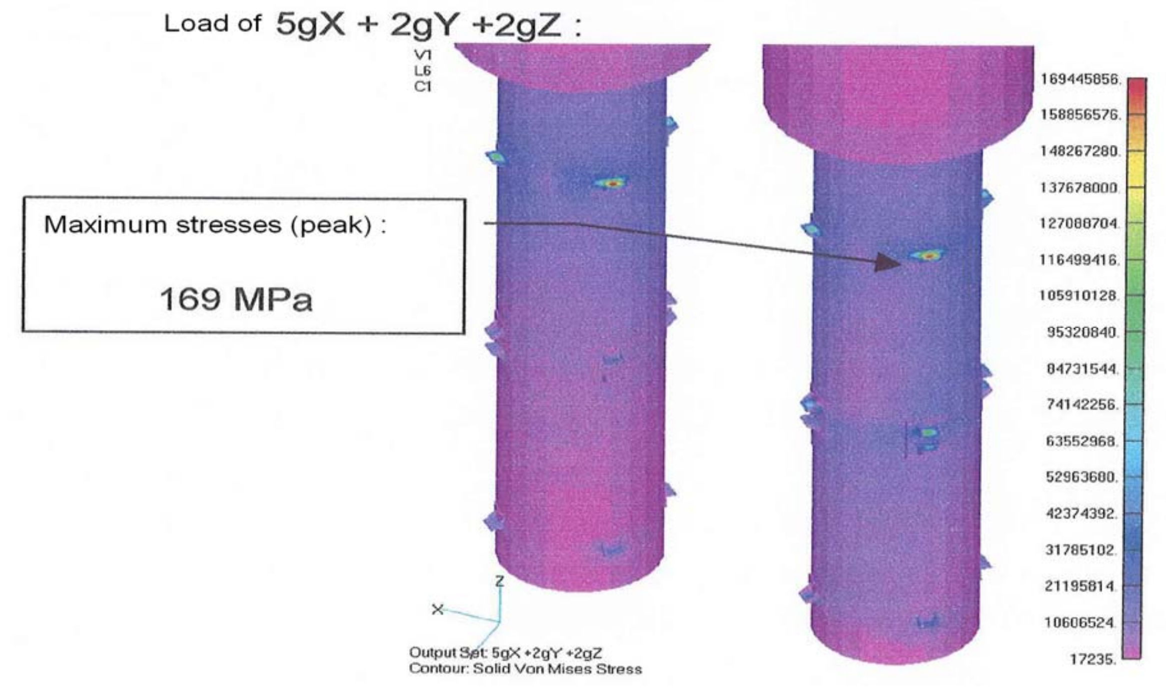
Maximum stresses in the aluminium cage are equal to 203 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 212 MPa in a welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.



Maximum stresses are equal to 154 MPa.



Maximum stresses are equal to 169 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 169 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Rail	+5gX +2gY -2gZ	2138	1692	0	575
	+5gX +2gY +2gZ	2732	2287	28	1047

Maximum tension is equal to 2732 daN.

For M6 screws, maximum shear force is equal to 5,918 N, and maximum shear stress is therefore 294 MPa.

CONFIGURATION: 2 VERTICAL PACKAGES - RAIL TRANSPORT

Maximum tension in straps is equal to 2732 daN.

Maximum shear stress in M6 screws (294 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 1.2.

Maximum shear stress in the steel structure (169 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 1.1.

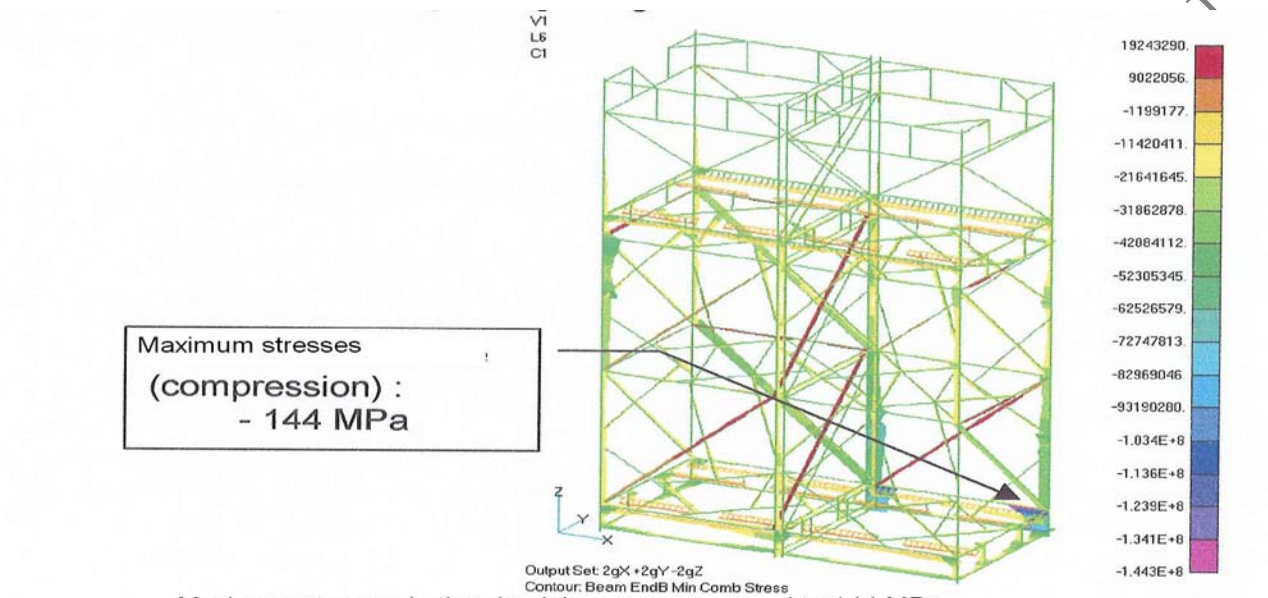
Maximum shear stress in the bars (212 MPa) is higher than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa). Stresses exceed limits with a weld coefficient of 0.7.

IV.3.4. Maritime transport

he following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

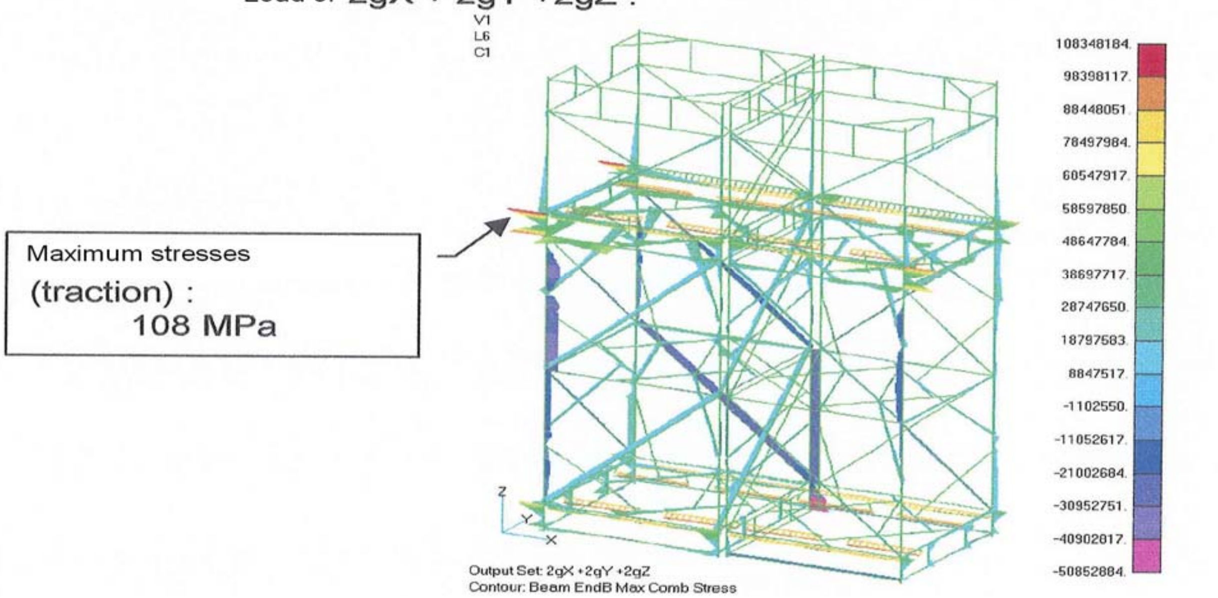
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 2gX + 2gY -2gZ:



Maximum stresses in the aluminium cage are equal to 144 MPa.

Load of 2gX + 2gY +2gZ :



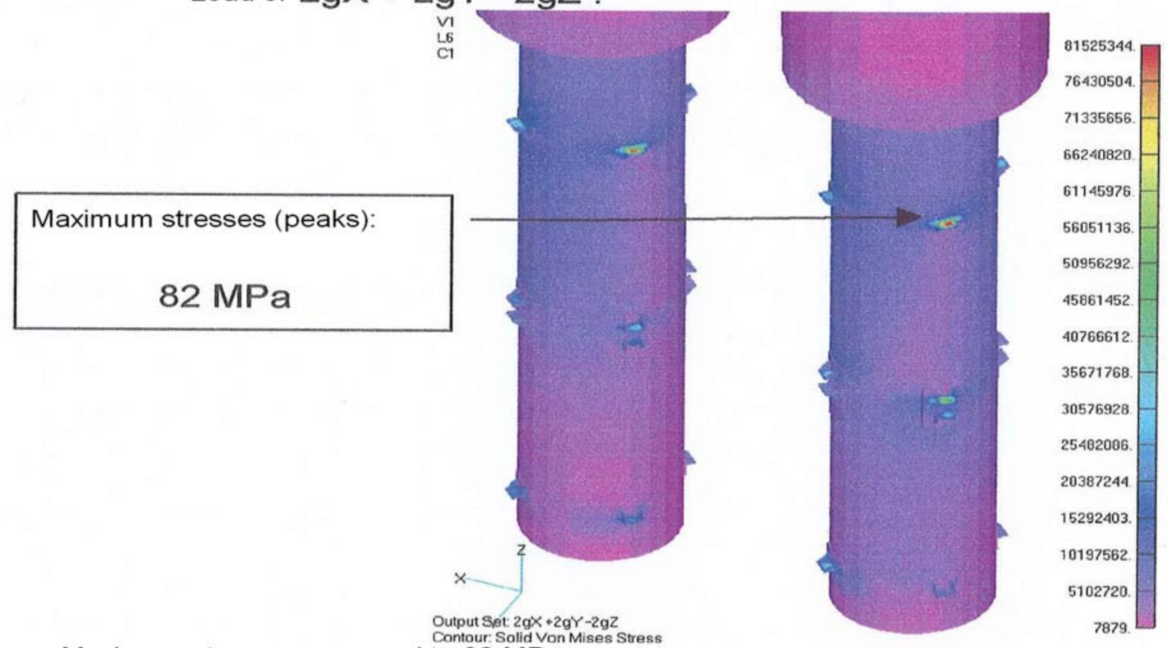
Maximum stresses in the aluminium cage are equal to 108 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 144 MPa in a

welded zone.

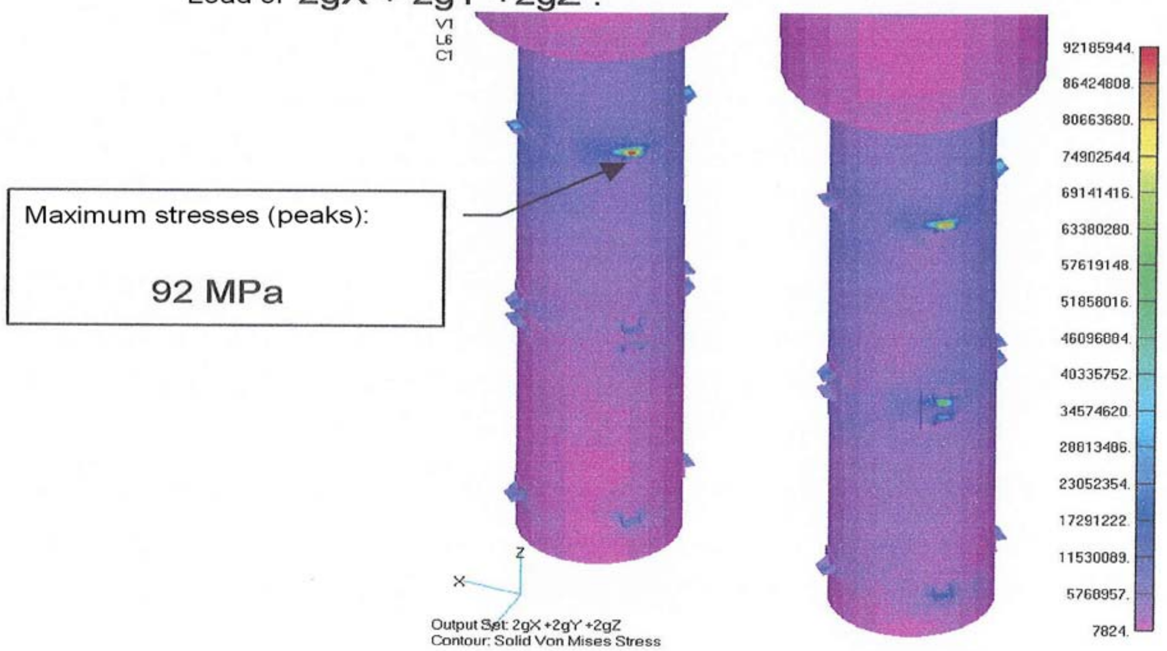
The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.

Load of 2gX + 2gY –2gZ :



Maximum stresses are equal to 82 MPa.

Load of 2gX + 2gY +2gZ :



Maximum stresses are equal to 92 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 92 MPa near to attachment brackets.

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The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Maritime	+2gX +2gY -2gZ	969	495	0	575
	+2gX +2gY +2gZ	1624	1029	28	1047

Maximum tension is equal to 1624 daN.

For M6 screws, maximum shear force is equal to 3,242 N, and maximum shear stress is therefore 161 MPa.

CONFIGURATION: 2 VERTICAL PACKAGES - MARITIME TRANSPORT

Maximum tension in straps is equal to 1624 daN.

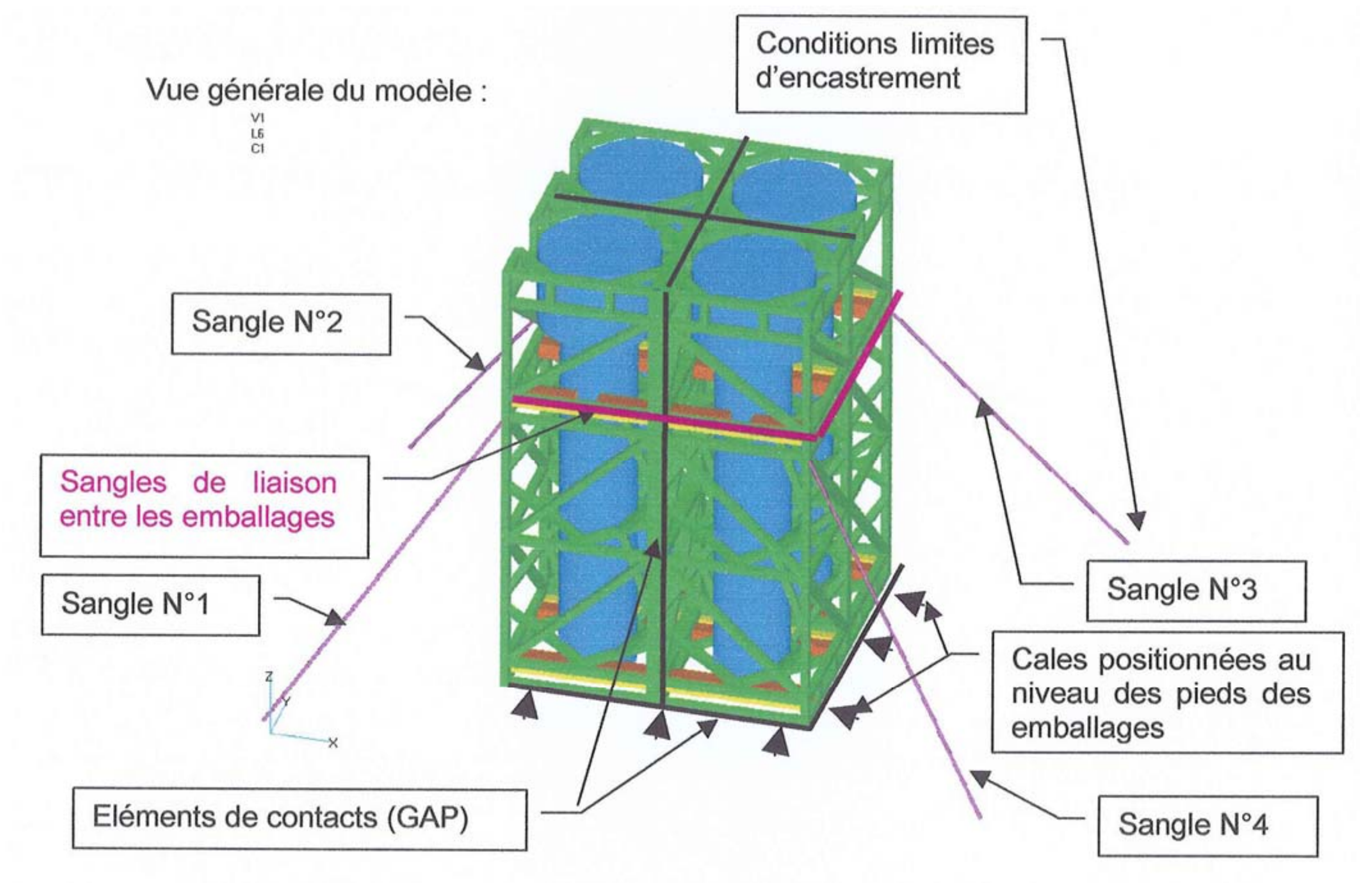
Maximum shear stress in M6 screws (161 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 2.2.

Maximum shear stress in the steel structure (92 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 2.

Maximum shear stress in the bars (144 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa), which corresponds to a safety coefficient of 1.2.

IV.4. configuration 3: 4 vertical packages

IV.4.1. Model



Vue générale du modèle	General view of the model:
Conditions limites d'encastrement	Threshold embedding conditions
Sangle	Strap
Sangles de liaison entre les emballages	Inter-package connecting straps
Cales positionnées au niveau des pieds des emballages	Blocks positioned at the package base
Elements de contact (GAP)	Contact elements (GAP)

The cages mutually support each other and are also supported by the truck chassis via contact elements (GAP) to prevent any sliding or the detachment of the packages.

Threshold embedding conditions apply for each strap end.

Straps are modelled with bars which only transfer traction (non-linear material). Pre-tension of 100 daN is applied to each strap.

Blocks are added at the base of the packages and connected to the truck.

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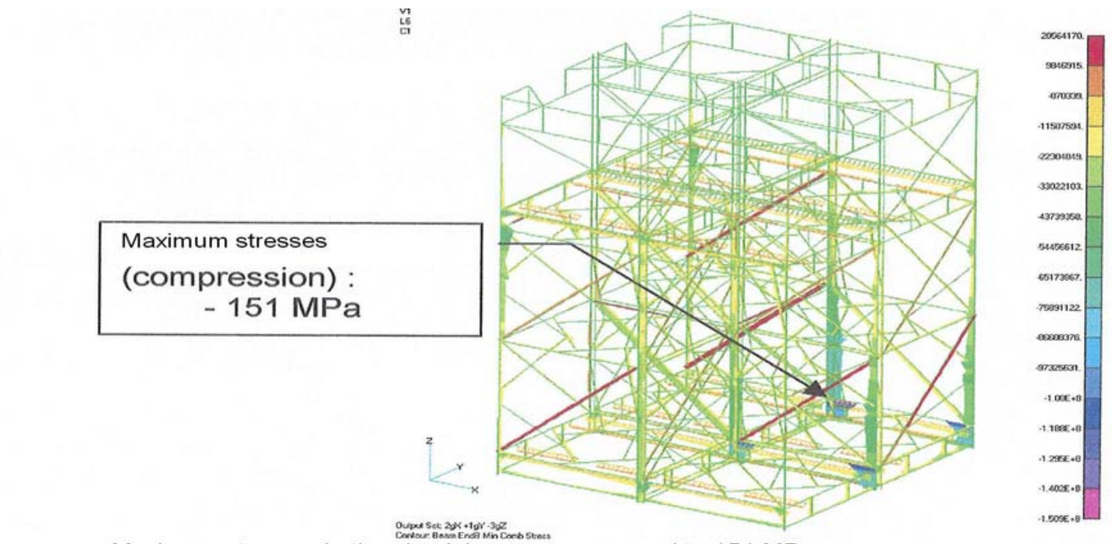
IV.4.2. Road transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

Important: maximum stresses may be in red or magenta (compression or traction values).

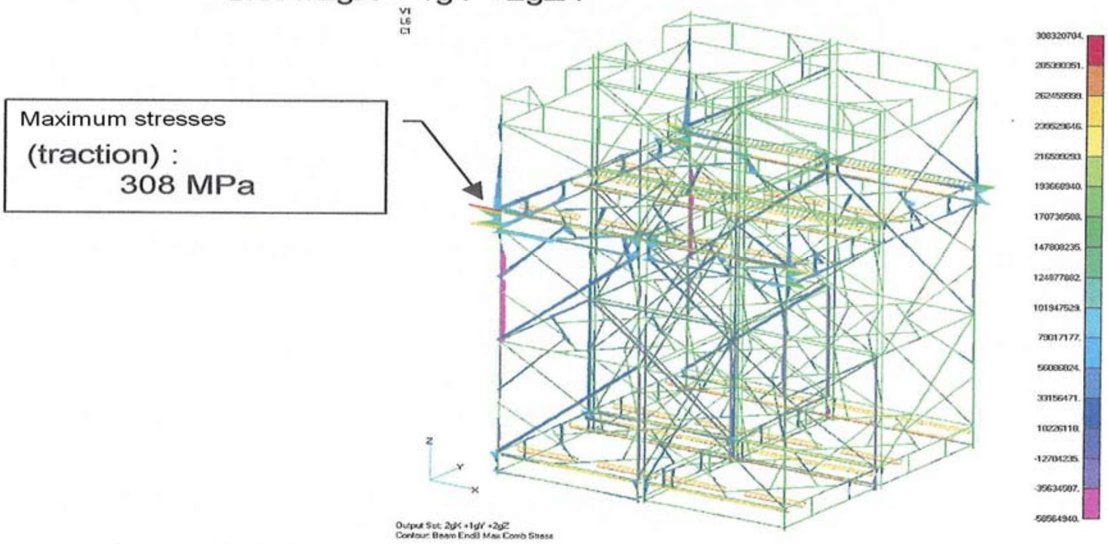
Load of 2gX + 1gY -3gZ:



Maximum stresses in the aluminium cage are equal to 151 MPa.

t de 151 MPa.

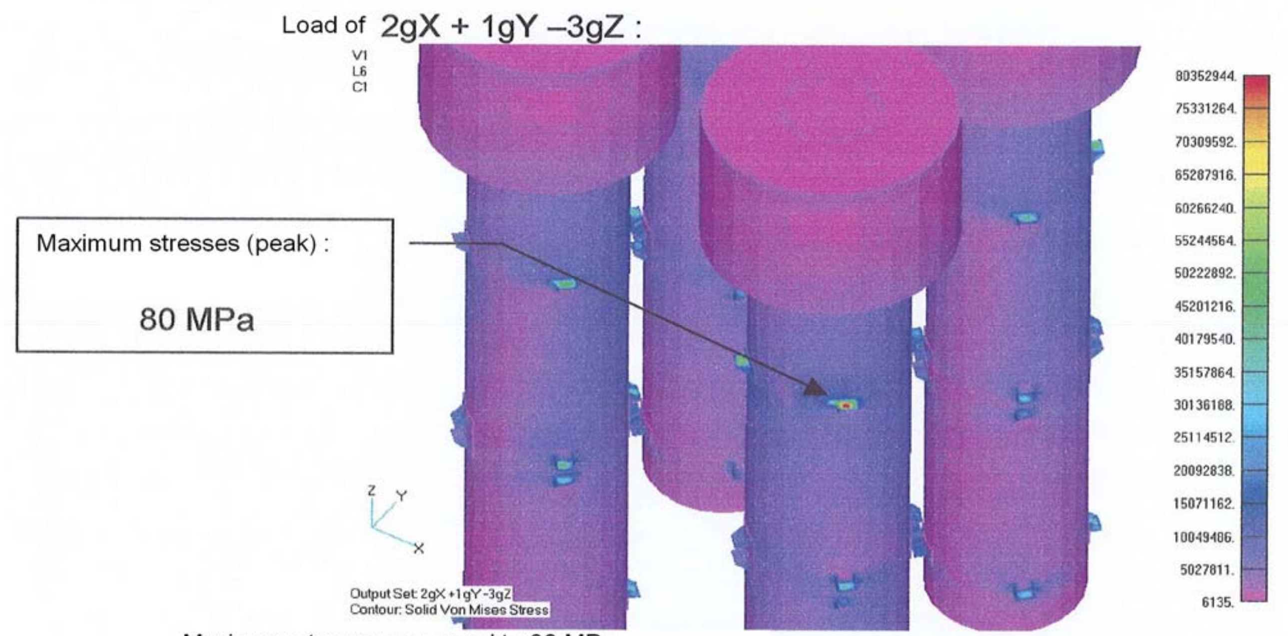
Load of 2gX + 1gY +2gZ :



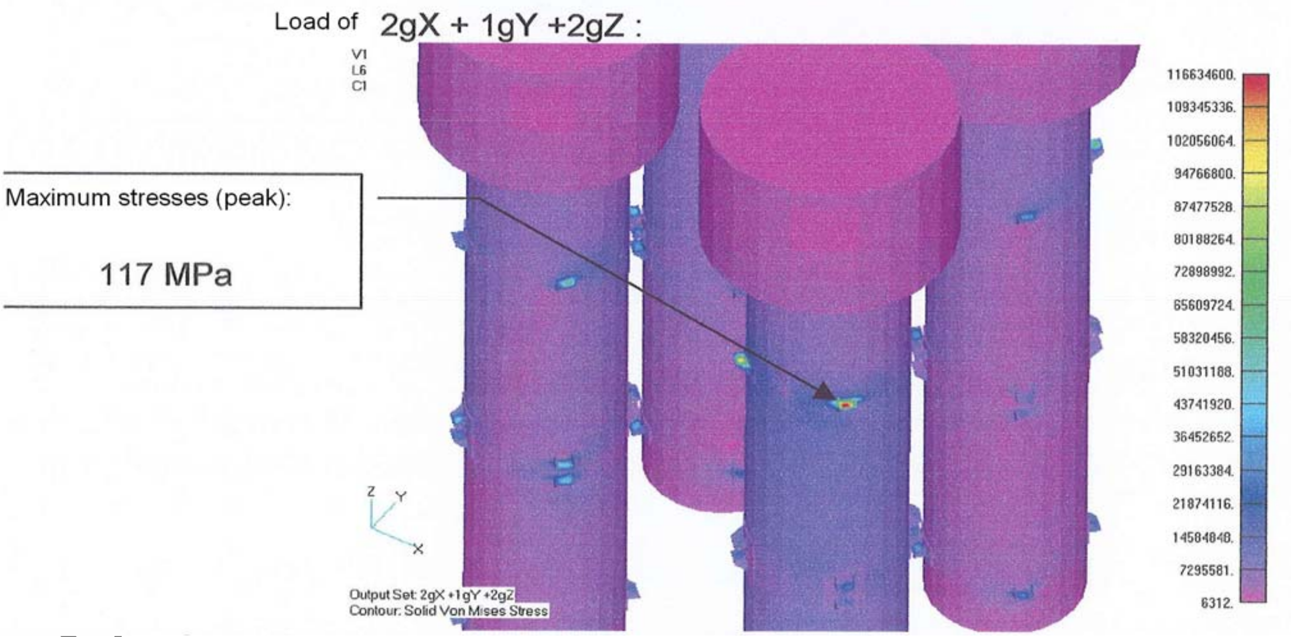
Maximum stresses in the aluminium cage are equal to 308 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 308 MPa in a welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.



Maximum stresses are equal to 80 MPa.



Maximum stresses are equal to 117 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 117 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Road	+2gX+1gY-3gZ	919	837	0	140
	+2gX+1gY+2gZ	3010	2455	995	1946

Maximum tension is equal to 3010 daN.

For M6 screws, maximum shear force is equal to 4,068 N, and maximum shear stress is therefore 202 MPa.

CONFIGURATION 3: 4 VERTICAL PACKAGES - ROAD TRANSPORT

Maximum tension in straps is equal to 3010 daN.

Maximum shear stress in M6 screws (202 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 1.8.

Maximum shear stress in the steel structure (117 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 1.6.

