Revalidation Application for French Approval Certificate of a Package Design, Number F/379/B(U)F-96 (Rev. Ct) for the TN-106 Package - Request for Revision to Competent Authority Certificate USA/0693/B(U)F-96, Revision 0

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Enclosure 4 to TN E-34732

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TN 106 PACKAGING

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***This English translation corresponds to the French Safety Analysis Report reference DOS-06-00032898-000 rev. 12**

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INTRODUCTION

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Revision	Date	Modifications	Prepared by / Checked by
Ref. : 5573-Z-00E			
0	05/00	Document first drawn up	F. PETIT / A. SALAÜN
Ref. : DOS-08-00126114-010			
00	07/08	New document reference New formalism Update of the applicability regulations and the useful length of the cavity (restriction : 2500 mm instead of 3200 mm)	S. CHEVET / JC .BOTT
1	02/13	Translation Of the document DOS-06-00032898-001 Rev. 1 Update to the applicable regulations and the range for the usable length of the cavity [2200 mm – 2400 mm] Details concerning the justification of the mechanical strength of the closure systems (introduction of numeric calculations). Modification concerning the use of the base plate.	R. BAHOU / D. HONDAGNEU

1. PURPOSE

The purpose of this safety file is to demonstrate that the package model TN 106, loaded with various fissile radioactive materials, is compliant with the applicable regulation mentioned in paragraph 4.

The list of chapters constituting the present safety file is given in the contents and a summary of each of them is attached in appendix 1 of the present chapter.

2. GENERAL INFORMATION CONCERNING THE TN 106 PACKAGE

The TN 106 package is a package of type B(U) or B(M) and may transport fissile materials.

This package is intended to transport sections of irradiated fuel rods and other content of miscellaneous origin (miscellaneous fissile materials, gamma and neutron sources, MTR assemblies…). All of these contents are described in chapter 0A. The thickness of the neutron-absorbing resin has been adapted to the thickness of the lead in order to optimise the quantity of transportable fuel from the radiological protection point of view.

This package must be able to be received and used in a large number of laboratories, research reactors and facilities in the fuel cycle. It has therefore been designed in such a way as to be able to be handled and loaded in several configurations. This package may be handled using trunnions or lugs, in the horizontal or vertical position. It may also be loaded in the horizontal or vertical position, dry or under water. The usable length of the cavity is variable and must be fixed when it is manufactured.

The package, shown in figure 00.1, is characterised by:

- A cylindrical cavity of a circular section, with a usable diameter of 203 mm and a variable usable length from 2200 to 2400 mm.
- A body composed of successive concentric shells made of stainless steel, lead, self-extinguishing resin and stainless steel. This succession of shells gives good mechanical strength, effective shielding for gammas and neutrons and protects the lead in case of fire.
- 2 pairs of trunnions used for securing and for tilting operations on the frame, as well as for vertical handling.
- 2 lugs, used for handling the package horizontally (with or without its frame), and during tilting operations on the frame.
- A system of loading by a front conduit seal associated with a push system at the rear. This push system maintains an internal fitting intended to receive the content and to transfer it during loading and unloading operations.
- A base plate on which the package can rest.

- 6 openings (front lid, front closure plate, orifices A and B, revolving plug closure plate, back closure plate), each being made leaktight by a system of double seals made of EPDM.
- 2 identical removable guards made of balsa, surrounded by a steel envelope and fixed by screws, to act as shock absorbers for the package in case it is dropped.
- The diameter of the guards is 1458 mm and the total length with guards varies between 3624 and 3824 mm.

3. GENERAL APPROACH OF THE SAFETY FILE

This file is composed of descriptive chapters (chapters 00, 0, 0A, 6A, 7A, 8A) and demonstrative chapters (1A, 2, 2A, 3A, 4A, 5A). The chapters that concern the contents are distinguished from those that directly concern the package by adding the letter A to their order number.

The safety of the package model in relation to regulatory requirements is justified as follows:

– **Containment:**

All of the constituents of the confinement enclosure are made of stainless steel and the 6 openings are closed by a lid fitted with a system of double seals made of EPDM, chosen for the strength of this material at -40°C.

The strength of the confinement envelope and closure systems are justified by the digital simulation of drops considered as the most severe. Additional calculations justify the strength of the screws for holding the lids under routine transport conditions. The strength of the confinement enclosure when subject to overpressure is also justified by calculation (chapter 1).

The thermal calculations show that the maximum temperatures of the seals under normal and accidental transport conditions are below the maximum usage temperatures (chapter 2).

The contents are limited in quantity (chapter 0A) in order to comply with regulatory criteria for activity release (chapter 3A).

The loading instructions (chapter 6A) specify a criterion for the overall leak rate to be complied with before transport (that used for the release calculations in chapter 3A).

– **Sub-criticality:**

The fuel data (chapter 0A) used in the safety-criticality studies (chapter 5A) gather together all of the information necessary for assessing the risk of criticality.

The programme of drops imposed on the mockup and the thermal calculations demonstrate that, apart from the guards and the [redacted] mm of the external layer of resin, the configuration of the package in accidental transport conditions is identical to the configuration of the package under normal transport conditions (chapter 1A).

– **Radiological protection:**

The radiological protection calculations are always carried out with the most penalising configuration in terms of geometry and positioning of content. This avoids any constraint on these two parameters in the description of the content (chapter 4A).

– **Thermal:**

The calculations take into account conditions of exposure to sunlight and a package geometry that is subject to regulatory conditions (chapter 2).

The programme of drops imposed on the mockup and the thermal calculations demonstrate that, apart from the guards and the [redacted] mm of resin withdrawn for accidental conditions, the configuration of the package in accidental transport conditions is identical to the configuration of the package under normal transport conditions (chapter 1A).

– **Other risks:**

The risk of accumulation of flammable gas is studied in chapter 3A and its appendices.

– **Quality assurance:**

The principles for quality assurance applied in all activities concerned by transport with the TN 106 package (design, safety studies, manufacture, transport…) are described in chapter 8A.

4. APPLICABLE CODES AND REGULATIONS

The packaging is designed and used in accordance with:

- The recommendations of the International Atomic Energy Agency and the National regulations, agreements and codes that refer to it,

- The safety regulations and the regulations applicable to loading and unloading operations, and in particular the regulations concerning appliances subject to internal pressure and those concerning lifting appliances in the country where the packages are manufactured,

The following is the list of regulations:

- International Atomic Energy Agency (IAEA) regulations for the safe transport of radioactive material, IAEA Safety Standards series, No. TS-R-1 2009 edition;

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- European agreement concerning the International Carriage of Dangerous Goods by Road (ADR);

- Regulations concerning the International Carriage of Dangerous Goods by Rail (RID);

- administrative order dated 29 May 2009 relative to the transport of dangerous materials by land (known as the "TDM order");

- European agreement relative to the international transport of dangerous materials by internal waterways (ADN) ;

- International Maritime Dangerous Goods Code (IMDG Code published by IMO)

- Order of 23 November 1987 (amended) concerning the Safety of Shipping, division 411 of the attached regulations (RSN Order);

The correspondence between the articles of the AIEA and the paragraphs in the safety file is given in appendix 00-2.

LIST OF FIGURES

FIGURE 00.1

DIAGRAM OF THE TN 106 PACKAGE

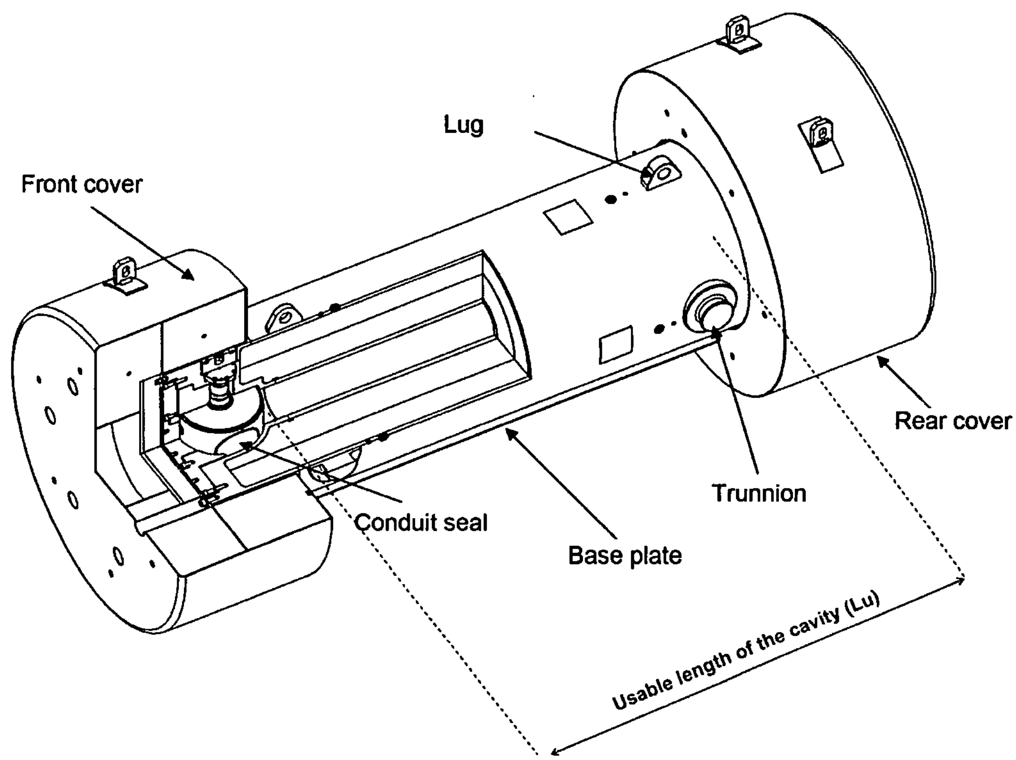
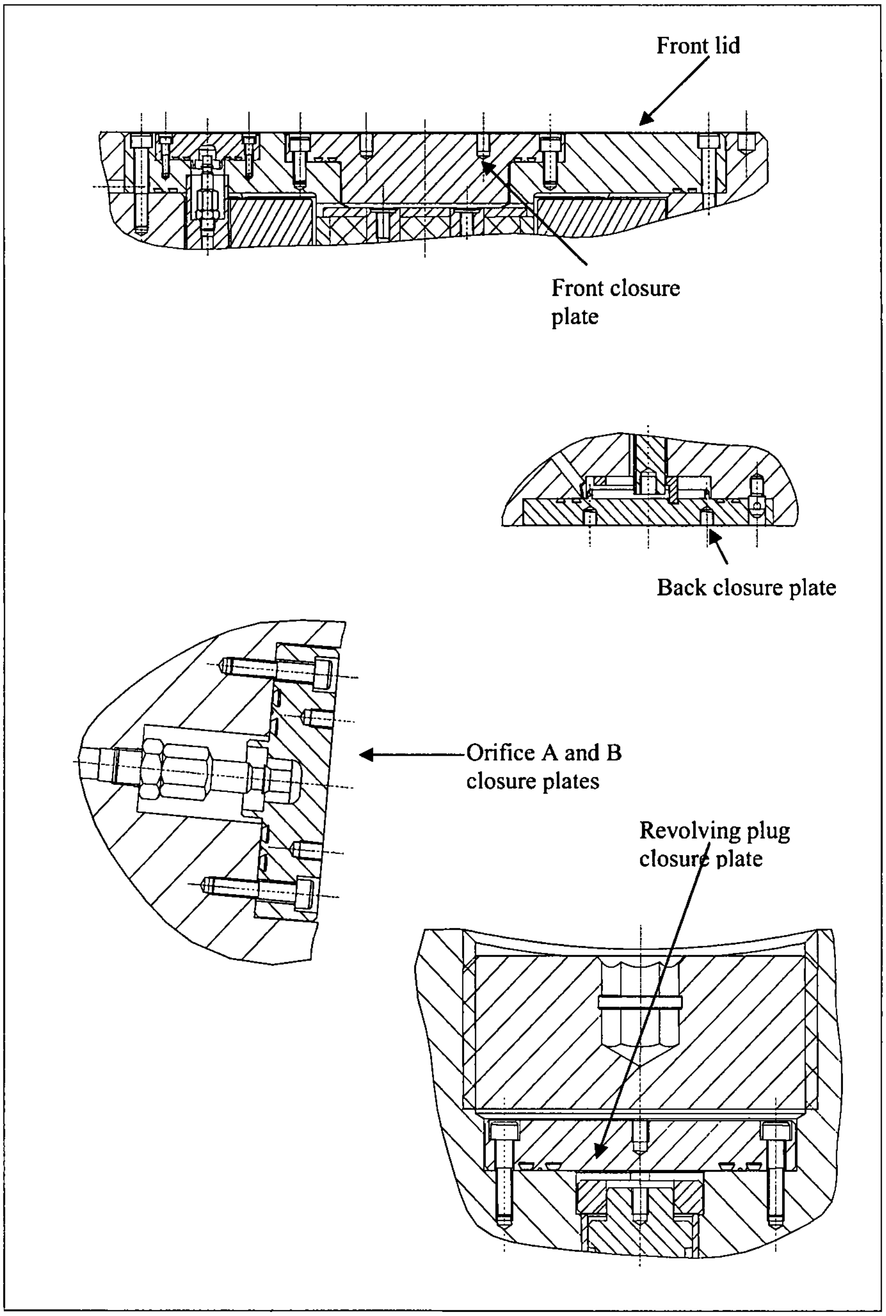


FIGURE 00.2

DIAGRAM OF THE ORIFICES IN THE PACKAGE



SUMMARY OF SAFETY ANALYSIS REPORT

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REVISION STATUS

Ref. : 5573-Z-00-1E			
0	01/01	Document first drawn up	L. MARIETTE / L. HANSEL
1	04/01	Incorporation of the modifications of Chapters 0A, 3A, 4A, 4A-1, 5A, 5A-1 and 6A Addition of the summary Chapter 5A-4.	L. MARIETTE / C. VALLENTIN
2	11/01	Incorporation of the modifications of Chapters 0A, 4A, 4A-1, 5A, 5A-1, 5A-2, 5A-3 and 5A-4	L. MARIETTE / A. SALAÜN
Ref. : DOS-08-00126114-011			
00	09/08	New document reference New formalism Incorporation of the modifications of Chapters 0, 0A, 1-3, 1-5, 1-10, 1A, 2, 2-1, 2-2, 2A, 3A, 4A, 4A-1, 5A,5A-1, 5A-3, 5A-4, 6A, 7A, 7A-1 Addition chapters 0A-1, 0A-2, 1-12, 2-3, 3A-1, 3A-2, 3A-3, 3A-4, 3A-5, 5A-5, 5A-8 and 5A-9	S. CHEVET / F. LANOY
1	06/11	Translation of the document DOS-06-00032898-002 rev 7 Incorporation of the modifications of Chapters 0A, 0A-1, 1A, 2, 2A 3A, 3A-4, 4A, 4A-1 5A, 6A. Incorporation of the new appendix 5A-10 Incorporation of the new appendix 3A 7 Incorporation of the new appendix 5A-11	B. GSIB/ C.GRANDHOMME
2	02/13	Translation of the document DOS-06-00032898-002 Rev. 9 Incorporation of the modifications of Chapters 0A, 0A-3, 0, 1, 1-1, 1-2, 1-3, 1-10, 1-11, 1-11, 1A, 2, 2-1, 2-2, 2A, 3A, 3A-2, 3A-4, 3A-6, 3A-9, 4A, 4A-1, 5A and 6A. Addition of chapter 1-13 and appendices 1.2 and 3 of chapter 1-12	R. BAHOU / D. HONDAGNEU

1. INTRODUCTION

This note assembles the summaries for each chapter in the safety analysis report. These summaries contain all the information necessary to the safety demonstrations and for justifying the compliance of the TN 106 package model with the regulatory requirements:

- objectives,

  It is intended to explain what we are seeking to demonstrate and to which paragraphs of the regulations we wish to respond.

- the essential parameters and their origins,

  An "essential parameter" is an important value, criterion, characteristic or dimension that characterises the package model covered by the safety analysis report and which determines the safety justification. In certain cases, it may concern encompassing values that do not necessarily correspond to the real data on the contents.

- assumptions and methods adopted,

  Only for the demonstrative chapters 1, 1A, 2, 2A, 3A, 4A and 5A and associated appendices, if applicable.

- results and conclusions,

  These are qualitative and/or quantitative results to be compared with the criteria.

  Only for the demonstrative chapters 1, 1A, 2, 2A, 3A, 4A and 5A and associated appendices, if applicable.

- the subsequent use of the results obtained

  in the case of chapters 1, 1A, 2, 2A, and 5A and associated appendices, if applicable, or essential parameters in the case of descriptive chapter 0.

2. CONTENT OF SAFETY ANALYSIS REPORT

Chapter 0: Description of the TN 106 package model

Objectives:

This chapter presents all of the basic data concerning the TN 106 package necessary for use and for justifying safety, particularly:

- A description of the elements constituting the package (components, masses, materials, mechanical and thermal properties),
- A description of the confinement enclosure (orifices and blanking devices) and the associated means of ensuring leak tightness (seals, screws).

Essential parameters:

The package, of a cylindrical shape, has a usable cavity length Lu, which may vary from 2200 to 2400 mm. Its overall dimensions are as follows:

- Length: Lu+1424 mm, namely between 3624 and 3824 mm,
- diameter with guards: 1458 mm,
- total mass when loaded: 3400 x Lu + 4140 (with Lu expressed in metres), namely between 11,620 and 12,300 kg.

The package is formed from a body, a front part and a welded rear part, and 2 shock-absorbing guards.

The body delimits a cylindrical cavity of diameter 203 mm with a usable length that may vary between 2200 and 2400 millimetres. It is successively composed of:

- a stainless-steel shell [redacted] mm thick,
- a lead shell [redacted] mm thick,
- a shell made of neutron-absorbing resin [redacted] mm thick,
- a stainless-steel shell [redacted] mm thick,
- two pairs of trunnions, one at the front and one at the rear, which are used for handling and for tilting operations on the frame,
- two lugs on the upper generatrix of the body, used for handling the package horizontally (with or without its frame), and possibly during tilting operations on the frame,
- a base plate on which the package may rest when it is not fitted with its guards.

The front part is composed of a flange made of stainless steel welded to the shell that receives:

- a revolving plug made of lead, which serves as the system for opening the cavity,
- two clamps screwed using 2 x M 42 screws, which serve as a bearing for the revolving plug in place,
- a revolving plug control opening with a protective plate above it,
- a front lid for maintaining the revolving plug,
- a front closure plate for loading the content,

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– a vent orifice (orifice A).

The back part is composed of a stainless-steel flange welded to the shell, which receives:

– A pushing device made of stainless steel, fitted with a shield disk made of tungsten,
– A back closure plate for accessing the pushing device,
– An orifice for filling and draining (orifice B).

Two removable guards, composed of balsa and plywood, surrounded by an envelope in stainless steel, are screwed to the extremities so as to act as shock absorbers for the package in case it is dropped. The presence of these guards prevents access to the openings during transport.

The 6 openings (front lid, front closure plate, orifices A and B, revolving plug control, back closure plate) are made leaktight by systems of double O-ring seals made of EPDM fitted into grooves. These systems allow leak tightness to be checked between the seals.

The essential parameters are grouped in the tables shown at the end of this chapter.

The design plan for the package is presented in appendix 0-1.

Later use of these essential parameters:

(1) The analysis of the structural strength of the package (definition of the mockup, drop tests and interpretations) and its ancillary structures (guards, trunnions and handling lugs) is given in chapter 1 and its appendices, based on the geometry of the package, the mass and the mechanical properties of the components of the package grouped in tables 0.6 and 0.4.

(2) The thermal analysis of the TN 106 package model under normal and accidental transport conditions is given in chapter 2 and its appendices based on the geometry of the package and the thermal properties of the materials used in the package (table 0.5).

(3) The analysis of the containment for the TN 106 package is given in chapter 3A based on the description of the containment chamber and its openings, and the authorised content, described in chapter 0A.

(4) The analysis of the shielding for the TN 106 package is given in chapter 4A based on the geometry of the package and the chemical compositions of the materials used for the gamma and neutron protection (steel, lead and resin) in table 0.8.