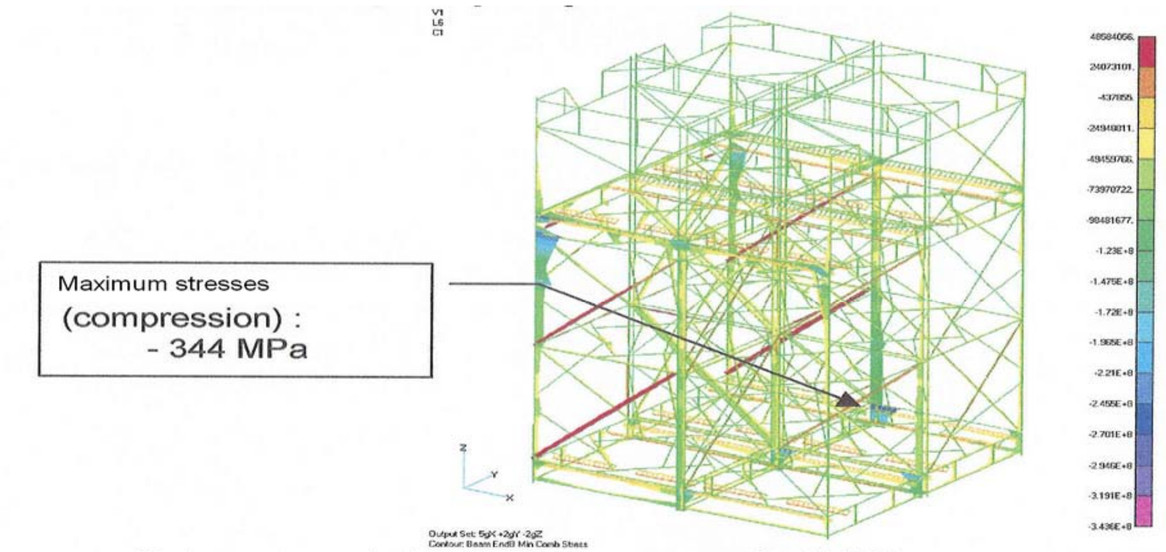
Maximum shear stress in the bars (308 MPa) is higher than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

IV.4.3. Rail transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

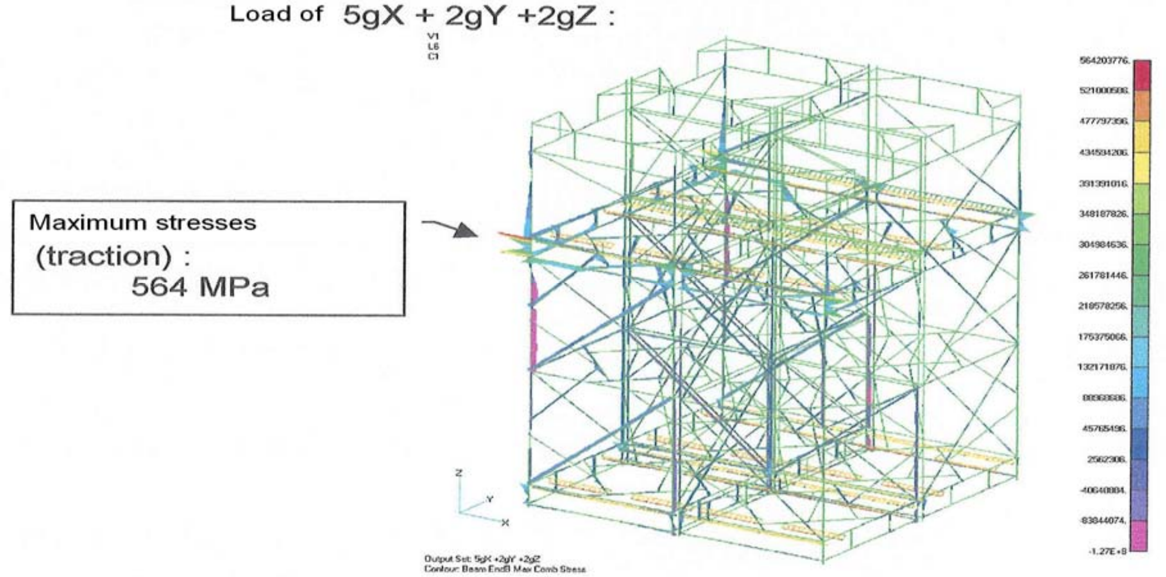
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 5gX + 2gY -2gZ:



Maximum stresses in the aluminium cage are equal to 344 MPa

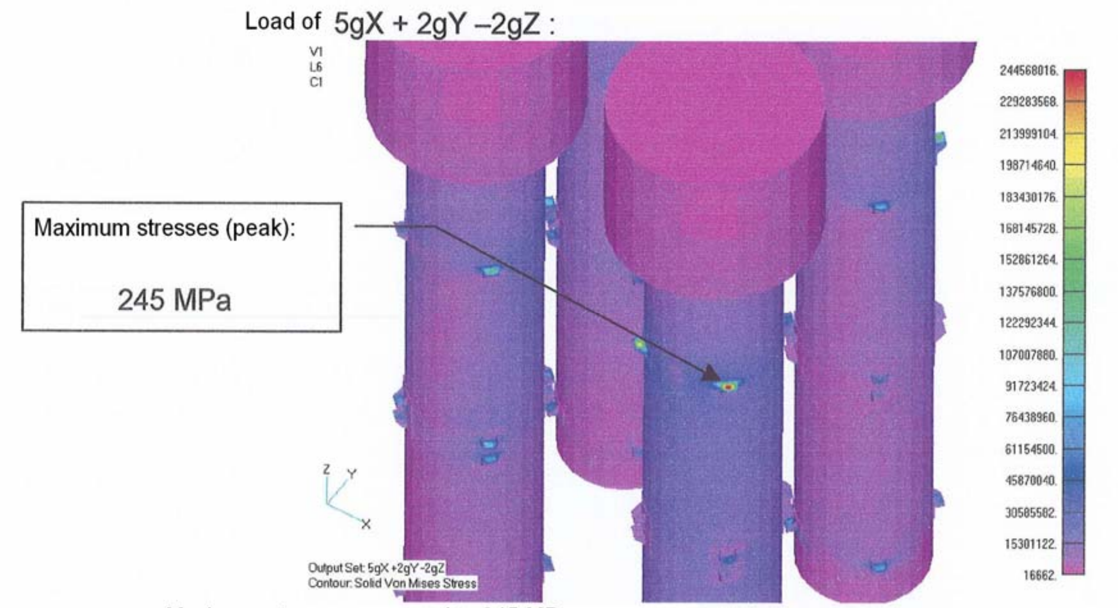
Load of 5gX + 2gY +2gZ :



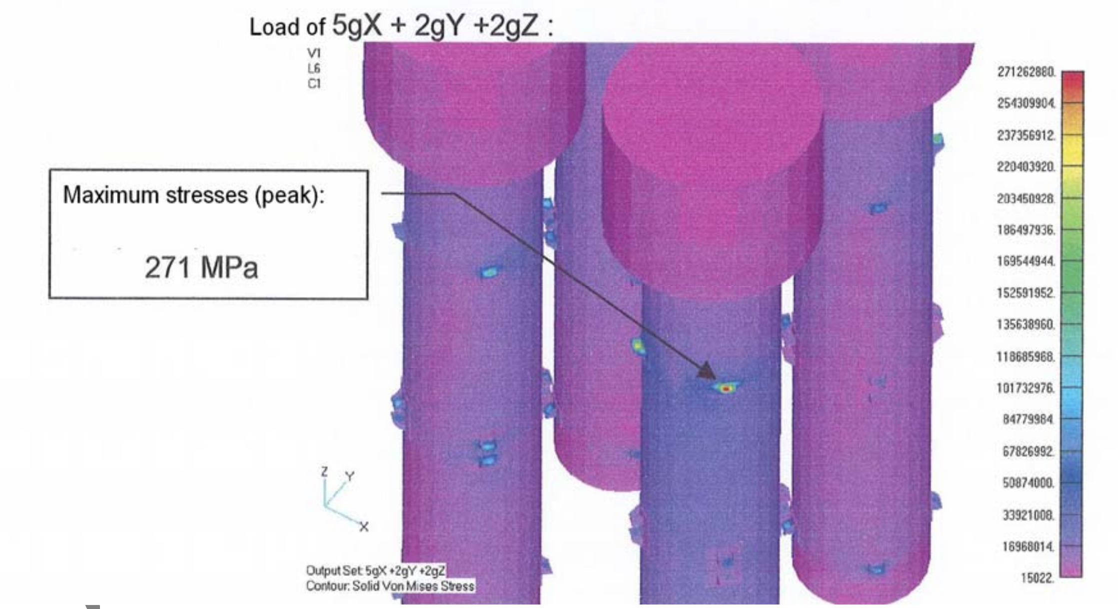
Maximum stresses in the aluminium cage are equal to 564 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 564 MPa in a welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.



Maximum stresses are equal to 245 MPa.



Maximum stresses are equal to 271 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 271 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Rail	+5gX+2gY-2gZ	4028	3234	0	1361
	+5gX +2gY +2gZ	5753	4644	995	2897

Maximum tension is equal to 5753 daN.

For M6 screws, maximum shear force is equal to 9,445 N, and maximum shear stress is therefore 470 MPa.

CONFIGURATIONS: 4 VERTICAL PACKAGES - RAIL TRANSPORT

Maximum tension in straps is equal to 5753 daN.

Maximum shear stress in M6 screws (470 MPa) is higher than the maximum acceptable stress of 360 MPa.

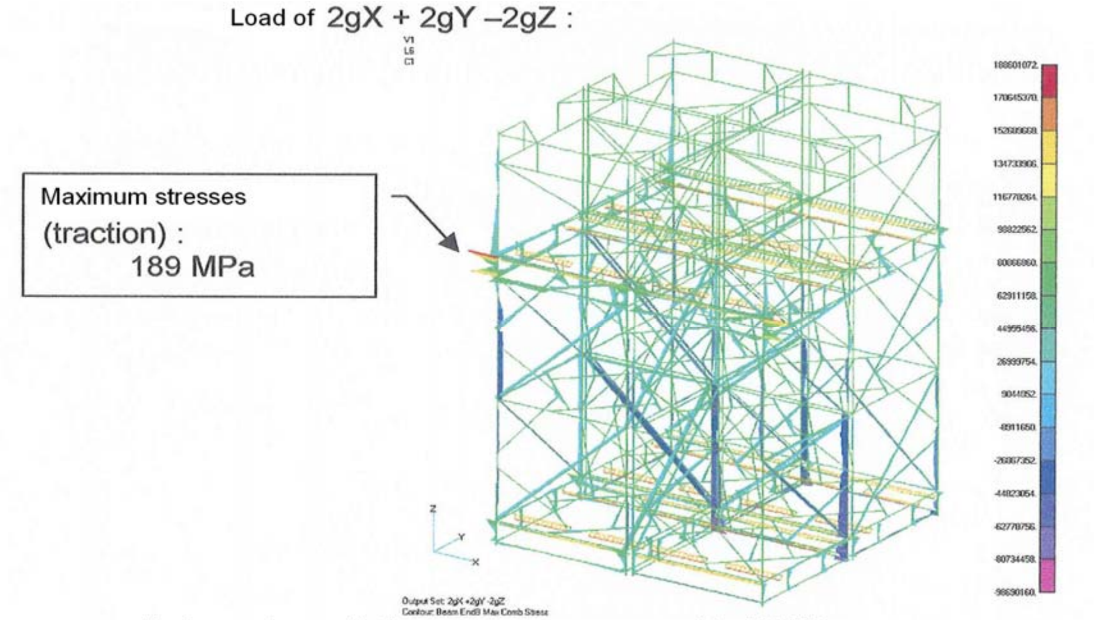
Maximum shear stress in the steel structure (271 MPa) is higher than the elastic limit of the 304L steel at 80°C (189 MPa). However, this refers to peak stresses in a local area, and the rest of the steel structure is not subjected to significant stresses.

Maximum shear stress in the bars (564 MPa) is higher than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

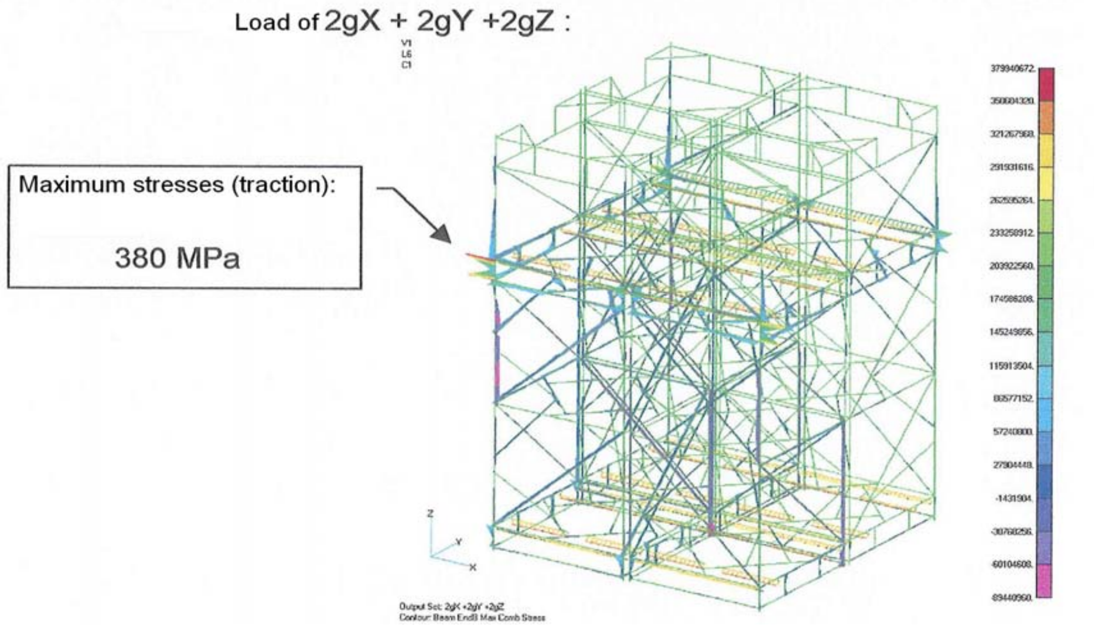
IV.4.4. Maritime transport

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

Important: maximum stresses may be in red or magenta (compression or traction values).



Maximum stresses in the aluminium cage are equal to 189 MPa.

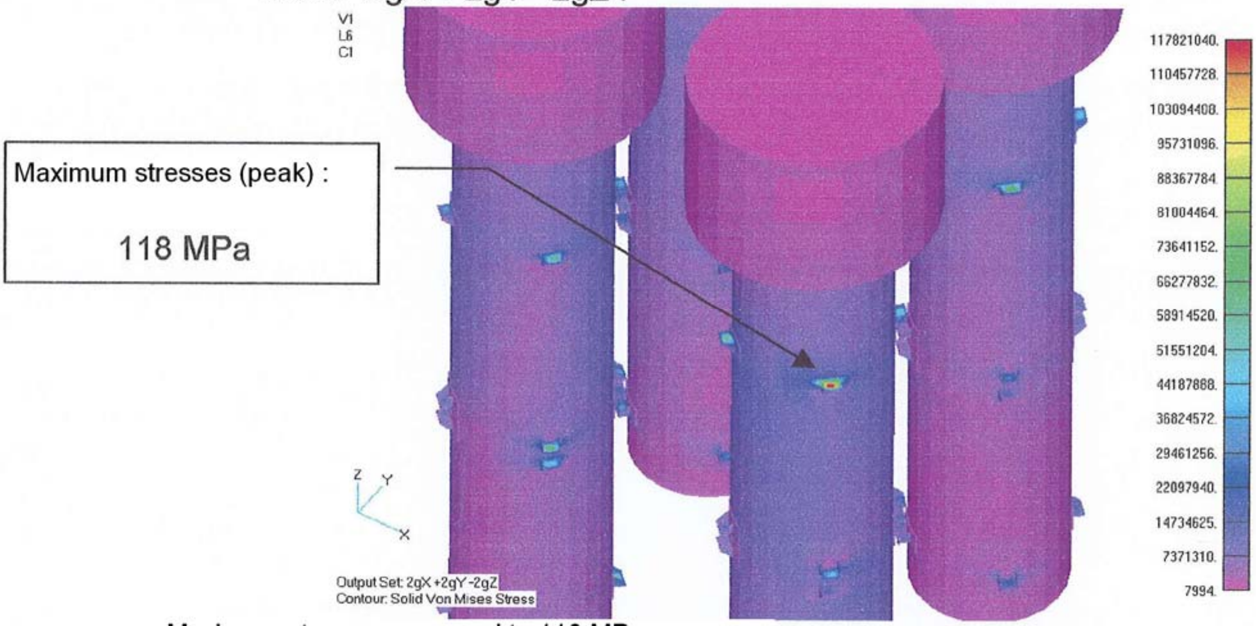


Maximum stresses in the aluminium cage are equal to 380 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 380 MPa in a welded zone.

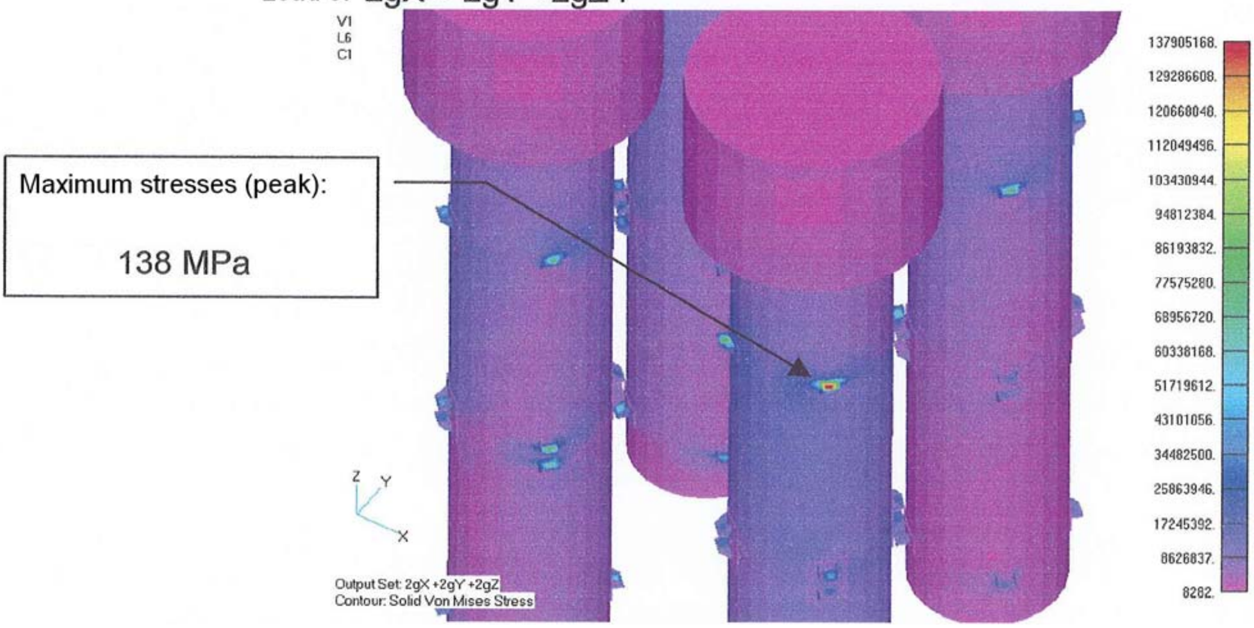
The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.

Load of 2gX + 2gY –2gZ :



Maximum stresses are equal to 118 MPa.

Load of 2gX + 2gY +2gZ :



Maximum stresses are equal to 138 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 138 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Load (X: longitudinal; Y: transversal; Z: vertical)		Sling tension (daN) Pre-tension 100 daN			
		Strap n°1	Strap n°2	Strap n°3	Strap n°4
Maritime	+2gX +2gY -2gZ	1839	1045	0	1361
	+2gX +2gY +2gZ	3564	2455	995	2897

Maximum tension is equal to 3564 daN.

For M6 screws, maximum shear force is equal to 4,918 N, and maximum shear stress is therefore 245 MPa.

CONFIGURATION 3: 4 VERTICAL PACKAGES - MARITIME TRANSPORT

Maximum tension in straps is equal to 3564 daN.

Maximum shear stress in M6 screws (245 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 1.5.

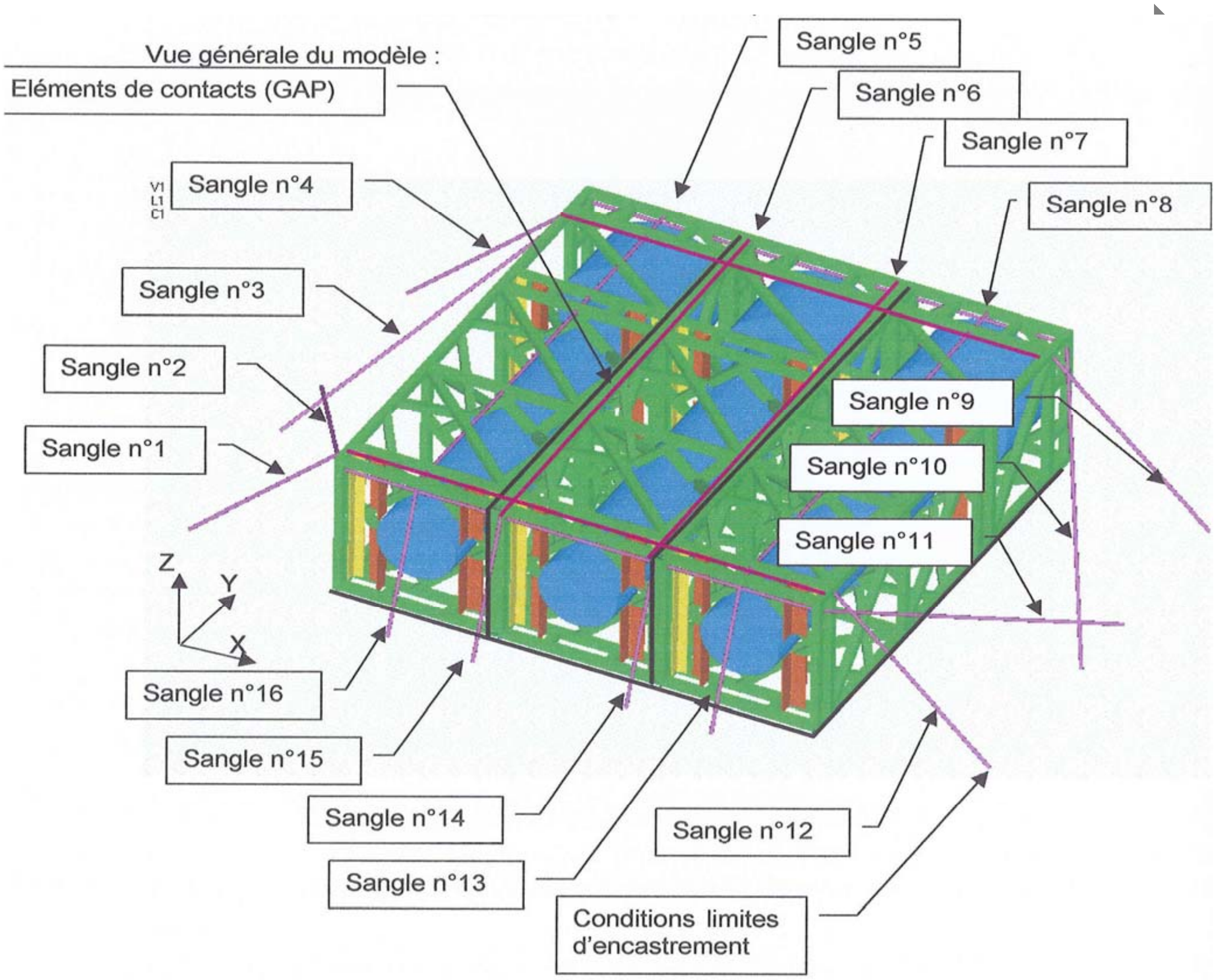
Maximum shear stress in the steel structure (138 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 1.3.

Maximum shear stress in the bars (380 MPa) is higher than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

IV.5. Configuration 4, Air transport, 3 packages

IV.5.1. Model

The following securing plan was considered for air transport.



Vue générale du modèle	General view of the model
Conditions limites de conditionnement	Embedded limit conditions
Sangle	Strap
Elements de contact (GAP)	Contact elements (GAP)

The cages mutually support each other and are also supported by the transport chassis via contact elements (GAP) to prevent any sliding or the detachment of the packages.

Threshold embedding conditions apply for each strap end.

Straps are modelled with bars which only transfer traction (non-linear material). Pre-tension of 100 daN is applied to each strap.

The following tensions exist in all straps (16) (clockwise numbering in top view).

- Straps n°1, n°4, n°9 and n°12 are inclined by approximately 45° thereby blocking packages both longitudinally and vertically.
- Straps n°2, n°3, n°10 and n°11 mainly block the 2 packages at transversal extremities.
- The 8 other straps block packages at extremities and the central package both transversally and vertically.

Important comment: in the context of calculations, only straps n°6, n°7, n°14 and n°15 block the central package both transversally and vertically.

Straps n°1, n°4, n°9 and n°12 are placed at the ends of bars to avoid inducing excessive bending stresses.

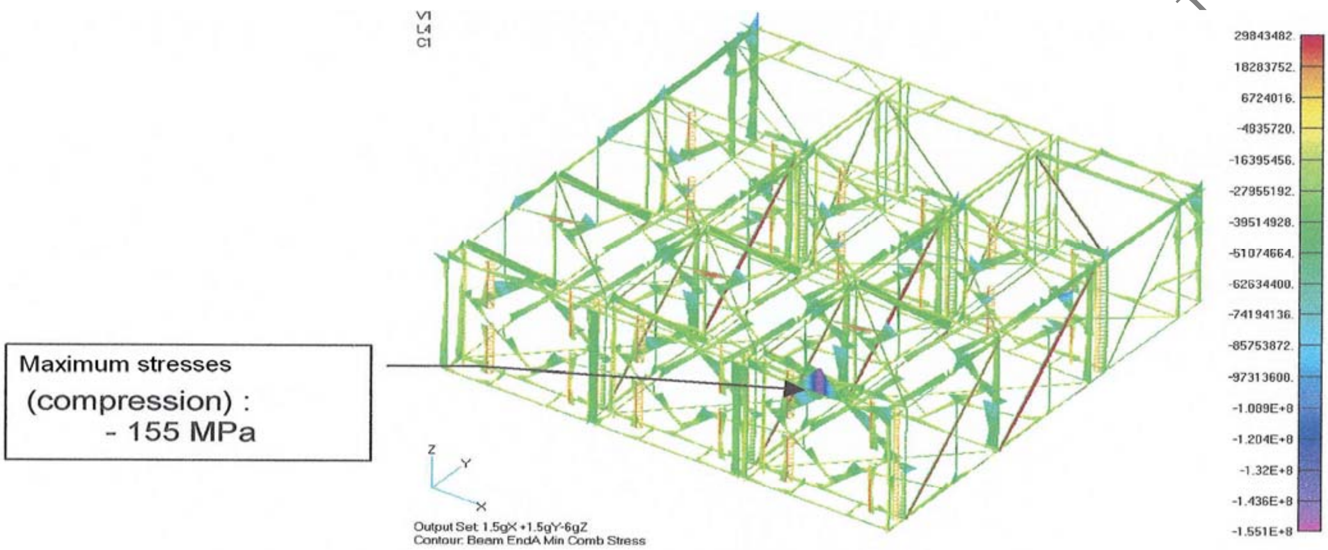
Straps n°6, n°7, n°14 and n°15 are supported by the bars at the ends of the central package to avoid creating bending effects.

IV.5.2. Air transport with protection net

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

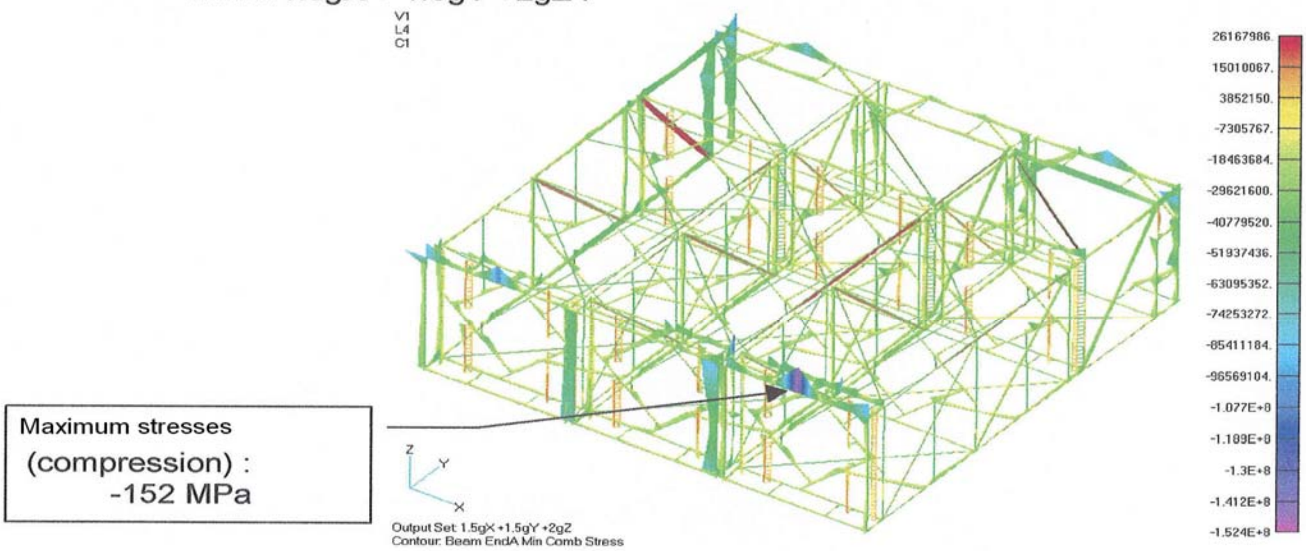
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 1.5gX + 1.5gY -6gZ:



Maximum stresses in aluminium cage are equal to 155 MPa.

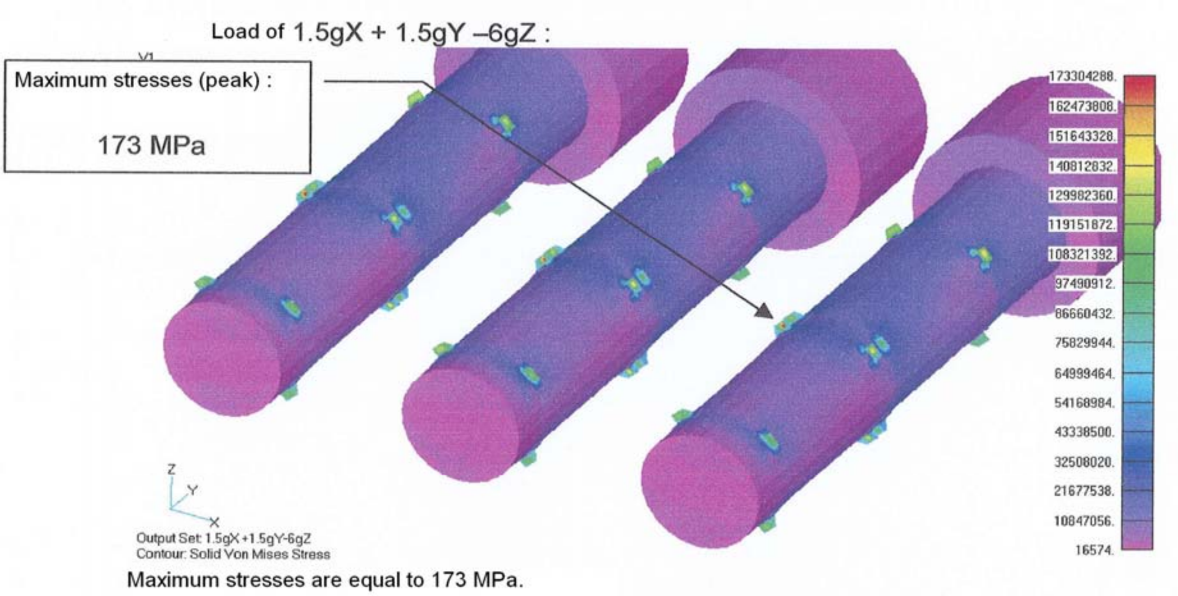
Load of 1.5gX + 1.5gY +2gZ :

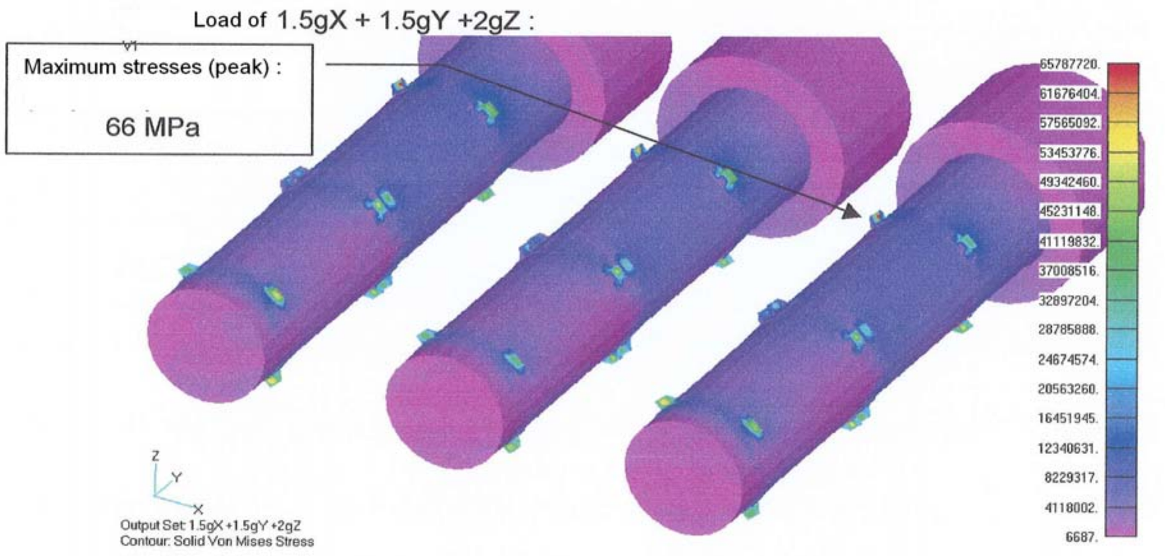


Maximum stresses in the aluminium cage are equal to 152 MPa.

Maximum stresses in the aluminium cage, for both loads, are equal to 155 MPa in a non-welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.





Maximum stresses are equal to 66 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 173 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Sling tension (daN) Pre-tension 100 daN	Air transport with net Load (X: longitudinal; Y: transversal; Z: vertical)	
	+1.5gX+1.5gY-6gZ	+1.5gX+1.5gY+2gZ
Strap n°1	998	978
Strap n°2	145	162
Strap n°3	839	852
Strap n°4	1184	1246
Strap n°5	0	286
Strap n°6	0	122
Strap n°7	0	455
Strap n°8	0	272
Strap n°9	0	540
Strap n°10	523	622
Strap n°11	0	0
Strap n°12	0	0
Strap n° 13	514	558
Strap N°14	822	1183
Strap n°15	938	1154
Strap n°16	115	412

Maximum tension is equal to 1246 daN.

For M6 screws, maximum shear force is equal to 3,603 N, and maximum shear stress is therefore 179 MPa.

CONFIGURATION 4: 3 HORIZONTAL PACKAGES - AIR TRANSPORT WITH PROTECTION NET

Maximum tension in straps is equal to 1246 daN.

Maximum shear stress in M6 screws (179 MPa) is less than the maximum acceptable stress of 360 MPa, which corresponds to a safety coefficient of 2.

Maximum shear stress in the steel structure (173 MPa) is less than the elastic limit of the 304L steel at 80°C (189 MPa), which corresponds to a safety coefficient of 1.1.

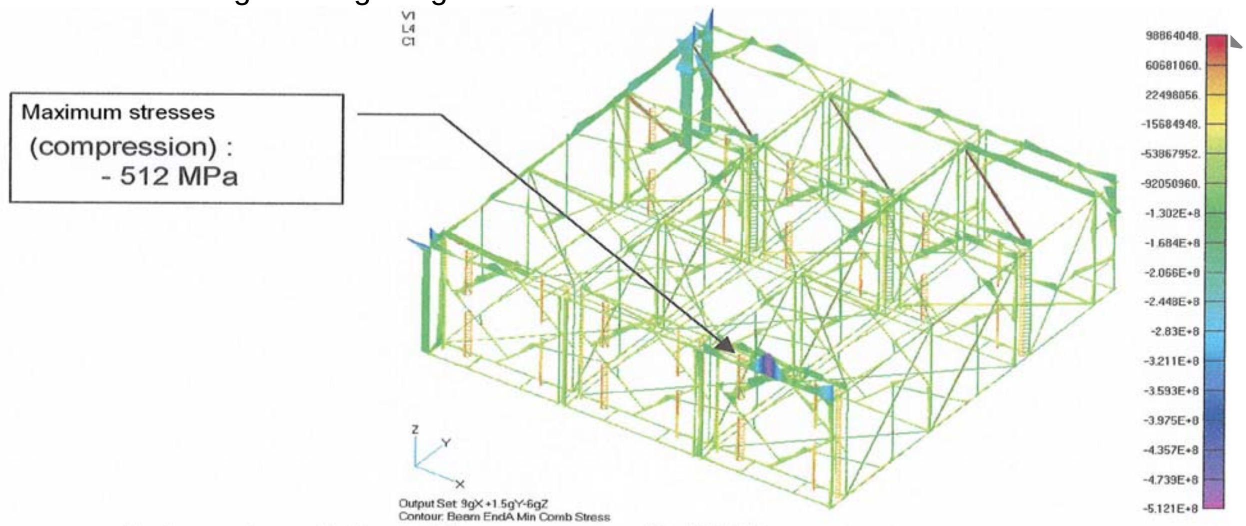
Maximum shear stress in the bars (155 MPa) is less than acceptable stresses for the aluminium alloy at 80°C (elastic limit of 249 MPa), which corresponds to a safety coefficient of 1.6.

IV.5.3. Air transport without protection net

The following figures show maximum stresses in Pa in the aluminium cage in the form of a diagram for both loads.

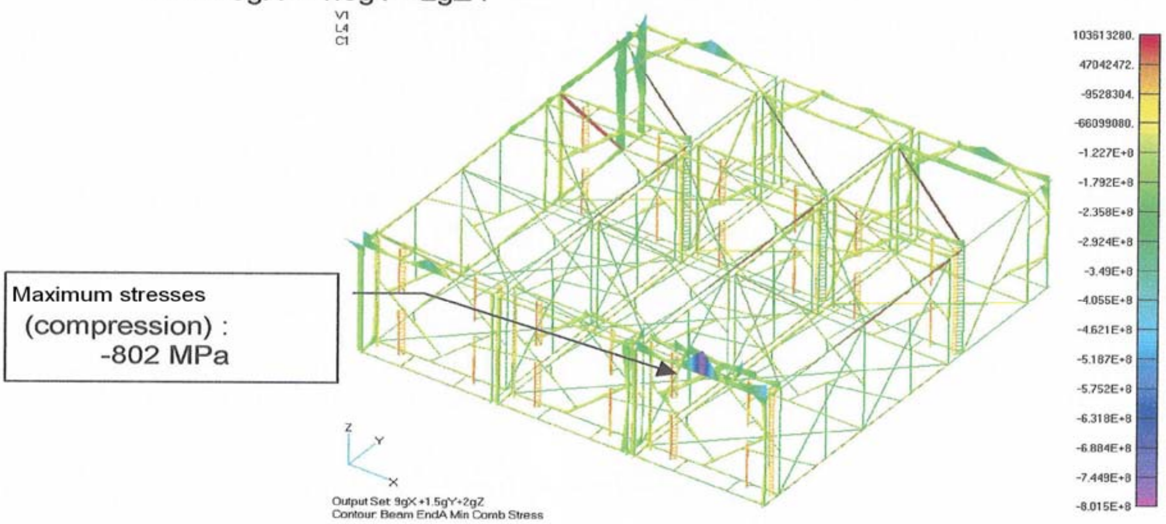
Important: maximum stresses may be in red or magenta (compression or traction values).

Load of 9gX + 1.5gY -6gZ:



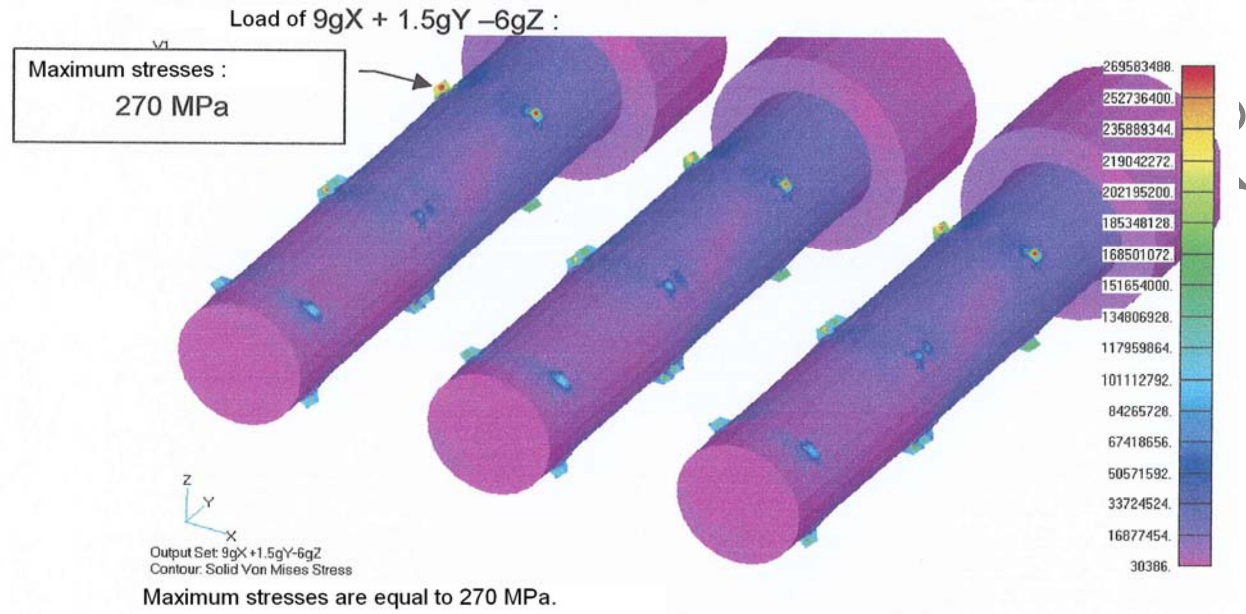
Maximum stresses in the aluminium cage are equal to 512 MPa.

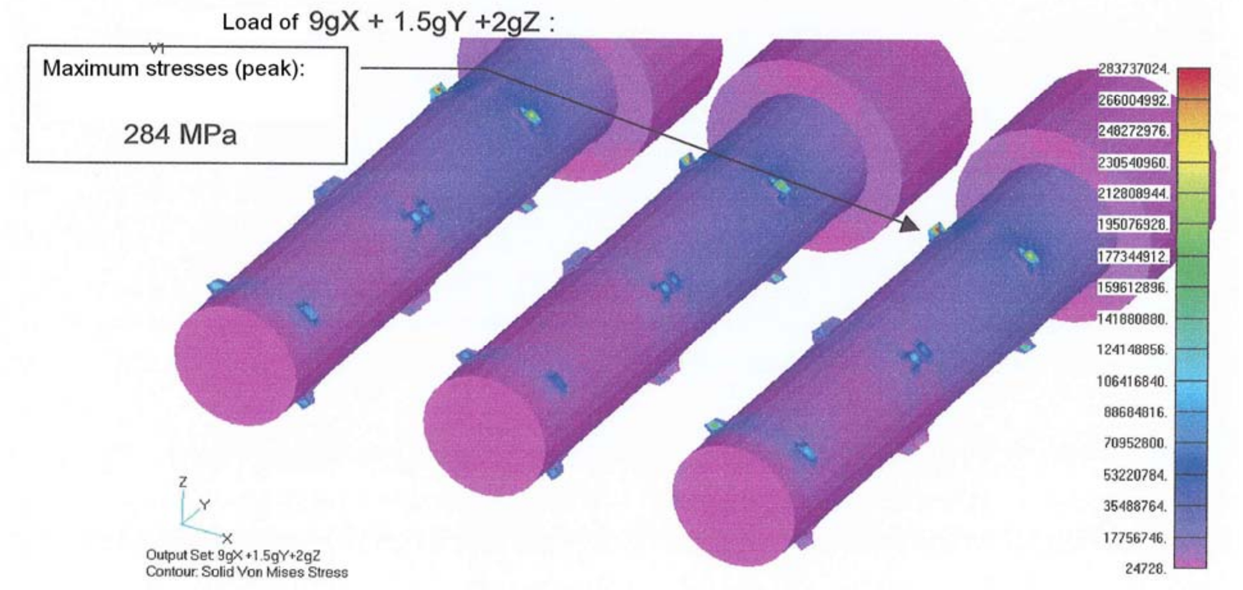
Load of 9gX + 1.5gY +2gZ :



Maximum stresses in the aluminium cage are equal to 802 MPa. Maximum stresses in the aluminium cage, for both loads, are equal to 802 MPa in a non-welded zone.

The following figures show equivalent Von Mises stresses in the steel structure of the container, in Pa for both loads.





Maximum stresses (peak): 284 MPa

Maximum stresses are equal to 284 MPa.

Maximum stresses in the steel structure of the container, for both loads, are equal to 284 MPa near to attachment brackets.

The following table indicates tensions in straps for both loads:

Sling tension (daN) Pre-tension 100 daN	Air transport without net Load (X: longitudinal; Y: transversal; Z: vertical)	
	+9gX+1.5gY-6gZ	+9gX+1.5gY+2gZ
Strap n°1	5161	5131
Strap n°2	2038	2053
Strap n°3	2787	2829
Strap n°4	6227	6625
Strap n°5	632	1480
Strap n°6	0	0
Strap n°7	0	1201
Strap n°8	0	1120
Strap n°9	0	0
Strap n°10	1865	50
Strap n°11	0	0
Strap n°12	0	0
Strap n°13	1662	2764
Strap N°14	658	2010
Strap n°15	1102	952
Strap n°16	614	1398

Maximum tension is equal to 6625 daN.

For M6 screws, maximum shear force is equal to 9,576 N, and maximum shear stress is therefore 476 MPa.

CONFIGURATION 4: 3 HORIZONTAL PACKAGES - AIR TRANSPORT WITHOUT PROTECTION NET

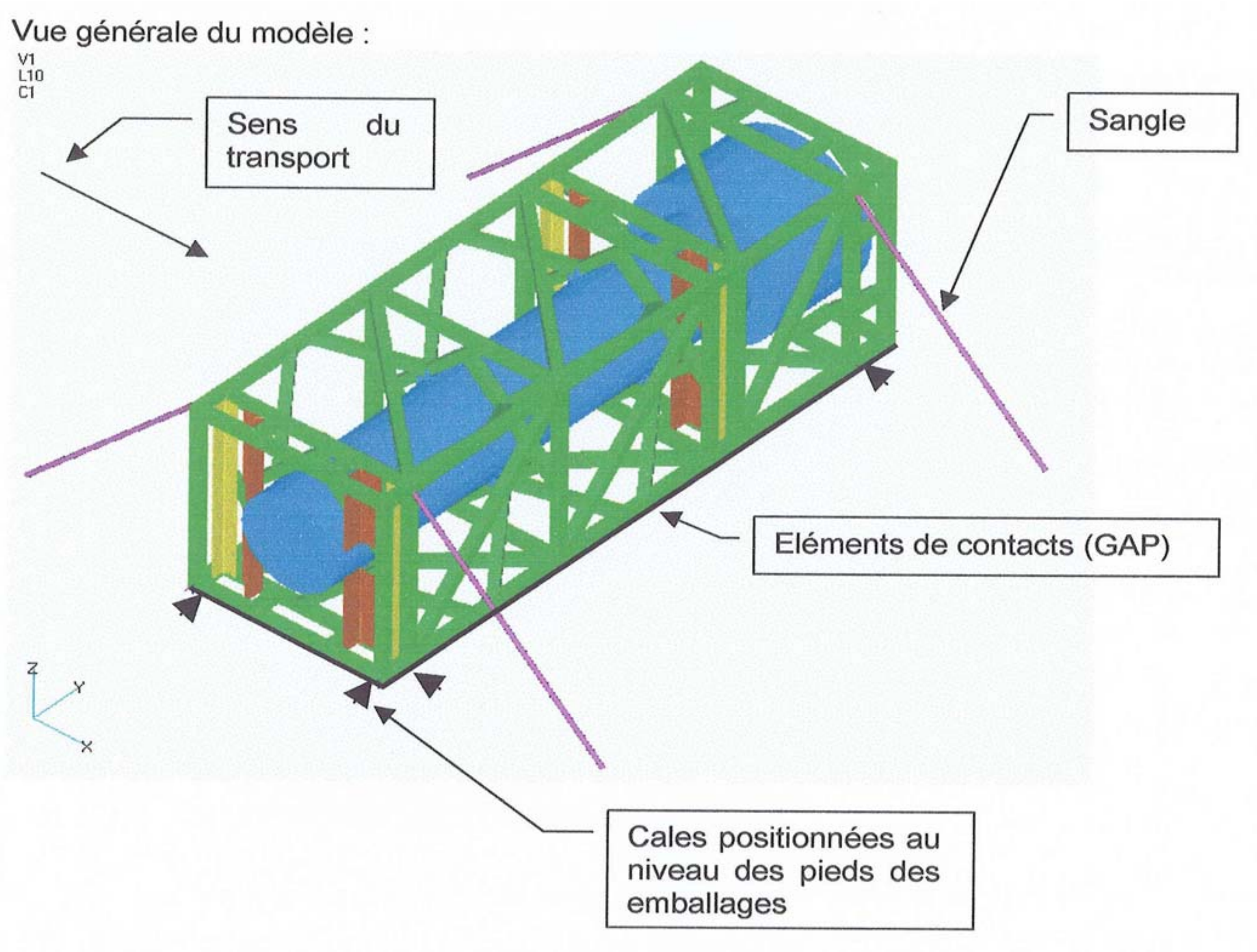
Maximum tension in straps is equal to 6625 daN.

Maximum shear stress in M6 screws (476 MPa) is higher than the maximum acceptable stress of 360 MPa.

Maximum shear stress in the steel structure (284 MPa) is higher than the elastic limit of the 304L steel at 80°C (189 MPa).

Maximum shear stress in the bars (802 MPa) is higher than acceptable stresses for the aluminium alloy at 80°C (elastic limit of 249 MPa).

IV.6. Configuration 5, 1 horizontal package IV.6.1. Model



Vue générale du modèle	General view of the model:
Sens du transport	Transport direction
Sangle	Strap
Eléments de contact (GAP)	Contact Elements (GAP)
Cales positionnées au niveau des pieds des emballages	Blocks positioned at the level of the feet of the package

Straps are used to prevent the package from tilting and block vertical displacement.

Blocks are positioned at the 4 corners of the package to block longitudinal and transversal movements.

The direction of transport is selected perpendicularly to the package axis as this is detrimental in terms of stresses parallel to the axis.

Threshold embedding conditions apply for each strap end.

Straps are modelled with bars which only transfer traction (non-linear material). Pre-tension of 100 daN is applied to each strap.

IV.6.2. General results

Calculations were conducted for the 10 loads proposed. Only the most detrimental load maps are shown for clarity. The following table summarises maximum stress and force values for all calculations.

Load		Maximum values			
(X: longitudinal; Y: transversal; Z: vertical)		Alu chassis - Stress (MPa)	Steel structure - Stress (MPa)	Strap tension (daN)	Screw - stress (MPa)
Road	+2gX+1gY-3gZ	64	86	164	94
	+2gX+1gY+2gZ	61	70	370	92
Rail	+5gX +2gY -2gZ	102	121	357	197
	+5gX +2gY +2gZ	101	141	554	217
Maritime	+2gX+2gY-2gZ	64	68	163	88
	+2gX +2gY +2gZ	62	73	417	86
Air transport with net	+1.5gX +1.5gY -6gZ	109	159	130	166
	+1.5gX+1.5gY+2gZ	55	65	370	69
Air transport without net	+9gX+1.5gY-6gZ	188	241	580	359
	+9gX+1.5gY+2gZ	162	235	775	383

For road transport:

Maximum tension in straps is equal to 370 daN.
Maximum shear stress in M6 screws (94 MPa) is lower than the maximum acceptable stress of 360 MPa.
Maximum shear stress in the steel structure (86 MPa) is lower than the elastic limit of the 304L steel at 80°C (189 MPa).
Maximum shear stress in the bars (64 MPa) is lower than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

For rail transport:

Maximum tension in straps is equal to 554 daN.
Maximum shear stress in M6 screws (217 MPa) is lower than the maximum acceptable stress of 360 MPa.
Maximum shear stress in the steel structure (141 MPa) is lower than the elastic limit of the 304L steel at 80°C (189 MPa).
Maximum shear stress in the bars (102 MPa) is lower than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

For maritime transport:

Maximum tension in straps is equal to 417 daN.
Maximum shear stress in M6 screws (88 MPa) is lower than the maximum acceptable stress of 360 MPa.
Maximum shear stress in the steel structure (73 MPa) is lower than the elastic limit of the 304L steel at 80°C (189 MPa).
Maximum shear stress in the bars (64 MPa) is lower than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

For air transport with protection net:

Maximum tension in straps is equal to 370 daN.
Maximum shear stress in M6 screws (166 MPa) is lower than the maximum acceptable stress of 360 MPa.
Maximum shear stress in the steel structure (159 MPa) is lower than the elastic limit of the 304L steel at 80°C (189 MPa).
Maximum shear stress in the bars (109 MPa) is lower than acceptable stresses for the aluminium alloy at 80°C (elastic limit multiplied by the weld coefficient, i.e. 174 MPa).

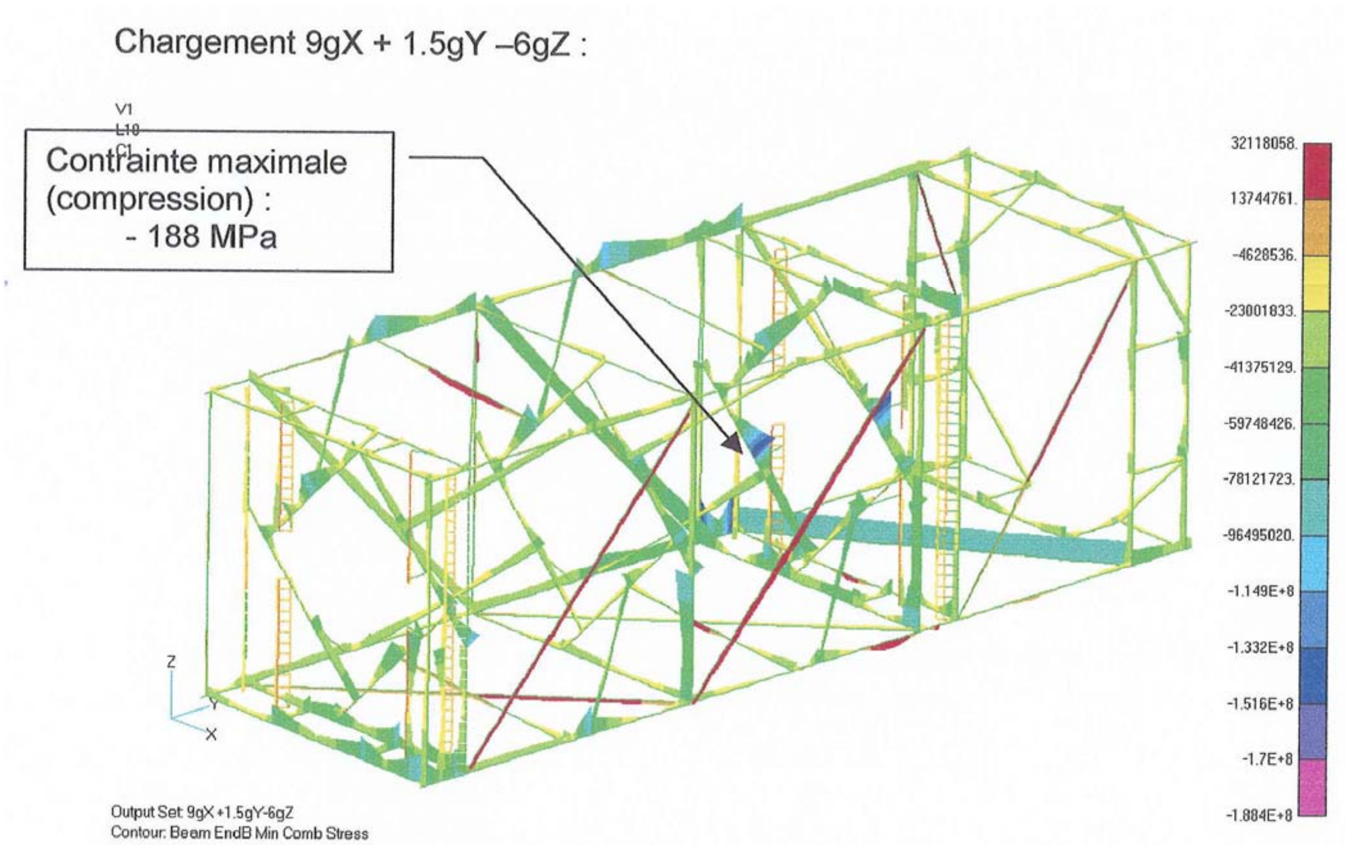
For air transport without protection net:

Maximum tension in straps is equal to 775 daN.
Maximum shear stress in M6 screws (383 MPa) is lower than the maximum acceptable stress of 360 MPa.
Maximum shear stress in the steel structure (241 MPa) is higher than the elastic limit of the 304L steel at 80°C (189 MPa), however this reflects a peak stress (see following paragraph).
Maximum shear stress in the bars (188 MPa) is lower than acceptable stresses for the aluminium alloy at 80°C (elastic limit of 249 MPa).

IV.6.3. Air transport without protection net

The following figure shows maximum stresses in Pa in the aluminium cage in the form of a diagram for the most detrimental load.

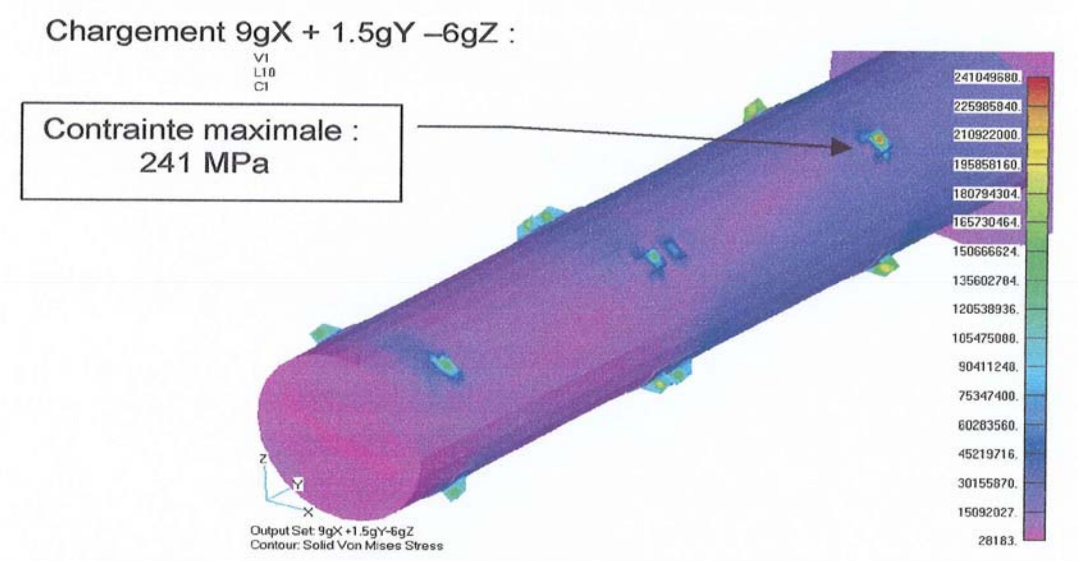
Important: maximum stresses may be in red or magenta (compression or traction values).



Maximum stresses in the aluminium cage are equal to 188 MPa in a non-welded zone

Chargement 9gX + 1.5gY -6gZ	Load of 9gX + 1.5gY -6gZ
Contrainte maximale (compression) : 188 MPa	Maximum stresses (compression): -188 MPa

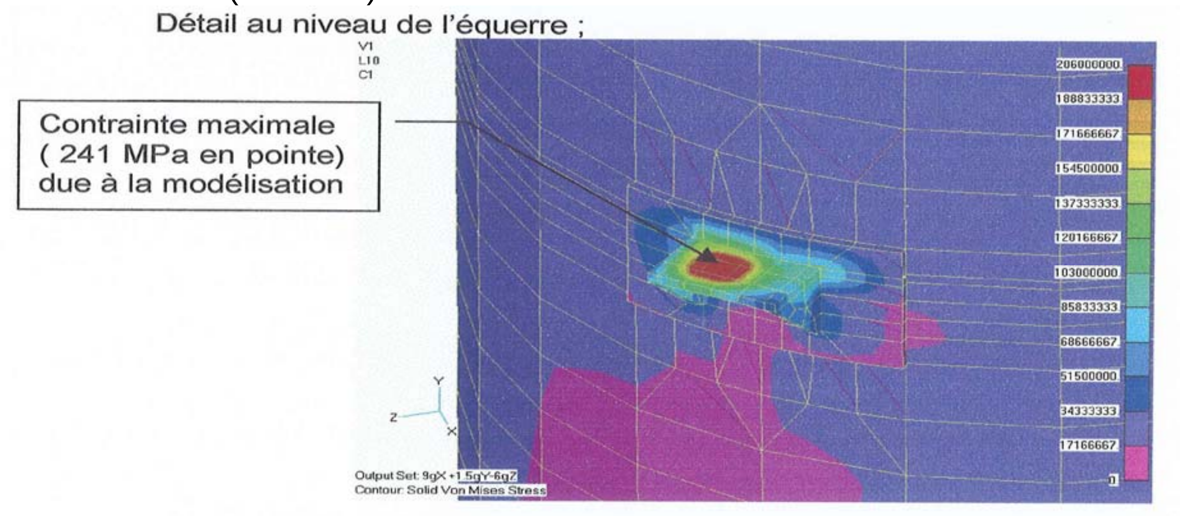
The following figure shows equivalent Von Mises stresses in the steel structure of the container, in Pa for the most detrimental load.



Maximum stresses are equal to 241 MPa.

Chargement 9gX + 1.5gY -6gZ	Load of 9gX + 1.5gY -6gZ:
Contrainte maximale 241 MPa	Maximum stresses: 241 MPa

The following figure shows an enlargement of the zone subjected to stresses with the scale of the stresses blocked, indicating the zones subjected to stresses beyond the elastic limit (188 MPa) in red.



The maximum stress (peak value) is due to modelling (bar type components creating punctual, but substantial, stresses). Stresses near to the shell/bracket interface are less than the elastic limit of 188 MPa.

Détail au niveau de l'équerre	Details near to the bracket
Contrainte maximale (241 MPa en pointe due	Maximum stresses (241 MPa peak value) due

à la modélisation)	to modelling

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CONCLUSION

Five securing studies with acceleration combinations and four types of transport as per ref. {2} were carried out:

	Satisfied acceptance criteria				
Configuration n°	Road transport	Rail transport	Maritime transport	Air transport with net	Air transport without net
N°1: 1 vertical package	yes	no	yes	yes	
N°2: 2 vertical packages	yes	no	yes		
N°3: 4 vertical packages	no	no	no		
N°4: 3 horizontal packages	yes				no
N°5: 1 horizontal package		yes	yes	yes	yes

For configuration 1 (1 vertical package), acceptance criteria are satisfied for road and maritime transport (air transport not studied). Criteria are not satisfied for rail transport, but only for 2 MPa on fixation axes.

For configuration 2 (2 vertical packages), acceptance criteria are satisfied for road and maritime transport (air transport not studied). Criteria are not satisfied for rail transport.

For configuration 3 (4 vertical packages), acceptance criteria are not satisfied for road, rail and maritime transport (air transport not studied).

For configuration 4 (3 horizontal packages), acceptance criteria are satisfied for air transport with a protection net and criteria are not satisfied for air transport without a protection net (3 other types of transport not studied).

For configuration 5 (1 horizontal package), acceptance criteria are satisfied for all types of transport (road, rail, maritime and air transport with or without a net).

VI. Reference documents

Ref. {1}: TRANSNUCLEAR plans, Package TN-BGC1
Main section, ref. 0892-29
Damper cover, ref. 0892-44
Cage, ref. 0892-41

Ref. {2}: IAEA safety standard - "Regulations for the safe transport of radioactive material" 1996 Edition Revised ST-1.

Ref. {3}: Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material - Safety standards series N° TS-G-1.1 (ST-2).

Ref. {4}: Specifications 160 EMBAL PFM CDC 0500478.

Ref. {5}: DEMA calculation memo, Heat studies of the package TN-BGC 1, reference 172C3W01

Ref. {6}: DEMA calculation memo, Mechanical studies of the package TN-BGC 1, reference 172E3W22 iss. B

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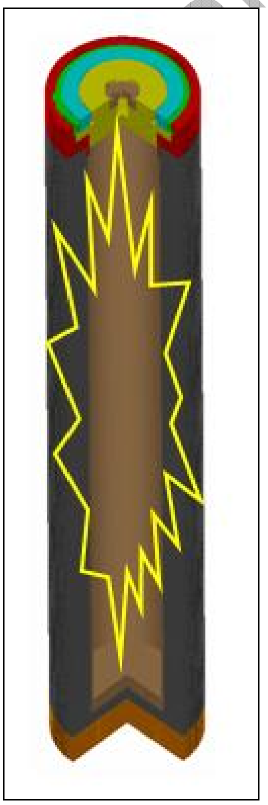
Technical report

EUROSIM
Ref.: 2BP6E042

CEA
Ref. : CEA/DEN/CAD/DTAP/SET DO 72

Mechanical resistance of package TN-BGC 1 to explosions



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Mechanical resistance of package TN-BGC 1 to explosions

Objectives

This study aims to determine the mechanical behaviour of package TN-BGC 1 if a load explodes, with consideration of the temperatures reached by the package following testing reproducing transport accident conditions, and estimation of maximum allowable pressure for this package.

Assumptions and modelling methods used in this study

The assumptions and modelling methods used in this study are globally based on those used in the previous study (cf. <9>).

The parts subject to the highest stresses in case of an explosion are considered as closing system components. Careful attention will therefore be paid to the modelling of this zone: bayonet ring, clamp ring, main section flange and plug are finely meshed and the clamping effects of the plug have been modelled. The threads of the bayonet ring and the clamp ring have been considered as stiff and undamaged by the explosion, to transmit the forces induced by the explosion under the plug to the supports of the bayonet ring on the flange shoulders in an optimum manner, in view of the apparent fragility of this zone.

This risk of rupture of closing system parts has been estimated based on the analysis of stresses and the plastic deformation of parts. The viscoelastic behaviour of seals in rapid dynamics is extremely difficult to model, therefore the risk of reduced sealing was initially assessed by observing openings between parts in the seal zone.

This study additionally proposes to account for the thermal effects of the fire test in transport accident conditions (CAT):

- The properties of the materials weaken depending on the temperature of each part subsequent to CAT.
- Pressure in the package containment prior to the explosion was equal to 8 bars.
- The thickness of the main section resin was reduced to account for burnt parts.

The temperature gradient via the thickness of parts and temperature variations induced by the explosion were not considered in simulations. The temperature of the part remained constant throughout calculations and was fixed at the maximum value recorded during the CAT.