(5) The analysis of the safety of the TN 106 package model is given in chapter 5A based on the geometry of the package and the chemical compositions of the materials given in table 0.8, as well as the authorised contents described in chapter 0A.

Chapter 0 - Appendix 1: Design plan for the TN 106 package

Chapter 0: Description of the internal constituents and the contents authorised in the TN 106 package model.

The purpose of this chapter is to present the fissile and non-fissile contents authorised to be transported in the TN 106 package.

– Fissile content authorised:

  - fuels, whether irradiated or not, based on uranium oxide (content n° 1),
  - fuels, whether irradiated or not, based on plutonium oxide or mixed oxide or carbide of plutonium and uranium (content n°2),
  - fuels, whether irradiated or not, based on plutonium and uranium such as Pu_{tot} / (U+Pu) ≤ 45% by mass, or experimental materials (content n°3),
  - uranium-bearing solids in various forms (content n°5),
  - fuels, whether irradiated or not, based on plutonium and uranium in metallic, nitride, carbide or oxide form, so that the masses are in accordance with: Pu_{tot}/(U+ Pu) ≤ 30%, possibly doped with actinides and irradiated in Fast Neutron Reactors (content n°8).
  - fuel, whether irradiated or not, based on uranium, with the possible presence of thorium and graphite (content n°9)
  - fuel, whether irradiated or not, based on uranium oxide or plutonium oxide or mixed oxide of uranium and plutonium (mixture of contents 1, 2) (content n°11)
  - fuel, whether irradiated or not, based on uranium and plutonium (mixture of contents 1, 2, 3 and 5) (content n°12)
  - fuels, whether irradiated or not, composed of uranium oxide UO_2 with the presence of polymer resin and the possible presence of thoria (content n°22)
  - fuels, whether irradiated or not, composed of uranium, plutonium, americium or neptunium in metallic or nitride form, and/or metallic technetium (content n°26)

– Non-fissile contents authorised: (contents n°4, n°6 and n°10) :

  - content n°4 : radioactive materials in solid form (contaminated and/or activated parts, sources whether sealed or not,...),
  - content n°6 : fuels composed of pellets based on americium oxide,
  - content n°10 : fuels, whether irradiated or not, based on uranium oxide or mixed oxide of plutonium and thorium, or mixed oxide of plutonium and uranium

- content n°23 : fuels, whether irradiated or not, based on americium oxide and uranium oxide,

- content n°24 : fuels, whether irradiated or not, based on mixed oxide of plutonium and americium and uranium oxide,

- content n°25 type 1 and/or type 2: fuels, whether irradiated or not, based on uranium oxide and/or mixed oxide of uranium and plutonium with or without the presence of depleted uranium oxide

Chapter 0 – Appendix 1: Basic plan of sheaths provided for criticality purposes

Chapter 0 – Appendix 2: Deleted

Chapter 0 – Appendix 3: Description of content n°22 – uranium oxide UO_2 with the presence of polymer resin and possibly the presence of thoria

Chapter 1: Structural strength of the package

Objectives:

The aim of this chapter is to analyse the mechanical strength of the TN 106 package model and to show that it meets the regulatory requirements concerning packages of type B loaded with fissile materials.

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials are taken from chapter 0.

The temperatures of the various elements are taken from chapter 2.

Results and Conclusions:

This chapter demonstrates that the TN 106 package is compliant with the instructions in the AIEA regulations applicable to packages of type B and to packages for fissile materials, particularly with regard to protection against radiation, containment and nuclear safety.

Subsequent use of the results obtained:

This chapter defines a damaged package used in chapter 3A for analysing containment, chapter 4A for protection against radiation, and in chapter 5 for analysing the nuclear safety of the package.

Chapter 1 - Appendix 1: Resistance of the TN 106 package to pressures defined in the regulations

This appendix presents the verification of the resistance of the TN 106 package to pressure. In particular, this analysis defines the maximum acceptable internal pressure and the resistance to exterior test pressures.

Objectives:

- To determine the maximum acceptable internal pressure,
- To determine the resistance to external test pressures,
- To fix the test pressure for the package.

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials used in the components for the package are taken from chapter 0.

The temperatures of the various elements are taken from chapter 2.

Hypotheses and methods used:

The requirements concerning the chamber pressure are:

1. Calculation of the maximum acceptable internal pressure according to the regulations of CODAP95.

2. Immersion in water test: resistance to an exterior gauge pressure of at least 150 kPa = 1.5 bar.

3. Immersion in water test for packages containing irradiated nuclear fuels: resistance to an exterior gauge pressure of at least 2 MPa = 20 bars.

The check on point 3, the immersion in water test for packages containing irradiated nuclear fuels, is performed by analytical calculations. This check covers point 2.

Results and Conclusions:

1. This calculation shows that the acceptable internal pressure is 24 bars in a normal service situation and 43 bars in exceptional service situations.
2. The exterior pressure of 20 bars is acceptable.

Subsequent use of the results obtained:

The test pressure is fixed at 11 bars, which is compatible with the results of the calculation for the maximum acceptable internal pressure, and with the different pressures to which the package is subject during its operation.

Chapter 1 - Appendix 2: Mechanical strength of ancillary structures

This appendix justifies the dimensioning, under normal conditions of handling and transport, of structures ancillary to the package as described in chapter 0 and in the plans in appendix 1 of chapter 0.

Objectives:

For the TN 106 package, these structures are limited to the shock-absorbing cover, the handling points and the base plate. Therefore, the check covers:

- The resistance to overpressure in the shock-absorbing cover, due to a hypothetical release of gas from the wood under normal conditions of transport. This pressure is taken as being equal to 0.1 bars,

- The resistance of the cover to impact under normal conditions of transport. We perform the check for accelerations of 2g,

- The strength of the handling points on the lid, the revolving plug and the covers for acceleration of 2g, to take into account sudden and jerky lifting,
- The strength of the base plate when the package is demounted. We perform the check for accelerations of 2g,

- The determination of the maximum pressure on the floor when the package without its covers is resting on its base plate in the horizontal position or on the rear flange in the vertical position when it is filled with water.

Essential parameters and their origins:

The dimensions, masses and characteristics of materials are taken from chapter 0.

The temperatures of the various elements are taken from chapter 2.

Hypotheses and methods used:

The stresses are calculated for a differential pressure P = 0.1 bars = 0.01 MPa (internal overpressure) taking into account the low level of a hypothetical release of gas from the wood under normal conditions of transport.

The calculation is performed only for the cover's external metal envelope. The calculation is not performed for the stiffeners because they are not subject to differential pressures.

The check is made by analytical calculations.

Results and Conclusions:

The maximum stress in the package's ancillary structures under normal conditions of handling and transport is [redacted] MPa. It occurs on the cover's upper sheet metal (513) when subject to a differential pressure of 0.1 bars. This stress is below the limit of [redacted] MPa for steel of type A.

The maximum pressure on the floor is [redacted] t/m^2 for the package in the horizontal position and [redacted] t/m^2 for the package in the vertical position filled with water.

Later use of these essential parameters:

Given the results under normal transport configurations, the cover is therefore compliant with the assumptions used for the analysis of accidental conditions.

In the horizontal position, the package may not be placed on the floor on the base plate other than on a structure that accepts a load on the floor of at least 11 t/m^2.

In the vertical position, the package may not be placed on the floor other than on a structure that accepts a load of at least 21 t/m^2.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

Chapter 1 - Appendix 3: Mechanical strength of securing and handling devices

Objectives:

The purpose of this appendix is to check the correct mechanical strength of the devices for securing and handling the package. The devices for handling are composed of two trunnions and two lugs, welded to the shell. The securing devices are composed of 4 trunnions, the base plate and the external shell of the TN106 package.

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials are taken from chapter 0.

The temperatures of the various elements are taken from chapter 2.

Hypotheses and methods used:

For the trunnions, the static calculation is done with the I-DEAS software and with a model representing a section of the package and the trunnion. The criterion is not to exceed the elastic limit.

For the lugs, the base plate and the external shell, the static check is done using analytical calculation.

The analysis of fatigue in the trunnions, the external shell, the base plate and the handling lugs is performed according to the following method:

- The intensity of the stress is calculated by combining the results of the numeric calculations with a spectrum of accelerations for transport and handling.
- From resistance-to-fatigue curves taken from ASME <1> and calculated stresses, it is then possible to determine the damage suffered by each element for all of these stresses.

Lastly, the number of cycles acceptable is determined from damage calculated according to the Palmgren-Miner cumulative damage rule.

Results and Conclusions:

The number of cycles acceptable is limited by the strength of the handling lugs and is 84,745 cycles (543 years). Also, we consider that the trunnions, the handling lugs, the external shell and the base plate are dimensioned for the total estimated lifespan of the package (40 years).

Subsequent use of the results obtained:

Given the results of the fatigue analysis, the components for securing and handling (trunnions, lugs, external shell and base plate) are dimensioned for the total estimated lifespan of the package.

Chapter 1 - Appendix 4: Determination of the length of the mockup and drop configurations

Objectives:

This document determines the length of the mockup which is intended to undergo the tests representative of normal and accidental transport conditions, as well as the ballast used. It also defines all of the drops that ensure that the package suffers the maximum damage on the safety components to be proved.

Basic data for the chapter:

- The dimensions and masses of the constituents of the package are taken from chapter 0 and appendix 0-1, and the masses of the empty package (Me) and the full package (Mt) may be expressed, according to the usable length of the cavity (Lu), approximately as follows:

  $Me \approx 3.0 \times Lu + 3910$
  $Mt \approx 3.26 \times Lu + 3910$

  with M in kg and Lu in mm,

- The accelerations and residual distortions obtained in the case of a lateral drop, according to the length of the package and the drop angle, are calculated by finite elements in appendices 1-5 and 1-6.

Hypotheses and methods used:

- In the case of an axial drop, we study each element stressed, namely:

  - the cover (crushing),
  - revolving plug axis,
  - the revolving plug fixing clamps,
  - the revolving plug (distortion),
  - the front lid and its closure plate,
  - the back closure plate,
  - the internal shell (buckling and compression due to the lead creeping),
  - the lead (settling),

  By seeking, through analytical calculation, the optimum configuration of the package, namely, the mass of the package (the usable length), the mass of the content and the direction of drop (on the head or on the base), which, in each case, leads to maximum damage.

- In the case of a drop on a corner, only the following elements are studied, also by analytical calculation, the others being more stressed in the other drop cases:

  - the cover (crushing),
  - The screws fixing the lid and the closure plate located on the side of the impact,
  - The screws fixing the cover on the side of the impact,

  - The revolving plug (opening).

- In the case of the lateral drop, the stressed components studied are the following:

  - The covers (crushing),
  - The screws on the covers,
  - The confinement chamber (distortion),
  - The closure plate for the revolving plug.

  The case of a drop leading to maximum damage is estimated by calculations using the finite element method: A first study (appendix 1-5) calculates acceleration levels according to the length of the package and the angle of drop. A second study (appendix 1-6) calculates the stresses and residual distortions after drops for the most penalising cases defined from acceleration calculations.

In case of drops onto a punch, only the sensitive zones are studied, namely the external shell and the closure plate.

From these results, the characteristics of the drop mockup are fixed, which cover the greatest number of cases causing the most damage, the others being checked by calculation.

Results and Conclusion:

The length that is most penalising for:

- Determining the maximum distortions of the confinement chamber and the package,
- Validating the cover dimensioning,
- Validating the strength of the axes of the revolving plug and the holding clamps,

is the maximum length.

We therefore choose to perform the drops with a mockup having the maximum usable length and the maximum content mass.

Additional calculations are nevertheless necessary to check the pre-tightening force in the screws for fixing the plugs.

Chapter 1 – Appendix 5: Determining the drop angle that is most penalising for a TN 106 package during a lateral drop of 9 metres

Objectives:

In the case of a lateral drop of 9 m, this appendix can determine the configuration (length of the cavity/angle of drop) that is most penalising from the point of view of acceleration for the package. This appendix also studies the influence of the Young's modulus of lead on the accelerations undergone by the TN 106 package of length 3200 mm during a lateral drop of 9 m.

Basic data for the chapter:

the dimensions and masses of constituents of the package are taken from chapter 0 and the appendix 0-1.

Hypotheses and methods used:

We consider that the body of the package can be distorted.

The structure is studied, as a flexible body, for impact angles going from -20° to +20°.

Because of the structural symmetry, only a half-model is produced.

The package drops on the side that has the handling lugs. These are modelled in the 3200 mm version (maximum mass) in order to check that these do not impact.

The sheet metal for the cover in the symmetrical plane is modelled and is considered, from the dimensioning point of view, as not being able to buckle.

The screw connections between the covers and the package, as well as the various contacts and clearances (excluding that between the shell and the intermediate cover and that between the internal shell and the mass of the content) are not represented. Connections are considered to be total.

The revolving plug and all of the zones located at the head and base of the package are modelled by their mass.

The content is modelled by a steel bar.

From these assumptions, the levels of acceleration are recorded at 3 points on the structure (at the head, at the centre and at the base of the package) and this is done for 3 lengths of cavity (3200 mm, 2200 mm and 1000 mm).

The various acceleration curves thus obtained are filtered at 1000 Hz. Appendix 1-7 justifies this value.

Results and Conclusions:

- The maximum accelerations at the head of the package are obtained by the following configurations:
  - length of 1000 mm and the case of a horizontal drop.
  - length of 2200 mm and the case of a horizontal drop.
  - length of 3200 mm and the case of a drop at an angle of 10° (1st impact on the base).

- The maximum accelerations at the centre of the package's shell are obtained for the following configurations:
  - length of 1000 mm and the case of a drop at an angle of 10° (1st impact on the head).
  - length of 2200 mm and the case of a drop at an angle of 10° (1st impact on the head).
  - length of 3200 mm and the case of a horizontal drop.

The handling lugs do not impact because the thicknesses of wood crushed are below the guard at the base of these lugs.

Subsequent use of the results obtained:

These results can determine, for each cavity length, the drop angle that maximises the accelerations.

The penalising configurations are used in appendix 1-6 in order to determine the stresses and distortions to the package.

Furthermore, the influence of the Young's modulus of lead is negligible concerning the distortion energies and the acceleration undergone by the shell (<5%). Neither does the Young's modulus of lead influence the most penalising drop angle.

Chapter 1 – Appendix 6: Additional study on the behaviour of the TN 106 package during a lateral drop of 9 metres

Objectives:

This appendix that supplements appendix 1-5 is intended to assess the stresses and distortions in the case of a drop considered the most penalising for the structure for the various lengths of packages studied.

Basic data for the chapter:

the dimensions and masses of constituents of the package are taken from chapter 0 and the appendix 0-1.

The cases used for this analysis are taken from appendix 1-5.

Hypotheses and methods used:

The hypotheses for these calculations are the same as those in appendix 1-5.

From each of the penalising cases chosen from appendix 1-5, the level of stresses and residual distortions to the steel shell are determined.

Results and Conclusions:

The maximum stresses in the package, whatever the usable cavity length, for lateral drops of 9 metres and whatever the drop angle, are 150 MPa. The maximum residual plastic distortions are 3.6%.

Subsequent use of the results obtained:

The results are used in chapter 1 in order to determine the configuration of the damaged package.

Chapter 1 – Appendix 7: Modal analysis of TN 106 package

Objectives:

This study is intended to assess the specific modes and frequencies associated with the TN 106 package in the configuration without supports (free/free) and the following versions of the package:

package version 3200 mm without source,
package version 3200 mm with source,
package version 2200 mm with source,
package version 1000 mm without source,
package version 1000 mm with source,
mockup of TN106 package version 3200 mm (½ scale) without source,
mockup of TN106 package version 3200 mm (½ scale) with source.

A package with source is a loaded package.

Basic data for the chapter:

The dimensions and masses of constituents of the package are taken from chapter 0 and the appendix 0-1.

Hypotheses and methods used:

The scope of this study is limited to elastic phenomena and small movements.

We are interested only in phenomena related to the flexion of the package according to a drop axis for the package.

Only a ½ structure following the axis of the package is modelled.

The covers are considered as participating mass.

Results and Conclusions:

Whatever the usable length of the package's cavity, whether it is loaded or not, the first frequencies specific to vertical flexion are less than 400 Hz.

Subsequent use of the results obtained:

The results are used in appendices 1-5, 1-6 and 1-10 in order to justify the filtering frequency.

Chapter 1 - Appendix 9: Plans for the 1/2 scale mockup

Chapter 1 - Appendix 10: Similarities between the package and the 1/2 scale mockup

Objective:

The objective of this appendix is to present the mockup for the TN 106 package intended to undergo the drop tests and to justify its representative character.

Essential parameters and their origins:

The mockup is at ½ scale and represents a TN 106 package of a usable length of 3200 mm at scale 1. This length corresponded to the initial maximum usable length of the TN 106 package model. The current maximum length of the TN 106 package model was reduced and is now 2400 mm (see chapter 0). The mockup and its ballasts are described on the plans presented in appendix 9 of chapter 1.

Results and Conclusions:

The mockup fitted with its ballasts is representative of the TN 106 package of a usable length equal to 3200 mm and loaded with the maximum acceptable content.

Chapter 1 - Appendix 11: Report and analyses of regulatory drop tests

Purpose:

This appendix is intended to present the results of the regulatory drop tests.

A campaign of tests was carried out on a mockup of the TN 106 package. The representative character of the mockup compared to the TN 106 package is described in appendix 1-10.

After describing the mockup, the main results of the drops are presented.

Results:

During the regulatory sequences of drops, the leak tightness criterion of $6.65,10^{-5}$ $Pa.m^3.s^{-1}$ (SRL) checked before the drop tests is also complied with after the drop tests.

This series of drop tests does not deteriorate the package's radiological protection.

The maximum axial acceleration obtained on the package is 160 g.

The maximum accelerations obtained on the package are:

- [redacted] g on the rear flange,
- [redacted] g on the front flange,
- [redacted] g on the shell.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

Chapter 1 - Appendix 12: Analysis of the behaviour of the shock-absorbing covers and the strength of the TN 106 package according to the temperature

Objectives

The objective of this appendix is to check the mechanical strength of the TN 106 package model under accidental transport conditions (combined with normal transport conditions) with the package considered between -40°C and the maximum temperatures for normal transport conditions (Tmax NCT).

The study is broken down into two stages:

- the first stage consists of recalibrating the drop tests on the ½ scale mockup in order to obtain a ½ scale digital model that is representative in terms of crushing and acceleration.
- the second stage consists of simulating drops representative of accidental transport conditions (combined with normal transport conditions) for the scale 1 package at -40°C and at Tmax NCT extrapolated from the ½ scale digital mockup obtained in stage 1.

Essential parameters and their origins

The input data is as follows:

- for the recalibration stage
  - geometric model of the ½ scale mockup,
  - materials: mechanical characteristics of the ½ scale mockup,
  - report of regulatory drop tests (see chapter 1-11).
- for the extrapolation stage:
  - geometric model described on the TN 106 design plan (see chapter 0 and appendices),
  - materials: mechanical characteristics taken from chapter 0.

Hypotheses and methods used

The ½ scale digital model is recalibrated in crushing and in acceleration for the lateral drop.

In order to validate the digital model for the three drop cases, comparisons in acceleration for the axial drop and in crushing for the oblique drop are also carried out.

Concerning the extrapolation stage, four calculation cases were chosen to cover all drop configurations representative of accidental transport conditions (combined with normal transport conditions) at -40°C and at Tmax NCT for the TN 106 package model:

- oblique drop on a corner at 9.6 m for the TN 106 package with a usable cavity length of 2400 mm at Tmax NCT. The case of maximum and minimum pre-load on screws is studied.

- lateral drop of 9.6 m for the TN 106 package of usable cavity length of 2,400 mm at Tmax NCT. A study on the influence of the drop angle is carried out.

- axial drop of 9.6 m for the TN 106 package of usable cavity length of 2,200 mm at -40°C. The cases of minimum and maximum pre-load on the screws are studied.

- lateral drop of 9.6 m for the TN 106 package of usable cavity length of 2,400 mm at -40°C. A study on the influence of the drop angle is carried out with maximum pre-loading of the screws. The case presenting the highest acceleration at the front flange has been chosen and is studied considering a minimum pre-load on the screws.

The coefficient for hardening balsa during transition from a temperature of 20°C to -40°C does not exceed 1.4 <1>.