Material laws weaken thanks to the third part of the Johnson-Cooke law: $1-\left(\frac{T_{CAT}-T_0}{T_{fusion}-T_0}\right)^m$ where T_0=25°C and m = softener exponent.

The profile of the explosion was also slightly modified: a sudden pressure surge of 80 bars appeared in the package in addition to the initial 8 bars. This surge was maintained for 100 milliseconds until the parts reached equilibrium. The pressure was

then released at the end of the simulation. Pressure was applied to the inner wall of the shell and to the outer surface of the plug.

Package resistance criteria were as follows:

- maximum opening of the closing system corresponding to a **level of crushing of the seal of 10 %** during the explosion phase,
- **no plastic deformation** during the explosion phase (or justification that any plastic deformation has no effect on package sealing),
- return to a "sealed" configuration after the explosion, meaning **minimum crushing of the seal of 15% and no plastic deformation** of the components of the closing system (or justification that any plastic deformation has no effect on package sealing).

Results

During the explosion, the package plug withdrew and the opening in the seals increased together with the forces between the bayonet ring and the shoulders of the main section flange under the impulsion of internal gases.

With the application of the surge at 88 bars for 100 ms, parts were not subjected to major stresses. Deformation was local near to the closing system: the main section flange, bayonet ring and plug are slightly caulked in their respective support zones, causing **slight plastic deformation of approximately 0.7%. This plastic deformation is less than 1% and is not significant for package sealing during and after the explosion.**

During the explosion, a **maximum opening of 1.34 mm** at the start of the surge period highlighted the dynamic effect of the rapid rise in pressure. **The seal was only compressed by 10% (instead of the initial 30%), which corresponds to the resistance criterion limit for the explosion.**

After the explosion, a **residual opening of 0.29 mm** remained, caused by the slight caulking of the flange and bayonet ring. This corresponds to **seal compression of 25%, which is conform to the minimum of 15% required by the post-explosion resistance criterion.**

Table of modifications

Revision	History	Pages modified	Date	Revised by	Approved by
1.0	Creation	All	15 03 06	ST	SD
2.0	Integration of the remarks of the CEA	3, 7, 9, 12, 27, 28, 32, 35, 37, 40	19 04 06	ST	SD
3.0	Integration of the remarks of the CEA	§2.2.2; overview; §3.6	02 05 06	ST	SD

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<1>	Specifications CEA/DEN/CAD/DTAP/SET/DO 72, CEA Cadarache, 24/01/2006.
<2>	Quote MH5544/FB/E063692, Eurosim, 30/01/2006.
<3>	TNBGC_température_eurosim_explosion.doc (temperature isovalue fields), DEMA (provided by CEA), February 2006
<4>	Radioss Theory Manual, Mecalog, September 2005.
<5>	Elevated Temperature Modulus Measurements using the Impulse Excitation Technique, J.-D. Lord and L.-P. Orkney, July 2000.
<6>	Material Modelling and Experimental Study of Serrated Chip Morphology, T. Mabrouki, L. Deshayes, R. Ivester, J.-F. Rigal and K. Jurrens, May 2004.
<7>	The Online Materials Database, ISO standard, February 2006.
<8>	Procurement of Bronzes for Rings and Nuts, Transnuclear, February 1988.
<9>	Mechanical resistance of package TN-BGC 1 to explosions (ref. 2CE3E100), Eurosim, 10/05/2004.
<10>	Justification of the selected pressure profiles for hydrogen explosions in package DGD-D-001, Eurosim, May 2004 (ref. CEA: DGD001MNTT541A).

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Rapport_explosion_TNBGC1_temperatures_rev2.doc

1. Introduction.

This report presents an overview of the study aiming to:

- Determine the mechanical behaviour of package TN-BGC 1 if a load explodes, with consideration of the temperatures reached by the package following testing reproducing transport accident conditions (CAT), and determination of maximum allowable pressure for this package.

This report includes the following chapters:

- Assumptions,
- Modelling,
- Results relating to the explosion of the package with consideration of temperatures,
- Conclusions.

2. Assumptions

2.1. Presentation of package TN-BGC 1

The TN-BGC1 package consists of:

- a rhomb cage with a structure in aluminium tubes with a 30 x 30 mm square section and a thickness of 2 mm. The cage has a section of 600x600 mm. The overall height of the cage represents 1,815 mm. The cage mainly consists of vertical uprights and horizontal bars defining 3 levels. Tubes are placed diagonally to ensure the lateral rigidity of this structure. Holes for fork lift trucks are reinforced with corner plates. A frame system attached to the main section transmits stresses between the main section and the cage. Cut sheets are placed around the periphery of the cage to prevent contact between personnel and the package and to reduce radiation exchange between the main section of the package and the surrounding environment.
- a cylindrical cavity intended to house a TN90-type load with an external diameter of 295 mm. This section consists of an internal stainless steel shell with a working inner diameter of 178 mm, an external shell with a diameter of 295 mm, a steel distribution plate, a wooden caisson and resin filler.
- a closing system involving a stainless steel plug, a bronze clamp ring and a stainless steel bayonet ring.
- a damper cover with an external diameter of 466 mm, consisting of two stainless steel caissons. The area around the main section is filled with the same resin as the main package. The inner cover has a diameter of 300 mm. The outer caisson contains poplar and balsa wood and this cover is fitted with two folding handles at the peak. The cover is attached to the main section by two bent rods and two grips.
- loads consist of a TN90-type container with a plug-side diameter of 148 mm and a distribution plate side diameter of 124 mm. Loads are surrounded with two spacers (E1 and E2), both of which are cylindrical. Spacer E1 has an internal diameter of 140 mm and an external diameter of 176 mm. Spacer E2 has an internal diameter of 126 mm and an external diameter of 139 mm.

2.2. Hypotheses and simplifications

2.2.1. General assumptions

The following assumptions have been made for this study:

- The aim of the study was to determine deformation and movement for the plug. The cage and cover have not been considered.
- The dynamic viscoelastic behaviour of the seals has not been modelled.
- O rings have not been modelled.
- Metals and the resin are considered as elastoplastic materials.
- Wood (balsa and poplar) are considered as orthogonal materials. Careful attention was paid to the direction of wood fibres in part meshing.
- Plug clamp effect has been integrated.
- No rupture exists between the clamp ring thread and the bayonet ring thread.

2.2.2. Explosion profile

The reference explosion profile was provided by the CEA for the previous study (cf. <9>). Reference <10> is a bibliographical overview of key factors to be integrated in the assessment of the explosion resistance of a structure. This reference indicates approximate values for influential parameters for the definition of a profile for an explosion envelope, but does not claim to be exhaustive, as the consequences of an explosion depend heavily on initial conditions and geometric limits. Minor changes in geometry can change the explosion pressure substantially. The initial conditions of the explosion must be identified in each case (pressure, ambient temperature, volume of gases, stoichiometry of the hydrogen/oxygen mix, energy and location of the source of energy for ignition), together with speed at which the flames spread, as these determine the status of the explosion and therefore the surge profile.

The explosion profile from the previous study (cf. <9>) was assimilated as a surge of 80 bars in 1 ms inside the package, maintained constant until the equilibrium of the parts at approx. 100 ms. The pressure was then released until returning to the initial pressure in 5 ms. This profile globally reflects an almost-static load with the exception of the initial pressure rise. When assessing the consequences of an explosion, the time taken to reach maximum pressure, the width of the peak and the air under the pressure curve over time, known as impulsion, must be considered in addition to peak pressure. With detonations, peak value is high, however width is low: the duration of the rise to the peak pressure is not affected by the above parameters and represents approximately 5 ms. However, with the selected pressure profile, P_{max} was maintained for 100 ms. **We can therefore conclude that these conditions are highly detrimental for the structure as the impulsion generated is substantial.**

The same type of profile has been used for this study, with a surge of 80 bars triggering the explosion calculations after an initial pressure of 8 bars in the containment.

Pressure was only applied to the inner walls of the inner shell and to the plug. Pressure was not applied to the o rings in contact between the main section and the plug.

Variations in temperature caused by the explosion have not been taken into consideration.

2.2.3. Influence of temperature

The temperature of the materials considered is the maximum value of that indicated in specifications (cf. <1> and <2>) and that recorded in temperature isovalue fields (cf. <3>), shown in figure 1 below.

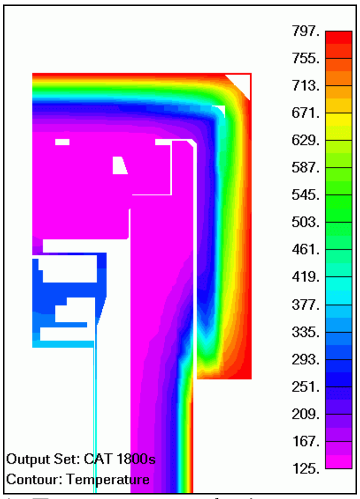


Figure 1: Temperature during an explosion

The properties of the materials weaken depending on the temperature based on a Johnson-Cook law.

The temperature of parts remained constant during the simulation.

Temperature is identical throughout the thickness of the part. Gradient is not considered.

The thickness of the resin reduced from 48 mm to 33 mm due to the fire.

2.2.4. Efforts due to the tightening of plugs

The tightening of the package cover is shown by connecting the clamp ring and the bayonet ring. Pre-stressing is equivalent to 30 kN and is considered to be uniformly distributed over the contact surface.

In the same way, pre-stressing in the Staubli plug is shown by linking the Staubli plug and the (main) plug. Pre-stressing is equivalent to 3520 N. This corresponds to the minimum effort transmitted by the plug clamp torque (50 N.m).

2.3. Description of the methodology and resources used

2.3.1. Methodology

Digital simulation was used to assess the behaviour of package TN-BGC 1 with internal explosions. The use of a digital tool has several advantages:

- ability to create a conservative model by selecting the right values in view of the masses in question and the behaviour of materials. This enables studies to be carried out with safe margins;
- Unlike testing using mockups or demonstration models, simulation enables the full understanding of the behaviour of all package components, and the identification of components with a key role in an explosion; modelling particularly enables the quantification of stresses and deformations induced in materials and the distribution of deformation energy within the package;

- Possibility to apply an iterative approach to a series of calculations, enabling the appraisal of the influence of the various key parameters identified;
- Finally, possibility to suggest means of optimising the design of parts in view of the results obtained, and to validate - or reject - these suggestions on the basis of complementary calculations.

2.3.2. Calculation tool

In view of:

- the complexity of the phenomena involved in this explosion (materials subjected to stresses exceeding their elastic limit, causing the plastic deformation of materials and sometimes rupture),
- the wide range of materials with a role in the structural resistance of packages (metal, wood, resin),
- the dynamic aspect of the simulations,

The simulation code was selected on the basis of its ability to process the above three elements. RADIOSS software was selected. The main properties of this software are described briefly below together with relevant references.

RADIOSS enables the study of any behaviour with dominant non-linear properties of a structure subjected to stresses (ranging from near-static to rapid dynamic stresses) using finished elements. RADIOSS integrates time-based elements in non-linear dynamic equations using an explicit approach.

This software was approved by EUROSIM and its customers on the basis of test campaigns organised over the last 15 years for impact studies of various types.

RADIOSS software applies advanced techniques enabling the accurate representation of the physical phenomena involved as far as possible:

- Meshing with narrow or thick hulls, beams, solid elements and contact interfaces, with the possibility to manage several hundred thousand degrees of freedom for all calculations. The geometric diversity of elements enables the use of a model which precisely resembles the package without need for the abusive simplification of the zones in question;
- Specialised laws of behaviour with influence of metal deformation speeds. All laws of behaviour are validated with comparisons to impact tests with speeds ranging from a few meters per second to a few hundred meters per second;
- General automatic correction of contact problems.

2.3.3. Acceptance criteria

The following are measured:
- Von Mises stresses and plastic deformations in parts to assess the risk of rupture of parts,
- changes in contact forces and distances between the cover and the flange in the sealing zone to estimate the risk of reduced sealing.

Package resistance criteria were as follows:

- maximum opening of the closing system corresponding to a **level of crushing of the seal of 10 %** during the explosion phase,
- **no plastic deformation** during the explosion phase (or justification that any plastic deformation has no effect on package sealing),
- return to a "sealed" configuration after the explosion, meaning **minimum crushing of the seal of 15% and no plastic deformation** of the components of the closing system (or justification that any plastic deformation has no effect on package sealing).

2.3.4. Limits to the validity of results

With this type of simulation where the physical phenomena modelled vary in type and involve complex processes (contact between different materials, rupture of materials, etc.), the reliability of the digital results obtained can rightfully be questioned. The value announced will depend on the quality of the elements, their size and the nature of adjoining surfaces at the time of impact.

Feedback on calculations carried out using RADIOSS reports excellent testing - calculation correlation for the dynamic definition of materials or testing of the crushing of hollow components. Calculated plastic deformation generally slightly exceeds actual deformation.

Accuracy of approximately 10 - 20% is expected for low-speed impact, in terms of changes in energy, speed and displacement over time. Levels of plasticity and any ductile rupture zones can be estimated to similar degrees of accuracy.

However, the global results depend on the aim when constructing the model: generally speaking, studies are approached from the most detrimental position, e.g. by using maximum masses and minimum properties for materials. The results obtained are, in principle, downgraded as compared with the potential results of actual testing.

2.3.5. Code version

Version 44r of RADIOSS is used for this study. For a more precise description of the particularities of RADIOSS, refer to the RADIOSS manual (cf. <4>).

2.3.6. Unit system

The unit system used for this study is:

- Mass in grams **[g]**
- Distance in millimetres **[mm]**
- Density in grams per millimetre cubed **[g/mm^3]**
- Time in milliseconds **[ms]**

- Speed in millimetres per millisecond **[mm/ms]**(= m/s)
- Acceleration in millimetres per millisecond squared **[mm/(ms)²]** (= 1000 m/s² = 101.9 g)
- Force in Newtons **[N]**
- Stresses and pressure in mega Pascals **[MPa]** (1 bar = 0.1 MPa)
- Energy in millijoules **[mJ]**

3. Modelling

3.1. Meshing

Only the outer shell is modelled with hull elements. The other parts are modelled using cubic elements due to their thick shapes. Interfaces process contact between parts. The direction of wood fibres has been modelled, giving the following radial models for fibres in the central sections of the balsa and the poplar.

- Package TN-BGC 1 plug

Figure 2 and table 1 below show the parts in the "plug" zone of the package.

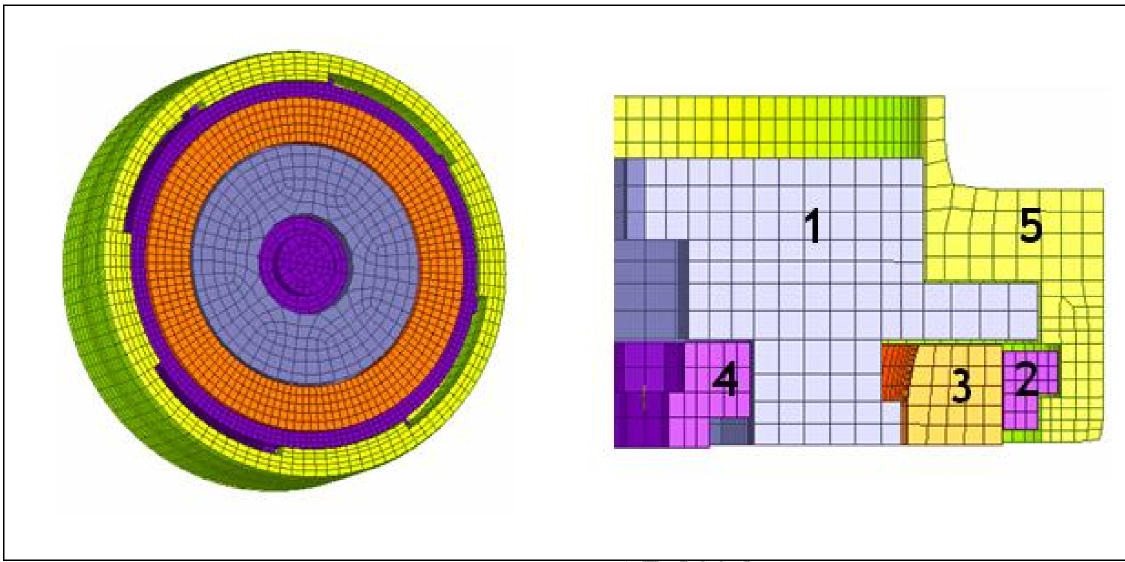


Figure 2: View of meshing in the plug zone of the package

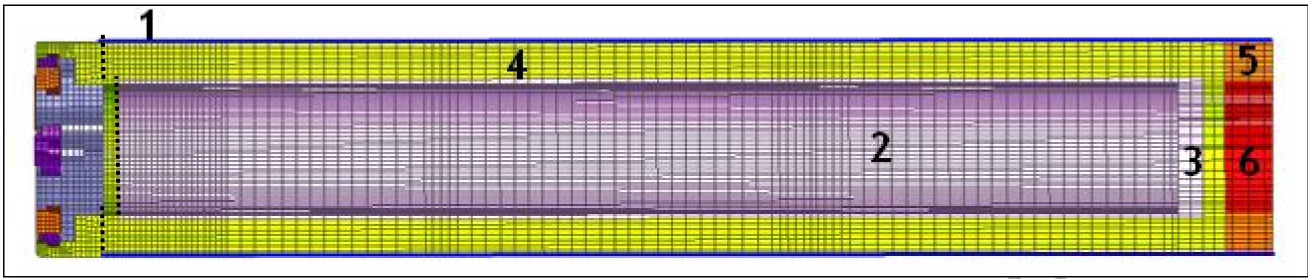
Part number	Part name	Property	Number of elements	Size of elements	Material
1	Plug (main)	volume	3868	6 - 12 mm	Z2 CN 18-10
2	Bayonet ring	volume	3216	3 - 6 mm	Z2 CN 18-10
3	Clamp ring	volume	3000	6 mm	Cu Al9 Ni5 Fe5 Y20
4	Staubli plug	volume	328	3 - 8 mm	Z2 CN 18-10
5	Main section flange of the shell	volume	8080	3 - 8 mm	Z2 CN 18-10

Table1: Details of parts in the plug zone of the package

Clearance and support between the different parts were modelled. The meshing of the bayonet ring and the flange were modelled more precisely to improve the distribution of stresses in probable deformation zones.

- <u>Package TN-BGC 1 main section</u>

Figure 3 and table 2 below show the parts in the "main section" zone of the package.



<u>Figure 3</u>: View of meshing in the main section zone of the package

Part number	Part name	Property	Number of elements	Size of elements	Material
1	External shell	Hull	13504	7 - 20 mm	Z2 CN 18-10
2	Internal shell (containment)	volume	10800	7 - 20 mm	Z2 CN 18-10
3	Distribution plate	volume			
4	Resin filler	volume	53648	7 - 20 mm	Resin
5	Wood filler	volume	3328	10 - 25 mm	Poplar
6	Wood filler	volume	1840	10 - 25 mm	Balsa

<u>Table2</u>: Details of parts in the main section zone of the package

Modelling of the distribution plate has been simplified by integrating the component in the inner shell base.

3.2. Materials

3.2.1. Influence of temperature

Variation in Young's modulus according to temperature is shown in figure 4 below (cf. <5>).

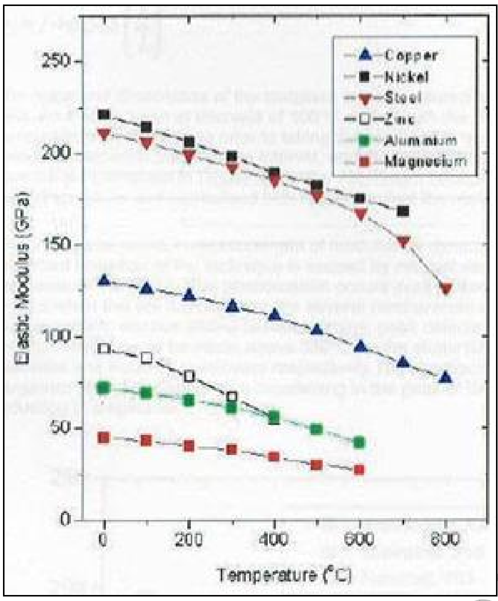


Figure 4: Influence of temperature on Young's modulus

Table 3 below lists the parts whose materials are influenced by temperature.

Part	*Material*	*Temperature*
Clamp ring	Cupro-aluminium Cu Al9 Ni5 Fe5 Y20	226 °C
Bayonet ring, (main) plug Staubli plug	Stainless steel Z2 CN 18-10	226 °C
Main section flange, inner shell, outer shell (zone under the cover)	Stainless steel Z2 CN 18-10	242 °C
Outer shell (zone outside of the cover)	Stainless steel Z2 CN 18-10	786 °C

Table3: List of parts influenced by temperature

Johnson-Cook law governs the behaviour of these materials. The general formula is (cf. <6>):

$\sigma_p = (a+b\varepsilon_p^n)(1-(T^*)^m)$ where $T^* = (T_{fire}-T_0)/(T_{fusion}-T_0)$

This law can be transformed:

$\sigma_p = a'+b'\varepsilon_p^n$ where $a' = a(1-(T^*)^m)$

$b' = b(1-(T^*)^m)$

et $\sigma_{max}' = \sigma_{max}(1-(T^*)^m)$

Figure 5 on the next page shows changes to the factor $1-(T^*)^m$ which influences the properties of the material according to temperature.

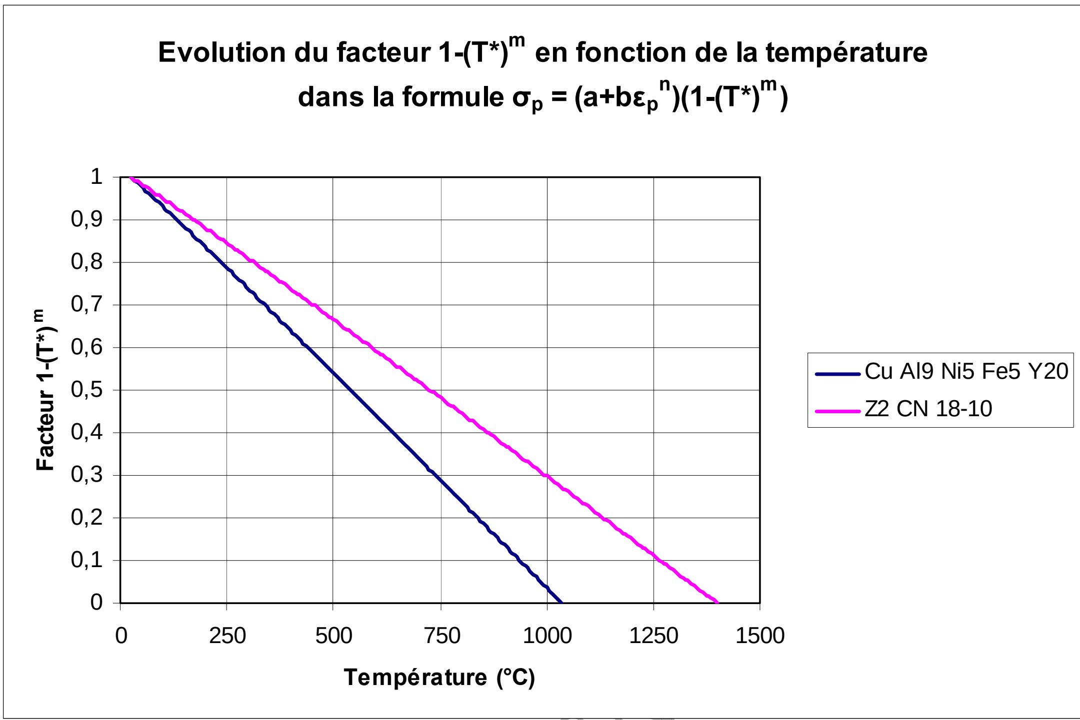


Figure 5: Changes to the factor $1\text{-}(T^*)^m$ according to temperature

Evolution du facteur 1 -(T*) ^{m} en fonction de la température dans la formule	Changes in factor 1 -(T*) ^{m} based on the temperature used in the formula
Facteur	Factor
Température	Temperature

3.2.2. Details of the new properties of the selected materials

➢ *Stainless steel Z2 CN 18-10*

Table 4 opposite shows details of the properties of the stainless steel law Z2 CN 18-10 (cf. <7>), at ambient temperature and at the different temperatures applied.

Z2 CN 18-10	**25 °C (ambient temperature)**	**226 °C**	**242 °C**	**786 °C**
E (MPa)	200 000	185 000	185 000	120 000
ν	0.29	0.29	0.29	0.29
d (g/mm^3)	0.0079	0.0079	0.0079	0.0079
n	0.5	0.5	0.5	0.5
T_{fire} (°C)	25	226	242	786
T_0 (°C)	25	25	25	25
T_{fusion} (°C)	1400	1400	1400	1400

m	1.03	1.03	1.03	1.03
$1-(T^*)^m$	1	0.862	0.851	0.456
a' (MPa)	220	189.6	187.2	100.4
b' (MPa)	448	386.0	380.9	204.5
$\sigma_{p\ max}$' (MPa)	520	448.2	442.4	237.3
$\varepsilon_{p\ max}$	0.45	0.45	0.45	0.45

Table4: Properties of Z2 CN 18-10 depending on temperature

Figure 6 below shows changes in stress graphs based on the deformation of the material Z2 CN 18-10, at ambient temperature and at the different temperatures applied.

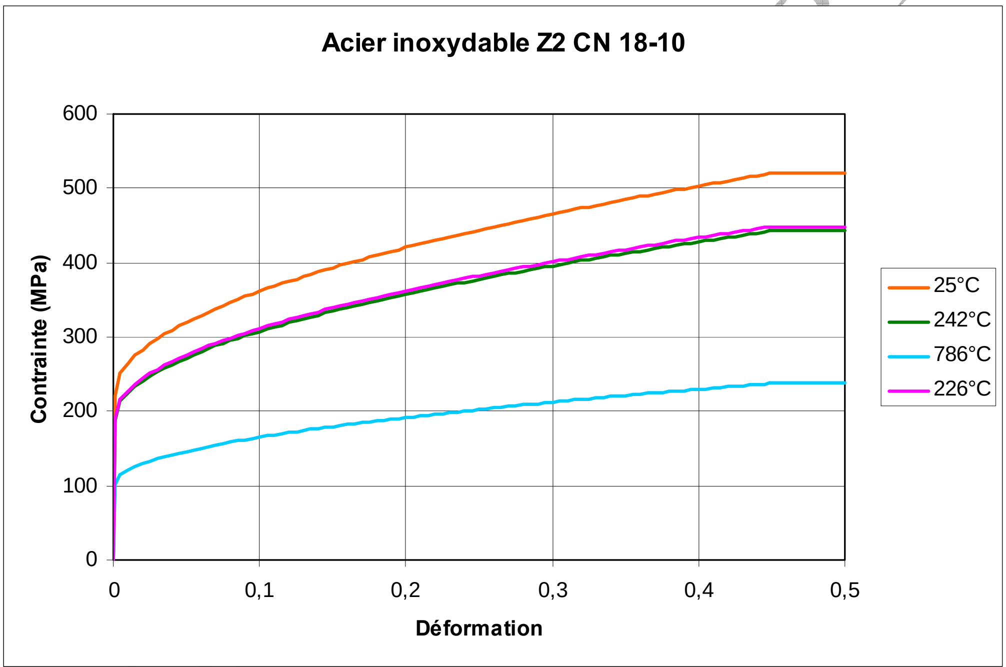


Figure 6: Stress/deformation graphs for Z2 CN 18-10 depending on temperature

Acier inoxydable Z2 CN 18-10 Constrainte (MPa) Déformation	Stainless steel Z2 CN 18-10 Stress (MPa) Deformation

- *Cupro-aluminium Cu Al9 Ni5 Fe5 Y20*

Table 5 below shows details of the properties of the cupro-aluminium law Cu Al9 Ni5 Fe5 Y20 (cf. <8>), at ambient temperature and at the different temperatures applied.

Cu Al9 Ni5 Fe5 Y20	**25 °C (temperature ambient)**	**226 °C**
E (MPa)	115 000	105 000
ν	0,33	0,33

d (g/mm^3)	0,0076	0,0076
n	0,5	0,5
T_{fire} (°C)	25	226
T_0 (°C)	25	25
T_{fusion} (°C)	1035	1035
m	1,03	1,03
$1-(T^*)^m$	1	0,810
a' (MPa)	250	202,6
b' (MPa)	1107	897,9
$\sigma_{p\ max}$' (MPa)	630	510,6
$\varepsilon_{p\ max}$	0,12	0,12

Table5: Properties of Cu Al9 Ni5 Fe5 Y20 depending on temperature

Figure 7 below shows changes in stress graphs based on the deformation of the material Cu Al9 Ni5 Fe5 Y20, at ambient temperature and at the different temperatures applied.

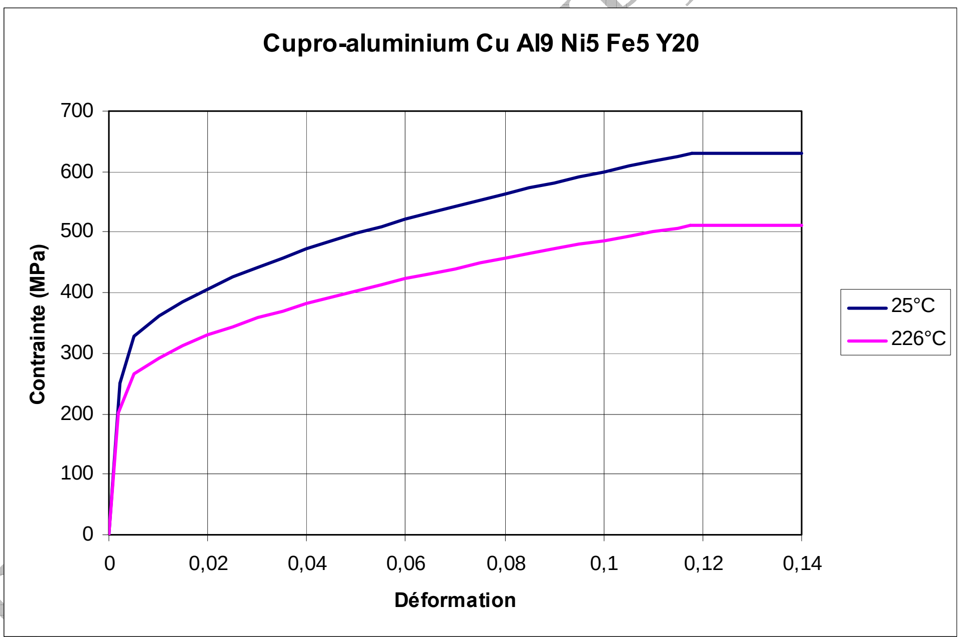


Figure 7: Stress/deformation graphs for cupro-aluminium depending on temperature

- *Resin*

Young's modulus: E = 26 000 MPa
Poisson's ratio: ν = 0.33
Density: d = 0.0016 g/mm^3

Resin is defined by a user-type law based on the specimen traction test chart, shown in figure 8 below:

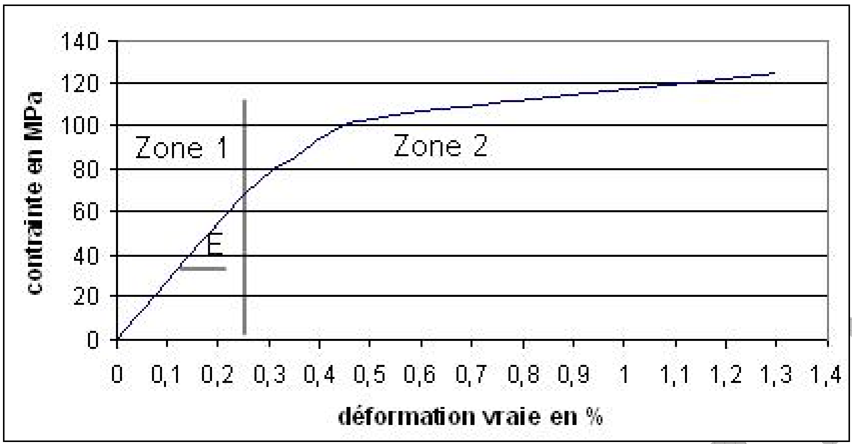


Figure 8: Stress graph according to deformation for resin

[images fig 7 and 8]

Cupro-aluminium Cu Al9 Ni5 Fe5 Y20-10	Cupro-aluminium Cu Al9 Ni5 Fe5 Y20
Coonstrainte (MPa)	Stress (MPa)
Déformation	Deformation
Zone 1	Zone 1
Zone 2	Zone 2
Constrainte en MPa	Stress in MPa
Déformation vraie en %	Actual deformation in %

The elastic part (zone 1) is described by the Young's modulus E and the plastic part is described by the chart for zone 2.

➢ *Balsa*

The direction of balsa fibres is integrated based on a local marker. The same material is used for all parts in balsa, only the direction of the local marker will change.

The direction of fibres is indicated with marker 1, and directions at an angle to fibres are indicated with markers 2 & 3. The Young's modulus in the direction of the fibres is noted E_{11} and Young's moduli at an angle to fibres are noted E_{22} and E_{33}. Shear modules are noted G_{ij} (see table 6 below and next page).

The plastic part is described in figure 9 below.

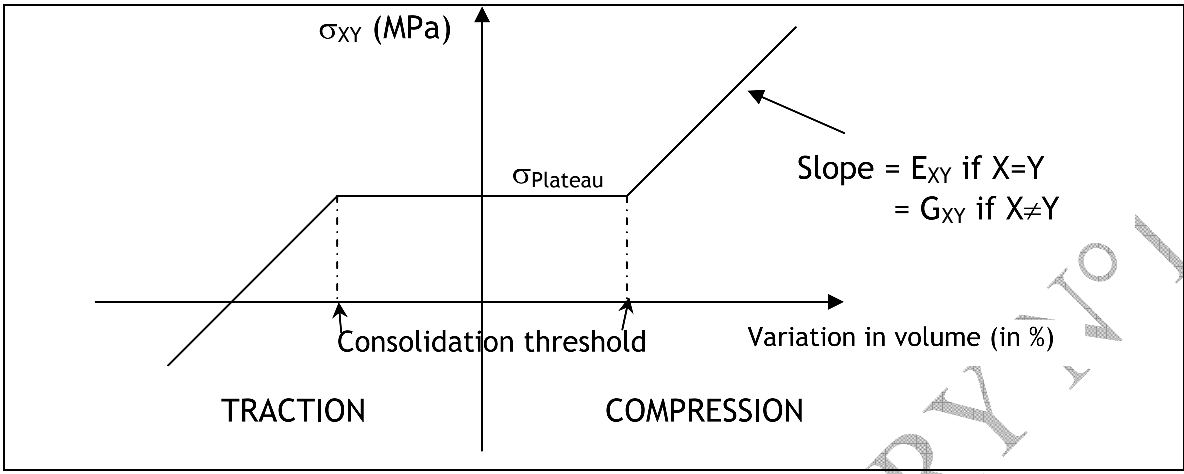


Figure 9: **Stress chart depending on variation in volume for balsa**

Behaviour with traction and compression are considered as identical. The compression consolidation threshold for balsa is crushing of over 60 %.

	Density (g/mm^3)	0,00015
Elastic part	E_{11} (MPa)	2300
	E_{22} (MPa)	460
	E_{33} (MPa)	460
	G_{12} (MPa)	120
	G_{23} (MPa)	120
	G_{31} (MPa)	120
Elastic part	σ_{11} (plateau) (in MPa)	9,5
	σ_{22} (plateau) (in MPa)	2
	σ_{33} (plateau) (in MPa)	2
	σ_{12} (plateau) (in MPa)	3
	σ_{23} (plateau) (in MPa)	0,6
	σ_{31} (plateau) (in MPa)	3

Table6: **Properties of the law representing balsa**

➢ *Poplar*

As is the case for balsa, the direction of poplar fibres is integrated based on a local marker. In the same way, the direction of the fibre is indicated by marker 1 (see table 7 below). Stress chart depending on variation in volume is similar to that for balsa. The consolidation threshold for poplar represents crushing of over 45 %.

	Density (g/mm^3)	0,00036
Elastic part	E_{11} (MPa)	3500
	E_{22} (MPa)	350
	E_{33} (MPa)	350
	G_{12} (MPa)	700
	G_{23} (MPa)	140
	G_{31} (MPa)	700
Elastic part	σ_{11} (plateau) (in MPa)	50
	σ_{22} (plateau) (in MPa)	10
	σ_{33} (plateau) (in MPa)	10
	σ_{12} (plateau) (in MPa)	18
	σ_{23} (plateau) (in MPa)	10
	σ_{31} (plateau) (in MPa)	18

Table7: Properties of the law representing poplar

3.3. Contact management

Contacts are processed using a specific Radioss function - the contact interface. Several types of interfaces exist depending on the type of contact between the parts. General interfaces prevent two parts from interlinking during impact. Repulsion, proportional to the rigidity of the parts, is generated by contact surfaces from a minimum gap between the two parts.

In our studies, these contact interfaces are used to manage contact between parts in the package liable to move on impact. This type of modelling also enables the identification of forces on surfaces in contact. It can be used, for example, between the bayonet ring and the main section flange (figure 10 below).

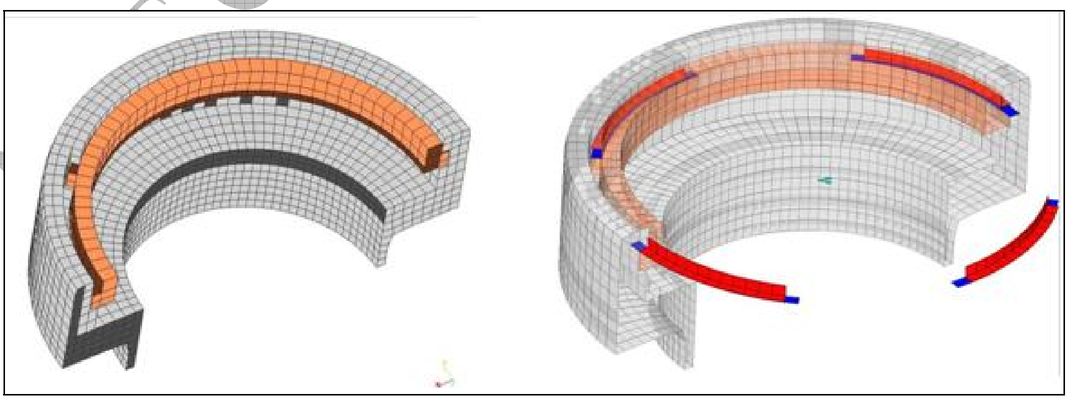


Figure 10: Contact management interface

3.4. Pre-stressing in plugs

Modelling accounts for pre-stresses due to cover grips and the Staubli plug.

- Pre-stressing in the cover

A rigid element links all of the nodes of the clamp ring threads. Another rigid element links all of the nodes of the bayonet ring threads. A compressed spring is placed between these two rigid elements. This spring will attempt to return to its rest position, i.e. extend. It pushes the bayonet ring against the flange and the clamp ring against the plug (see figure 11 below). This modelling may be used thanks to the symmetry of the main section and cover.

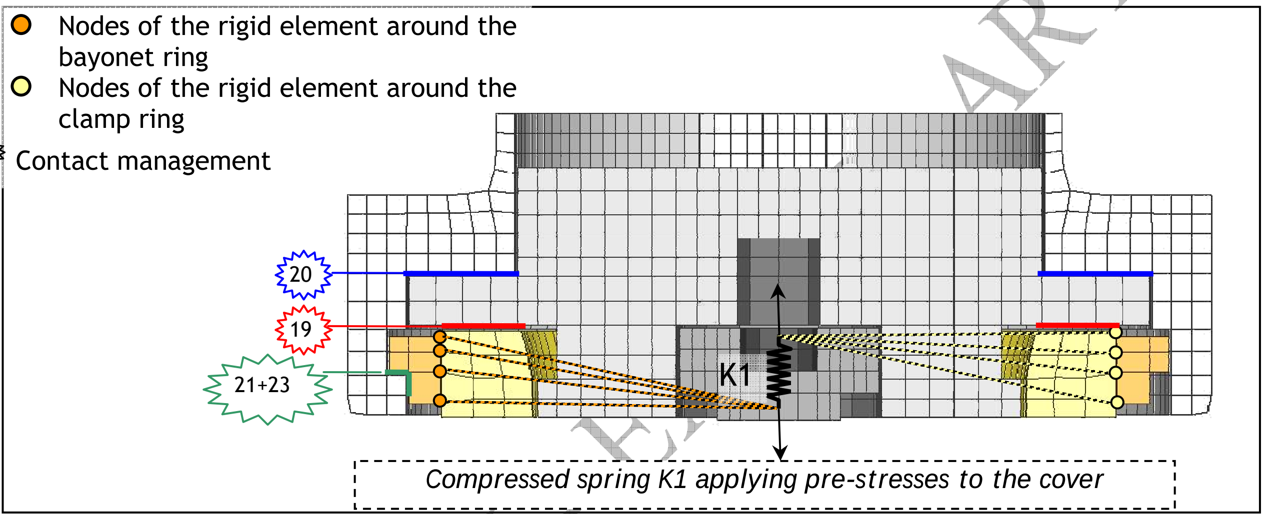


Figure 11: Modelling of pre-stresses in the cover

Spring K1 is defined by the graph shown in figure 12 below.

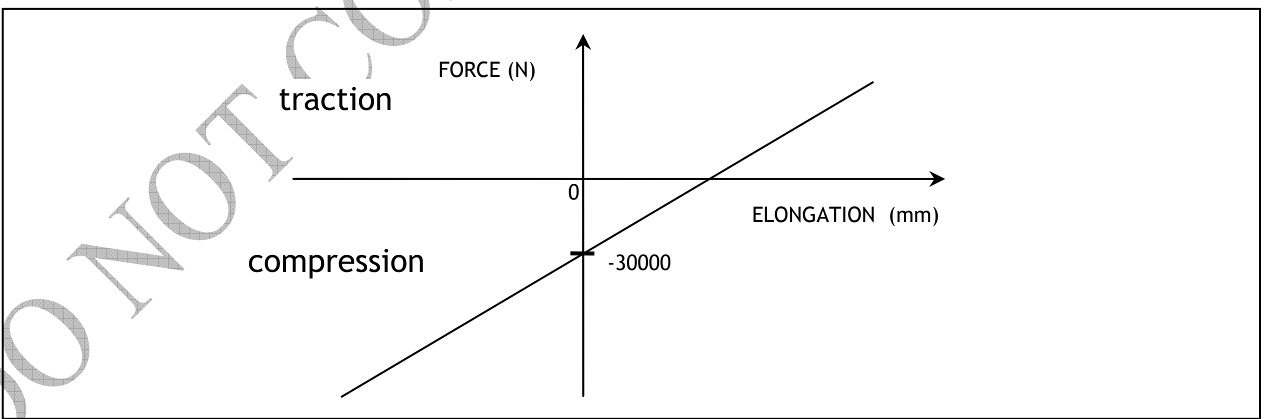


Figure 12: Definition of spring K1 (cover pre-stressing)

The first part of the calculation involves loading the plug and waiting until the spring force (figure 13 below) balances the forces on the contact surfaces. Oscillations are controlled by a damper.

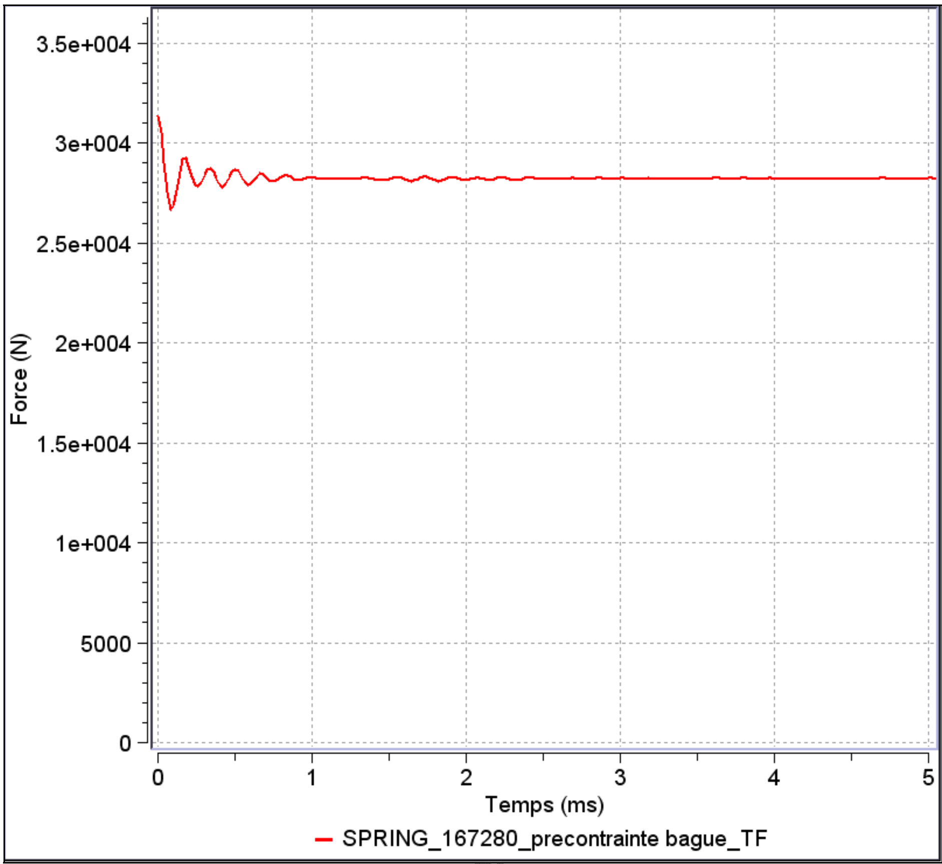


Figure 13: Pre-stressing forces in spring K1

Force (N) Temps (ms) - SPRING_167280_precontrainte bague_TF	Force (N) Time (ms) - SPRING_167280_ring_pre-stressing_TF

It must then be checked that forces are correctly distributed over the different contact surfaces. The following interfaces are affected by the loading of the cover:

- the interface between the main section flange and the bayonet ring (interface 21+23),
- the interface between the clamp flange and the plug (interface 19),
- the interface between the plug and the main section flange (interface 20),

The forces applied by the spring are also transmitted to these interfaces, therefore the pre-stressing of 30 kN is transferred between the plug and the main section (figure 14 below).

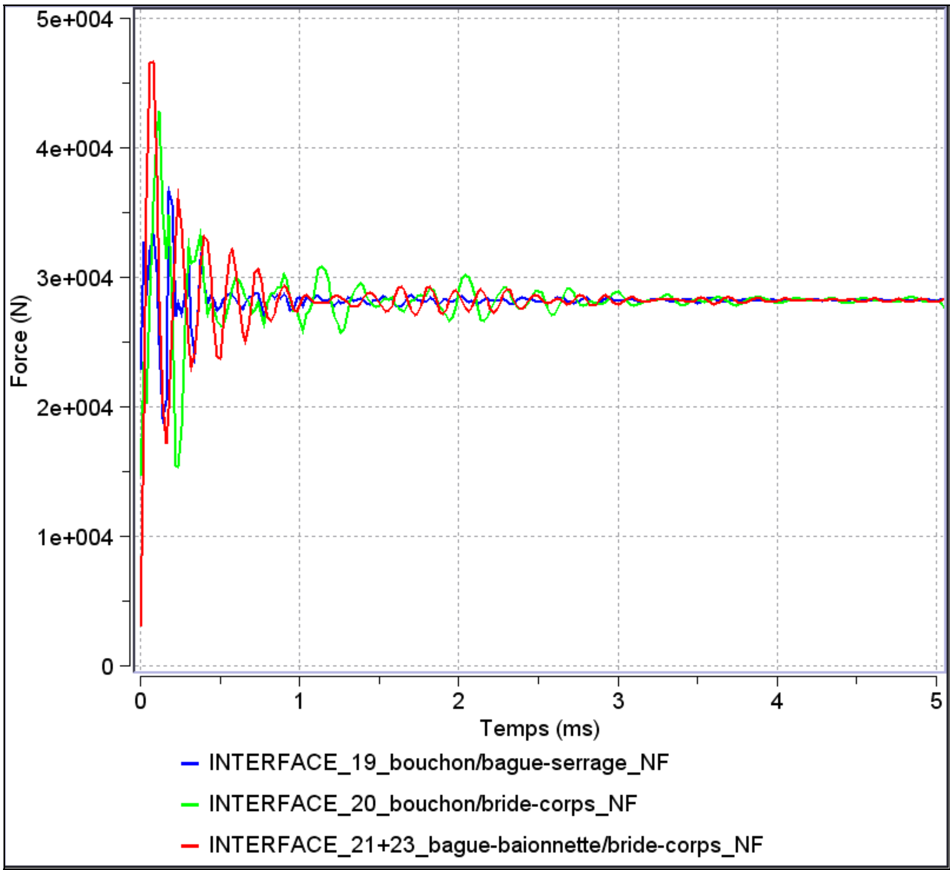


Figure 14: Forces on interfaces due to pre-stressing in the cover

Force (N) - INTERFACE_19_bouchon/bague-serrage_NF - INTERFACE_20_bouchon/bride-corps_NF - INTERFACE_21+23_bague-baiennette/bride-corps_NF	Force (N) - INTERFACE_19_plug/clamp-ring_NF - INTERFACE_20_plug/main-section-flange_NF - INTERFACE_21+23_bayonet-ring/main-section-flange_NF

- Pre-stresses in the Staubli plug

In the same way as for the pre-stressing in the cover, the pre-stressing of the Staubli plug is modelled using two rigid elements and a spring. One of the rigid elements links the nodes of the Staubli plug threaded surface. The second rigid elements links the nodes of the plug threaded surface. A compressed spring links the two nodes for the rigid elements (see figure 15 on the next page). Torque of 50 N.m is applied and corresponds to an axial force in the screw of 3 520 N.

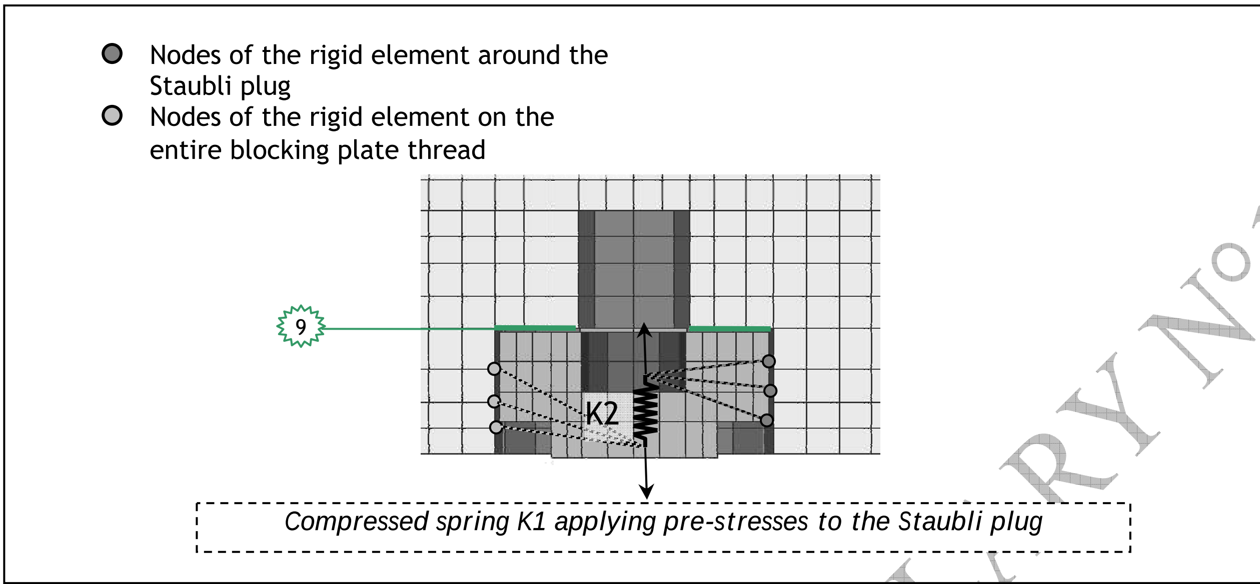


Figure 15: Modelling of pre-stresses in the Staubli plug

Spring K2 is defined by the graph shown in figure 16 below.

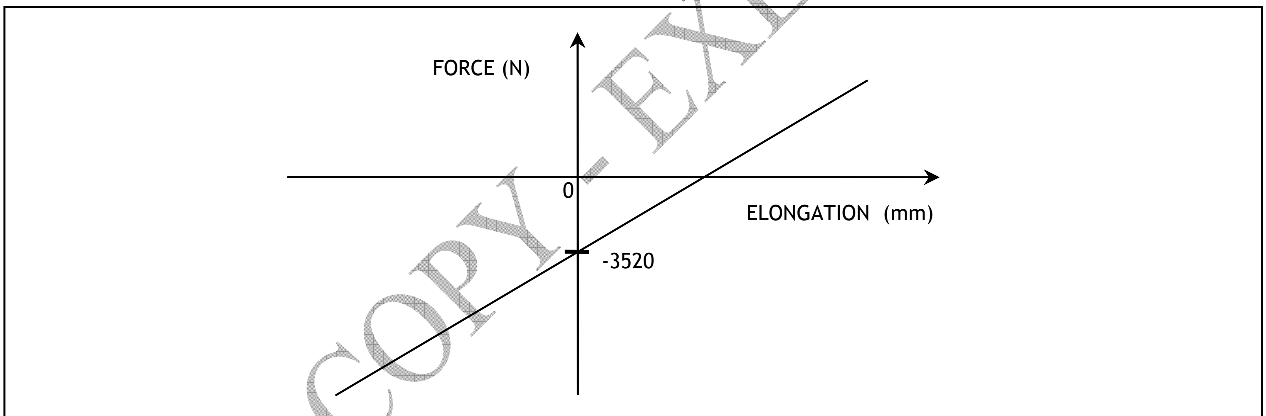


Figure 16: Definition of spring K2 (Staubli plug pre-stressing)

The first part of the calculation involves loading the plug and waiting until the forces balance (see figure 17 on the next page).

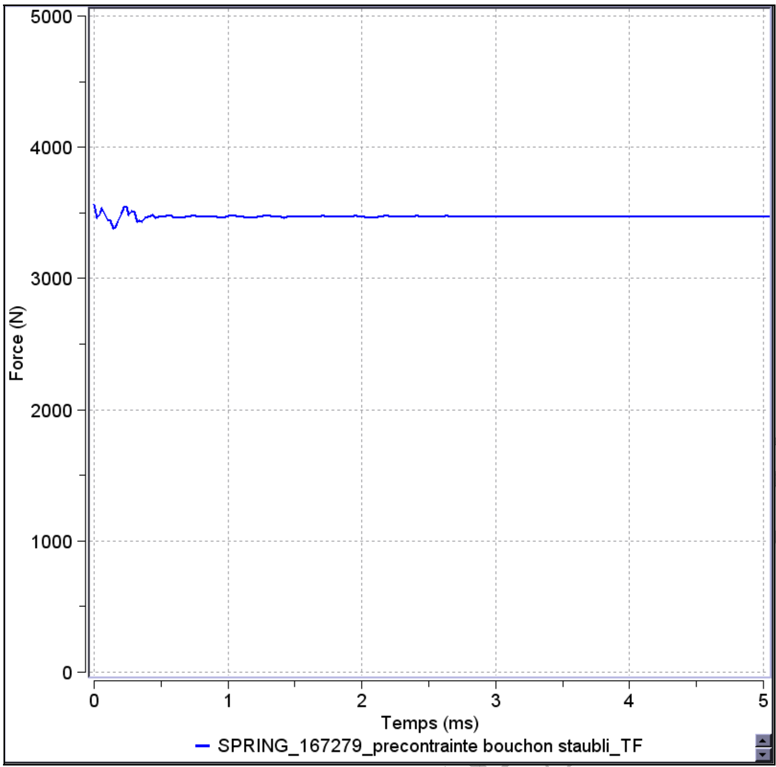


Figure 17: Pre-stressing forces in spring K2

In the same way, the forces applied by the spring are integrally transmitted to the interface (9), see figure 18 below.

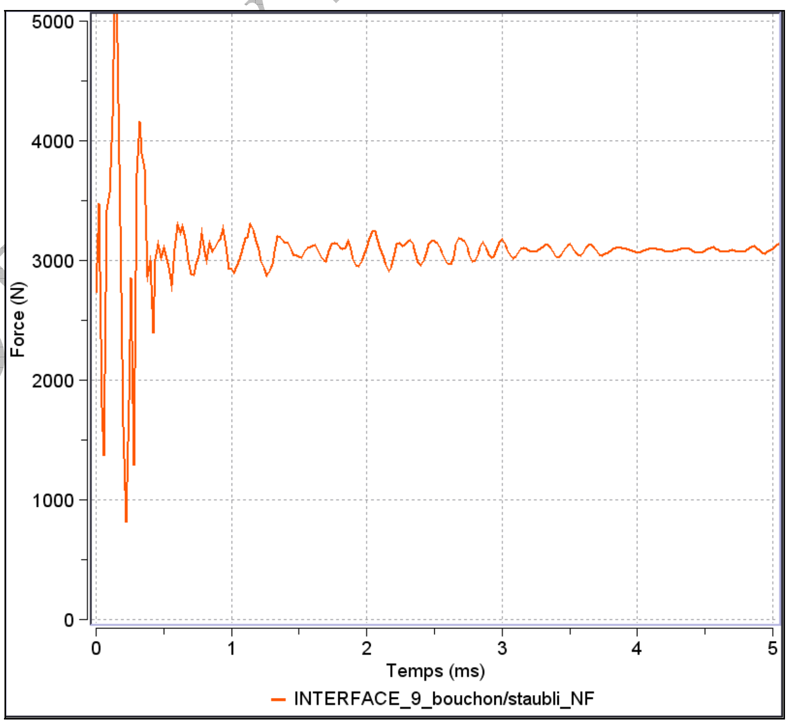


Figure 18: Forces in interface 9 due to the pre-stressing of the Staubli plug

[figures 17 and 18]

Force (N) Temps (ms) - SPRING_167279_precontrainte bouchon staubli_NF Force (N) Temps (ms) - INTERFACE_9_bouchon/staubli_NF	Force (N) Time (ms) - SPRING_167279_Staubli-plug-pre-stressing_NF Force (N) Time (ms) - INTERFACE_9_plug/Staubli_NF

3.5. Mass report

Table 8 below reports on total package mass ("plug" and "main section" zones).

	Mass
Plug (Staubli, clamp ring and bayonet ring)	26.3 kg
Main package section	151.5 kg
Total	**177.8 kg**

Table8: Mass report

3.6. Pressure applied

- General comments

  - Torque is applied for the first 5 milliseconds (reminder).
  - Pressure is then increased to 8 bars within the containment.
  - A surge of 80 bars is applied for 100 ms (equilibrium phase of the system during which parts move).
  - Pressure is then reduced to 0 more gradually than the rise in pressure (check that the plug has returned to its initial position after releasing the pressure).

- Pressure profile

Table 9 below shows the pressure profile for detonation.

Time (ms)	Pressure (bars)
0	0
5	0
6	8
20	8
21	88
121	88
126	0

200	0

Table9: Changes in pressure over time

Figure 19 below shows the pressure chart for detonation.

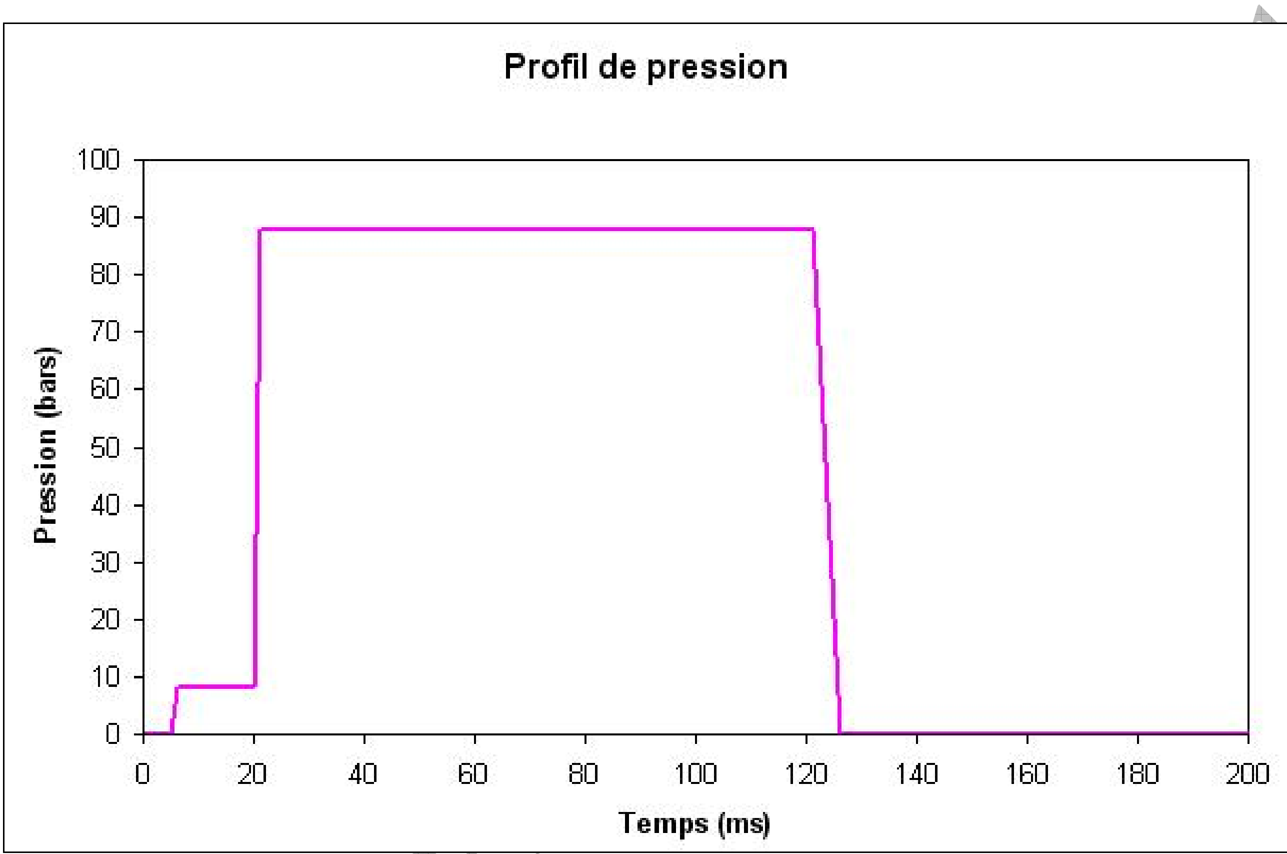


Figure 19: Applied pressure

Profil de pression Pression (bars) Temps (ms)	Pressure profile Pressure (bars) Time (ms)

- Area of application

Figure 20 below shows the area of application for pressure.

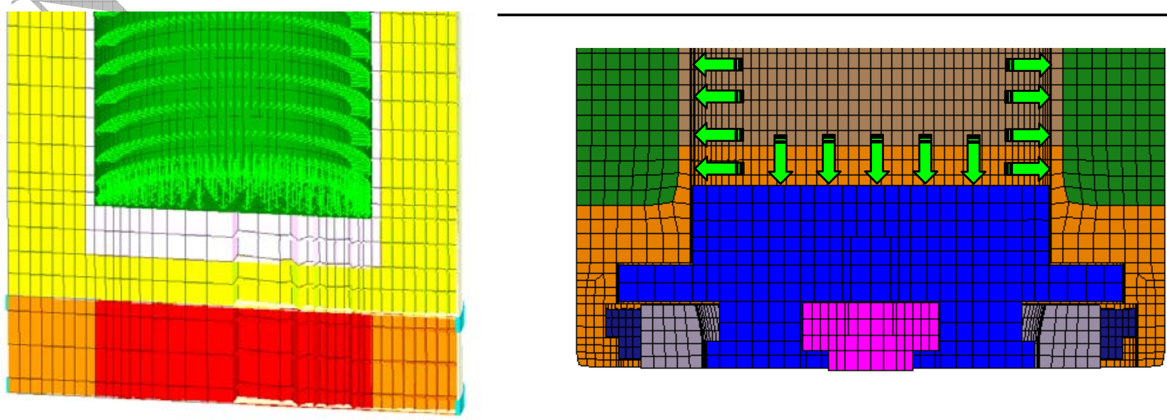


Figure 20: Area of application for pressure

The pressure profile is applied to all nodes:

- of the lateral section of the inner shell of the 10 mm stainless steel recess to the upper section of the shoulder,
- of the head of the inner shell of the 10 mm stainless steel recess,
- of the lower surface of the plug,
- of the entire lateral plug shell.