A reduction in the balsa stress by 40% is considered for the case of extrapolation to Tmax NCT <1>.

The strength of the closure systems is studied.

Results

The most penalising drop configurations lead to:

- a maximum acceleration in the package's axis of [redacted] g.

- a maximum acceleration in the axis perpendicular to the axis of the package of [385] g (including an acceleration peak of [redacted] g due to the impact on the trunnion).

- residual maximum separation of the upper lid of [redacted] mm. This separation does not compromise the leaktightness of the upper lid.

Conclusions

The mechanical strength and leaktightness of the TN106 model is checked for temperatures going from -40°C to Tmax NCT.

Chapter 1 - Appendix 13: Justification of the mechanical strength of the screws used in the TN106 package under routine transport conditions

Objectives:

The objective of this appendix is to check the non-separation of the systems for closing the containment chamber and the correct mechanical strength of the screws for the TN106 package under routine transport conditions.

The screws concerned are as follows:

- screw on the revolving plug (item 205),
- screw on the front lid (item 207),
- screw on the closure plate (item 210),
- screw on the plug for orifice A (item 212),
- screw on the clamp (item 217),
- screw on the lower lid (item 308),
- screw on the plug for orifice B (item 310),
- screws and washers for the cover (item 519/520).

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials are taken from chapter 0.

The temperatures of the various components following normal conditions of transport are encompassed by the temperatures specified in chapter 2.

Hypotheses and methods used:

The calculations for the tightening torque, the stresses in the screws and pressures on the screw heads are performed using the standard <1>.

The screws are not greased and are zinc bichromate plated (or equivalent) (see chapter 0).

The coefficient of friction used is 0.15 with uncertainty of ± 20% <4>.

The stresses considered in this analysis of the screwed assemblies are of two origins:

- the pressure conditions, namely an internal pressure considered in a penalising manner at 11 bars, corresponding to the design internal pressure (see chapter 1-1),
- the accelerations related to routine transport conditions, representing a longitudinal or transversal acceleration of 2 g.

The check on the strength of screws is performed according to the methods of the standard <1> which consists of checking the non-separation of the assembled elements, while ensuring that the stresses in the screws and the pressures under the heads are acceptable for the materials in question (see chapter 0).

The check on thread shearing is carried out according to <3>.

Results

The non-separation of the head lid, the closure plate, the base lid, the plug for the revolving plugand the plugs for orifices A and B are checked, taking into account accelerations representative of routine transport conditions.

The maximum equivalent stresses undergone by the screws are below the criteria.

There is no risk of shearing the screw threads and the threaded holes.

The stresses due to pressure under their heads for a tightening torque $F_{st\ max}$ are below the criteria.

Conclusion

Given the stresses considered for the calculations on the assembly screws, these are dimensioned to ensure containment and to ensure the mechanical strength of the package under routine transport conditions.

Note TRANSNUCLEAIRE 5573-C19: Report on drop tests on the ½ scale mockup of the TN 106 package

The purpose of this report is to present the results of the regulatory drop test over 1 m onto a punch and over 9 m, performed on a ½ scale mockup of the TN 106 package.

These tests took place from 4 to 10 November 1999 on the test site at LAUDUN.

Chapter 1: Structural strength of the internal fittings

Objectives:

This analysis is intended to define the minimum thicknesses of the internal fittings for ensuring that their geometry is retained under normal and accidental transport conditions.

Essential parameters and their origin,

The internal fittings in question are steel sheaths and may have the diameters given in chapter 0A, namely 120 mm, 110 mm and 60 mm. The mechanical characteristics of the steel composing the fittings is considered at temperatures determined from the maximum linear thermal power (300W/m, chapter 0A).

Hypotheses and methods used:

The justification of the mechanical strength of the internal fittings is based on analytical calculations. These fittings are centred in the cavity using the centring collar and the dimensioning is based on the analysis of the resistance to flexion of the fitting between the collars.

The accelerations in question are taken from the analysis of the drop conditions for the package presented in appendix 12 of chapter 1.

This chapter begins with a reminder of the accelerations undergone by the package under accidental transport conditions, as well as through a calculation of the maximum acceptable masses in the various internal fittings and the calculation of the maximum dynamic coefficient.

The method of dimensioning internal fittings is as follows:

1) Dimensioning the internal fitting according to the maximum mass of the content supported in a lateral drop.
2) Determination of the frequency specific to the fitting dimensioned in this way.
3) Calculation of the excitation frequency of the drop, using the impact time recorded during drop simulations.
4) Determination of the maximum dynamic coefficient associated with these frequencies
5) Verification that the static stress increased by the dynamic coefficient is below the elastic limit of the steel at its functioning temperature

Beforehand, we will check the strength of the internal fitting under an axial drop (compression and buckling).

The method of dimensioning the centring collars (spacers) is the following:

1) Dimensioning the spacer according to the acceleration undergone under a lateral drop (Appendix 1A.3)
2) Calculation of the critical buckling stress for the spacers under a lateral drop and checking that this is greater than the elastic limit of the spacer.
3) Calculation of the stress internal to the welds and checking that this is below the elastic limit of the spacer.

Finally, we check that the pads have no influence on the behaviour of the internal fittings.

Results and Conclusions:

The mechanical calculations on the strength of the internal fittings (sheaths) can ensure that the maximum stresses are below the elastic limit of the steel in question. The maximum masses acceptable according to the thicknesses of the sheaths are presented in table 1A.1. Under these conditions, the diameters of sheaths described in chapter 0A are retained and may be used for the safety-criticality analysis.

The distance separating two spacers must be a maximum of 300 mm. These spacers must be made of steel of a minimum length of 21 mm.

Chapter 2: Thermal analysis of the package

Objectives:

The TN 106 package is designed to dissipate the residual thermal power of radioactive content under normal and accidental transport conditions, while maintaining acceptable temperatures in the package.

The thermal analysis of the TN 106 is presented in this chapter according to the regulatory requirements. It consists of:

- determining the maximum temperatures reached by the various components of the package under normal and accidental transport conditions.
- checking that, for the maximum acceptable power, the temperature on the surface of the package does not exceed 85°C (excluding exposure to sunlight).

Essential parameters:

Several cases of thermal loading are considered:

- loading with linear power of 300 W/m (maximum power),
- localised loading of 100 W (any position).

For a load of a linear power of 70 W/m in the cavity (reduced power), we determine the temperature of the internal shell and the seals from the temperatures obtained for the case of a load with maximum linear power of 300 W/m.

The geometry of the package used for the modelling is that of the design plan in appendix 0-1.

The thermal properties of the materials are given in table 0.5 in chapter 0.

The limit conditions are those imposed by the regulations.

Hypotheses and methods used:

The package is in a horizontal position for all the calculations. This position corresponds to the transport position for normal transport conditions. The justification of the penalising character of this position under accidental transport conditions is given in appendix 2-2.

Under normal and accidental transport conditions, the package is placed in free air.

Under accidental conditions, the influence, at the temperatures of the components, of puncturing a cover close to the plug for the revolving plugor orifice B is analysed.

The thermal calculations were carried out using a 3-D calculation model according to a half-structure of the package. The revolving plugis modelled by a cylinder with an equivalent volume of air.

The extremities of the package are considered as adiabatic due to the presence of covers.

The calculations for the package were performed using the I-DEAS software.

The thermal evaluations under normal transport conditions are presented in appendix 2-1 and in the same chapter for the reduced linear power of 70 W/m.

The thermal evaluation under accidental transport conditions is presented in appendix 2-2.

Results and Conclusions:

The thermal behaviour of the TN 106 package transporting:

- a load with a linear power of 300 W/m (maximum power) divided over the entire cavity,
- localised loading of 100 W (any position),
- a load of linear power of 70 W/m in the cavity (reduced power),

is acceptable under normal and accidental transport conditions.

In particular, it has been demonstrated that:

- the temperature reached by the seals is acceptable and the confinement of the radioactive material is retained after a fire test,
- the temperature of the lead is below its melt temperature, therefore protection against radiation is retained,
- the temperature on the surface of the package, excluding exposure to sunlight, is always below 85 °C.

It is also demonstrated that the rate of filling the grooves for the seals in the containment chamber remains limited under normal and accidental transport conditions (less than 108%).

Subsequent use of the results obtained:

The calculated temperatures determine the mechanical characteristics of the different components given in chapter 1.

They ensure the presence of the shielding material shown in chapter 4A.

Chapter 2 - Appendix 1: Thermal analysis of package under normal transport conditions

Objectives:

The thermal analysis of the TN 106 under normal transport conditions is presented in this chapter.

It is intended to:

- determine the maximum temperatures reached by the various components of the package under normal transport conditions.
- checking that, for the maximum acceptable power, the temperature on the surface of the package does not exceed 85°C (excluding exposure to sunlight).

Essential parameters:

Several cases of thermal loading are considered:

- loading with linear power of 300 W/m (maximum power),
- localised loading of 100 W (any position).

The geometry of the package used for the modelling is that of the design plan in appendix 0-1. The length of the cavity considered for this study is 2400 mm.

The thermal properties of the materials are given in table 0.5 in chapter 0.

The limit conditions are those imposed by the regulations.

Hypotheses and methods used:

The package is placed in free air. The package transported horizontally is modelled by a tri-dimensional structure. The thermal exchanges thus reconstituted are of the convection, radiation and conduction types.

The walls in contact with the shock-absorbing covers are considered as adiabatic. There is nil clearance between the shells.

The calculations for the package were performed using the I-DEAS software.

Results and Conclusions:

The table below presents the maximum and average temperatures reached by the main components of the TN106 under NCT in the case of thermal loading of a power of 300 W/m.

300 W/m	T_{max} (°C)	$T_{avg\ max}$ (°C)
Packaging		
Lead	[redacted]	[redacted]
Resin	[redacted]	[redacted]
External surface of the package	79.7	75.8
Internal shell	91.9	90.2
At the trunnions	77.5	77.0
Seal		
Revolving plug	84.1	83.4
Head lid	83.7	83.6
Base lid	88.4	88.4
Orifice A	83.8	83.7
Orifice B	88.1	88.0
Closure plate	84.0	84.0

The table below presents the maximum and average temperatures reached by the main components of the TN106 under NCT in the case of thermal loading of a power of 100 W/m.

100 W	T_{max} (°C)	$T_{avg\ max}$ (°C)
Packaging		
Lead	[redacted]	[redacted]
Resin	[redacted]	[redacted]
External surface of the package	73.1	64.6
Internal shell	81.8	65.3
At the trunnions	69.8	69.0
Seal		
Revolving plug	76.6	76.2
Head lid	76.5	76.4
Base lid	80.9	80.9
Orifice A	76.6	76.5
Orifice B	80.1	79.9
Closure plate	76.8	76.8

Subsequent use of the results obtained:

The penalising distribution of temperatures in the package under normal transport conditions constitutes the initial state of the analysis of the package under fire conditions.

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Chapter 2 - Appendix 2: Thermal analysis of the package under accidental transport conditions

Objectives:

The objective of this chapter is to evaluate the thermal behaviour of the TN106 package of a length of between 2200 mm and 2400 mm under accidental transport conditions with the inclusion of a puncture in the plug for orifice B or in the plug for the revolving plug.

Essential parameters:

The drop tests have shown that the package would retain its geometry under Accidental Transport Conditions (ATC) and the package calculation model is identical to that in appendix 2-1 for all the calculations except the study on the influence of piercing on the plug for orifice B

The distribution of temperatures in the package under normal transport conditions constitutes the initial state of the analysis of the package under fire conditions.

The fire is modelled by an ambient temperature of 800°C for half an hour.

The piercing effect is created in the axis of the plug for orifice B by a punch of diameter 150 mm. We consider, conservatively, that it tears off wood to a width of 173 mm over the entire height of the cover as far as its internal surface, which we assume to be intact

Hypotheses and methods used:

The package is considered to be in the horizontal position during the fire test. It is modelled by a tri-dimensional structure. The thermal exchanges thus reconstituted are of the convection, radiation and conduction types.

A study on the influence of the position of the TN106 package, and on the loss of [redacted] mm of resin, is performed.

Likewise, the inclusion of piercing the package at the level of the plug for the revolving plugor orifice B is studied.

Results and Conclusions:

The table below presents the maximum and average temperatures reached by the main components of the TN106 under ATC in the case of thermal loading of a power of 300 W/m.

300 W/m	T_{max} (°C)	$T_{avg\ max}$ (°C)
Packaging		
Lead	[redacted]	[redacted]
Resin	[redacted]	[redacted]
External surface of the package	687.3	665.7
Internal shell	152.8	141.8
Seal		
Revolving plug	135.0	115.7
Head lid	115.9	115.8
Base lid	118.8	118.7
Orifice A	116.1	115.9
Orifice B	118.3	118.1
Closure plate	116.5	116.5

The table below presents the maximum and average temperatures reached by the main components of the TN106 under ATC in the case of thermal loading of a power of 100 W/m.

100 W	T_{max} (°C)	$T_{avg\ max}$ (°C)
Packaging		
Lead	[redacted]	[redacted]
Resin	[redacted]	[redacted]
External surface of the package	684.2	661.8
Internal shell	143.8	118.2
Seal		
Revolving plug	128.1	109.5
Head lid	109.7	109.6
Base lid	112.5	112.4
Orifice A	109.9	109.8
Orifice B	111.6	111.3
Closure plate	110.3	110.3

Considering the partial calcination of the resin over a thickness of [10 mm] does not influence the maximum temperature of the seals for the package model.

The vertical position of the package during and after the fire has no influence on the temperature of the package model.

Subsequent use of the results obtained:

The inclusion of piercing on the plug for orifice B or the revolving plugcauses a maximum temperature increase of 43°C on the seals.

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The maximum temperature of the seals for the TN106 package is therefore 179.0°C. It is therefore below the thermal criterion of 220°C and is therefore acceptable,

The maximum temperature of the lead is [redacted]°C. It is therefore below the thermal criterion of 327°C and is therefore acceptable,

The maximum temperature of the internal shell is [redacted]°C.

Chapter 2: Thermal analysis of content

This document presents the thermal analysis of the content of the TN106 package under normal and accidental transport conditions as defined by the regulatory requirements.

Objectives:

The objective is to determine the maximum temperature reached by the fuel elements and maximum average temperature reached by the gas for filling the cavity.

Essential parameters and their origin:

The study is carried out considering a load of a maximum power of 300 W/m as defined in chapter 0A. The case of a load with a reduced linear power of 70 W/m is the subject of a specific analysis in this chapter.

The geometries of the package cavity and the internal fitting used for the modelling are described in chapters 0 and 0A. The thermal properties of the materials are given in table 0.5 in chapter 0. The limit conditions used in this chapter are encompassed by the limit conditions taken from the study in chapter 2

Hypotheses and methods used:

The study is performed in two stages:

- For elements of the rod or needle type, seek the configuration that leads to the maximum cavity temperature (nature of filling gas, number of elements, array pitch, dimensions of the internal fitting and diameter of the elements) and determine the maximum temperature of the elements and the cavity gas under normal and accidental transport conditions. In the case where the temperature criteria are exceeded for a load of 300 W/m, the maximum acceptable thermal power is calculated.
- For plates of the MTR type, determine the maximum acceptable thermal power according to whether an internal fitting is present or not.

<u>Results and Conclusion:</u>

The principal results are:

– *For the transport of elements (of the rod or needle type)*

In the presence of elements of the rod or needle type of variable diameter, compliance with a cladding temperature of less than 500°C leads to the definition of a maximum acceptable thermal power for the content:

Diameter of the element	Linear power in the cavity (W/m)	Linear power per element (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

– *Fuel plates*

The thermal study for fuel elements of the MTR type has shown that the limitations on total linear thermal power and thermal power per element must be applied according to whether or not an internal fitting is present.

These limitations are presented in the table below:

		Dimensions of the internal fitting		
Maximum acceptable thermal power (W/m)	**No fitting, (for purposes of criticality, neither shovel or sleeve)**	**160 mm ≤ ϕ < 203 mm**	**120 mm ≤ ϕ < 160 mm**	**60 mm ≤ ϕ < 120 mm**
Linear power acceptable in the cavity in case of distributed thermal loading	$\min\begin{cases}\frac{2021{,}5\times p_e}{0{,}92+p_e}\\300\end{cases}$	$\min\begin{cases}\frac{495{,}3\times p_e}{0{,}23+p_e}\\300\end{cases}$	$\min\begin{cases}\frac{395{,}7\times p_e}{0{,}18\div p_e}\\300\end{cases}$	$\min\begin{cases}\frac{219{,}3\times p_e}{0{,}10+p_e}\\300\end{cases}$

When several fuel elements or fuel sets are present in the cavity, p_e is the perimeter (in metres) of the element (or the set of elements when they are connected to each other) having the smallest section.

– *Temperature of the cavity gas*

The average temperature of the cavity gas used in chapter 3A of the present file is that calculated for fuels of the rod or needle type. As the maximum temperature of the elements is much higher than the maximum temperature of elements of the plate type (for the same cavity temperature), we may consider that the average temperature of the gases for loading fuels of the rod or needle types is conservative. The temperatures used for the thermal loading at 300 W/m are as follows:

- 283°C under normal transport conditions,

- 309°C under accidental transport conditions.

For a maximum linear power equal to 70 W/m in the cavity, the temperatures used are:

- 102°C under normal transport conditions,

- 158°C under accidental transport conditions.

Subsequent use of the results obtained:

The maximum average temperature of the gas used for filling the cavity is used in chapter 3A.

Chapter 2 - Appendix 1: Deleted

Chapter 3: Activity release

Objectives:

The objective of this chapter and its appendices 3A-2, 3A-4, 3A-6 and 3A-9 is to justify compliance with the regulatory criteria for the release of activity under normal and accidental conditions of transport when the TN 106 package is loaded with various contents defined in chapter 0A.

This chapter describes the method used in the appendices 3A-2, 3A-4, 3A-6 and 3A-9 for the analysis of the release of activity for contents 1 to 6, 8 to 10 and 22 to 26. In this chapter, we also determine the maximum quantity of hydrogenated products (of the resin type) acceptable in the package's cavity for all of the contents (with the exception of contents 22 to 26) and the maximum acceptable number of non-intact rods (which may contain water) from the point of view of radiolysis and the definition of the measurements of hydrogen associated with these rods.

Essential parameters:

The masses of radioactive materials are taken from chapter 0A.

The temperatures of the gases and the seals for the contents 1 to 6, 8 to 10 and 22 to 26, are taken from chapter 2 and its appendices, and are specified in the appendices 3A-2, 3A-4, 3A-6 and 3A-9, according to the powers in question.

The sum of the rates of leaks from the seals checked before transporting the TN 106 package corresponds to a rate of $6.65{,}10^{-5}$ $Pa.m^3.s^{-1}$ SLR for all of the contents, except content n° 23, which must be less than $6.00{,}10^{-5}$ $Pa.m^3.s^{-1}$ SLR.

Hypotheses:

Releases of gaseous activity, aerosols and releases through permeation are taken into account.

Six cases may be considered for each content:

- either all the content is intact upon loading and no enclosure is pressurised,
- or all the content is intact upon loading and at least one enclosure is pressurised,
- or all the content is not intact on loading and no enclosure is pressurised, with the possible presence of water,
- or all the content is not intact on loading and no enclosures are pressurised, without water,
- or all the content is not intact upon loading and at least one enclosure is pressurised, with the possible presence of water,
- or all the content is not intact upon loading and at least one enclosure is pressurised, without water.

According to the content in question, one or more of these cases are studied.

Under normal transport conditions, the justification of the containment of the content of the package is based on the use of rates of leakage from the chamber measured before shipping ($6.65,10^{-5}$ $Pa.m^3.s^{-1}$ SLR for all content, except for content n° 23 which must be less than $6.00,10^{-5}$ $Pa.m^3.s^{-1}$ SLR) and severe rupture conditions, namely at least 5% of the enclosures ruptured (100% in the very penalising case of contents 22 to 25 and 20% for content n° 26 representing the rupture of an enclosure).

Under accidental transport conditions, we consider that 100% of the enclosures are ruptured.

Approach:

The release calculation is performed according to the following process:

1. reminder of free volumes of content,
2. calculation of pressure in the cavity under normal transport conditions and of the maximum normal usage pressure,
3. calculation of the pressure within the cavity under accident conditions of transport,
4. calculation of rates of leakage under normal and accidental transport conditions,
5. calculation of flows of activity from gases and aerosols by permeation.