- Calculation process

Calculations involve two phases. The first stage enables the prestressing of screws. Equilibrium is achieved between screw forces and contact interfaces. This phase lasts 5 ms. The second phase involves the application of the pressure profile.

4. Results for the explosion of the package

The results of the explosion in the package are analysed as follows:

- Analyses of impulsion and contact forces, variations in the opening in the seal zone and energy absorbed.
- Analyses of maximum Von Mises stress values and plastic deformation of the parts most subjected to forces.

4.1. Impulsion

Screws are tightened to a torque of 3000 daN in the first phase, prior to the application of an initial pressure of 8 bars. The explosion is then triggered. This explosion will cause a surge in pressure of 80 bars in the recess. This pressure of 88 bars (8.8 N/mm²) on the plug (ø 179 mm) represents an impulsion of approximately 22 tonnes. The plug will press against the clamp ring due to this impulsion. The clamp ring is screwed in the bayonet ring, therefore both rings will be displaced, while held in place by the main section flange (see figure 21 below).

$$\text{Im}\,pulsion = \frac{\pi \times D^2}{4} \times pression = \frac{\pi \times 179^2}{4} \times 8{,}8 = 221451N \approx 22t$$

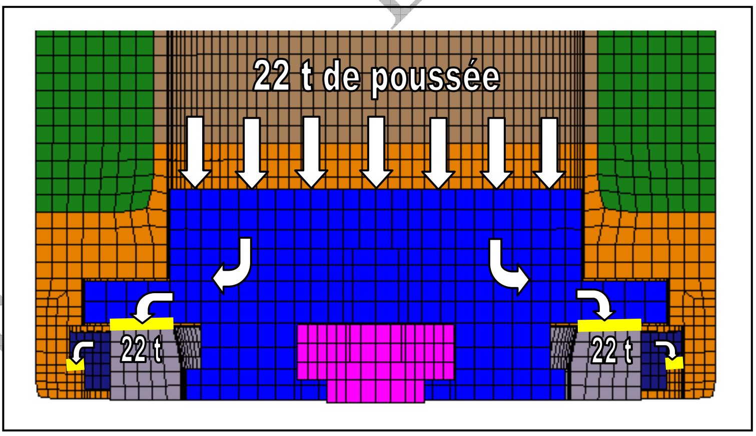


Figure 21: Transmission of contact forces during the explosion

Poussée = impulsion

The screw above the Staubli plug is not shown. As the traction forces on a screw of ø 14 mm prior to rupture represent approximately 12 tons, we can state that force F applied to the Staubli plug screw is negligible:

$$F = \frac{\pi \times D^2}{4} \times pression = \frac{\pi \times 14^2}{4} \times 8{,}8 = 1355N \approx 136kg$$

4.2. Contact forces

If we consider the effects in the contacts between the plug and the clamp ring and between the bayonet ring and the main section flange (inner shell), it appears that the impulsion of 22 t spreads instantaneously (see figures 22 and 23 below). Plug clamp force is 3000 daN before the explosion. Parts and torque return to their initial positions and levels after the explosion.

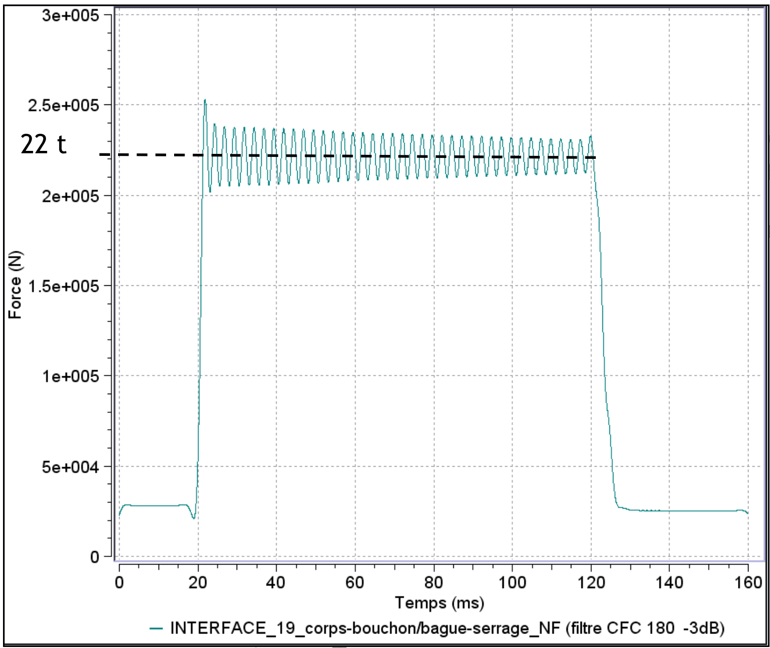


Figure 22: Plug/clamp ring contact force

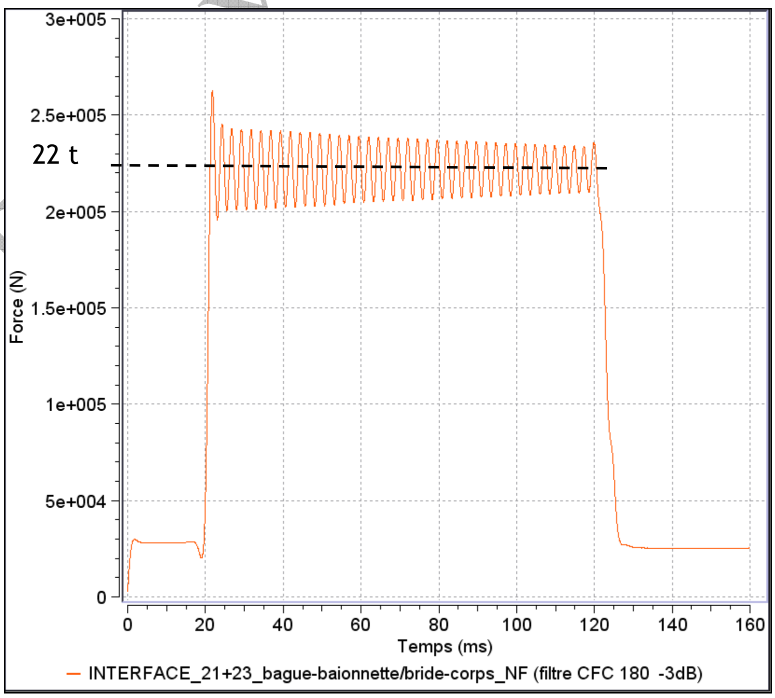


Figure 23: Bayonet ring/main section flange contact force

Force (N) Temps (ms) - INTERFACE_19_corps-bouchon/bague-serrage_NF (filter CFC 180 -3dB) Force (N) Temps (ms) - INTERFACE_21+23_bague-baionnette/bride-corps_NF (filter CFC 180 -3dB)	Force (N) Time (ms) - INTERFACE_19_main-section-plug/clamp-ring_NF (CFC 180 -3dB filter) Force (N) Time (ms) - INTERFACE_21+23_bayonet-ring/main-section-flange_NF (CFC 180 -3dB filter)

4.3. Seal opening

Two o rings seal the recess between the main package section and the plug. The depth of the weld throat housing the o rings is equal to 4.93 mm and the nominal diameter of the throat is 6.99 mm. Crushing is equal to 30 % in normal conditions when the plug is tightened. **During the explosion**, the maximum opening between the plug and the main section represents **1.34 mm** (see figures 24 and 25 below), which induces minimum crushing of: 1-(4.93+1.34)/6.99 = **10%. This value corresponds to the 10% criterion for the resistance of the seal during the explosion.**

At the end of the simulation, a residual opening of **0.29 mm** exists, inducing minimum crushing of: 1-(4,93+0,29)/6,99 = **25%**. This is due to the minor plastic deformation of certain parts (cf. § 3.5.). **This value is conform to the minimum seal compression of 15% required by the post-explosion resistance criterion.**

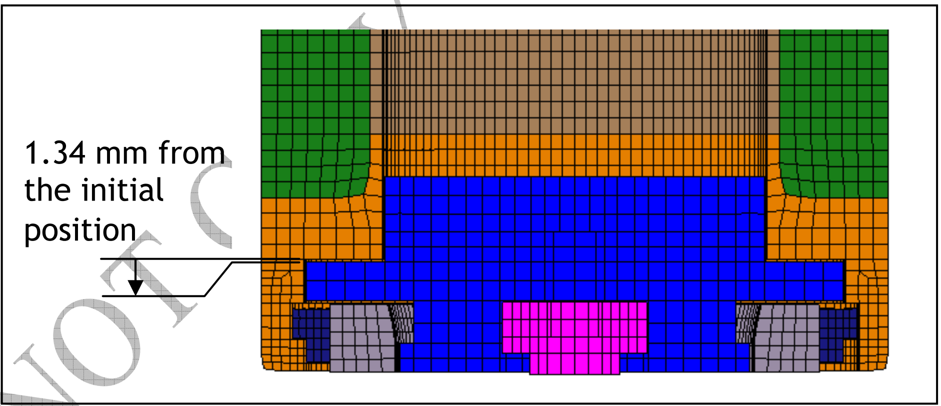


Figure 24: Displacement of the plug during the explosion in the recess

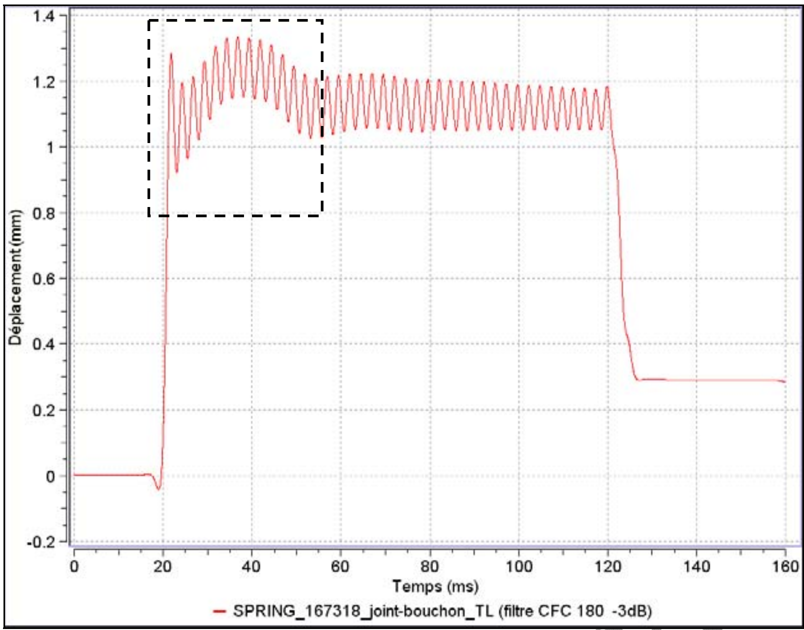


Figure 25: Changes to the displacement of the plug

4.4. Internal energy

Internal energy is the energy absorbed by the deformation of parts. This energy consists of elastic energy (reversible), which may be transformed into kinetic energy and/or plastic energy (irreversible). The explosion deforms the parts little as deformation energy is less than 0.35 kJ. Between 20 and 120 ms, this energy remains stable for the entire surge in the recess (see figure 26 below). This energy drops to almost zero when the pressure is released. This occurs as the energy absorbed only consists of elastic energy. Parts return to their initial condition.

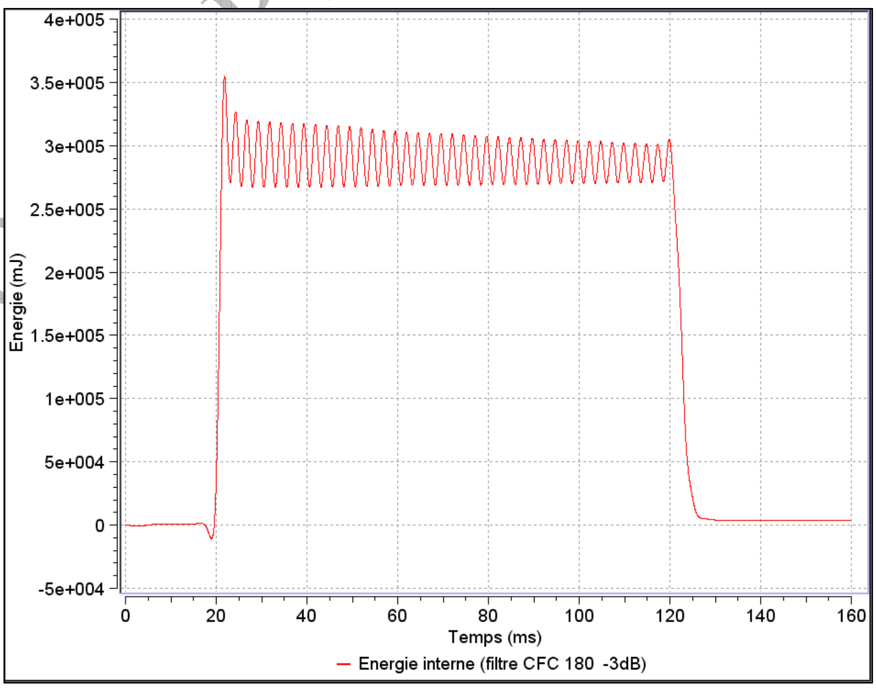


Figure 26: Deformation energy absorbed by the package during the explosion

Force (N) Temps (ms) - SPRING_167318_joint-bouchon_TL (filter CFC 180 -3dB)	Force (N) Time (ms) - SPRING _167318_ plug-seal_TL (CFC 180 -3dB filter)

4.5. Von Mises stresses and plastic deformations

The scale of colours from blue to red indicates increasing stress levels and plastic deformation in the part. Plug tightening induces low stresses of a few MPa prior to the explosion.

4.5.1. Plug

Maximum stresses in the plug (Staubli) during the constant overpressure phase are relatively low: they will not exceed 58 MPa (see figure 27 on next page). These stresses are located on the lower edge of the clamp ring. The above 22 t were applied near to this contact. These stresses are not adequate to allow the material (stainless steel at 226 °C) to return to the plastic field and deform locally.

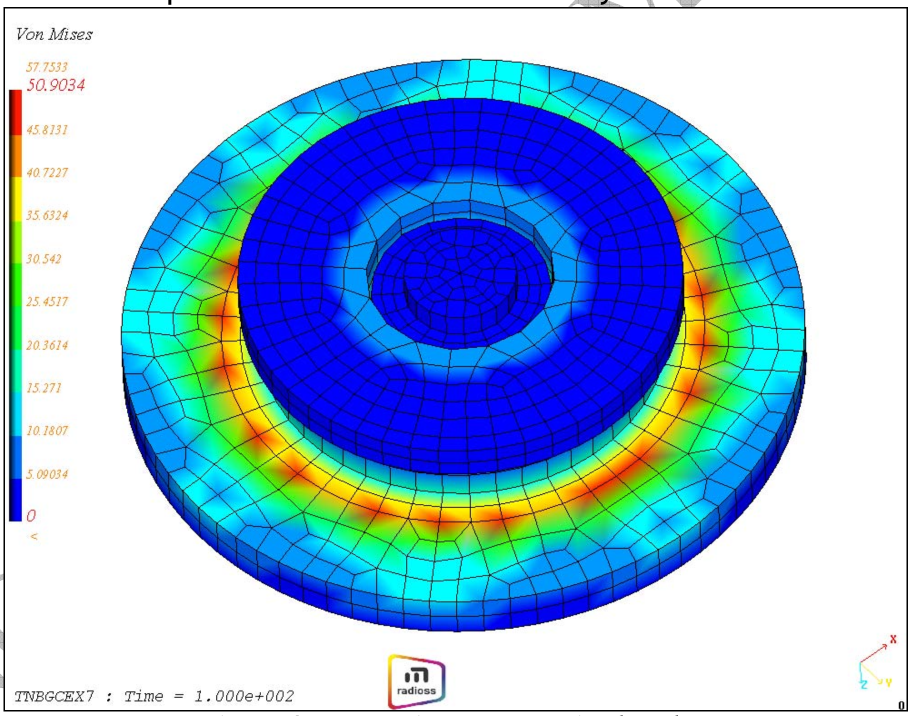


Figure 27: Von Mises stresses in the plug

4.5.2. Bayonet ring

The shoulders of the bayonet ring are the parts subjected to the most stresses during the explosion. Finally, stresses reached 182 MPa during the constant overpressure phase (see figure 28 below).

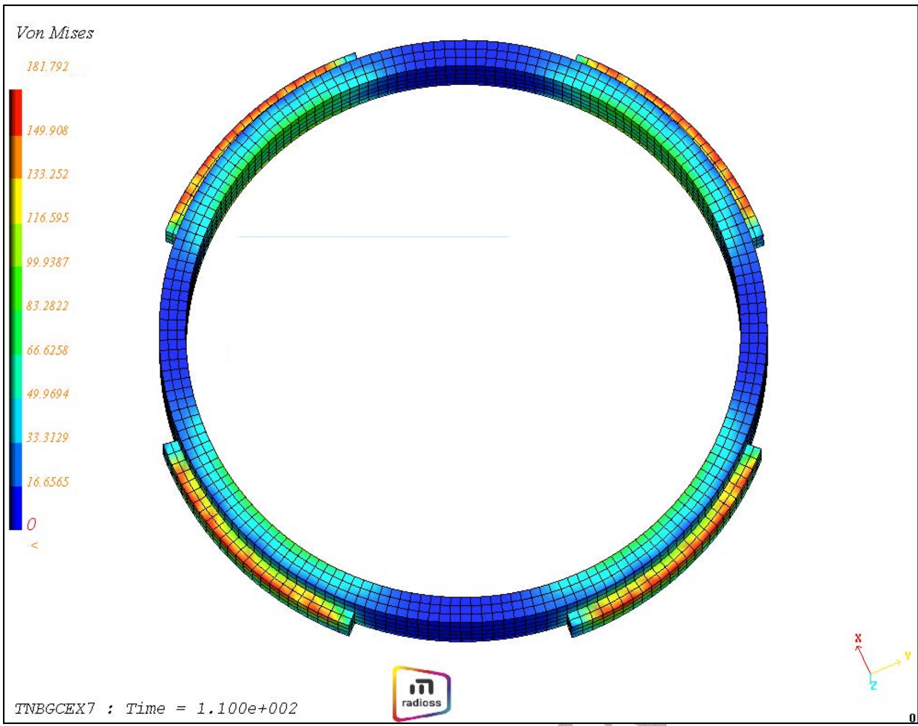


Figure 28: Von Mises stresses in the bayonet ring

Maximum stresses are reached at the point at which the surge is applied (dynamic effect). These stresses occur in the same zone as the previous figure and reach 222 MPa (see figure 29 below), which is higher than the elastic limit of the material (stainless steel at 226 °C).

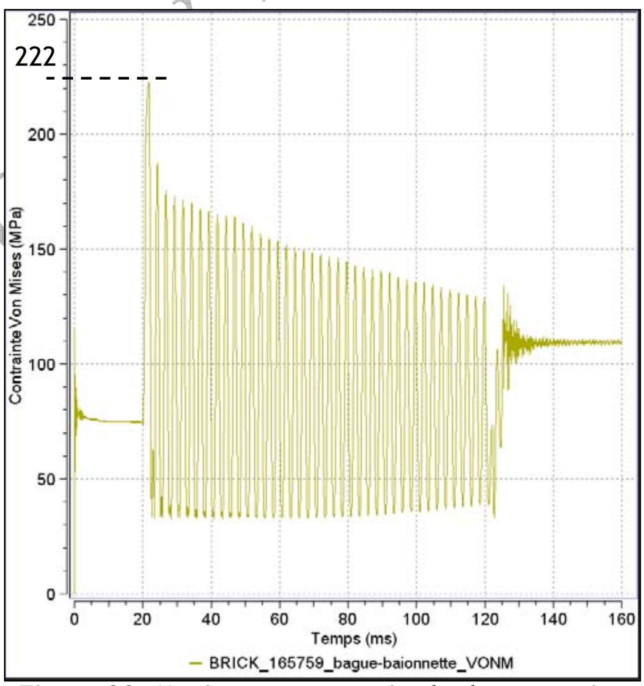


Figure 29: Maximum stresses in the bayonet ring

Force (N) Temps (ms)	Force (N) Time (ms)

- BRICK_165759_bague-baionnette_VONM	- BRICK_165759_bayonet-ring_VONM

This will induce minor plastic deformations (insignificant) of approximately 0.7% (see figure 30 below).

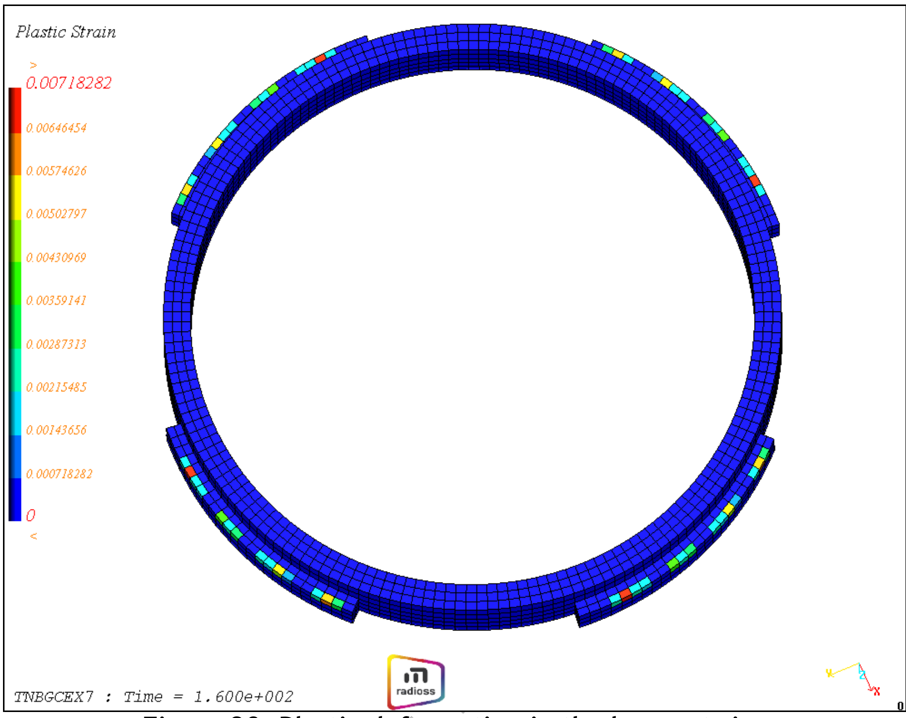


Figure 30: Plastic deformation in the bayonet ring

4.5.3. *Clamp ring*

Maximum stresses in the clamp ring during the explosion reach approx. 41 MPa (see figure 31 below), which is far lower than the elastic limit of the material (cupro-aluminium at 226 °C).

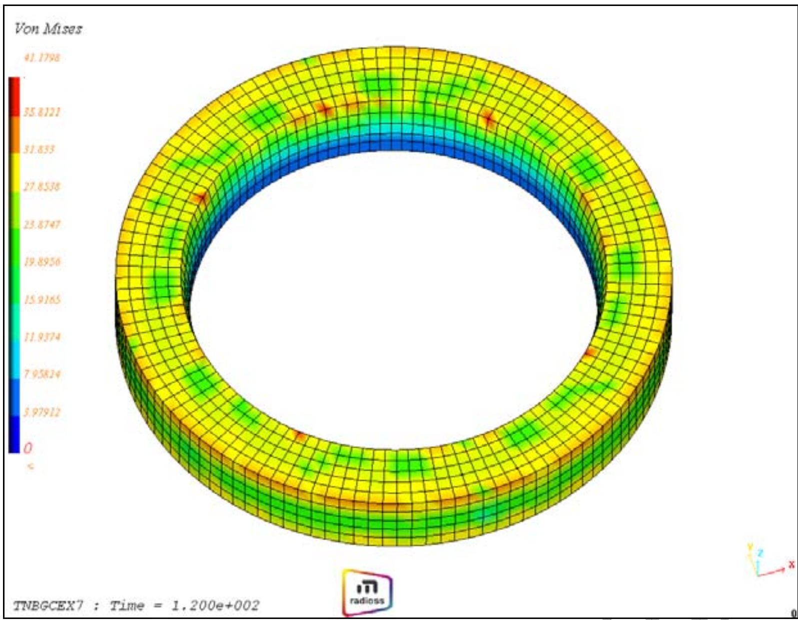


Figure 31: Von Mises stresses in the clamp ring

4.5.4. Main section flange

Figure 32 below shows the condition of Von Mises stresses in the main section flange during the constant overpressure phase: approximately 160 MPa on the discontinuous shoulders supporting the bayonet ring.

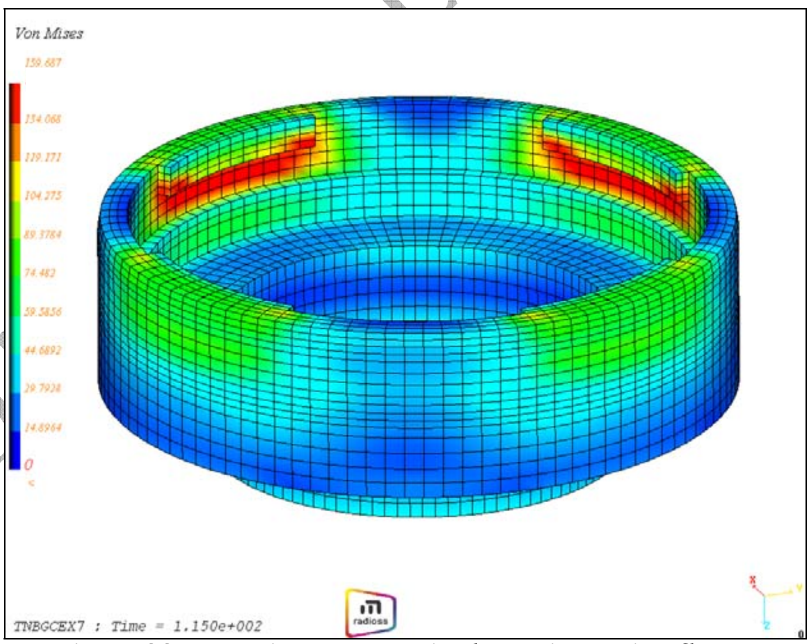


Figure 32: Von Mises stresses in the main section flange

Maximum stresses are reached at the point at which the surge is applied. These stresses occur in the same zone as the previous figure and reach 201 MPa (see figure 33 below), which is higher than the elastic limit of the material (stainless steel at 242 °C).

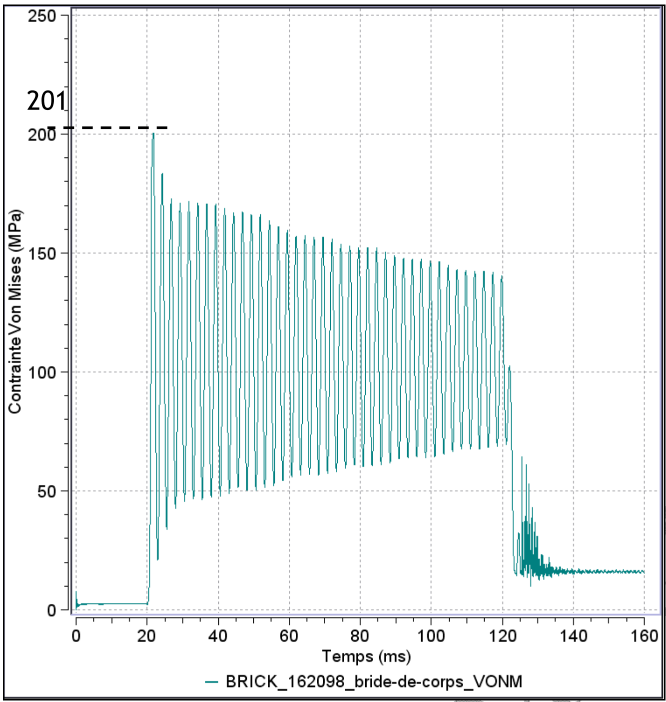


Figure 33: Maximum stresses in the main section flange

Force (N) Temps (ms) - BRICK_162098_bride-de-corps_VONM	Force (N) Time (ms) - BRICK_162098_main-section-flange_VONM

This will induce minor plastic deformations (insignificant) of approximately 0.2 % (see figure 34 below).

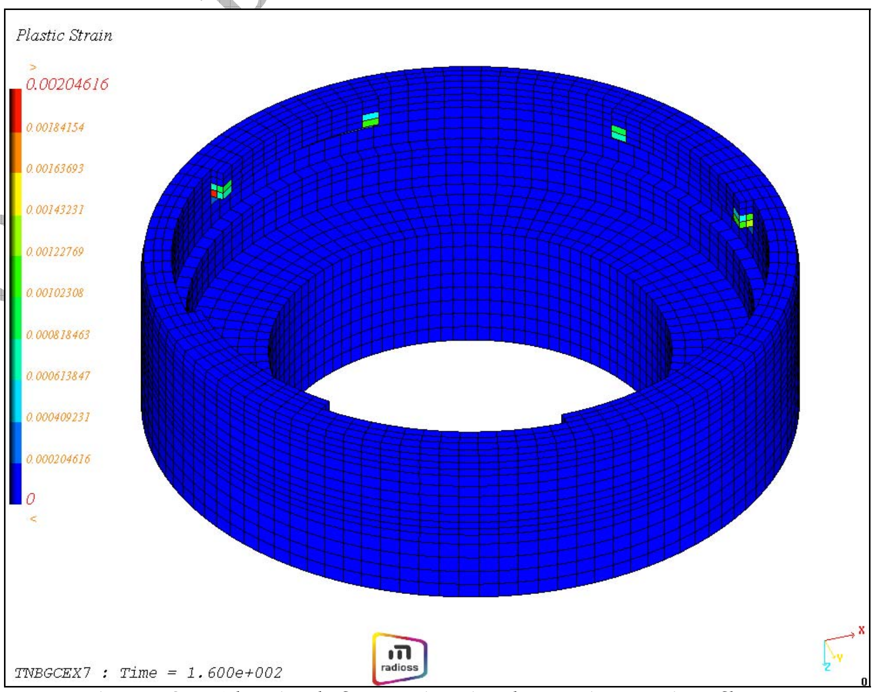


Figure 34: Plastic deformation in the main section flange

4.5.5. *Inner shell*

Maximum stresses in the inner shell during the explosion (induced by the pressure) reach approx. 81 MPa (see figure 35 below), which is far lower than the elastic limit of the material (stainless steel at 226 °C).

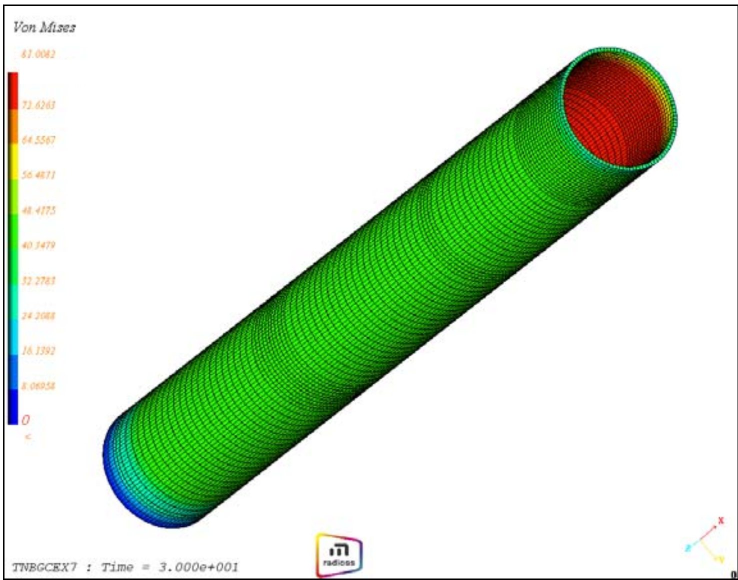


Figure 35: Von Mises stresses in the inner shell

4.5.6. *Outer shell*

Maximum stresses in the outer shell during the explosion do not exceed 27 MPa (see figure 36 below), which is far lower than the elastic limit of the material (stainless steel at 226 °C or at 786 °C). The outer shell is only subjected to minor stresses as deformations are mainly absorbed by the outer shell and by the resin filler.

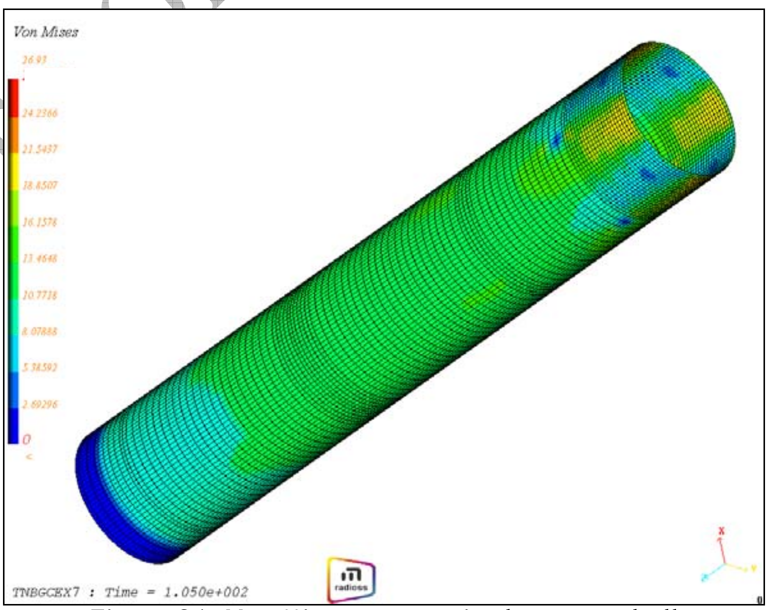


Figure 36: Von Mises stresses in the outer shell

4.5.7. Resin

Maximum stresses reached by the resin filler during the explosion are low: approx. 16 MPa (see figure 37 below), which is far lower than the elastic limit of the material.

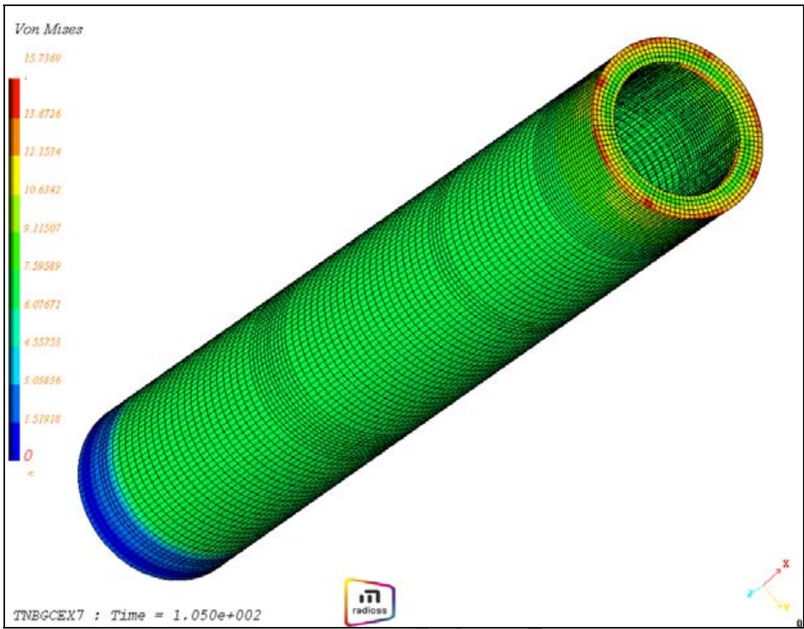


Figure 37: Von Mises stresses in the resin

4.5.8. Wood base

Maximum stresses reached by the wood base during the explosion are low: less than 1 MPa (see figure 38 below).

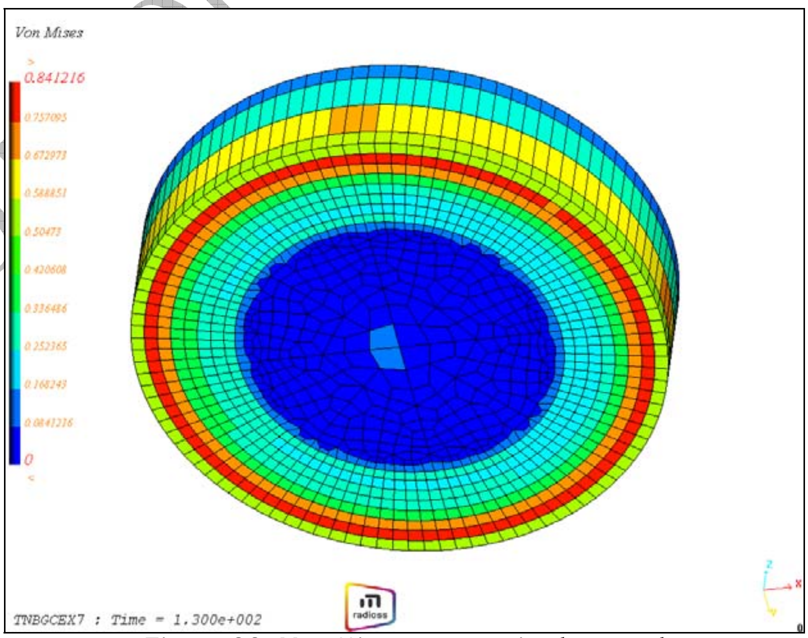


Figure 38: Von Mises stresses in the wood

5. Conclusion

The plug was pushed upwards and pressed against the clamp ring screwed in the bayonet ring by the forces created in the explosion. The entire unit pushed against the shoulder of the main section flange. Two o rings seal the recess between the flange and the plug.

Maximum opening between the plug and the flange during the explosion was 1.34 mm (for approx. 1 ms), leading to seal crushing of **10%** (30% under normal circumstances), **which corresponds to the resistance criterion limit for the explosion.**

After the explosion, a **residual opening of 0.29 mm** remained, caused by the slight caulking of the flange and bayonet ring. This corresponds to **seal compression of 25%, which is conform to the minimum of 15% required by the post-explosion resistance criterion.**

Stress levels in all parts during the explosion remained low. Deformation was local near to the closing system: the main section flange, bayonet ring and plug are slightly caulked in their respective support zones, causing **slight plastic deformation of approximately 0.7%. This plastic deformation is less than 1% and is not significant for package sealing during and after the explosion.** Table 10 below lists Von Mises stresses and maximum plastic deformations for all parts during the explosion.

Part	Elastic limit of the material according to temperature (MPa)	Maximum Von Mises stresses (MPa)	Maximum plastic deformation (%)
Plug	190	58	0
Main section flange	187	201	0,2 (insignificant)
Clamp ring	203	41	0
Bayonet ring	190	222	0,7 (insignificant)
Inner shell	187	81	0
Outer shell	100	27	0
Resin	85	16	0
Wood base	-	1	0

Table10: Overview of stresses and deformation during the explosion

Reference: 159A3W03
07 January 2003

CEA CADARACHE

MODAL ANALYSIS OF PACKAGE TN-BGC1

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AQ 002RAP

Title:. Modal analysis of package TN-BGC 1

Customer : CEA CADARACHE

To the attention of : Mr. CUVILLIER

DEMA reference : 159A3W03

Author : Pascal VERNAY

Summary:

The modal analysis is conducted for the entire package TN-BGC1, with consideration of several models and limit conditions.

3 limit conditions were used for the model of the main section, cover and cage unit

- CL n°1: free-free
- CL n°2: supported by the 4 cage base tabs
- CL n°3: supported by the 4 cage base tabs and the top of the cover

2 limit conditions were used for the model of the main section + cover unit,

- CL n°1: free-free
- CL n°2: supported by the top of the cover

The natural frequencies considered for the dynamic study vary between 20 Hz and 450 z.

The package is subjected to entirely non-linear stresses at impact (clearance, plasticizing of materials, etc.) and the cover is far less rigid than in elastic mode. Natural frequencies will be far lower (particularly in the main section) than in this analysis in linear mode by definition.

The connection (rubber pads) between the cage and the main section may remain in linear mode at impact. In this case, the highest frequency induced represents 144 Hz.

Calculations were conducted using the following software per finished element: MSC NASTRAN 2002 (FEMAP 8)

	Name	Date	Signature
Emitted by:	Pascal VERNAY		
Checked by:	Yves BRUN		

TABLE OF CONTENTS

I. PURPOSE OF THE CALCULATION MEMO.

The modal analysis relates to the entire system, main package section, damper cover and protection cage. The aim is to determine the natural frequencies and modes which would be excited in the impact after a vertical fall of 9 m (cover facing downwards). The highest of the frequencies concerned (in terms of mass) will enable the definition of a filter frequency (low-pass filter) to be applied to the acquisition signal to overcome noise and only integrate the mechanical signal.

The aim of the memo is therefore to define natural frequencies.

II. ASSUMPTIONS AND DATA

II.1. Materials

The following table summarises the main data for package materials. Various sources are used for information. Maximum values are taken into consideration for the Young's modulus, wood, rubber and resin (increased stiffness and therefore higher natural frequencies).

Matière		Module d'Young	Coefficient de poisson	Masse volumique
	symbole	E	ν	ρ
	Unité	Pa		Kg/m^3
Aciers 304L et 30 CD 4		1.80E+11	0.3	7900
Aluminium		6.95E+10	0.33	2700
Résine neutrophage		2.20E+10	0.3	1600
Bois Balsa		2.30E+09	0.2	150
Bois peuplier		1.00E+10	0.3	450
Caoutchouc néoprène		2.00E+06	0.3	1000

Source: CEA specifications TN-BGC

II.2. Initial data

The mass of the package with cage and cover is taken as 280 kg for the purposes of calculations.

The mass of the selected content is the minimum acceptable mass, i.e. 60 kg. The contribution of the mass will reduce natural frequencies.

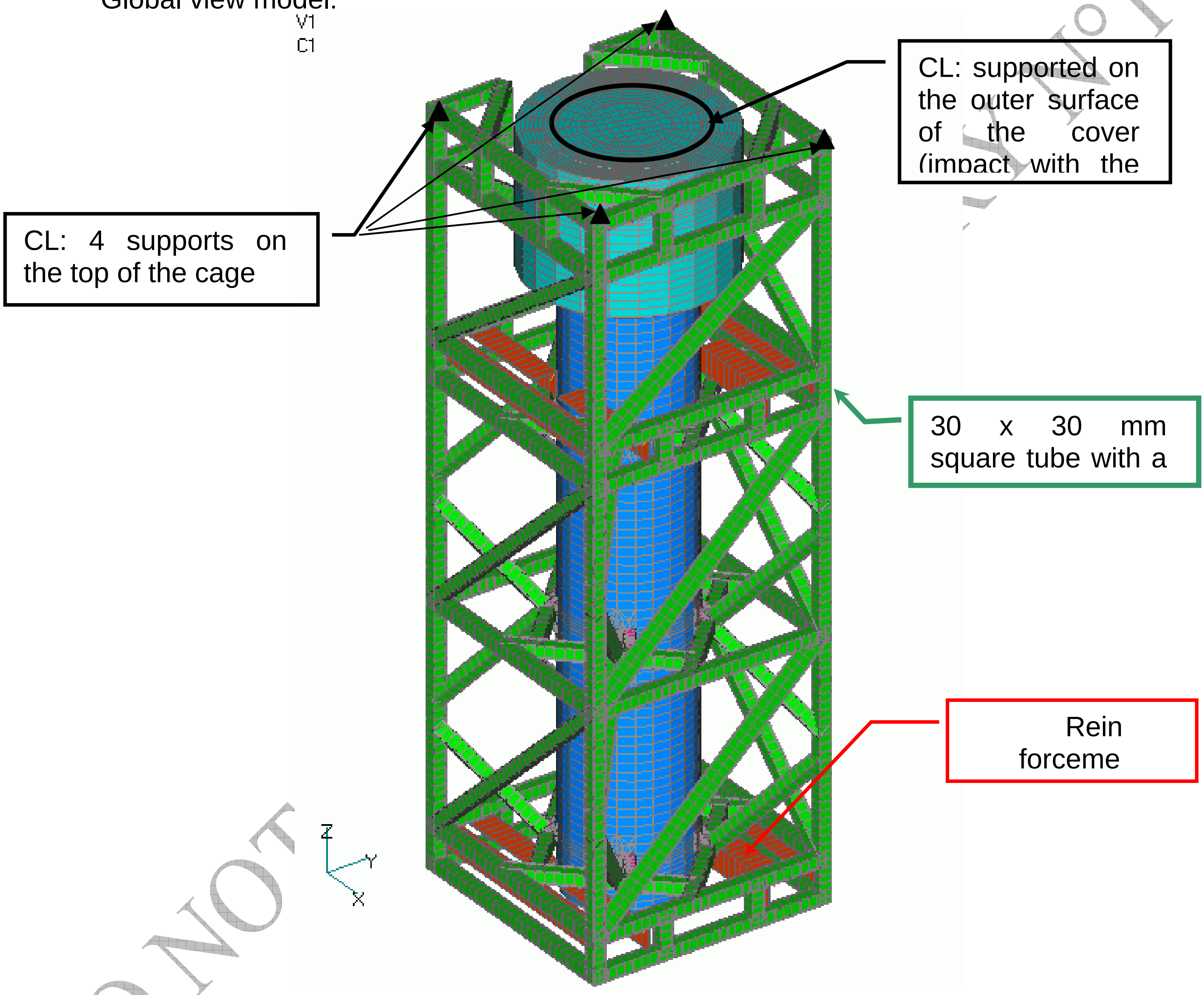
With modal analyses, the properties of materials involve linear elasticity by definition. The balsa will very quickly switch to non-linear deformation mode with the impact on the cover, and will rapidly become less stiff than balsa in elastic mode. The natural frequencies and modes indicated in this report are only excited in the initial phase of the impact when behaviour is globally linear. The system will then react in a **less rigid** manner and therefore answer at lower frequencies. The analysis then relates to higher ranges of frequencies.

III. PRESENTATION OF THE MODEL

The complete 3D model was created based on drawings ref. {2}. The cut sheets in the cage are not considered as their masses and stiffnesses are insignificant.

"CL" refers to Limit Conditions.

Global view model:



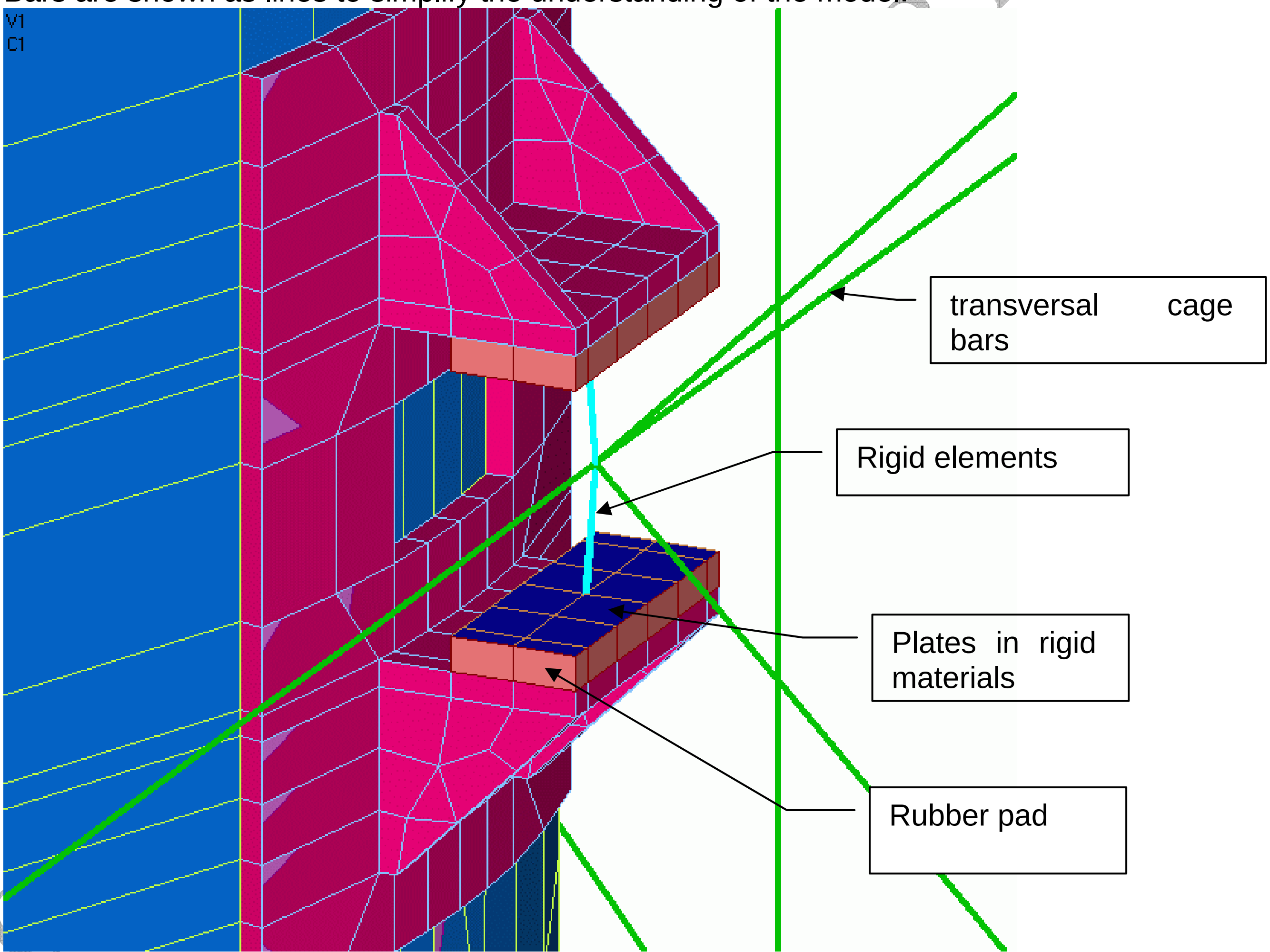
Several situations are analysed:

1. The system is in free-free in terms of CL for the first situation, modelling the behaviour of the package both before and after the impact.
2. For the second situation, 4 supports are defined for the upper section of the cage base. Impact occurred with the head stopped. This CL models contact for the cage alone.
3. For the 3rd situation and in addition to the 4 previous supports, the upper sheet of the cover is used as an impact surface, modelling a contact distributed over the cage and main section.

4. The natural frequencies of the main section + cover are studied separately in a second model without the cage. Two limit conditions are defined: free-free and flat support on the upper section of the cover.

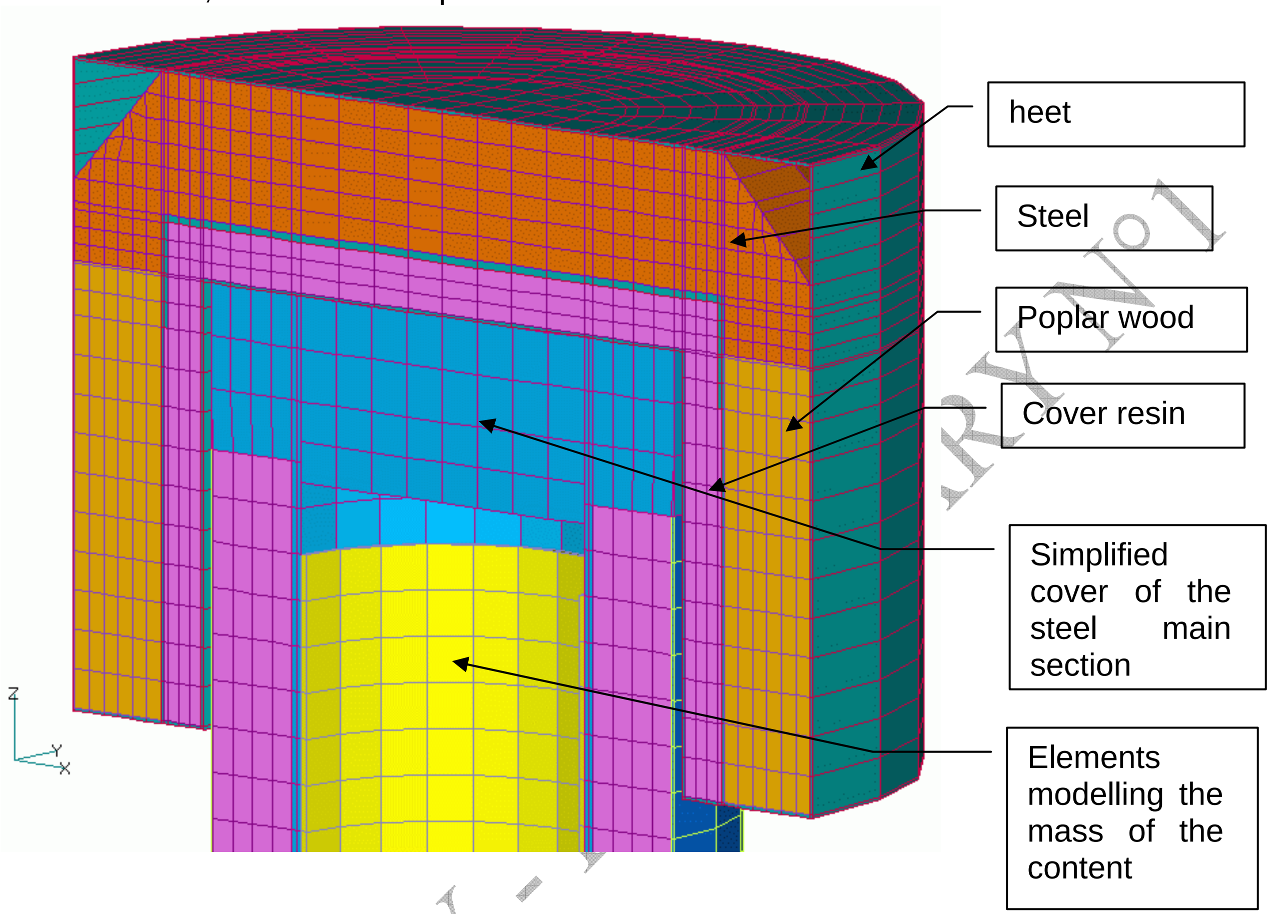
Rubber pads are modelled as solid elements and plate elements with a rigid material (E = $2^{e}13$MPa) rigidifying the inner surface of pads supported by the rubber. Rigid elements bind the centre of the pads (inner surface) with the transversal bars of the cage. Other rigid elements enable radial blocking between the cage brackets and bars to model the attachment axis. This model must be detailed for the mechanical filter role of the rubber pads.

Model, main section/cage liaison details:
Bars are shown as lines to simplify the understanding of the model.

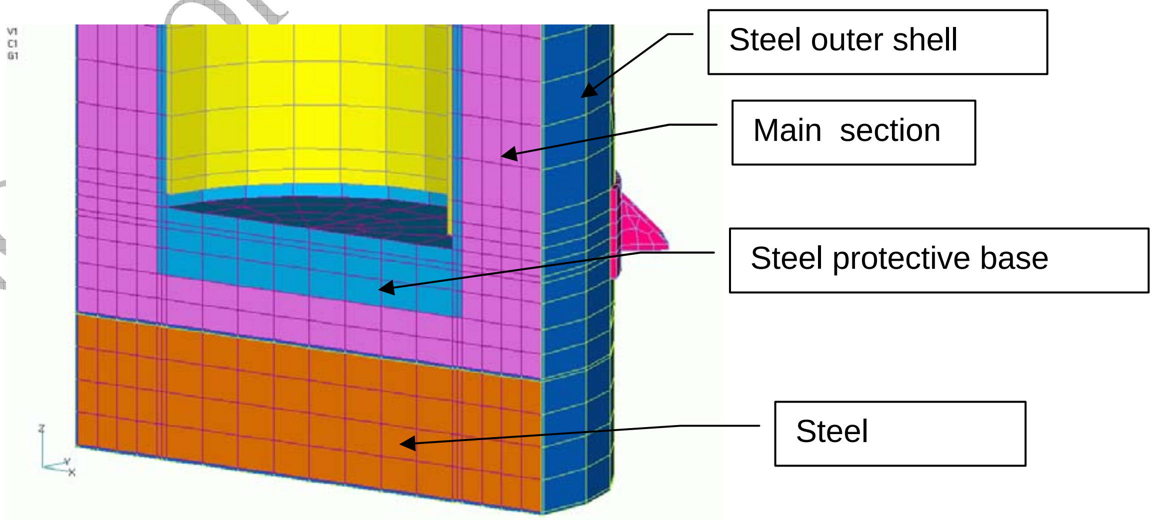


The following two images show section views of the main package section with its protective cover. The connection between the cover and the main section is simplified and located on the top of the cover with a flat support.

Section model, details of the top of the main section and cover:



Section model, details of the bottom of the main section:



IV. Results of the complete model

The following figures show significant natural modes for the complete model. Modes are shown separately for the main section and cage to improve clarity. The colour scale (relative displacement without unit) is identical for both figures.

IV.1. Free-free limit conditions

The first 9 modes are calculated and summarised in the following table. Text in red refers to the modes shown in the images.

Summary of the first 9 modes:

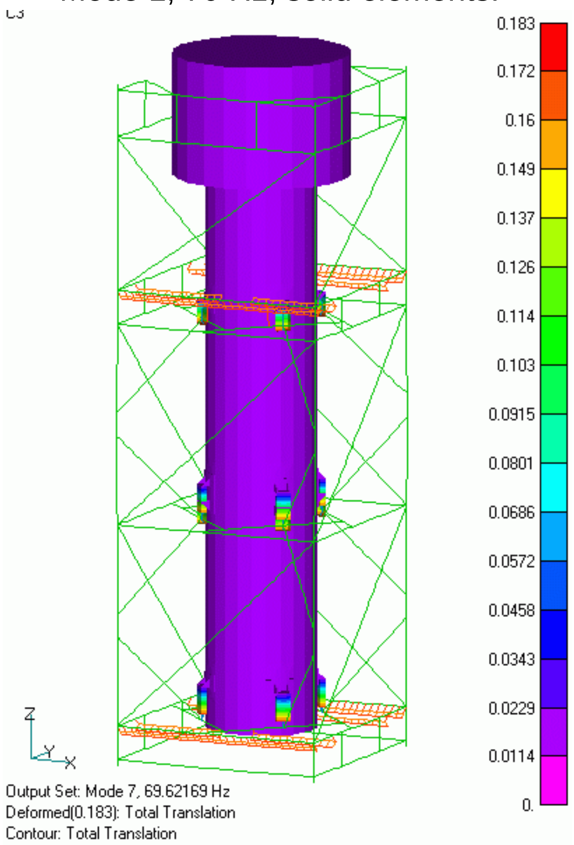
Mode n° 1	69.6 Hz	Traction - compression, z axis, rubber pads, relative displacement between the main section and cage
Mode n° 2	138.8 Hz	Relative bending between the main section and cage, y axis
Mode n° 3	144.1 Hz	Relative bending between the main section and cage, x axis
Mode n° 4	229.4 Hz	Bending of the top of the cage
Mode n° 5	237.2 Hz	Cage bending mode
Mode n° 6	247.7 Hz	Cage bending mode
Mode n° 7	260.0 Hz	Cage and main section bending mode
Mode n° 8	261.7 Hz	Cage and main section bending mode
Mode n° 9	267.3 Hz	Cage only bending mode

Rubber pads are subjected to extensive forces and the system practically vibrates in relative mode between the main section and the cage for the first three frequencies. The first frequency, 70 Hz, is the main frequency excited during the vertical impact with the head stopped.

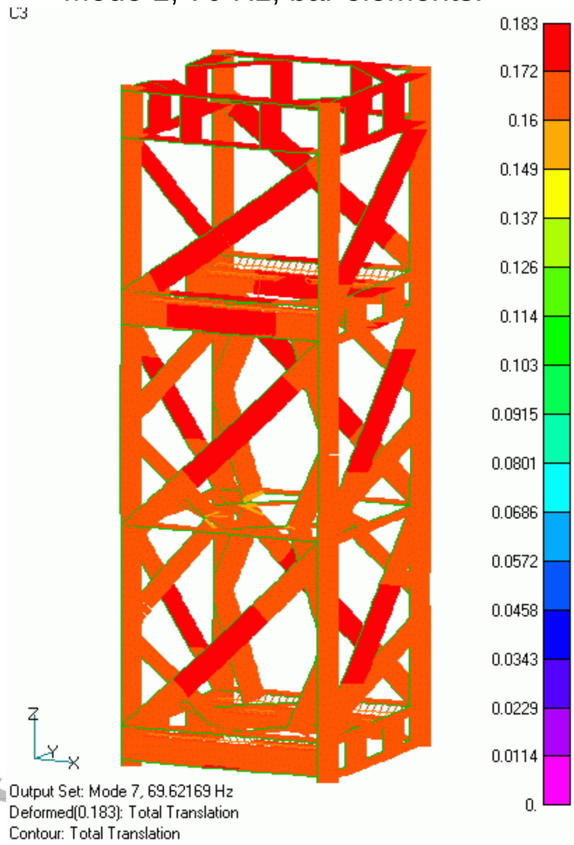
For the other frequencies, main deformation affects the bars of the cage in bending. This occurs at impact, however the vibrations of the cage must not be extensively transmitted to the main section (positioning of accelerometers) thanks to the filtering of rubber pads.