The maximum quantity of hydrogenated products acceptable in the cavity for all content (except n° 22 to 26) is determined assuming that all hydrogen present is liberated in the form of H_2 and by checking that the percentage of hydrogen in the air remains below the flammability threshold. Also, a radiolysis study is performed in appendix 3A-6 for content 22.

Results and conclusion:

The digital applications are performed:

- in appendix 3A-2 for the following contents, for a maximum linear power of 300 W/m:
  - Content n°1 type 1, 2 and 4,
  - Content n°2 type 1, 2 and 4,
  - Content n°3 type 1, 2 and 4,
  - Content n°5 type 1 to 6,
  - Content n°6, type 1 and 2,
  - Content n°8 type 1,
  - Content n°10 type 2,

  - Content n°25,
  - Content n°26
- in the appendix 3A-4 for the following contents, for a maximum power of 100 W:
  - Content n°1 type 3,
  - Content n°2 type 3,
  - Content n°9, type 1 to 4,
  - Content n°10 type 1 and 3
  - Content n°23
  - Content n°24
- in the appendix 3A-6 for the case of content n° 22 considered at a linear power of 70 W/m,
- In appendix 3A-9 for the following contents, for a maximum linear power of 300 W/m:
  - Content n°1 type 5,
  - Content n°2 type 4,
  - Content n°3 type 4 and 5,
  - Content n°5 type 5 and 6.
- The following contents are covered by the release studies presented here:
  - Contents n°11 and 12: the mixtures of contents are covered by the restrictions imposed in chapter 0A,
  - Contents n°13 to 20: the contents that are non-fissile at small masses are covered by the release studies on the corresponding fissile contents (see chapter 0A).

The releases of activity are calculated for an exterior ambient pressure of 0.6 bars.

The results in these appendices verify that, for all of the contents defined in chapter 0A, the total release under normal and accidental transport conditions does comply with the following regulatory criteria <4>:

- $q_{tn} \leq 10^{-6}$ A_2/ hour under normal transport conditions,
- $q_{ta} \leq 1$ A_2 in one week under accidental transport conditions.

The regulatory criteria for the release of activity under normal and accidental transport conditions are checked when the TN 106 package is loaded with the contents defined in chapter 0A.

Also, the total mass of hydrogenated products acceptable in the cavity (except for contents 22 to 26) according to the mass percentage of hydrogen present in the compound must comply with the following values (Lu is the usable length of the package's cavity in metres):

Mass percentage P_H of hydrogen	$P_H \leq 5\%$	$5\% < P_H \leq 10\%$	$10\% < P_H \leq 11\%$
Mass of hydrogenated products authorised (in g)	≤ 0.11 x Lu	≤ 0.06 x Lu	≤ 0.037 x Lu

Lastly, for contents 1 to 3, 5, 6 and 8 to 12, a maximum of 22 rods that are not intact upon loading and that may contain water are acceptable per package. For content 22, there is no risk of the dihydrogen in the package's cavity catching fire. For contents 23, 24 and 26, the integrity of the cladding at loading, and their dryness, is guaranteed. For content n° 25, the absence of water in the envelopes in which the material is repackaged after the first irradiation is guaranteed.

In the presence of burst elements that may contain water, measures to concentrate hydrogen must be taken before transport (see chapter 6A).

The lower explosive limit for hydrogen in the air, known as the LEL, must be less than 2%.

Chapter 3 – Appendix 1: Deleted

Chapter 3 – Appendix 2: Release of activity at maximum power (300 W/m)

Objective:

The objective of this appendix is to justify compliance with regulatory criteria for the release of activity under normal and accidental transport conditions when the TN 106 package is loaded with content having a maximum power equal to 300 W/m according to conditions:

- content 1 types 1, 2, 4 and 5
- content 2 types 1, 2 and 4
- content 3 types 1, 2, 4 and 5
- content 5 all types
- content 6 all types
- content 8 type 1
- content 10 type 2
- content 25 type 1 and/or type 2
- content 26

The masses of content in question are described in chapter 0A and in table 3A-2.1.

The calculations on the release of activity are performed according to the method described in chapter 3A.

Data:

The temperatures of the gases and seals for the maximum total power of 300 W/m taken into account in the release calculation are more penalising than those presented in chapter 2 for the seals and are taken from 2A for the gases. They are equal to:

- Under normal conditions of transport
  - 556 K for gases
  - for the seals:

groove	$T^{(1)}_{CNT}$ (K)	$T^{(2)}_{CNT}$ (K)
G1 (plug for orifice A)	357.25	366.25
G1 (plug for orifice B)	356.85	370.75
G3 (back closure plate)	361.55	371.05
G5 (plug for revolving plug)	356.95	366.35
G7 (front lid)	361.25	366.55
G9 (lid plug)	357.15	366.25

(1) Values taken from chapter 2
(2) Values used for the release calculations.

- under accident conditions of transport:
  - 582 K for gases
  - for the seals:

groove	T (K)
G1 (plug for orifice A)	389.25
G1 (plug for orifice B)	435.15
G3 (back closure plate)	391.95
G5 (plug for revolving plug)	452.15
G7 (front lid)	389.65
G9 (lid)	389.05

To conclude, the maximum pressure reached in the cavity is:

- 7.22 bars under normal conditions of transport,
- 10.7 bars under accidental conditions of transport.

Maximum total releases of activity are:

- $9.85{,}10^{-7}$ A_2/h under normal conditions of transport,
- $2.45{,}10^{-2}$ A_2 cumulated over one week under accidental conditions of transport.

Therefore, the regulatory criteria on the release of activity under normal and accidental transport conditions are verified.

Chapter 3 – Appendix 3: Deleted

Chapter 3 – Appendix 4: Release of activity at reduced power (maximum total power of 100 W)

Objective:

The objective of this appendix is to justify compliance with regulatory criteria for the release of activity under normal and accidental transport conditions when the TN 106 package is loaded with a total power that does not exceed 100 W, namely with the following contents:

- content 1 type 3,
- content 2 type 3,
- content 9 all types,
- content 10 types 1 and 3,
- content 23
- content 24

The masses of content in question are described in chapter 0A and in the tables 3A-4.2 to 4.

The calculations on the release of activity are performed according to the method described in chapter 3A.

Data:

The temperatures of the gases and the seals for a maximum total power of 100 W are determined from the results presented in chapters 2 and 2A and are equal to:

- Under normal conditions of transport
  - 556 K for gases
  - for the seals:

Groove	T (K)
G1 (plug for orifice A)	349.75
G1 (plug for orifice B)	353.35
G3 (back closure plate)	354.15
G5 (closure plate for revolving plug)	349.85
G7 (front lid)	349.95
G9 (lid plug)	349.65

- under accident conditions of transport:
  - 582 K for gases
  - for the seals:

Groove	T (K)
G1 (plug for orifice A)	383.05
G1 (plug for orifice B)	435.15
G3 (back closure plate)	385.65
G5 (closure plate for revolving plug)	452.15
G7 (front lid)	383.45
G9 (lid plug)	382.85

The temperatures of the plug for orifice B and for the revolving plug take into account the piercing effect, which was calculated for a power of 300W/m (see chapter 2 and appendices), which is penalising.

To conclude, the maximum pressure reached in the cavity is:

- 3.98 bars under normal conditions of transport,
- 7.30 bars under accidental conditions of transport.

Maximum total releases of activity are:

- $9.22{,}10^{-7}$ A_2/h under normal conditions of transport,

- $1.79,10^{-2}$ A_2 cumulated over one week under accidental conditions of transport.

Therefore, the regulatory criteria on the release of activity under normal and accidental transport conditions are verified.

Chapter 3 – Appendix 5: Deleted

Chapter 3 – Appendix 6: Study on the release of activity and study on radiolysis for content 22

Objective:

The objective of this chapter is to justify compliance with the regulatory criteria for the release of activity under normal and accidental transport conditions when the TN 106 package is loaded with content n° 22 as defined in appendix 0A-3.

Also, in this chapter, we check that there is no risk of flammability.

Data:

For the study on the release of activity, the temperatures of the gases and seals are taken from chapter 2 and 2A in the case of content with a maximum linear power equal to 70 W/m in the cavity and are equal to:

- Under normal conditions of transport
  - 375.15 K for the gases
  - 345.15 K for all the seals
- under accident conditions of transport:
  - 431.15 K for the gases
  - 406.15 K for all the seals

For the radiolysis study, the temperatures of the contents are taken from chapter 2A in the case of content with a maximum linear power of 70 W/m in the cavity and are equal to:

- Under normal conditions of transport
  - 375.15 K
- under accident conditions of transport:
  - 431.15 K

Hypotheses:

Content n° 22 is composed of non-leaktight elements, non-pressurised, coated with polymer resin.

The calculation on the release of activity under normal and accidental transport conditions is performed by considering that all the elements of the content of the "burst" type.

This calculation uses the activity rates created by the liberation of fission gases and aerosol products within the cavity and the impact of the permeability of the confinement chamber seals.

Concerning the radiolysis study, in order to avoid any risk of the hydrogen in the hydrogen-helium mixture catching fire in the package's cavity, we check that the mole fraction of air/helium in the hydrogen-helium mixture is such that whatever the quantity of hydrogen in the cavity, there is no risk of flammability.

Results and Conclusions:

Under normal transport conditions, the maximum activity flow is $1.56{,}10^{-7}$ A_2/h.

Under accidental transport conditions, the maximum activity flow is $2.23{,}10^{-4}$ A_2 in one week.

The regulatory criteria for the release of activity under normal and accidental transport conditions are therefore verified when the TN 106 package is loaded with content 22 defined in appendix 0A-3.

The flammability limit, in the package's cavity, for the hydrogen in the hydrogen-helium mixture, is not reached when combining normal and accidental transport conditions. There is therefore no risk of the hydrogen in the hydrogen-helium mixture catching fire in the package's cavity.

Chapter 3 – Appendix 7: Deleted

Chapter 3 – Appendix 9: Additional release calculations for contents 1 to 5

The document in the appendix constitutes chapter 3A of the safety analysis report for the IR200 package. The objective of this chapter is to justify compliance with regulatory criteria on the release of activity under normal and accidental transport conditions when the TN106 package is loaded with the content presented below (based on the calculations performed on the IR200 package):

- n°1 type 5 (covered by the study on the IR200 for content n° 1, combustion rate 100 GWj/t_{ML} cooled for 3 months),
- n°2 type 4 (covered by the study on the IR200 for content n° 2, combustion rate 80 GWj/tML cooled for 6 months),
- n°3 type 4 and 5 (covered by the study on the IR200 for content n° 3),
- n°5 type 5 and 6 (covered by the study on the IR200 for content n° 5, combustion rate 680 GWj/tML cooled respectively for 1 year and 75 days).

The following paragraphs compare the different parameters studied between the TN106 loaded with the previously-described contents and the IR200:

- Temperature of the gases in the cavity: the same temperatures were used for both packages (556 K under normal conditions of transport and 582 K under accidental conditions of transport),
- Seal temperatures under normal conditions of transport:

groove	T_{CNT} (K) TN106 (see chapter 2)	T_{CNT} (K) IR200
G1 (plug for orifice A)	357.0	368
G1 (plug for orifice B)	361.3	375
G3 (back closure plate)	361.6	375
G5 (closure plate for revolving plug)	357.3	368
G7 (front lid)	357.2	368
G9 (lid plug)	356.9	368

The temperatures in the seals of the IR200 are higher than the temperatures in the seals of the TN106. These temperatures are therefore penalising for the release analysis carried out.

- Seal temperatures under accident conditions of transport:

groove	T_{CAT} (K) TN106 (see chapter 2)	T_{CAT} (K) IR200
G1 (plug for orifice A)	389.3	400
G1 (plug for orifice B)	435.2	410
G3 (back closure plate)	392.0	406
G5 (closure plate for revolving plug)	452.2	408
G7 (front lid)	389.7	400
G9 (lid plug)	389.1	400

Certain temperatures used for the IR200 are lower than the temperatures to which the TN106 package model was subject. However, it was shown in chapter 3A that the temperatures of the seals have little influence on release under accidental transport conditions, and given the existing margins in relation to the criterion for accidental transport conditions, these differences have no impact on the compliance of the release criterion under these conditions.

- Rupture rates: the rupture rates are the same for both packages (for intact elements 5% under NCT and 100% under ATC, and for the non-intact elements 100% in all cases)

- Leaktightness criterion: the leaktightness criterion is the same for both packages ($6.65{,}10^{-5}$ $Pa.m^3.s^{-1}$ SLR).

- Free volume in the cavity: The free volumes in the cavity for the IR200 and the TN106 are identical for the content studied in this note (52.1 litres).

- The maximum number of sound elements for the contents covered by this appendix is identical between the IR200 and the TN106 (40 elements).

- The permeation calculations are according to the ring diameters of the seals and the diameters and depths of the grooves. The groove diameters and the ring diameters of the seals are identical. The groove depths are greater in the IR200. However, the calculation on the rate of permeation is proportional to the depth of the groove. Therefore the calculation on rates of permeation is more penalising for the IR200.

Consequently, the calculations performed in the chapter on release from the IR200 package (in appendix 3A-9.1) can cover the contents of the previously-presented TN106 package model.

Chapter 4: Evaluation of dose equivalent rates around the TN 106 package

Objectives:

This chapter presents the calculations on dose equivalent rates around the package composed of the TN 106 and authorised radioactive content. We show, through typical content, that the regulatory instructions of the AIEA are met under normal and accidental transport conditions.

Essential parameters and their origin:

Given the low level of distortion suffered by the package during the tests under normal and accidental transport conditions, the geometry of the package for the calculation model is that described in chapter 0 and in appendix 0-1. However, in a penalising manner, we assume that the resin has disappeared over [redacted] mm and we do not take into account the shock-absorbing covers for the calculations under accidental transport conditions. The chemical composition of materials is taken from table 0.8 of chapter 0.

Hypotheses and methods used:

The neutron and gamma source terms were determined using the code ORIGEN 2.1 (for the fuels UOX0, UOX2, MOX2 and FNR) and the code CESAR 4.34 (for the fuels UOX1 and MOX1). The neutron and gamma source terms used for the plate MTR fuels UAl and UMo-Al are taken respectively from documents <4A.6> and <4A.7> and the code ORIGEN 2.1. The neutron and gamma source terms used for the contents n°23, 24, 25 types 1 and 2, and n°26 are taken from the files <4A.22>, <4A.23>, <4A.24> and <4A.25>.

The dose equivalent rates are than calculated (except for the fuel UOX0 and the contents n° 23, 24, 25 type 1 and 2, and 26) with the codes MERCURE 5.2 for the gamma radiation and SN1D for the neutron radiation. The dose equivalent rates for the fuel UOX0 and the contents n° 23, 24, 25 type 1 and 2, and 26 are calculated with the codes MERCURE 6 for the gamma radiation and SN1D for the neutron radiation.

The neutron and gamma source terms used for the fuels UOX3, MOX3, (U+Pu)C, UOX-HTR are determined using the code ORIGEN 2.1 from data on the activities of isotopes taken from the note <4A.15> and the calculations <4A.16>.

The calculations determine the maximum acceptable activity according to the mass transported for the sources as long as the maximum dose equivalent rates comply with the AIEA instructions. They also confirm compliance with these instructions for different typical loads of irradiated fuels (UOx, MOX, RNR, UNGG, plate MTR and UOx irradiated in FNR) as defined below:

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

Type of fuel	UOX				MOX			FNR	MTR	
	UOX 0	UOX 1	UOX 2	UOX 3	MOX 1	MOX 2	MOX 3		UAl	UMoAl
Density	10.95	10.95	10.95	10.95	11	11	11	11	2.99	-
Rates of combustion (MWj/t m.l)	110,000	100,000	104,000	120,000	80,000	90,000	165,000	150,000	680,000	120,000
Enrichment : $^{235}U/U_{total}$ or content in Pu: $Pu_{tot}/(U+Pu)_{tot}$	5 (% ^{235}U)	10 (% ^{235}U)	20 (% ^{235}U)	93 (% ^{235}U)	12.5 (% Pu_{tot})	16 (% Pu_{tot})	26 (% Pu_{tot})	45 (% Pu_{tot})	93.5 (% ^{235}U)	20 (% ^{235}U)
Cooling time (years)	4	4	0.5	8	4	0.5	19	5	3	0.5
Mass of heavy metal: U, U+Pu (kg)	11.46	100	1.2	100	15	1.2	100	100	3.18	0.61

The shielding for the TN 106 package allows compliance with dose equivalent rates for contents n° 23, 24, 25 types 1 and 2 and 26, for which the characteristics are taken from the referenced files <4A.22>, <4A.23>, <4A.24> and <4A.25> (see appendix 4A-1).

The source calculations <4A.23> for the content n°24 are performed for a combustion rate of 8.7 at% for americium and plutonium in the element of type 1 and 5.6 at% for americium and plutonium in the element of type 2. A minimum variation of 1% is observed on combustion rates (in at%) taken from the files <4A.23> and the maximum combustion rate for the elements. According to the results presented in appendix 4A-1, a safety margin in relation to the regulatory criteria of 36 is apparent. Therefore, the minimum variation on the combustion rates does not call into question the conclusions of the study.

The neutron and gamma sources of fuels of the UNGG type irradiated at 9,500 MWj/t m.l and cooled for 15 years are less than the sources for the UOX fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel of the UNGG type are covered by those performed for fuel of the UOX type.

The neutron and gamma sources of fuel of the UOx type irradiated in Fast Neutron Reactors and cooled for 6 months (35,000 MWj/t m.l) are less than the sources for the MTR fuel UMoAl cooled for 6 months (120,000 MWj/t m.l). Consequently, the calculations for dose equivalent rates for fuel of the UOx type irradiated in Fast Neutron Reactors are covered by those performed for the MTR-type fuel UMoAl, for the same mass of heavy metal of 0.61 kg (see table above).

The neutron and gamma sources of a load composed of a needle of americium oxide irradiated at 74,000 MWj/t of initial americium and cooled for 6 months are less than those for a FNR fuel irradiated at 150,000 MWj/t of heavy metal, cooled for 0.2 years. Consequently, the calculations on dose equivalent rates for americium oxide are covered by those performed for the fuel of the FNR type.

The neutron and gamma sources for a load composed of an experimental needle of AmOx + MgO with blocks made of UO2 irradiated at a combustion rate of 37 at% and cooled for 6 months are less than those for an FNR fuel irradiated at 150,000 MWj/tML, cooled for 0.2 years. Consequently, the calculations of dose equivalent rates for the needle of AmOx with blocks made of UO_2 are covered by those carried out for the fuel of the FNR type.

The fuel UOX0 cooled for 4 years (110,000 MWj/t m.l) with an enrichment in ^{235}U of 5% is encompassed, from the point of view of radiological protection, by the load of uranium oxide UO_2 (initial enrichment of 6.85% by mass), whether or not pre-irradiated in a reactor of the PWR or MTR type with a rate of combustion of 23.4 GWj/t m.l followed by a minimum cooling time of 9 years and whether or not re-irradiated in a reactor of type PWR or MTR with a combustion rate of 165 MWj/t m.l followed by a minimum cooling time of 12 years and 11 months. Consequently, the calculations of dose equivalent rates for this content are covered by those carried out for the fuel of type UOX0 (see chapter 4A-1).

The neutron and gamma sources of the fuel of type UOX2 cooled for 6 months (104,000 MWj/t m.l) are less than the sources for the UOX1 fuel cooled for 4 years (100,000 MWj/t m.l). Consequently, the calculations on dose equivalent rates for fuel of the UOX2 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of type MOX2 cooled for 6 months (90,000 MWj/t m.l) are less than the sources for MOX1 fuel cooled for 4 years (80,000 MWj/t m.l). Consequently, the calculations on dose equivalent rates for fuel of the MOX2 type are covered by those performed for fuel of the MOX1 type.

The neutron and gamma sources of fuels of the UOX3 type irradiated at 120,000 MWj/t m.l and cooled for 8 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the UOX3 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the MOX3 type irradiated at 165,000 MWj/t m.l and cooled for 19 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the MOX3 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the (U+Pu)C type irradiated at 15,000 MWj/t m.l and cooled for 26 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the (U+Pu)C type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the UOX-HTR type irradiated at 60,000 MWj/t m.l and cooled for 22 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the UOX-HTR type are covered by those performed for fuel of the UOX1 type.

Results and Conclusion:

The results are presented in the appendix 4A-1.

It is thus demonstrated that the dose equivalent rate criterion is always complied with under ATC, as long as the CRT regulatory criterion is checked. The measurements made after loading and before each shipment perform this verification.

Note: this chapter presents the calculation for dose rates around the package in order to see whether the content is acceptable. However, the compliance of the package (with the regulatory instructions concerning the dose rates) is validated by measurements taken before shipment.

Chapter 4 - Appendix 1: Study on shielding the TN 106 package

Purpose:

This chapter is intended to show that, for content to be transported in the TN106 package, the dose equivalent rate values are below the limits imposed by the regulations.

Hypotheses and methods used:

As the content transported is variable (UOX, MOX or FNR irradiated fuel rods, either whole or in pieces, plates or pieces of plate fuels based on UAl and UMoAl alloys of the MTR type, irradiated fuel cartridges of UNGG, (U+Pu)C, UOX-HTR, AmO_2 needle, (Pu, Am)O_2 needles with blocks made of UO_2), it is a generic study composed of two parts.

The first part is intended to determine the acceptable neutron and gamma sources (in equivalent ^{60}Co) inside the TN106 package according to the mass of transported material.

This was performed on a range of masses going from 0 to 800 kg, considering a source medium of density 7.85. The maximum acceptable neutron and gamma sources were calculated from unitary neutron and gamma dose equivalent rate calculations carried out around the package at various points, and from the regulatory limits in terms of dose equivalent rates. The location of the calculation points, and the geometrical shape of the source volume, were chosen so as to obtain maximum unitary dose equivalent rates. Thus, the values deducted for the neutron and gamma sources are the maximum acceptable values and are independent of the source geometry.

The second part is intended to check compliance with regulatory criteria concerning the TN 106 package loaded with fuel of type UOX, MOX, FNR, UNGG or MTR plate fuels of UAl or UMoAl, (U+Pu)C or UOX-HTR, of contents n°23, 24, 25 types 1 or 2 or n°26 for the given combustion rates and cooling times.

This second part was performed with the calculation models used in the first part.

The gamma and neutron source terms were determined using the code ORIGEN 2.1 <4A-1.2> (for the fuel of the FNR and UOX0 type) and the code CESAR 4.34 (for the other

fuels of the UOX and MOX type). The neutron and gamma source terms used for the MTR plate fuels of UAl and UMoAl are taken respectively from the notes <4A-1.7> and <4A-1.9> and the code ORIGEN 2.1. The gamma source terms used for the UNGG fuel are taken from the note <4A-1.8>. The neutron and gamma source terms used for the fuels UOX3, MOX3, (U+Pu)C, UOX-HTR are determined using the code ORIGEN 2.1 <4A-1.2> from data on the activities of isotopes taken from the note <4A-1.14> and the calculations <4A-1.15>.
The neutron and gamma source terms used for contents n° 23, 24 and 25 types 1 and 2 are taken from the files <4A-1.19>. The neutron and gamma source terms for the content n° 26 are taken from the Excel references <4A-1.24> (1 to 5).
The gamma dose equivalent rates are determined with the code MERCURE-5.2.
For the fuel of type UOX0 and the contents n° 23, 24, 25 types 1 and 2 and n° 26, the dose equivalent rates were determined with the code MERCURE-6.

The neutron dose equivalent rates were evaluated with the code SN1D and take into account the directives of the standard CIPR 60. The keff considered for the calculations is equal to 0.2.

For the fuel of type UOX0 and the contents n° 23, 24, 25 types 1 and 2 and n° 26, the neutron dose equivalent rates were evaluated with the code SN1D taking into account the directives of the CIPR 60 standard. The keff used for the calculations for the UOX0 fuel is equal to 0.3. The keffs used for the contents n° 23, 24 and 25 types 1 and 2 are calculated with the code APOLLO2-MORET4B2. For the content n° 26, the keff used for the calculations is equal to 0.3 and is calculated with the code APOLLO2-SnKeff <4A-1.21> and <4A-1.22>.

Results and Conclusions:

- The maximum activity authorised depends on the mass of the content. For a mass of 800 kg, it is 360 TBq for the gamma emission spectrum (^{60}Co envelope).
- The dose equivalent rate criterion is always complied with in ATC, as long as the CRT regulatory criterion is checked.
- The shielding for the TN 106 package allows compliance with the criteria for dose equivalent rates for various typical loads of irradiated fuels (UOX, MOX, FNR, UNGG or MTR plates) as defined below:

Type of fuel	**UOX**				**MOX**			**FNR**	**MTR**	
	UOX 0	**UOX 1**	**UOX 2**	**UOX 3**	**MOX 1**	**MOX 2**	**MOX 3**		**UAl**	**UMoAl**
Density	10.95	10.95	10.95	10.95	11	11	11	11	2.99	-
Rates of combustion (MWj/t m.l)	110,000	100,000	104,000	120,000	80,000	90,000	165,000	150,000	680,000	120,000
Enrichment : $^{235}U/U_{total}$ or content in Pu: $Pu_{tot}/(U+Pu)_{tot}$	5 (% ^{235}U)	10 (% ^{235}U)	20 (% ^{235}U)	93 (% ^{235}U)	12.5 (% Pu_{tot})	16 (% Pu_{tot})	26 (% Pu_{tot})	45 (% Pu_{tot})	93.5 (% ^{235}U)	20 (% ^{235}U)

Cooling time (years)	4	4	0.5	8	4	0.5	19	5	3	0.5
Mass of heavy metal: U, U+Pu (kg)	11.46	100	1.2	100	15	1.2	100	100	3.18	0.61

The shielding for the TN 106 package allows compliance with dose equivalent rates for contents n° 23, 24 and 25 types 1 and 2, for which the characteristics are taken from the reference files <4A-1.19> (1 to 13).

The shielding for the TN 106 allows compliance with the dose equivalent rate criteria for content n° 26, the characteristics of which are taken from the referenced files <4A-1.24> (1 to 5).

The neutron and gamma sources of fuel of the UNGG type cooled for 15 years (9,500 MWj/t m.l) are below the sources for the UOX fuel cooled for 4 years (100,000 MWj/t m.l). Consequently, the calculations on dose equivalent rates for fuel of the UNGG type are covered by those performed for fuel of the UOX type.

The neutron and gamma sources of the fuel of type UOX2 cooled for 6 months (104,000 MWj/t m.l) are less than the sources for the UOX1 fuel cooled for 4 years (100,000 MWj/t m.l). Consequently, the calculations on dose equivalent rates for fuel of the UOX2 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of type MOX2 cooled for 6 months (90,000 MWj/t m.l) are less than the sources for MOX1 fuel cooled for 4 years (80,000 MWj/t m.l). Consequently, the calculations on dose equivalent rates for fuel of the MOX2 type are covered by those performed for fuel of the MOX1 type.

The neutron and gamma sources of fuel of the UOx type irradiated in Fast Neutron Reactors and cooled for 6 months (35,000 MWj/t m.l) are less than the sources for the MTR fuel UMoAl cooled for 6 months (120,000 MWj/t m.l). Consequently, the calculations for dose equivalent rates for fuel of the UOx type irradiated in Fast Neutron Reactors are covered by those performed for the MTR-type fuel UMoAl, for the same mass of heavy metal of 0.61 kg (see table above).

The neutron and gamma sources of fuels of the UOX3 type irradiated at 120,000 MWj/t m.l and cooled for 8 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the UOX3 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the MOX3 type irradiated at 165,000 MWj/t m.l and cooled for 19 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the MOX3 type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the (U+Pu)C type irradiated at 15,000 MWj/t m.l and cooled for 26 years are less than the sources for the UOX1 fuel irradiated at

100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the (U+Pu)C type are covered by those performed for fuel of the UOX1 type.

The neutron and gamma sources of fuels of the UOX-HTR type irradiated at 60,000 MWj/t m.l and cooled for 22 years are less than the sources for the UOX1 fuel irradiated at 100,000 MWj/t m.l and cooled for 4 years. Consequently, the calculations on dose equivalent rates for fuel loads of the UOX-HTR type are covered by those performed for fuel of the UOX1 type.

The fuel UOX0 cooled for 4 years (110,000 MWj/t m.l) with an enrichment in ^{235}U of 5% is encompassed, from the point of view of radiological protection, by the load of uranium oxide UO_2 (initial enrichment of 6.85% by mass), whether or not pre-irradiated in a reactor of the PWR or MTR type with a rate of combustion of 23.4 GWj/t m.l followed by a minimum cooling time of 9 years and whether or not re-irradiated in a reactor of type PWR or MTR with a combustion rate of 165 MWj/t m.l followed by a minimum cooling time of 12 years and 11 months. Consequently, the calculations of dose equivalent rates for this content are covered by those carried out for the fuel of type UOX0.

Chapter 5: Analysis of the nuclear safety of the TN 106 package

Objectives:

The objective of this chapter is to determine the acceptable masses and contents defined in chapter 0A in order to check that the package thus constituted meets the regulatory requirements.

Essential parameters and their origins:

The dimensions of the package are taken from chapter 0 and the definition of the content from chapter 0A.

Hypotheses and methods used:

- According to the regulatory instructions (see chapter 00, the criticality-safety analysis must consider the following cases:
  - A package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water,
  - A group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a [redacted] mm layer of water,
  - A group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water.
- The criticality-safety criteria selected are:
  - $K_{eff} + 3\sigma \leq 0.950$ for the isolated package,
  - $K_{eff} + 3\sigma \leq 0.980$ for the group of packages.

For No. 26 Contents, the criticality-safety criteria are determined using an Upper Safety Limit (USL) calculation.

Results and Conclusions:

The masses determined in this chapter can guarantee that the content remains sub-critical under the following conditions:

- Under normal and accidental transport conditions, we authorise the presence of hydrogenated materials within the package, excluding all those for which the concentration in hydrogen is greater than that of water,
- Partial draining of the package cavity is permitted,
- For all of the envisaged configurations, any number N of packages may be transported (N is infinite). The value of the criticality-safety index is therefore 0.

Subsequent use of the results obtained:

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The masses determined in this chapter allow definition of the maximum acceptable masses for content defined in chapter 0A.

Chapter 5 - Appendix 1: Analysis of the nuclear safety of the TN 106 package – Content: fissile material with different enrichment in uranium 235

This study demonstrates, according to regulatory instructions, the criticality-safety of the package composed of the TN 106 package loaded with irradiated fissile material based on uranium in metallic form or oxide form (UO2).

The package and the content are presented respectively in chapters 0A.

The study covers the analysis of an isolated damaged and undamaged package, and the analysis of a set of 2N packages under accidental transport conditions and of 5N packages under normal transport conditions.

The calculation takes place in two stages:

- Firstly, we determine the cross sections of the fissile media from code APOLLO2.
- These cross sections are then used for calculating the $k_{eff}+3\sigma$ with the code MORET IV.

The package complies with the criticality-safety criteria if the content complies with the following maximum acceptable masses, whatever the length of the cavity and for three containment diameters D:

Fissile material based on uranium in metallic form:

Enrichment in ^{235}U (% by mass)	Mass of ^{235}U (kg) D=60 mm	Mass of ^{235}U (kg) D=120 mm	Mass of ^{235}U (kg) D=203 mm
100	No limit	2.90	0.6256
50	No limit	7.00	0.7065
10	No limit	No limit	1
5	No limit	No limit	1.50
4	No limit	No limit	2.00
≤ 3	No limit	No limit	No limit

Fissile material based on uranium in oxide form (UO_2):

Enrichment in ^{235}U (% by mass)	Mass of UO_2 (kg) D=60 mm	Mass of UO_2 (kg) D=120 mm	Mass of UO_2 (kg) D=203 mm
10	No limit	No limit	11.00
5	No limit	No limit	53.00
≤ 4	No limit	No limit	No limit

Results:

- $k_{eff} + 3\sigma$ (σ = 200 pcm) = **0.944 as an isolated package**
- $k_{eff} + 3\sigma$ (σ = 200 pcm) = **0.944 in a group of packages**

Chapter 5A - Appendix 2: Analysis of the nuclear safety of the TN 106 package – Content: 100 % plutonium

This study demonstrates, according to the regulatory instructions (AIEA 96), the criticality-safety of the package composed of the TN106 package loaded with irradiated fissile material based on plutonium in any form.

Input data:

- The package and its contents are presented in Chapters 0 and 0A respectively.
- According to regulatory instructions (AIEA 96), the criticality-safety analysis must consider the following cases:

– A package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a [200] mm layer of water,

– A group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a [redacted] mm layer of water,

– A group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water.

- The criticality-safety criteria selected are:

– $K_{eff} + 3\sigma \leq 0.950$ for the isolated package,

– $K_{eff} + 3\sigma \leq 0.980$ for the group of packages.

Output data:

The TN106 package loaded with irradiated fissile material based on plutonium in any form complies with the criticality-safety criteria under the following conditions:

- An infinite number 'N' - corresponding to a CSI (Criticality-Safety Index) of 0.
- Under normal and accidental transport conditions, we authorise the presence of hydrogenated materials within the package, excluding all those for which the concentration in hydrogen is greater than that of water,

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- Partial draining of the package cavity is permitted,
- Content allowed: irradiated fissile material based on plutonium in any form for which the maximum acceptable masses are given in the following table, whatever the height of the cavity:

Content in Pu (% by mass)	Mass of Pu D=60 mm	Mass of Pu D=120 mm	Mass of Pu D=203 mm
100	4.0 kg	3.2 kg	0.36 kg

- Results:
  - $k_{eff} + 3\sigma$ (σ = 200 pcm) = **0.944 as an isolated package**
  - $k_{eff} + 3\sigma$ (σ = 200 pcm) = **0.945 in a group of packages**

Chapter 5 - Appendix 3: Analysis of the nuclear safety of the TN 106 package – Content: irradiated fissile material based on uranium and plutonium

This study demonstrates, according to regulatory instructions, the criticality-safety of the package composed of the TN 106 package loaded with irradiated fissile material based on uranium and plutonium.

Input data:

- The package and its contents are presented in Chapters 0 and 0A respectively.
- According to regulatory instructions (AIEA 96), the criticality-safety analysis must consider the following cases:
  - A package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water,
  - A group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a [redacted] mm layer of water,
  - A group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water.
- The criticality-safety criteria selected are:
  - $K_{eff} + 3\sigma \leq 0.950$ for the isolated package,
  - $K_{eff} + 3\sigma \leq 0.980$ for the group of packages.

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Output data:

The TN106 package loaded with irradiated fissile material based on uranium and plutonium in any form complies with the criticality-safety criteria under the following conditions:

- An infinite number 'N' - corresponding to a CSI (Criticality-Safety Index) of 0.
- Under normal and accidental transport conditions, we authorise the presence of hydrogenated materials within the package, excluding all those for which the concentration in hydrogen is greater than that of water,
- Partial draining of the package cavity is permitted,
- Content allowed: irradiated fissile material based on uranium and plutonium in metallic form for which the maximum acceptable masses are given in the following tables:

Enriched U:

Enrichment in ^{235}U (% by mass)	Mass of ^{235}U (kg) D=60 mm	Mass of ^{235}U (kg) D=120 mm	Mass of ^{235}U (kg) D=203 mm
100	No limit	2.9	0.560

Mixed compound based on plutonium and natural uranium:

Content in Pu (% by mass)	Mass of Pu (kg) D=60 mm	Mass of Pu (kg) D=120 mm	Mass of Pu (kg) D=203 mm
100	4.0	3.2	0.360
50	No limit	6.0	0.380
10	No limit	No limit	0.500

Mixture of enriched U + Pu:

The acceptable masses of uranium and plutonium must comply with the following mixing rule:

$$\frac{m(Pu_t)}{mPu(D)} + \frac{m(U_t)}{mU(D, e_{max})} \leq 1$$

With $mU(D, e_{max}) = \frac{m^{235}U(D)}{e_{max}}$

where

mPu(D) – represents the maximum acceptable mass of plutonium for a given diameter D,

$mU(D,e_{max})$ – represents the maximum acceptable mass of uranium for a given diameter D and a given maximum enrichment e_{max},

e_{max} – represents the maximum enrichment in ^{235}U of the various loaded fissile materials.

$m^{235}U(D)$ – represents the maximum acceptable mass of ^{235}U for a given diameter D,

The following tables give the values of $m^{235}U(D)$ and mPu(D).

- Uranium 100% enriched in ^{235}U:

Mass of ^{235}U (kg) D=60 mm	Mass of ^{235}U (kg) D=120 mm	Mass of ^{235}U (kg) D=203 mm
No limit	2.900	0.560

- Plutonium at 100% of ^{239}Pu:

Mass of Pu (kg) D=60 mm	Mass of Pu (kg) D=120 mm	Mass of Pu (kg) D=203 mm
4.000	3.200	0.360

Chapter 5A - Appendix 4: Analysis of the nuclear safety of the TN 106 package – Content: irradiated fissile material based on mixed oxide of *uranium and plutonium*

This study demonstrates, according to regulatory instructions, the criticality-safety of the package composed of the TN 106 package loaded with irradiated fissile material based on mixed oxide of uranium and plutonium $(U+Pu)O_2$.

Input data:

The package and the content are presented respectively in chapters 0 and 0A.

According to the regulatory instructions (AIEA 1996), the criticality-safety analysis must consider the following cases:

- an isolated package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water,

- a group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a [redacted] mm layer of water,

- a group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water.

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The criticality-safety criteria selected are:

- $k_{eff} + 3\sigma \leq 0.950$ for an isolated package,
- $k_{eff} + 3\sigma \leq 0.980$ for a group of packages.

The calculation takes place in two stages:

- firstly, the cross sections of the fissile materials and structural materials are determined from the code APOLLO2,
- these cross sections are then used to calculate the k_{eff} with the code MORET4.

The assumptions used for the calculations are the following:

- the density of the mixed oxide of uranium and plutonium is taken as equal to 11,
- the enrichment of the uranium is taken as equal to 0.72%,
- the overall isotopic composition of the plutonium used for the calculations is the following (in % by mass):
  - 100 % of ^{241}Pu for the cases of plutonium content less than 5.5%,
  - ^{239}Pu / ^{240}Pu / ^{241}Pu / ^{242}Pu = 71 / 17 / 11 / 1 for the higher contents.
- For the specific case of mixtures of fissile materials (types a and b), the isotopic composition of plutonium used for the calculations is the following (in % by mass):
  - 100 % of ^{241}Pu for the case of a medium with a plutonium content less than 6% (type a),
  - ^{239}Pu / ^{240}Pu / ^{241}Pu / ^{242}Pu = 71 / 17 / 11 / 1 for the case of a medium with a plutonium content less than 45% (type b).

<u>Output data:</u>

The criticality-safety of the package is demonstrated under the following conditions:

- The density of the mixed oxide of uranium and plutonium is less than or equal to 11.

- The enrichment of the uranium is less than or equal to 0.72% ($^{235}U/U_{tot} \leq 0.72$ %).

- The isotopic composition of the transported plutonium is covered by the following isotopic vectors (in % by mass):
  - 100 % of ^{241}Pu for the case of plutonium contents less than or equal to 5.5%,
  - ^{239}Pu / ^{240}Pu / ^{241}Pu / ^{242}Pu = 71 / 17 / 11 / 1 for the higher contents.

- For the specific case of mixtures of fissile materials types a and b), the isotopic composition of plutonium used for the calculations is the following (in % by mass):
  - 100 % de ^{241}Pu for the case of a medium with a plutonium content less than 6% (type a),

- ^{239}Pu / ^{240}Pu / ^{241}Pu / ^{242}Pu = 71 / 17 / 11 / 1 for the case of a medium with higher plutonium content (type b).