The frequencies in question rise as high as 150 Hz in free-free mode

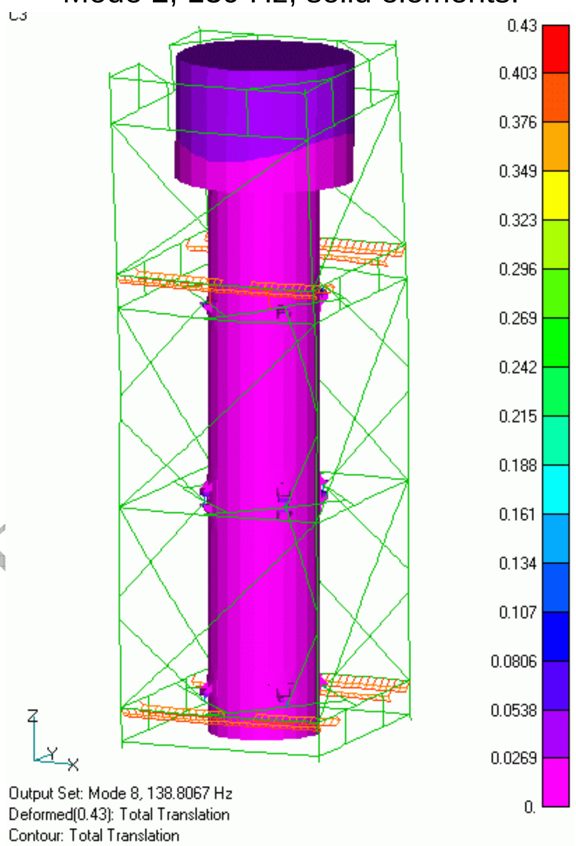
Mode 1, 70 Hz, solid elements:



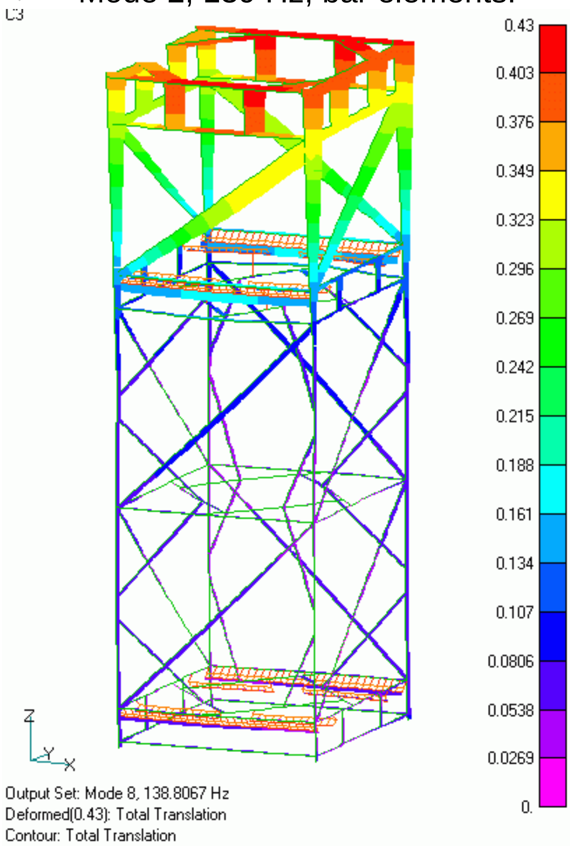
Mode 1, 70 Hz, bar elements:



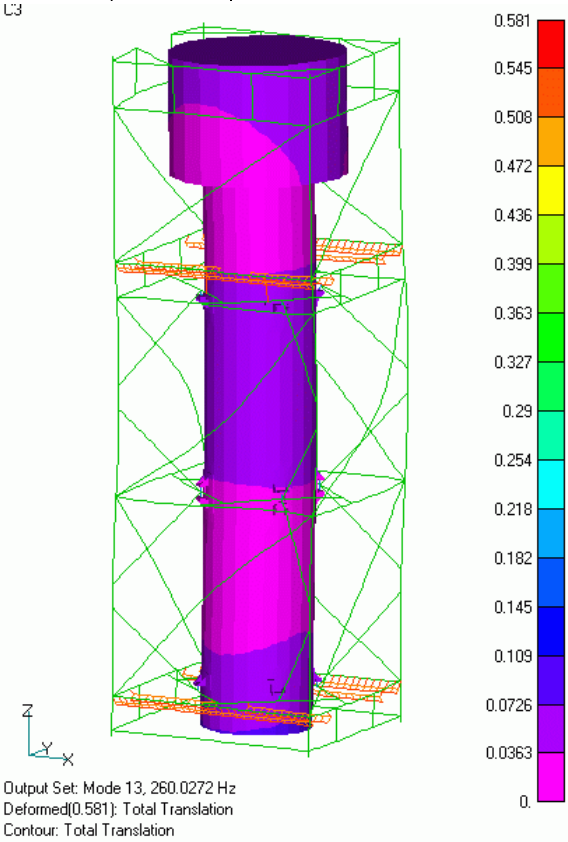
Mode 2, 139 Hz, solid elements:



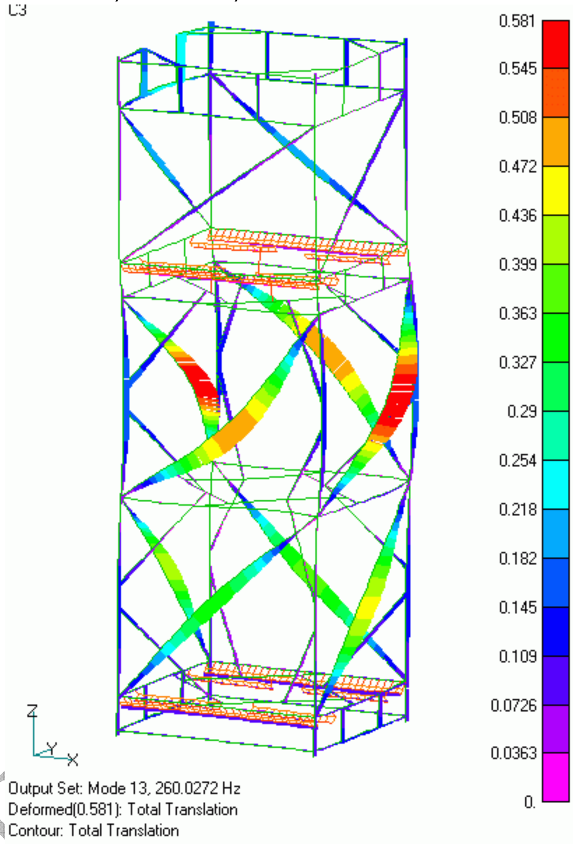
Mode 2, 139 Hz, bar elements:



Mode 7, 260 Hz, solid elements:



Mode 7, 260 Hz, bar elements:



IV.2. Limit conditions, supported by the 4 tabs at the top of the cage

The first 7 modes are calculated and summarised in the following table. Text in red refers to the modes shown in the images.

Summary of the first 7 modes:

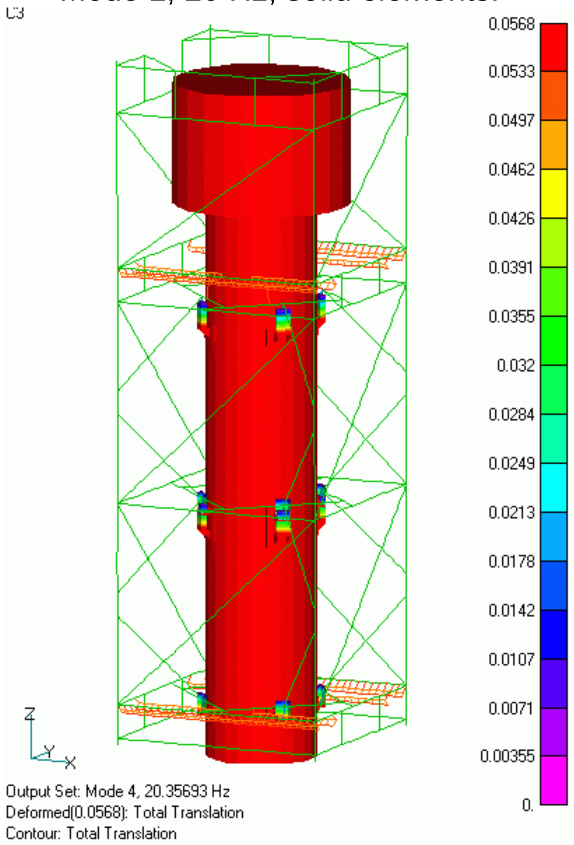
Mode n° 1	20.4 Hz	Traction - compression, z axis, rubber pads, relative displacement between the main section and cage
Mode n° 2	27.4 Hz	Relative bending between the main section and cage, y axis
Mode n° 3	27.8 Hz	Relative bending between the main section and cage, x axis
Mode n° 4	184.4 Hz	Bending of cage bars
Mode n° 5	190.6 Hz	Cage bending mode
Mode n° 6	220.5 Hz	Cage bending mode
Mode n° 7	231.6 Hz	Cage bending mode

Rubber pads are subjected to extensive forces and the system practically vibrates in relative mode between the main section and the cage for the first three frequencies. This behaviour is equivalent to that observed for the previous limit conditions (free-free), but with far lower frequencies. The vibrations of the heavier main section are dominant, and hence reduce natural frequencies.

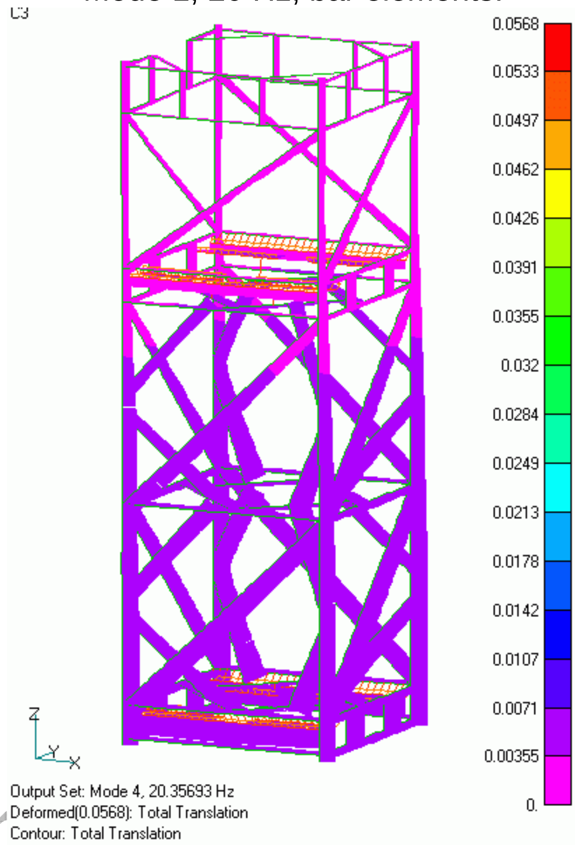
For the other frequencies, main deformation affects the bars of the cage in bending. This deformation is equivalent to results in free-free mode.

With these limit conditions, the frequencies in question rise as high as 30 Hz. However, the first natural frequencies (approximately 200 Hz) of the cage must not be neglected despite the rubber pads.

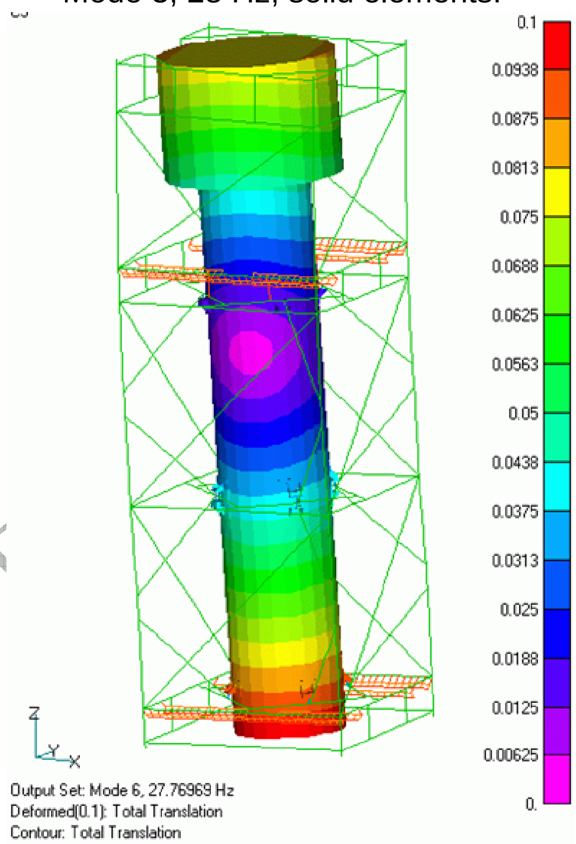
Mode 1, 20 Hz, solid elements:



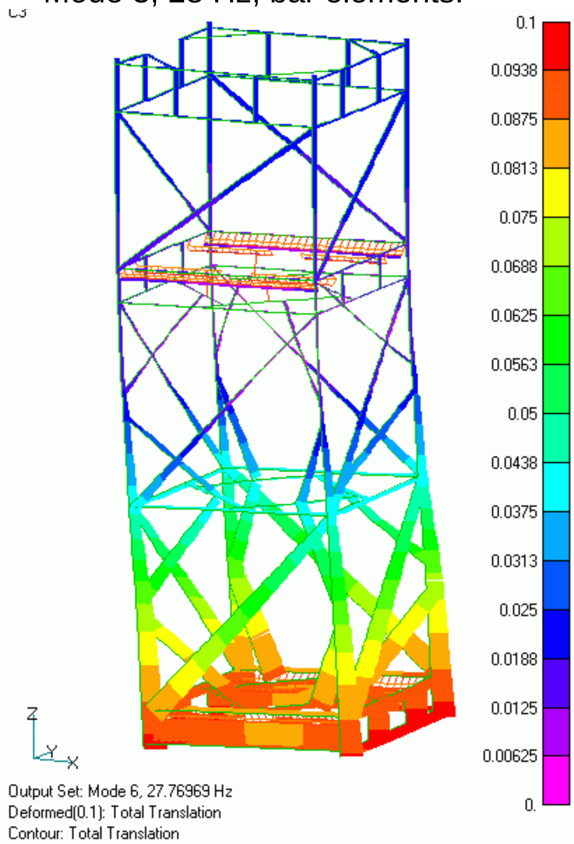
Mode 1, 20 Hz, bar elements:



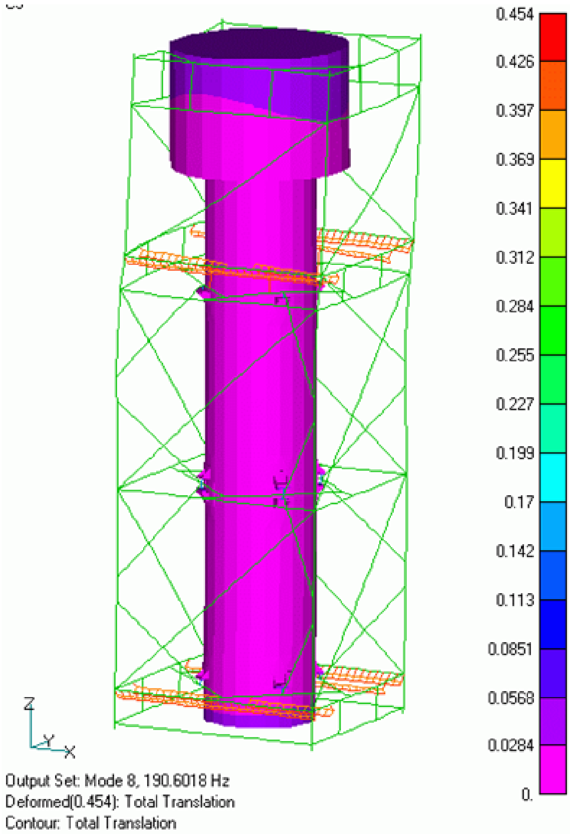
Mode 3, 28 Hz, solid elements:



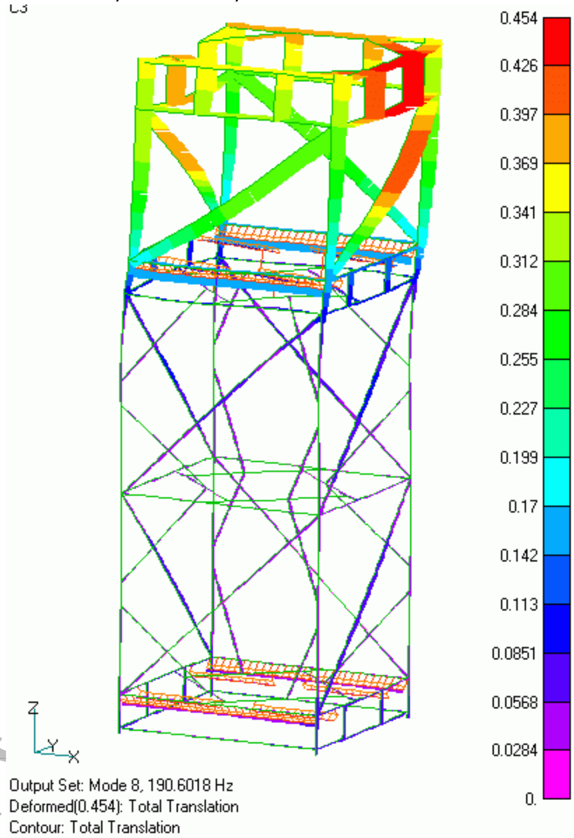
Mode 3, 28 Hz, bar elements:



Mode 5, 191 Hz, solid elements:



Mode 5, 191 Hz, bar elements:



IV.3. Limit conditions, supported by the base of the cage and damper cover

The first 7 modes are calculated and summarised in the following table. Text in red refers to the modes shown in the images.

Summary of the first 7 modes:

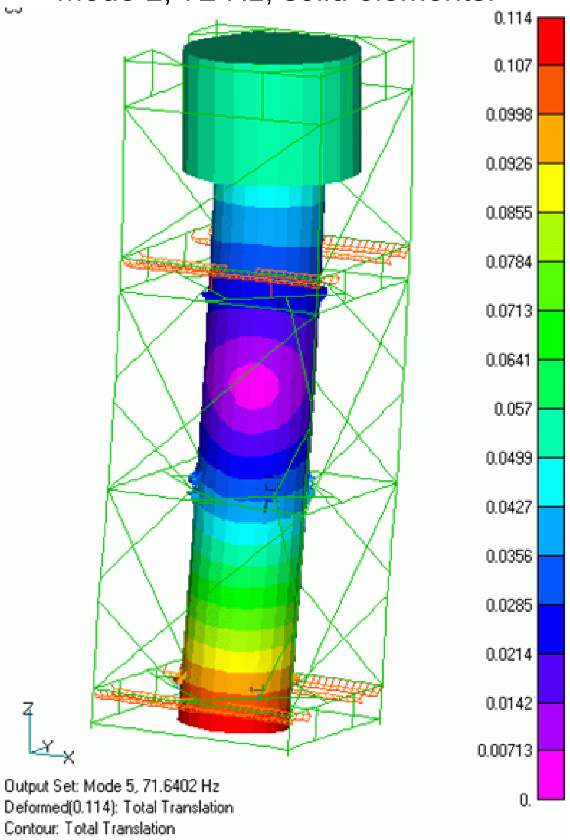
Mode n° 1	71.6 Hz	Relative bending between the main section and cage, y axis
Mode n° 2	71.6 Hz	Relative bending between the main section and cage, x axis
Mode n° 3	189.0 Hz	Cage bending mode
Mode n° 4	195.6 Hz	Cage bending mode
Mode n° 5	220.4 Hz	Cage bending mode
Mode n° 6	232.0 Hz	Cage bending mode
Mode n° 7	258.5 Hz	Cage bending mode

Rubber pads are subjected to extensive forces and the system practically vibrates in relative mode between the main section and the cage for the first two frequencies. This behaviour is almost identical to the previous situations with the logical disappearance of the traction-compression mode. The frequency (72 Hz) is between the first two situations.

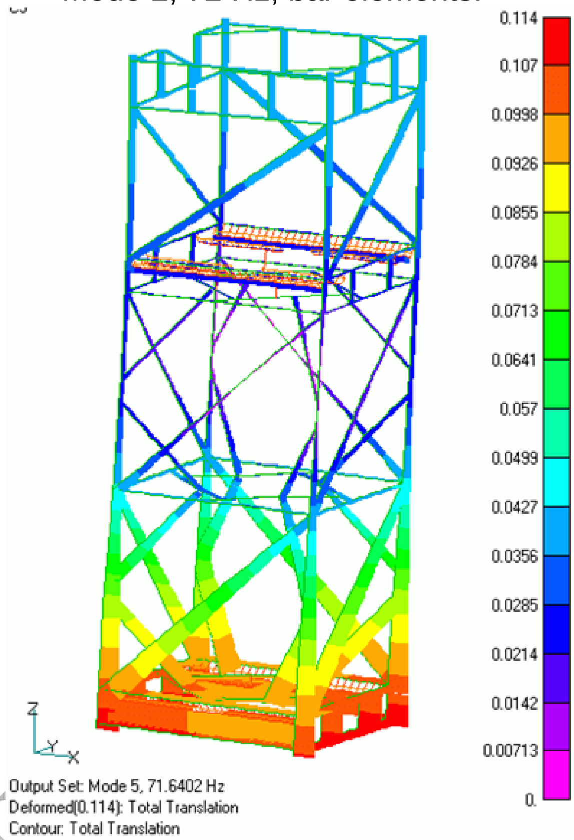
For the other frequencies, main deformation affects the bars of the cage in bending. This deformation is equivalent to results for the other situations.

With these limit conditions, the frequencies in question rise as high as 72 Hz. However, the first natural frequencies (approximately 200 Hz) of the cage must not be neglected despite the rubber pads.

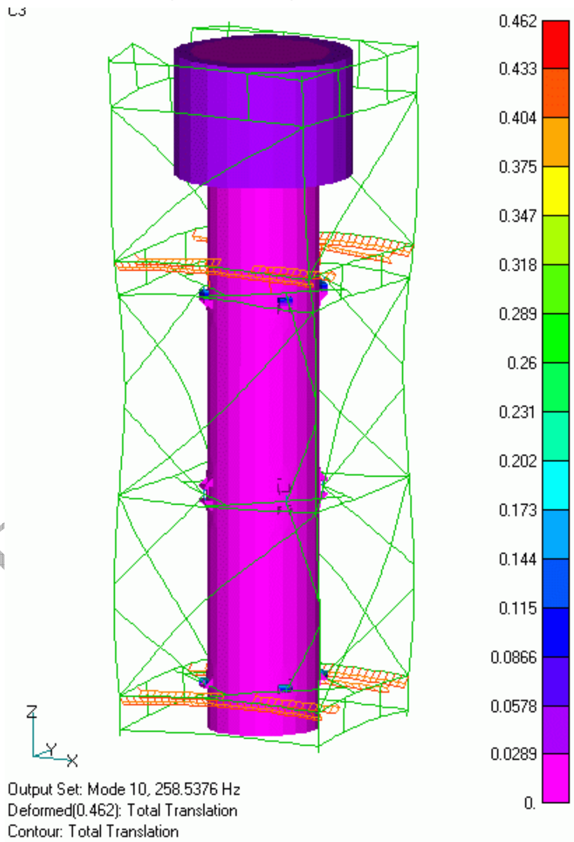
Mode 2, 72 Hz, solid elements:



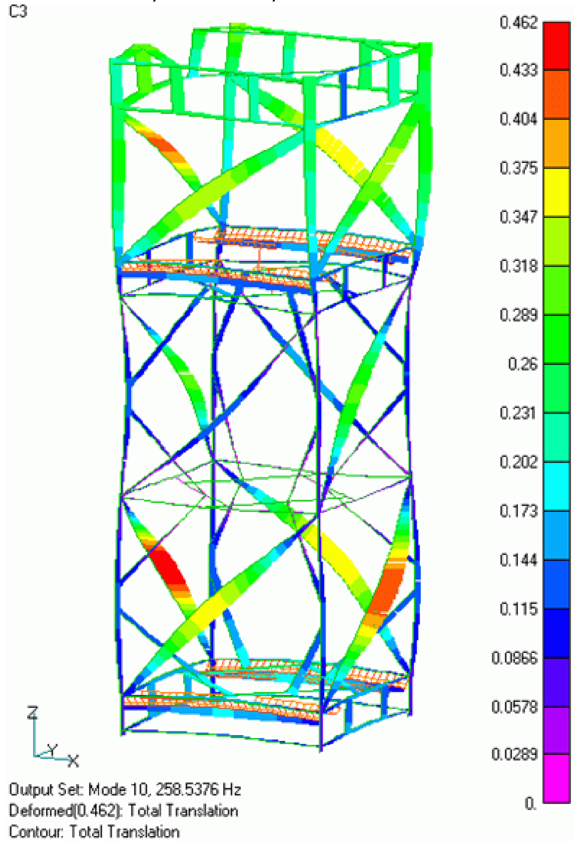
Mode 2, 72 Hz, bar elements:



Mode 7, 259 Hz, solid elements:



Mode 7, 259 Hz, bar elements:



V. Results of the model of the main section and cover

It is worth determining the natural frequencies of the main section without the cage to remove the multitude of natural frequencies of the latter close to 250 Hz.

The following figures show natural modes for certain natural frequencies of the system.

V.1. Free-free limit conditions

The first 6 modes are calculated and summarised in the following table. Text in red refers to the modes shown in the images.

Summary of the first 6 modes:

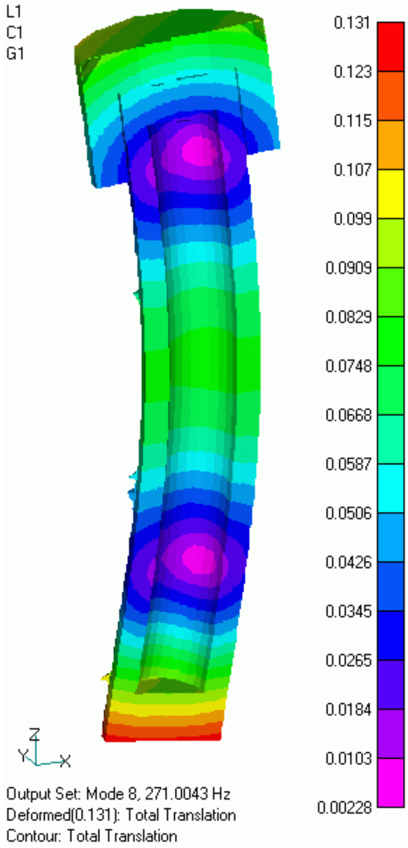
Mode n° 1	271 Hz	Bending 1, y axis, antinode
Mode n° 2	271 Hz	Bending 1, x axis, antinode
Mode n° 3	496 Hz	Twisting, z axis
Mode n° 4	654 Hz	Bending 2, y axis, antinodes
Mode n° 5	654 Hz	Bending 2, x axis, antinodes
Mode n° 6	824 Hz	Traction - compression, z axis

The first two frequencies (271 Hz) are bending modes with 1 single antinode in the two radial directions. The second bending modes were detected at 654 Hz (modes 5 & 6).

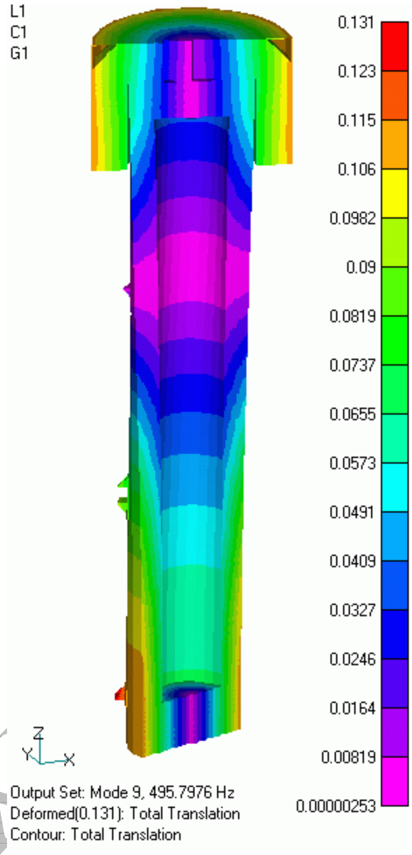
Mode 3 (496 Hz) is a twisting mode and must not be excited at impact.

The traction-compression mode at 824 Hz intervenes after the impact during the rebound. The following limit conditions reflect reality at impact more closely. In addition, this frequency heavily depends on the resin module and must be extensively dampened.

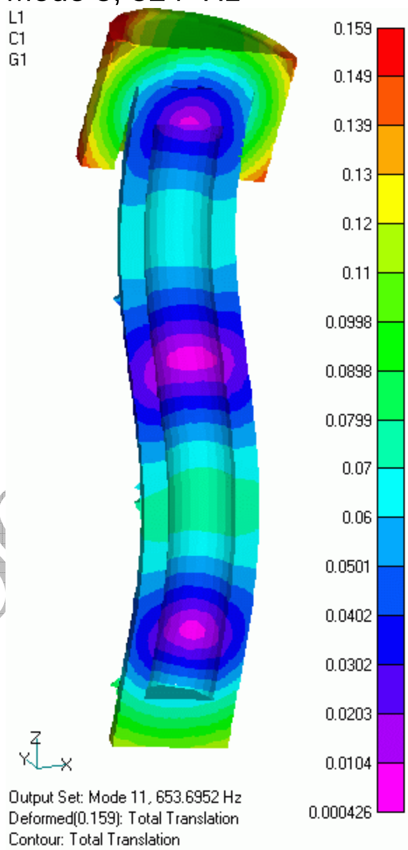
Mode 2, 271 Hz:



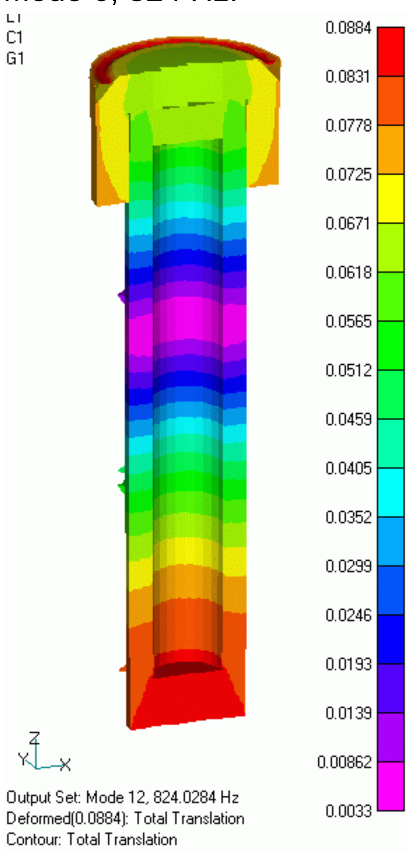
Mode 3, 496 Hz:



Mode 5, 524 Hz



Mode 6, 824 Hz:



V.2. Limit conditions, damper cover supports

The first 7 modes are calculated and summarised in the following table. Text in red refers to the modes shown in the images.

Summary of the first 7 modes:

Mode n° 1	67 Hz	Bending 1, y axis, antinode
Mode n° 2	67 Hz	Bending 1, x axis, antinode
Mode n° 3	337 Hz	Bending 2, y axis, antinodes
Mode n° 4	337 Hz	Bending 2, x axis, antinodes
Mode n° 5	432 Hz	Traction - compression, z axis
Mode n° 6	496 Hz	Twisting, z axis
Mode n° 7	767 Hz	Bending 3, y axis, antinodes

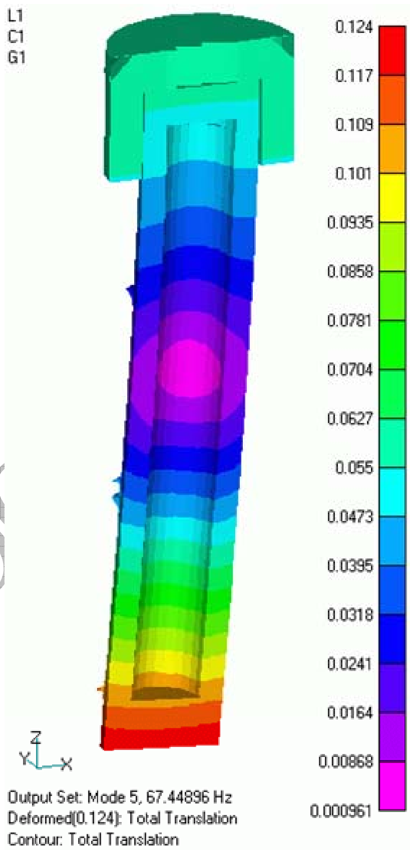
The first two frequencies (67 Hz) are bending modes with 1 single antinode in the two radial directions. For free-free CL, the frequency is equal to 271 Hz. The second bending modes drop to 337 Hz.

Mode 6 (496 Hz) is the non-modified twisting mode.

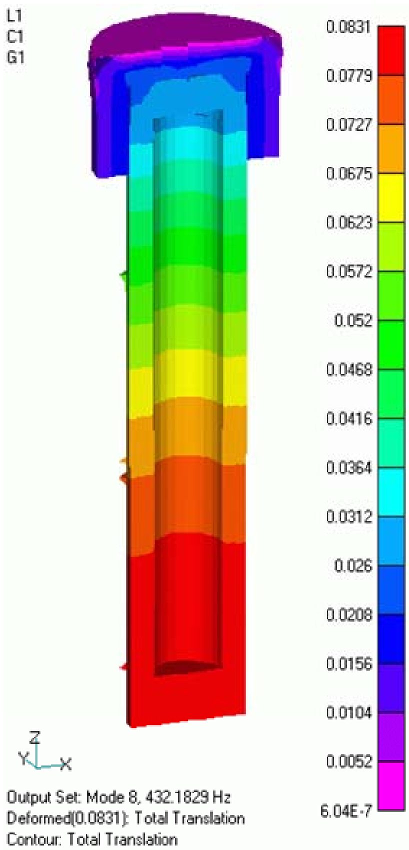
The traction-compression mode at 432 Hz intervenes at impact, but depends on the actual behaviour of the materials (mainly of the balsa wood).

The frequencies in question rise as high as 432 Hz for this model.

Mode 2, 67 Hz:



Mode 5, 432 Hz:



VI. CONCLUSION

The modal analysis is conducted for the entire package TN-BGC1, with consideration of several models and limit conditions.

3 limit conditions were used for the model of the main section, cover and cage unit,
- CL n°1: free-free
- CL n°2: supported by the 4 cage base tabs
- CL n°3: supported by the 4 cage base tabs and the top of the cover

2 limit conditions were used for the model of the main section + cover unit,
- CL n°1: free-free
- CL n°2: supported by the top of the cover

The natural frequencies considered for the dynamic study vary between 20 Hz and 450 z.

The package is subjected to entirely non-linear stresses at impact (clearance, plasticizing of materials, etc.) and the cover is far less rigid than in elastic mode. Natural frequencies will be far lower (particularly in the main section) than in this analysis in linear mode by definition.

The connection (rubber pads) between the cage and the main section may remain in linear mode at impact. In this case, the highest frequency induced represents 144 Hz.

VII. Reference documents

Ref. {1}: TRANSNUCLEAR plans, Package TN-BGC 1
- Main section, ref. 0892-29
- Damper cover, ref. 0892-44
- Cage, ref. 0892-41