The maximum acceptable masses in oxide are given in the table below according to the plutonium content and the diameter D of the internal fitting, whatever the envisaged height H of the cavity (H varying from 1000 to 3200 mm):

Content in Pu $t = Pu_t/(U+Pu_t)$ (in %)	**Isotopic vector**	**Mass of oxide (kg) D=60 mm**	**Mass of oxide (kg) D=120 mm**	**Mass of oxide (kg) D=203 mm [(1)]**
$t \leq 4$	Variable	No limit	No limit	8.000
$t \leq 5.5$	Variable	No limit	No limit	5.445
$t \leq 13$	$^{240}Pu/Pu_t \geq 17$ % $^{241}Pu/^{240}Pu \leq 64.7$ % $^{242}Pu/^{241}Pu \geq 9.1$ %	No limit	No limit	9.000
$t \leq 45$	$^{240}Pu/Pu_t \geq 17$ % $^{241}Pu/^{240}Pu \leq 64.7$ % $^{242}Pu/^{241}Pu \geq 9.1$ %	No limit	95	1.900

(1) No internal fitting for purposes of criticality.

For the specific case of a mixture of fissile materials (types a and b), the maximum acceptable masses of oxide are given in the table below according to the plutonium content and for the diameter 203 mm (the demonstration is presented in appendix 5A-4.2):

Type	**Content in Pu $t = Pu_t/(U+Pu_t)$ (in %)**	**Isotopic vector**	**Mass of oxide (kg) D=203 mm**
a	$t \leq 6$	Variable	0.700
b	$t \leq 45$	$^{240}Pu/Pu_t \geq 17$ % $^{241}Pu/^{240}Pu \leq 64.7$ % $^{242}Pu/^{241}Pu \geq 9.1$ %	1.400

- Partial draining of the package cavity is permitted.

- The number 'N' is infinite The criticality-safety index is: CSI = 0.

When the fissile material $(U+Pu)O_2$ is in the presence of a non-irradiated fertile medium made of natural or depleted uranium, the maximum mass of mixed oxide of uranium and plutonium (in kg) in the fissile medium is equal to two thirds of the mass given in the previous table.

The maximum mass of uranium oxide (in kg) in the non-irradiated fertile medium is equal to a third of the mass given in the previous table.

The demonstration for the case of a package without an internal fitting loaded with mixed oxide of uranium and plutonium with a plutonium content of 45% is presented in appendix 5A-4.1

Chapter 5A - Appendix 5: Analysis of the nuclear safety of the TN 106 package – Content: Fissile material based on nitride or carbide of uranium and plutonium

This study demonstrates, according to regulatory instructions, the sub-criticality of the package composed of the TN 106 package loaded with irradiated fissile material based on nitride and/or carbide of uranium and plutonium: (U+Pu)N and (U+Pu)C.

Input data:

The package and the content are presented respectively in chapters 0 and 0A.

According to the regulatory instructions (AIEA 1996), the criticality-safety analysis must consider the following cases:

- an isolated package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water,

- a group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a [redacted] mm layer of water,

- a group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a [redacted] mm layer of water.

The criticality-safety criteria selected are:
- $k_{eff} + 3\sigma \leq 0.95$ for an isolated package,
- $k_{eff} + 3\sigma \leq 0.98$ for a group of packages.

The calculation takes place in two stages. Firstly, the cross sections of the fissile media and the structural media are determined from the code APOLLO2. These cross sections are then used to obtain the effective multiplication factor k_{eff} with the code MORET IV.

The assumptions used for these calculations are:

- The plutonium content by mass is taken as equal to 23%.

- The isotopic composition of plutonium used for the calculations is ^{240}Pu / $Pu_t \geq$ 12%, ^{241}Pu / $^{240}Pu \leq 25\%$, ^{242}Pu / $^{241}Pu \geq 0\%$ representing an isotopic vector 85 / 12 / 3 / 0.

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- The enrichment of uranium is taken as equal to 0.72% ($^{235}U/U_{tot} \leq 0.72\%$).
- The maximum density of carbide of (U+Pu) is taken as equal to 13.63 for the calculations.
- The maximum density of nitride of (U+Pu) is taken as equal to 14.38 for the calculations.

Output data:

The package is sub-critical if the content, in any form whatsoever, complies with the following conditions:

- The plutonium content by mass is less than or equal to 23%.
- The isotopic composition of plutonium is covered by ^{240}Pu / $Pu_t \geq 12\%$, ^{241}Pu / $^{240}Pu \leq 25\%$, ^{242}Pu / $^{241}Pu \geq 0\%$ representing the isotopic vector 85 / 12 / 3 / 0.
- The enrichment of the uranium is less than or equal to 0.72% ($^{235}U/U_{tot} \leq 0.72$ %).
- The maximum density of carbide of (U+Pu) is less than or equal to 13.63.
- The maximum density of nitride of (U+Pu) is less than or equal to 14.38.
- The mixture, in any proportions, of nitride and carbide of (U+Pu) is authorised providing the mass of the mixture remains below the maximum acceptable masses specified below.

The maximum acceptable masses for the mixture of nitride and carbide of (U+Pu) are given in the table below according to the plutonium content and the diameter D of the internal fitting, whatever the envisaged height H of the cavity (H varying from 1000 to 3200 mm):

Content in Pu $Pu_t/(U+Pu_t)$ (in %)	Mass of the mixture of nitride and carbide of (U+Pu)		
	D = 60 mm	D = 120 mm	D = 203 mm (1)
≤ 23 %	No limit	No limit	3.25 kg

(1) no internal fitting for purposes of criticality

- Under normal and accidental transport conditions, we authorise the presence of hydrogenated materials within the package, excluding all those for which the concentration in hydrogen is greater than that of water.
- Partial draining of the package cavity is permitted.
- The number 'N' is infinite The criticality-safety index is: SCI = 0.

Chapter 5A Appendix 8: Analysis of the criticality-safety of the TN 106 package loaded with fuel based on uranium and plutonium in metallic form

This study demonstrates, according to regulatory instructions, the criticality-safety of the package composed of the TN 106 package loaded with fuel, whether irradiated or not, based on uranium and plutonium in metallic form.

Input data:

- The package and its contents are presented in Chapters 0 and 0A respectively.
- State of the package after the regulatory tests.
- The fissile environment is similar to a homogeneous mixture (U-Pu) metal + water, with the characteristics of the fissile material given in the table below:

Fissile material	Characteristics
Chemical form	(U, Pu) metal
$^{235}U/U_{total}$ (mass %)	≤ 0.8
Maximum Pu content (% by mass) $Pu_{total}/(U + Pu)_{total}$	≤ 30
Overall Pu isotopic vector	100 % ^{239}Pu
Pu isotopic vector	Any (*)

(*): Does not cover the fertile covers coming from FNRs

The fuel may contain up to 4 g of neptunium, 2.4 g of americium (including a maximum of 0.24 g of ^{242m}Am, 1.3 g of curium (including a maximum of 0.39 g of ^{245}Cm). The presence of rare earths is authorised (neutron absorbent).

- The hypotheses selected for the criticality-safety analysis of the TN106 package are:

  As per regulatory requirements, for single packages and groupings of packages, under the following conditions of transport:

  - Routine transport conditions (single package only),
  - Normal Conditions of Transport
  - normal conditions followed by accidental conditions.

  The criticality-safety criteria selected are:

  - $K_{eff} + 3\sigma$ ($\sigma = 0.002$) ≤ 0.950 for the isolated package,
  - $K_{eff} + 3\sigma$ ($\sigma = 0.002$) ≤ 0.980 for the group of packages.

The calculations performed in the appendixes to chapter 5A showed that the reactivity of an isolated package is very close to that of an infinite group of packages. Thus, in a penalising manner, the calculations are performed by considering an infinite group of packages in the state resulting from tests representing accidental transport conditions combined with normal transport conditions, with total reflection of neutrons on the external surface of the package. This calculation covers the case of the isolated package and the case of a group of packages of an infinite number. We then check that $K_{eff} + 3\sigma$ ($\sigma = 0.002$) ≤ 0.950.

Conservatively, the following assumptions are used for the fissile medium:

- the rare earths are not taken into account. The neptunium, americium and curium are considered in the same category as ^{239}Pu in equivalent proportions in terms of reactivity. The isotopes with the minimum critical masses amongst the isotopes of neptunium, americium and curium are respectively ^{237}Np, ^{241}Am and ^{242m}Am, ^{243}Cm and ^{245}Cm. The minimum critical masses as given in Ref. <6> are shown in the table below:

Nuclide	Critical Mass (g)
^{239}Pu	450
^{237}Np	30,000
^{241}Am	24,000
^{242m}Am	13
^{243}Cm	90
^{245}Cm	30

Conservatively, we consider americium at ^{242m}Am and curium at ^{245}Cm. Bearing in mind that the TN106 package may contain up to 4 g of neptunium, 2.4 g of americium and 1.3 g of curium, the equivalence in terms of reactivity is performed as follows:

- for the ^{237}Np:

$$4 \times \frac{450}{30000} \approx 0{,}06\ g$$ of ^{237}Np considered in the same category as ^{239}Pu

- for the ^{242m}Am

$2{,}4 \times \frac{450}{13} \approx 83{,}1\ g$ of ^{242m}Am considered in the same category as ^{239}Pu

- for the ^{245}Cm:

$1{,}3 \times \frac{450}{30} \approx 19{,}5\ g$ of ^{245}Cm considered in the same category as ^{239}Pu

Representing a mass of 103 g of ^{239}Pu to be taken into account in the fuels, whether irradiated or not, based on uranium and plutonium in metallic form.

This assumption is conservative to the extent that the real mass of the ^{242m}Am is 0.24 g, and that of the ^{245}Cm is 0.39 g.
The real equivalence in terms of reactivity is therefore:

- for the ^{237}Np:

$4 \times \frac{450}{30000} \approx 0{,}06\ g$ of ^{237}Np considered in the same category as ^{239}Pu

- for the ^{241}Am and the ^{242m}Am

$0{,}24 \times \frac{450}{13} + 2{,}16 \times \frac{450}{24000} \approx 8{,}35\ g$ of ^{241}Am + ^{242m}Am considered in the same category as ^{239}Pu

- for the ^{243}Cm and the ^{245}Cm:

$0{,}39 \times \frac{450}{30} + 0{,}91 \times \frac{450}{90} \approx 10{,}4 g$ of ^{243}Cm + ^{245}Cm considered in the same category as ^{239}Pu

Representing a mass of 19 g of ^{239}Pu to be taken into account in the fuels, whether irradiated or not, based on uranium and plutonium in metallic form (for 103 g taken in the calculations).

The internal layout of the package is not taken into account when modelling.

Output data:

The TN106 package loaded with irradiated fissile material based on uranium and plutonium in metallic form complies with the criticality-safety criteria under the following conditions:

- An infinite number 'N' - corresponding to a CSI (Criticality-Safety Index) of 0.

Permitted content: fuel, whether irradiated or not, based on uranium in metallic form, for which the characteristics are given in the table below:

Fissile material	Characteristics
Chemical form	(U, Pu) metal
$^{235}U/U_{total}$ (mass %)	≤ 0.8
Maximum Pu content (% by mass) $Pu_{total}/(U + Pu)_{total}$	≤ 30
Pu isotopic vector	Any (*)

(*): Does not cover the fertile covers coming from FNRs

- The fuel may contain up to 4 g of neptunium, 2.4 g of americium and 1.3 g of curium. The presence of rare earths is authorised (neutron absorbent).
- Partial draining of the package cavity is permitted.
- The presence of hydrogen-bearing materials is authorised, excluding those materials with a hydrogen concentration (at/cm^3) greater than that of water.
- The maximum acceptable mass of ^{239}Pu in the fuel, whether irradiated or not, based on uranium and plutonium in metallic form is **360 g** and **257 g** with the presence, before irradiation, of a maximum 4 g of Np, 2.4 g of Am (including a maximum of 0.24 g of Am^{242m}) and 1.3 g of Cm (including a maximum of 0.39 g of Cm^{245}).

    - In the case of fissile material doped with Am, Cm and/or Np, the maximum masses of plutonium and the uranium (natural or depleted) and plutonium assembly, in the fissile medium, before irradiation, must comply with the values defined in the following table:

	Pu content as a %	Cavity without internal fitting provided for purposes of criticality	
		Mass of Pu (kg)	Mass of U + Pu (in kg)
(U + Pu) metal	$\leq 30\%$	≤ 0.257	$\leq \text{Minimum}\left\{2{,}570; \frac{25{,}7}{t_{max}(Pu)}\right\}$

In this table, the maximum content in total plutonium $t_{max}(Pu)$ is defined by that of the pellet or "powder batch" having the maximum Pu_{total} content from all of the pellets present in each fuel element (or part of an element) or "powder batches" present. $t_{max}(Pu)$ Is expressed as a mass percentage. The uranium must not be dissociated from the plutonium.

- In the case of fissile material that is not doped with Am, Cm and/or Np, the maximum masses of plutonium and the uranium (natural or depleted) and plutonium assembly, in the fissile medium, before irradiation, must comply with the values defined in the following table:

	Pu content as a %	Cavity without internal fitting provided for purposes of criticality	
		Mass of Pu (kg)	Mass of U + Pu (in kg)
(U + Pu) metal	≤ 30%	≤ 0.360	≤ 1.200
(U + Pu) nitride or carbide (*)	≤ 30%	≤ 0.279	≤ 0.930

(*) The quantity of uranium in the fertile material must be less than 270 g before irradiation and the Pu content must be less than 6% after irradiation. The isotopic vector of plutonium may be any.

In this table, the maximum content in total plutonium is defined by that of the pellet or "powder batch" having the maximum Pu_{total} content from all of the pellets present in each fuel element (or part of an element) or "powder batches" present. In the fissile material, the uranium must not be disassociated from the plutonium.

Chapter 5A Appendix 9: Analysis of the criticality-safety of the TN 106 package loaded with irradiated fissile material based on uranium oxide coated with thoria in a graphite matrix

This study demonstrates, according to the regulatory instructions (AIEA 96), the criticality-safety of the package consisting of the TN 106 package loaded with irradiated fissile material based on uranium oxide coated with thoria in a graphite matrix.

<u>Input data:</u>

- The package and its contents are presented in Chapters 0 and 0A respectively.
- According to regulatory instructions (AIEA 96), the criticality-safety analysis must consider the following cases:
  - A package taken under routine transport conditions, in the state resulting from tests representative of normal transport conditions, and accidental transport conditions combined with normal transport conditions, surrounded by a 200 mm layer of water,
  - A group of 5N packages taken in the state resulting from tests representative of normal transport conditions, surrounded by a 200 mm layer of water,
  - A group of 2N packages taken in the state resulting from tests representative of accidental transport conditions combined with normal transport conditions, surrounded by a 200 mm layer of water.

- The criticality-safety criteria selected are:
  - $K_{eff} + 3\sigma \leq 0.950$ for the isolated package,
  - $K_{eff} + 3\sigma \leq 0.980$ for the group of packages.

Output data:

The TN 106 package loaded with irradiated fissile material based on uranium oxide coated with thoria in a graphite matrix complies with the criticality-safety criteria under the following conditions:

- An infinite number 'N' - corresponding to a CSI (Criticality-Safety Index) of 0.
- Under normal and accidental transport conditions, the presence of graphite and hydrogenated materials within the package is authorised, excluding all hydrogenated materials for which the hydrogen concentration is greater than that of water,
- Content allowed: irradiated fissile material based on uranium oxide coated with thoria, for which the characteristics are specified in the following table:

Maximum enrichment in ^{235}U	93%
Maximum mass of U in UO_2	500 g
Maximum mass of Th in ThO_2	243 g
Maximum mass of graphite	No limit

Chapter 5A Appendix 10: Deleted

Chapter 5 - Appendix 11: Analysis of the nuclear safety of the TN 106 package loaded with fissile material based on plutonium and/or uranium, whether in metallic form or not, which may contain americium and neptunium.

Input data:

- The package and the content are respectively present in chapters 0 and 0A of the present safety analysis report,
- Following completion of the regulatory tests, the concentration of neutron absorbing material is limited to 75% of the guaranteed minimum value, a thickness of 10 mm of resin has been removed and the wood has all been removed.
- The permissible contents for the TN106 package in terms of its criticality-safety comprises irradiated/non-irradiated plutonium and/or uranium-based fuels in metallic or other form, which may contain americium and neptunium,
- The fissile medium is considered in the same category as a homogeneous mixture of (U-Pu) metal + and water or (Pu) metal + water for which the characteristics of the fissile material are given in the following table:

Fissile material	Characteristics
Chemical form	Metallic (U, Pu) or (Pu)
$^{235}U/U_{total}$ (mass %)	≤ 10
Maximum Pu content (% by mass) $Pu_{total}/(U + Pu)_{total}$	≤ 100
Overall Pu isotopic vector	100 % ^{239}Pu

The mass of Uranium and Plutonium is 330 g, alternatively, 42 g prior to irradiation with a maximum of 6.2 g Americium and 2.1 g Neptunium.

- The following conservative figures are used for the fissile environment:
  - the americium and the neptunium are considered in the same category as ^{239}Pu in equivalent proportions in terms of reactivity. The isotopes having the minimum critical masses amongst the isotopes of neptunium and americium are respectively ^{237}Np and ^{242m}Am. The minimum critical masses taken from <5A-11.6> are given in the table below:

Nuclide	Critical mass [g]
^{239}Pu	450
^{237}Np	30,000
^{241}Am	24,000
^{242m}Am	13

In the calculations, americium and neptunium are conservatively considered in the same category as ^{242m}Am. Given that the TN106 package may contain up to 6.2 g Americium and 2.1 g Neptunium, the equivalence, in terms of reactivity, is calculated as follows:

$$(6{,}2 + 2{,}1)d'^{242m}\,Am \times \frac{450}{13} \approx 288\ g,$$
equivalent mass in ^{239}Pu.

Thus, an additional mass of 288 g of ^{239}Pu to be taken into account for irradiated/non-irradiated metallic plutonium and/or uranium-based fuels. Therefore, a total mass of U + Pu (288 + 42) = 330 g is used.

- The hypotheses selected for the criticality-safety analysis of the TN106 package are:

As per regulatory requirements <5A-11.1>, for single packages and groupings of packages, under the following conditions of transport:

- o Routine transport conditions (single package only),
- Normal Conditions of Transport
- Normal Conditions of Transport following Accident Conditions of Transport.

The criticality-safety criteria selected are:

- $k_{eff} + 3\sigma$ ($\sigma = 0.002$) $\leq 0.950 - \Delta ku \leq 0.9331$ for the single package,
- $k_{eff} + 3\sigma$ ($\sigma = 0.002$) $\leq 0,980 - \Delta ku \leq 0.9631$ for the group of packages.

Where Δku is the margin calculated using the USL method. The USL calculation is detailed in Appendix 5A-11.2.

Assuming a worst case scenario, the calculation for the multiplication coefficient (k_{rms}) is done for a single, damaged package and an infinitely large grouping of damaged packages.

The internal layout of the package is not taken into account when modelling.

The impact of the quantity of steel within the cavity is however studied.

Output data:

The TN 106 package loaded with fissile material, whether irradiated or not, based on plutonium and/or uranium, whether in metallic form or not, which may contain americium and neptunium, complies with the criticality-safety criteria under the following conditions:

- An infinite number 'N' - corresponding to a CSI (Criticality-Safety Index) of 0.
- Permitted contents: Irradiated/non-irradiated, metallic or non-metallic, plutonium and/or uranium-based fissile material, which may or may not contain Americium and Neptunium, the characteristics for which are given in the following table:

Fissile material	Characteristics
Chemical form	Metallic (U, Pu) or (Pu)
$^{235}U/U_{total}$ (mass %)	≤ 10
Maximum Pu content: (% by mass) $Pu_{total}/(U + Pu)_{total}$	≤ 100
Overall Pu isotopic vector	100 % ^{239}Pu

The mass of Uranium and Plutonium is 330 g, alternatively, the mass (U+Pu) is 42 g prior to irradiation with a maximum of 6.2 g Americium and 2.1 g Neptunium.

- Partial draining of the package cavity is permitted.
- The presence of hydrogen-bearing materials is authorised, excluding those materials with a hydrogen concentration (at/cm^3) greater than that of water.
- Under these conditions the maximum reactivity levels noted are:
  - $k_{eff} + 3\sigma$ ($\sigma = 0.001$) = 0.932 as a single package,
  - $k_{eff} + 3\sigma$ ($\sigma = 0.001$) = 0.933 as an infinite group of packages.

Chapter 6: Instructions for the use of the package

This chapter contains the usage instructions specified for the TN 106 package model.

Chapter 7: Acceptance test and maintenance programme

This chapter describes the programmes of tests for acceptance, commissioning and maintenance planned during the use of the package.

Chapter 7 – appendix 1: Classification plan for the components of the TN 106 package model

This appendix is intended to present the list of components of the TN 106 package and the internal fittings provided for purposes of criticality, specifying the nature and extent of the checks to be made when manufacturing the various elements composing the package model.

Chapter 8: Quality assurance applicable to the TN 106 package

3. CONCLUSION

Given the nuclear safety analysis presented in the safety analysis report, the package satisfies the regulatory instructions applicable to packages of type B(U) and loaded with fissile materials.

CORRESPONDENCE TABLE BETWEEN THE ARTICLES OF THE REGULATIONS AND THE CHAPTERS OF THE SAFETY ANALYSIS REPORT

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-00-2E			
0	06/00	Document first drawn up	F. PETIT / A. SALAÜN
1	05/01	Updating of the document following modification for revision 1 of the Safety Analysis Report	L. MARIETTE / C. VALLENTIN
Ref. : DOS-08-00126114-012			
00	07/08	New document reference New formalism Containment system definition taken into account	S. CHEVET / JC. BOTT
01	02/13	Translations of the document DOS-06-00032898-003 Rev 0. Modification of the applicable regulation. Addition of a table of cross reference between the structure of the safety analysis report and the structure of the European guide PDSR.	R. BAHOU / D. HONDAGNEU

1. CORRESPONDENCE WITH THE AIEA REGULATION

	Sections of the IAEA <1>	**Applicable Sections of the Safety Analysis Report**
Definition	209	Chapter 5A, Section 5
General requirements for all packagings and packages	606	Chapter 0, Section 4
	607	Chapter 1, Appendix 3, Section 9
	608	Chapter 0, Section 4
	609	Chapter 0, Section 4
	610	Chapter 0, Section 4
	611	*Not applicable*
	612	Chapter 3A, Section 2.5.1
	613	Chapter 3A, Section 2.5.3
	614	Not applicable
	615	Chapter 1, Section 3
	616	Not applicable
Requirements for Type A packages	617 to 619	*Not applicable*
	634	Chapter 0, Section 3
	635	Chapter 0, Section 4.6
	636	Chapter 1, Appendix 3, Section 5
	637	Chapter 0, Section 6
	638	Chapter 00, Section 4 Chapter 7A
	639	Chapter 3A,Section 2.4 and 2.5 Chapter 1, Appendix 1, Section 2
	640	Not applicable
	641	Not applicable
	642	Chapter 3A, Section 2.5 Chapter 1, Appendix 1, Section 2
	643	Chapter 1, Appendix 1, Section 2
	644	Not applicable
	645	Not applicable
	646 (a)	Chapter 1, Appendix 11
	646 (b)	*Chapter 1, Appendix 4, Section 2*
	647	*Not applicable*
	648	*Not applicable*
	649	*Not applicable*

	Sections of the IAEA <1>	Applicable paragraphs of the Safety Analysis Report
Requirements for Type B packages	657 (b) (i)	Chapter 4A, Appendix 1
	651 (a) (b) (c)	Chapter 2, Appendix 1 Chapter 0, Section 6
	652	Chapter 6A, Section 2.3
	653	Chapter 6A
	654	Chapter 2, Appendix 1, Section 4.4.5
	655	Chapter 2, Appendix 1, Section 4.4.5
	656	Chapter 1, Section 11
	657 (a)	Chapter 3A, Section 6
	657 (b) (ii)	Chapter 3A, Section 6 Chapter 1, Appendix 1, Section 5
	658	Chapter 1, Appendix 1, Section 5
	659	Chapter 3A, Section 2
	660	*Not applicable*
	661	Chapter 1 appendix 1 Section 2 Chapter 3A, Section 2.5.1
	662	Chapter 3A, Section 2.6.1
	663	*Not applicable*
	664	Chapter 0, Section 6 Chapter 2, Appendix 1, Section 4.4.5
	666	*Not applicable*

	Sections of the IAEA <1>	Applicable sections of the Safety Analysis Report
Requirements for packages containing fissile material	671 (a)	Chapter 5A, Section 4
	671 (b) (i)	Chapter 0
	672	*Not applicable*
	673	*Not applicable*
	674 (a)	Chapter 5A
	674 (b)	*Not applicable*
	675	Chapter 1, Appendix 11 Chapter 5A, Section 4
	676	Chapter 1, Appendix 11 Chapter 0, Section 6 Chapter 1, 2, 4A, 5A
	677 (a)	Chapter 5A, Section 4 Chapter 6A, Section 2 and 3
	677 (b)	*Not applicable*
	678	Chapter 5A, Section 4
	679 (a)	Chapter 5A, Section 4
	680	*Not applicable*
	681 (a)	Chapter 5A, Section 4
	681 (b)	Chapter 5A, Section 4
	682 (a)	Chapter 5A, Section 4
	682 (b)	Chapter 5A, Section 4
	682 (c)	Chapter 5A, Section 4
Tests	713	Chapter 1, Appendix 11
	714	Chapter 0, Section 5
	715	Chapter 1, Appendix 11
	716	Chapter 1, Appendix 11
	717	Chapter 1, Appendix 11
	721	Chapter 1, Appendix 4
	722	Chapter 1, Appendix 4, Section 2
	723	*Not applicable*
	724	Chapter 1, Appendix 4, Section 2
	727	Chapter 1, Appendix 4
	728	Chapter 2, Appendices 1 and 2
	729	Chapter 1, Appendix 1, Section 5
	730	Chapter 1, Appendix 1, Section 5

	Sections of the IAEA <1>	**Applicable sections of the Safety Analysis Report**
Requirements for transport	501 (a) (b) (c)	Chapter 7A, Section 3
	502 (a) (b) (c) (d) (e) (g) (h)	Chapter 6A
	506	Chapter 0A, Section 3
	507	Chapter 6A
	523	Chapter 5A
	524	Chapter 6A
	525	Chapter 4A and 6A
	527	Chapter 6A
	531	Chapter 0, Section 4.8
	533	Chapter 0, Section 4.8
	534	Chapter 0, Section 4.8
	536	Chapter 6A
	537	Chapter 6A
	538	Chapter 6A
	569 (a) (b) (c)	Chapter 4A, Appendix 1
Acceptance, approval and administrative provisions	807 (a)	Chapter 0A
	807 (b)	Chapter 0 Appendix 0-1
	807 (c)	Chapter 1, Appendix 11 Chapter 3A, 4A and 5A
	807 (d)	Chapter 6A and 7A
	807 (e)	Chapter 7A
	807 (f)	Chapter 0A, 1A and 2A
	807 (g)	Chapter 6A
	807 (h)	Chapter 0, Figure 0.1
	807 (i)	Chapter 8A
Quality Assurance	306 (a) (b)	Chapter 8A

2. CORRESPONDENCE WITH THE PDSR EUROPEEN GUIDE

European guide structure « Package Design Safety Reports » (PDSR) <2>	**Safety analysis report of the packaging TN106**
Part 1	
1.1 List of PDSR chapter	Summary
1.2 Administrative informations	Chapter 00
1.3 Relative specification to radioactif contents	Chapter 0A
1.4 Relative specification to the packaging	Chapter 0 and appendix, Chapter 7A and appendix
Concept drawing, list of components, list of drawings, materials specification , manufacturing specification....	
Relative specification to the system of isolation and to the containment building	Chapter 0
1.5 Characteristics of performance of the package	Chapter 0 and appendix
1.6 Compliance with the statutory requirements	Chapter 00-2
1.7 Exploitation	Chapter 6A
1.8 Maintenance	Chapter 7A and appendix
1.9 Management system (of the quality)	Chapter 8A
1.10 Illustration of the package	Chapter 00 and appendices
Part 2	
2.1 Common configurations to all the technical analyses of the part 2 of the PDSR	
2.1.1 Reference to the model of package	Chapter 1 Chapter 2 Chapter 4A Chapter 5A
2.1.2 Acceptance criterion and hypotheses of design	
2.1.3 Description and justification of the methods of analysis	
2.1.4 Analysis of the package model	
2.1.5 Comparison between acceptance criteria and analysis results	
2.2 Technical analyses	
2.2.1 Structural analysis	Chapter 1 and appendices
2.2.2 Thermal analysis	Chapter 2 and appendices
2.2.3 Analysis of design of containment	Chapter 3A
2.2.4 Analysis of the external dose rates	Chapter 4A
2.2.5 Analysis of nuclear criticality safety	Chapter 5A

3. REFERENCES

<1> Revision of the applicable AIEA: see chapter 00.

<2> Technical European guide "Package Design Safety Reports for the Transport of Radioactive Material" – Guide européen PDSR Révision 1 (Juin 2008).

DESCRIPTION OF THE TN 106 PACKAGING DESIGN

SUMMARY

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-0E			
0	06/00	Document first drawn up	F. PETIT / L. HANSEL
NEW REF. : DOS-08-00126114-020			
00	07/08	New document reference New formalism Taken the VYAL B resin into account Deletion of tensile force Correction of the formula to calculate the weight packaging according to the useful length packaging	S. CHEVET / JC. BOTT
1	12/12	Translation of the document DOS-06-00032898-004 rév 03 Range's update of the cavity's useful length [2200 mm - 2400 mm], of thermal data and data concerning the packing's gaskets. Deletion of the resin VYAL B and the packaging's electro-polishing. Precision concerning the description of the packaging Increase of the package's maximum mass. Mechanical characteristics' update of materials and screws' tightening torques. Modification of the gasket's dimensions further to the change of the containment building's internal gaskets. Correction concerning the description of the internal envelope Correction concerning the unity used for the resin's specific heat.	R. BAHOU / D. HONDAGNEU

SUMMARY

Purpose:

This chapter sets out all the basic data concerning the TN 106 packaging and necessary for its use and the safety justification, in particular:

- A description of the elements which make up the packaging (components, masses, materials, mechanical and thermal characteristics),
- A description of the containment system (orifices and closure devices) and the associated means to ensure its leaktightness (gaskets, screws).

Essential Parameters:

The packaging, whose overall shape is cylindrical, has an effective length of cavity Lu which can vary from 2200 to 2400 mm; its overall dimensions are as follows:

- Length: Lu + 1424 mm, which is between 3624 and 3824 mm,
- Diameter with covers: 1458 mm,
- Total mass when loaded (Kg): 3400 x Lu + 4140 (where Lu is expressed in meters), which ranges between 11620 and 12300 kg.

The packaging comprises a body, a welded front part and back part and two shock-absorbing covers.

The body bounds a cylindrical cavity of diameter 203 mm and of a useful length. It comprises in the following order:

- A [redacted] mm thick stainless steel shell,
- A [redacted] mm thick lead shell,
- A [redacted] mm thick neutron-poisoning resin shell,
- A [redacted] mm thick stainless steel shell,
- Two pairs of trunnions, one at the front and one at the back, which are used for handling as well as for tipping operations onto the frame,
- Two lifting lugs on 0° of the body, used for handling the package in the horizontal position (with or without its frame) and, if necessary, during tipping operations onto the frame,
- One base plate upon which the package can rest when it is not fitted with its lids.

The front part comprises a stainless steel flange welded to the shell to which the following is fitted:

- One revolving plug made from lead which provides a cavity opening system,
- Two clamps fixed with two M42 screws which act as a bearing for the revolving plug in place,
- One revolving plug control orifice upon which a protective plug is fitted,
- One front lid to allow maintenance of the revolving plug,
- One front closure plate for loading contents,
- A vent orifice (orifice A) and an orifice closure plate.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

The back part comprises a stainless steel flange welded to the shell to which the following is fitted:

- One pushing device made from stainless steel, fitted with a tungsten shielding disc,
- A back closure plate providing access to the pushing device,
- A filling and draining orifice (Orifice B) and an orifice closure plate,

Two removable covers made from balsa wood and plywood, covered by a stainless steel envelope, are screwed to the ends to provide the packaging with shock-absorbency in the event of a drop. These covers prevent access to the closures and lids during transportation.

The leaktightness of the 6 openings (front lid, front closure plate, orifices A and B, revolving plug control, back closure plate) is ensured by double EPDM O-ring gaskets recessed in grooves. These systems make it possible to measure the leaktightness between the gaskets.

The essential parameters are set out in the tables which can be found at the end of this chapter.

The design drawing of the packaging is given in Appendix 0-1.

<u>Subsequent Use of Essential Parameters:</u>

(1) The analysis of the structural strength of the packaging (definition of the model, drop tests and interpretations) and of its additional structures (covers, trunnions and handling lugs) is set out in Chapter 1 and its appendices. It is based on the geometry of the packaging, the mass and the mechanical properties of the packaging elements, which can be found in Tables 0.6 and 0.4,

(2) The thermal analysis of the TN 106 packaging design in normal and accident conditions of transport is set out in Chapter 2 and its appendices and is based on the geometry of the packaging and the thermal properties of the packaging materials (Table 0.5),

(3) The analysis of the containment of the TN 106 packaging is set out in Chapter 3A and is based on the description of the containment system and the orifices as well as the authorised contents described in Chapter 0A,

(4) The shielding of the TN 106 packaging is analysed in Chapter 4A based on the geometry of the packaging and the chemical composition of the materials used for gamma and neutron protection (steel, lead, resin) of Table 0.8,

(5) The safety analysis of the TN 106 package design can be found in Chapter 5A and is based on the geometry of the packaging and the chemical composition of the constituent materials from Table 0.8, as well as the authorised contents described in Chapter 0A.

1. INTRODUCTION

The TN 106 packaging is designed for dry transportation of different radioactive material and in particular:

- Assemblies, rods or segments of fuel rods, irradiated or not. These rods contain uranium and/or plutonium oxides,
- Elements or pieces of elements comprising flat or cylindrical fuel plates containing enriched uranium,
- Solid irradiated non fissile material of any chemical composition.

These elements can be placed in an internal arrangement, which is leaktight or not, and all together form the contents defined in Chapter 0A.

2. DESIGN DRAWING OF THE PACKAGING

Packaging TN 106 is shown in the design drawing in Chapter 0-1.

This drawing shows:

- The dimensions and allowance or gap related to the use of the packaging and safety analysis contained in the SAR,
- The identification items of the various components used in the rest of this SAR.

3. GENERAL DESCRIPTION

The packaging, which is mostly cylindrical in shape, comprises a body, a welded front part and back part and two shock-absorbing covers.

The body bounds a cylindrical cavity of variable length; it is made up of the following from the inside outwards:

- An internal stainless steel plate envelope,
- A primary biological shield (gamma shielding) made from lead,
- A secondary biological shield (neutron shielding) made from borated resin,
- An external stainless steel envelope with a base plate and handling and tie-down devices.

The front part comprises a stainless steel flange welded to the shell to which the following is fitted:

- A revolving plug made from lead which provides access to the cavity,
- Two screwed clamps which hold the revolving plug in place,
- A revolving plug control orifice made from stainless steel upon which a protective plug is fitted,
- A front lid made from stainless steel for revolving plug maintenance,
- A front closure plate made from stainless steel for loading contents,
- A vent orifice (orifice A) and an orifice closure plate made from stainless steel.

The back part comprises a stainless steel flange welded to the shell to which the following is fitted:

- A stainless steel pushing device with a tungsten shield disc,
- A back closure plate made from stainless steel providing access to the pushing device,
- A fill and drainage orifice (orifice B).

Two removable covers made from balsa wood and plywood, covered by a stainless steel envelope are screwed to the ends to provide the packaging with shock-absorbency in the event of a drop. These covers prevent access to the openings during transportation.

The leaktightness of the 6 openings (front lid, front closure plate, orifices A and B, revolving plug control, back closure plate), is ensured by double EPDM O-ring gaskets recessed in grooves. These systems are used to check leaktightness between the gaskets. In the rest of this chapter only the internal gasket JI is mentioned, the outer gasket corresponds to reference JI+1.

In order to guarantee a low level of contamination of the packaging, the outer surfaces of the packaging are carefully conditioned (by electropolishing or any other procedure) and the welds are ground and polished.

The main dimensions are as follows:

- Inner cavity:
  - Effective length (Lu): Variable from 2200 to 2400 mm
  - Effective diameter: 203 mm

- Overall dimensions:
  - Total length: Lu + 1424 mm (Therefore ranges from 3624 to 3824 mm)
  - Length without covers: Lu + 778 mm (Therefore ranges from 2978 to 3178 mm)
  - Diameter with covers: 1458 mm
  - Diameter without covers (at the trunnions): 958 mm
  - External diameter of the body: 820 mm

The main masses (in kg) are as follows as a function of the effective length Lu (in m):

- Mass of the empty packaging (and without the covers): 3146 x Lu + 2750 (And therefore ranges between 9671 and 10300 kg).

- Mass of the empty packaging (with the covers): 3146 x Lu + 4140 (And therefore ranges between 11 061 and 11 690 kg).

- Maximum total mass of the loaded package (with covers): 3400 x Lu + 4140 (And therefore ranges between 11 620 and 12 300 kg).

The masses of the main components are given in Table 0.6.

4. DESCRIPTION OF THE PACKAGING SUB-ASSEMBLIES

4.1 Body

- The minimum [redacted] mm thick internal envelope (101), witch made from stainless steel, bounds the cylindrical inner cavity. A glass wool tape (102) allowing to test the leaktightness of the internal envelope's extremity welds (101) during maintenance operations, is deposited along its extern face.

- The gamma biological protection (103) is made from Lead; it is poured around the inner envelope. Its partially current thickness is equal to [redacted] mm at least,

- The neutron biological shield (104) is made from borated resin, and is poured between the lead and the outer envelope. Its thickness is constant and equal to [redacted] mm as a minimum requirement,

- The outer envelope (105) made from a minimum [redacted] mm thick stainless steel sheeting is cylindrical. It comprises "Poral" type pellets (110) and fusible plugs (109) which prevent overpressure in the event of fire. A closed base plate is fitted at its ends (108) and it has two pairs of trunnions (106) and two lifting lugs (107) which are described in Section 4.7,

- The inner and outer envelopes are welded to two stainless steel flanges.

4.2 Front Flange

- The front flange (201) contains the revolving plug system (400), the revolving plug closure plate (204), the front lid (207), the front closure plate (209) and the orifice A closure plate (211). The front flange comprises the six M20 tappings which ensure the fastening of the front shock-absorbing cover (500),

- A duct leads from the bottom of the flange and emerges in the compartment of the front lid at orifice A. Its end is connected to a "Staübli" type quick-connect coupling (213). A gasket (J13) ensures its leaktightness. It serves as a cavity vent orifice during the draining of the packaging when the loading is under water. It can also be used for depressurisation prior to transport,

- The revolving plug closure plate is protected by a plug (206) with an acme thread. A gasket (J5) ensures its leaktightness. It is fitted with eight M8 screws (205) and is used to access the revolving plug control axis (202). This axis comprises an anti-dirt gasket (J12) and is fitted with a polarising device (203). This polarising device prevents the rotation of the revolving plug during transport and can only be fitted if the revolving plug is closed,

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- The revolving plug closure plate is connected to the polarising device (203) which has a dual role: to keep the revolving plug in the closed position in normal and accident conditions of transport and to ensure the closed position of the revolving plug when the revolving plug closure plate (polarising device) is fitted. The connection is by means of two M3 stud bolts. The connection between the two parts (203) and (204) is ensured in such a way that radial and axial gap is maintained and any transmission of forces from the revolving plug to the closure plate is prevented,

- The front lid is fixed by means of twenty-four M16 screws (208) and provides access to the revolving plug during maintenance. A gasket (J9) ensures leaktightness. The front closure plate is screwed to its centre by means of twelve M16 (210) screws and it is fitted with a centring pin which allows the contents to be loaded. A gasket (J7) ensures its leaktightness. It is also fitted with the orifice A closure plate which is screwed in place by means of eight M8 screws (212). A gasket (J1) ensures its leaktightness.

4.3 Revolving Plug

- The revolving plug is made from a stainless steel drum (401, 403 and 404) filled with lead (405) and has a passage section made from stainless steel (402) of diameter 203 mm It provides axial shielding when it is closed (during transportation) and radial shielding when it is open (during loading),

- The top (406) and bottom (407) axes of the revolving plug are guided by two alloy antifriction rings (408). Two clamps (216 and 218) each one screwed by two M 42 screws (217) witch hold the revolving plug at its axes,

- The revolving plug is controlled by an axis (202) and blocked from rotation during transportation by the polarising device (203). A stop (409) limits the rotation of the revolving plug at 90°,

- The revolving plug contains two tapped inserts M16 (410) to allow handling during the assembly and the dismantling.

4.4 Back Flange

- The back flange (301) contains the pushing device, the back closure plate (307) and the orifice B closure plate (309). The back flange comprises the six (6) M20 tappings which ensure the fastening of the back shock-absorbing cover (500),

- A duct leads from the bottom of the cavity and splits into two ducts, one of which leads to the back closure plate, the other to the radial part of the flange at orifice B. Its end is linked to a "Staübli" type quick-connect coupling (213) fitted with a leaktightness gasket (J13). It is used as a filling and drainage orifice during underwater loading. Its radial position allows line connection when the packaging is vertical. It can also be used for depressurisation prior to transportation,
- The orifice B closure plate (309) is screwed in place by eight M8 screws (310), a gasket (J1) insures its leaktightness.

- The back closure plate is held by twelve (12) M16 screws (308). A gasket (J3) ensures its leaktightness,

- The pushing device, made from stainless steel, is formed by a cone (302), by an additional sheeting (303) in tungsten [redacted] mm in thickness and a lid (304). It is fitted at each end with a tapped M20 hole designed for the possible fitting of a device for handling the contents (such as a shovel) at the front and the stem of the poker at the back. It is screwed and blocked in rotation in its compartment by a sliding device (305) fixed by means of two M8 screws (306).

4.5 Common Characteristics of the Closure Systems

The 6 closure systems (front lid, front closure plate, orifice A closure plate. revolving plug closure plate, back closure plate, orifice B closure plate) are equipped with:

- A leaktightness system made up of two concentric O-ring gaskets which form an inter-gasket space. An orifice providing access to this inter-gasket space is used to carry out the leaktightness test. The orifice is blanked off by an M20 plug (115) with an O-ring gasket,

- One or more handling tappings: six M16 for the front lid, four M16 for the front closure plate, two M8 for orifice A and B closure plates, one M8 for the revolving plug closure plate, four M16 for the back closure plate and two M16 for the revolving plug.

The tightening torques of all packaging's screws is set out in Table 0.3.

4.6 Shock absorbing Covers

The front and back covers are identical. They are made from stainless steel plate and have a balsa wood and plywood filling. The wood provides shock-absorbency and heat insulation in the case of regulatory tests.

These covers are fixed on the body of the packaging by six CHC M20 screws Outing of imperdables washers and their position is defined by a centring pin.

The screw inserts which have shoulders that sit proud on the external surface of the covers are drilled allowing a metal anti-tamper gasket to be put in place for transportation.

The covers are fitted with valves in order to avoid overpressure in the event of fire.

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4.7 Handling Devices and stowing

The handling devices comprise:

- Two pairs of welded trunnions, one at the front and one at the back, which are used for transportation (Under use of the frame version 1) and tipping the packaging onto the frame as well as for handling,
- Two welded lugs on the generator in 0 ° of the body, used for handling the package in the horizontal position (with or without its frame) and, if necessary, during tipping operations onto the frame,
- A base plate on which the package can rest when it is not fitted with its covers, this base plate guarantees a load on the ground less than 11t/m² whatever the packaging effective length.

During transportation, tie-down is provided in the horizontal position by the trunnions, thelay down bed plate.

4.8 Marking

The packaging is fitted with stainless steel plates etched and welded to the outer envelope:

- One manufacturer's plate on the 0° centreline indicating the maximum mass of the package,
- Two statutory plates on the 90° and 270° centrelines bearing the following:
    - Regulatory trefoil symbol,
    - Type B(U) F,
    - Design identification mark,
    - Number in series of the design,
    - Gross mass.

The external surface of the front flange shall be marked with the longitudinal traits at the angles 0 °, 90 °, 180° and 270° (0° on the top centreline).

5. DESCRIPTION OF THE CONTAINMENT SYSTEM

The containment system corresponds to the envelope of free space which the contents will occupy. Figure 0.2 shows the diagrams of the orifices of the containment system.

The containment system is made from:

- The inner cylindrical cavity of the packaging bounded by the central tube, the compartment of the revolving plug and the compartment of the pushing device,

- The 14 mm drainage and vent ducts,

- The front lid, the front closure plate, orifices A and B closure plates, the revolving plug closure plate and the back closure plate.

Leaktightness is provided for each orifice by means of the double EPDM O-ring gasket systems described in Section 4.5. The packaging body is made leaktight by its inner shell and front and back flanges which are welded together (a device is used to check leaktightness during maintenance operations).

6. CHARACTERISTICS OF THE MATERIALS USED FOR THE PACKAGING

The materials used to manufacture the packaging are as follows (see Table 0.1):

- Stainless steels,
- Lead,
- Additional shielding: tungsten,
- Resin,
- Balsa wood,
- plywood
- Welding material,
- Gasket materials,
- Fuse materials.

All these materials have the mechanical and thermal properties specified in Tables 0.4 and 0.5 respectively.

These materials do not degrade in regulatory temperature conditions, which range from -40°C to 70°C.

Equivalent materials to those specified in this safety analysis report could be used subject to justification of behaviour which does not contradict the conclusions of the safety demonstrations.

6.1 Stainless Steel

All steel parts, excepting screws, handling devices, top closure plate and revolving plug control axis are made from stainless steel X2CrNi19-11 or equivalent (NF EN 10088/2 or NF EN 10088/3).

The handling devices, trunnions, lifting lugs, front lid and the revolving plug control axis are made from stainless steel type X2CrNiMoN22-5-3 or equivalent (NF EN 10088/2 or NF EN 10088/3).

The mechanical properties of these two steels are set out in Table 0.4.

6.2 Steel of Threaded Fasteners

The screws are made from high quality, forged steel, and are heat treated to ensure compliance with the mechanical properties described in Table 0.4.

Screws of class 8.8, 10.9 and 12.9 have a minimum resilience of KVmin = 27 J at -40°C.

All the screws are not greased and zinc-coated, bichromated (or equivalent surface treatment) to protect them from corrosion.

The covers screws are cut and equipped with steel washers having a hardness equal at least to that of the screws.

The cover head screws, the top closure plate, the thorough cover, the covers of orifices A and B and the barrel's cover are cut.

6.3 Lead

The pouring is done using lead with a minimum density of 11.2. The purity of the lead must be at least 99.7%.

The temperature at which lead melts is 327 °C.

6.4 Additional Shielding

The additional back axial shielding situated in the pushing device is made from tungsten of nominal density 18.

6.5 Resin

The resin used for the neutron protection is TN International resin type “F”

The “TN International” resin is a self-extinguishing resin.

The thermal characteristics of this resins are given in Table 0.5.

6.6 Wood

6.6.1 Balsa Wood

The balsa wood used to fill the shock-absorbing covers has an approximately square cross-section and a density of 0.12 (for information purposes).
The compressive stress of the balsa wood must fall within the following range:
9 MPa $\leq \sigma_{Compression} \leq$ 11 MPa

- Compression rate: 78 % minimum (in fiber direction),
- Maximum moisture content: 15 %.

6.6.2 Plywood

The density of the plywood used in the shock-absorbing covers is approximately 0.5.

6.7 Gaskets

All the used gaskets except those equipping quick connect couplings are in elastomer EPDM.

The used nuances of gaskets are the following ones:

- EP8517 of the French Joint.
- 48DRL13 of STACEM.

Hardness: [redacted] shore.

Maximum temperature of use: [redacted] °C

Minimum temperature of use: -40 °C

6.8 Welds

The mechanical properties of the filler metal must, as a minimum requirement, be equal to those of the present metals.

The main welds of the packaging are set out in Table 0.7.

6.9 "Poral" Type Pellets and Fuses

"Poral" Type Pellets

"Poral" type pellets, which allow outgassing, are made from sintered stainless steel pellets fitted in a welded insert on the outer shell.

Fuses

The safety fuses which allow the vaporisation of the water of the thermal insulation in the event of a fire are made from alloy pellets with a low melting point (lower than 180 °C). They are screwed in the thickness of the outer envelope and Leaktightness on conical threading is provided by PTFE tape.

7. CONSTRUCTION CODES

Packaging TN 106 is manufactured in compliance with CODAP 95 regulations or equivalent (in particular, the ASME regulations).

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8. CHARACTERISTICS TO BE COMPLIED WITH

The packaging characteristic requirements which must be met in order to ensure compliance with the assumptions of the SAR are described next. The other values used in this SAR are nominal values.

8.1 Dimensional Characteristics

The thicknesses of the steel of the outer and inner shell made from lead and resin shown in the design drawing (Appendix 0-1) are the minimum values to be complied with.

8.2 Mass

The maximum weight of the empty packaging (body, lid and shock-absorbing cover) must be less than the value specified in Table 0.6.

8.3 Properties of the Materials

The yield strength and tensile strength shown in Table 0.4 are minimum values to be complied with.

LIST OF TABLES

LIST OF FIGURES

TABLE 0.1
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LIST OF PACKAGING COMPONENTS

Ref.	Description	Quantity	Material
100	**Body**	**1**	
101	Inner Shell	1	X2CrNi19-11
102	Glass Wool	-	Glass Wool
103	Gamma Shielding	1	Lead
104	Neutron Shielding	1	Neutron Resin
105	Outer Shell	1	X2CrNi19-11
106	Trunnion	4	X2CrNiMoN22-5-3
107	Lug	2	X2CrNiMoN22-5-3
108	Base Plate Support	1	X2CrNi19-11
109	Thermal Fuse	6	Eutectic Fuse
110	Poral Pellet	6	X2CrNi19-11
112	Regulatory plate	2	Polished X2CrNi19-11
113	Manufacturer's Plate	2	Polished X2CrNi19-11
115	M20 Test Plug	7	X2CrNiMo17-2-2 or bronze
116	Poral Pellet Nut	6	X2CrNiMo17-2-2
117	Poral Pellet Gasket	6	EPDM

Ref.	Description	Quantity	Material
200	**Front Part**	**1**	
201	Front Flange	1	X2CrNi19-11
202	Revolving Plug Control Axis	1	X2CrNi19-11
203	Revolving Plug Positioning Piece	1	X2CrNi19-11
204	Revolving Plug Closure Plate	1	X2CrNi19-11
205	M8 screw	8	10.9
206	Plug	1	X2CrNiMo17-2-2
207	Front Lid	1	X2CrNi19-11
208	M16 Screw	24	8.8
209	Top Closure Plate	1	X2CrNiMoN22-5-3
210	M16 Screw	12	8.8
211	Orifice A Closure Plate	1	X2CrNi19-11
212	M8 Screw	8	10.9
213	Quick-Connect Coupling	2	Stainless steel
214	Insert	1	X2CrNiMo17-12-2
216	Top Clamp	1	X2CrNi19-11
217	M42 Screw	4	10.9
218	Bottom Clamp	1	X2CrNi19-11
220	Centring Pin	5	X2CrNi19-11

TABLE 0.1
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LIST OF PACKAGING COMPONENTS

Ref.	Description	Quantity	Material
300	**Back Part**	**1**	
301	Back Flange	1	X2CrNi19-11
302	Bottom of the Pushing Device	1	X2CrNi19-11
303	Pushing Device Shielding	1	Tungsten
304	Top of the Pushing Device	1	X2CrNi19-11
305	Stop plate	1	X2CrNi19-11
306	M8 Screw + Washer	2	A2-70
307	Back closure plate	1	X2CrNi19-11
308	M16 Screw	12	8.8
309	Orifice B Closure Plate	1	X2CrNi19-11
310	M8 Screw	8	10.9

Ref.	Description	Quantity	Material
400	**Revolving Plug**	**1**	
401	Outer Shell	1	X2CrNi19-11
402	Internal Tube	1	Z2CN18-10
403	Top Plate	1	X2CrNi19-11
404	Bottom Plate	1	X2CrNi19-11
405	Gamma Shielding	1	Lead
406	Top Axis	1	X2CrNiMoN22-5-3
407	Bottom Axis	1	X2CrNiMoN22-5-3
408	Bearing	2	Antifriction
409	Stop	1	X2CrNi19-11
410	Handling Insert	2	X2CrNi19-11

Ref.	Description	Quantity	Material
500	**Cover**	**2**	
501	Outer Shell	1	X2CrNi19-11
502	Bottom Plate	1	X2CrNi19-11
503	Bottom Inner Shell	1	X2CrNi19-11
504	Bottom Gusset Plate	6	X2CrNi19-11
505	Bottom Sector of the Shock Absorber	6	Radially Fibred Balsa Wood
506	Intermediate Plate	1	X2CrNi19-11
507	Intermediate Plate	1	X2CrNi19-11
508	Plate	1	Ply Wood
509	Puncture Protection Plate	1	X2CrNiMoN22-5-3
510	Top Gusset Plate	6	X2CrNi19-11

TABLE 0.1
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LIST OF PACKAGING COMPONENTS

Ref.	Description	Quantity	Material
514	Top Inner Shell	1	X2CrNi19-11
516	Handling Lug	2	X2CrNi18-9
517	Handling Lug Plate	2	X2CrNi18-9
518	Support Bracket	2	X2CrNi18-9
519	M20 Screw	6	12.9
520	Captive Washer	6	
530	Valve	1	Stainless Steel
109	Thermal Fuse	12	Eutectic Fuse

TABLE 0.2

LIST OF GASKETS

Ref.	Description	Inner diameter (mm/mm)(1)	Ring du diameter (mm/mm)(1)	Number	Materials
J1	Orifice A and B Closure Plate Internal Gasket	Proprietary Information Withheld Pursuant to 10 CFR 2.390		2	Part of containment system/ EPDM
J3	Back closure plate inner Gasket			1	
J5	Revolving Plug Closure Plate Inner Gasket			1	
J7	Front Closure Plate Inner Gasket			1	
J9	Front Lid Inner Gasket			1	

(1) : First nombre = nominal value ; seconde number = maximum tolerance.

Other packaging gaskets

Ref.	Description	Inner diameter (mm/mm)(1)	Ring du diameter (mm/mm)(1)	Number	Materials
J2	Orifice A and B Closure Plate External Gasket	Proprietary Information Withheld Pursuant to 10 CFR 2.390		2	Part of containment system/ EPDM
J4	Back closure plate External Gasket			1	
J6	Revolving Plug Closure Plate External Gasket			1	
J8	Front Closure Plate External Gasket			1	
J10	Front Lid External Gasket			1	
J11	M20 Inter-Gasket Test Plug			7	
J12	Revolving Plug Control Axis			1	
J13	Quick-Connect Coupling			2	

Gaskets J_i are fitted in grooves G_i in the design drawing respectively

TABLE 0.3

SCREWS SPECIFICATION

	Front Lid	**Front Closure Plate**	**Back Closure Plate**	**Clamp**	**Revolving Plug Closure Plate**	**Drainage Closure Plate (orifice B)**	**Vent Closure Plate (orifice A)**	**Covers**
Item	208	210	308	217	205	310	212	519
Number of Screws	24	12	12	4	8	8	8	12
Diameter in mm	16	16	16	42	8	8	8	20
Minimum Class	8.8	8.8	8.8	10.9	10.9	10.9	10.9	12.9
Tightening torque in N.m	105	140	110	2100	15	15	15	380
Uncertainty on the tightening torque	± 10							

TABLE 0.4
(PAGE 1/2)

MECHANICAL PROPERTIES OF PACKAGING STEELS

Stainless Steel Type A								
Temperature (°C)	-30	40	100	150	200	250	300	350
Minimum Yield Strength at 0,2% (MPa)	200	200	147	132	118	108	100	94
Minimum Ultimate Tensile Strength (MPa)	500	500	410	380	360	350	350	350
Young's Modulus (GPa)	198	194	189	186	183	179	179	179
Coefficient de dilatation thermique (10^{-6} .K^{-1})	14,75	15,5	16,1	16,55	17,05	17,4	-	-
Minimum Elongation A%	45							

Stainless Steel Type A (Except covers steel [(1)]) Example : X2CrNi19-11, X2CrNi18-9						
Temperature (°C)	20	150	200	250	300	350
Minimum Yield Strength at 0,2% (MPa)	175	130	118	108	100	94
Minimum Ultimate Tensile Strength (MPa)	450	-	360		-	-
Young's Modulus (GPa)	198					
Minimum Elongation A%	48					

(1) The minimum mechanical characteristics of the stainless steel type A In covers are: Re = 200 MPa and Rm = 500 MPa.

Steel A Type of the Front Lid rep. 207 (Only characteristics that are different than the steel standard A type)	
Temperature (°C)	20
Minimum Yield Strength at 0,2% (MPa)	239
Minimum Ultimate Tensile Strength (MPa)	517

TABLE 0.4
(PAGE 2/2)

MECHANICAL PROPERTIES OF PACKAGING STEELS

Stainless Steel B Type Example : X2CrNiMoN22-5-3		
Temperature (°C)	20	150
Minimum Yield Strength at 0,2% (MPa)	239	335
Minimum Ultimate Tensile Strength (MPa)	517	-(*)
Young's Modulus (GPa)	198	-(*)

*Values stemming from the standard

Steel screw in carbon			
Screw Class	8.8	10.9	12.9
Temperature (°C)	20		
Minimum Yield Strength at 0,2% (MPa)	640	900	1080
Minimum Ultimate Tensile Strength (MPa)	800	1000	1200
Young's Modulus (GPa)	212	212	212
Minimum Elongation A%	12	9	8

TABLE 0.5

THERMAL PROPERTIES OF PACKAGING MATERIALS

Steels

Acier Type A						
Temperature (°C)	-30	40	100	150	200	250
Conductivity ($W.m^{-1}.K^{-1}$)	13	15	16,2	17	17,9	18,6
spécific heat ($J.kg.^{-1}K^{-1}$)	484	500	511	522	532	541
Density ($kg.m^{-3}$)	7 920					
	Before Fire		During Fire		After Fire	
Emissivity	0,3		0,8		0,8	
Solar absorptivity	0,4		-		0,9	

Steel Type B						
Temperature (°C)	-30	40	100	150	200	250
Conductivity ($W.m^{-1}.K^{-1}$)	16,5	17,25	18	18,5	19	19,5
Spécific heat ($J.kg.^{-1}K^{-1}$)	400	400	450	475	500	525
Density ($kg.m^{-3}$)	7 800					
	Before Fire		During Fire		After Fire	
Emissivity	0,3		0,8		0,8	
Solar absorptivity	0,4		-		0,9	

Resin F

Proprietary information withheld pursuant to 10 CFR 2.390

Lead

Proprietary information withheld pursuant to 10 CFR 2.390

TABLE 0.6

BREAKDOWN OF PACKAGE MASSES

Component	Nominal Mass (kg)*
Front Lid	208
Front Closure Plate	32
Orifice Closure Plate A (or B)	2.5
Revolving Plug	168
Revolving Plug Closure Plate	3
Back Closure Plate	16
Shock-Absorbing Cover (x2)	695
Top Clamp Flange	41
Bottom Clamp Flange	33
Pushing Device	35

* Masses estimated using nominal dimensions.

Cavity Length	Empty packaging (kg)	Package mass with maximal Load (kg)
2 200 mm	11 061	11 620
2 400 mm	11 690	12 300

TABLE 0.7
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WELD DETAILS

Weld	Location	**Type of Weld**	**Inspection**	**Figure**
S_1	<u>Containment envelope</u> Inner Shell of the Body and Front Flange.	Buttweld Full Penetration	X-ray 100% Dye-penetrant 100%	
S_2	<u>Containment envelope</u> Inner Shell of the Body and Back Flange	Buttweld Full Penetration	X-ray 100% Dye-penetrant 100%	
S_3	<u>External envelope:</u> Outer Shell of the Body and Front Flange	Buttweld Full Penetration	Dye-penetrant 100%	
S_4	<u>External envelope:</u> Outer Shell of the Body and Back Flange	Buttweld Full Penetration	Dye-penetrant 100%	
S_5 and S_6	<u>External envelope:</u> Longitudinal Weld of the Outer Shell	Buttweld Full Penetration	Dye-penetrant 100%	

TABLE 0.7
Page 2/2
WELD DETAILS

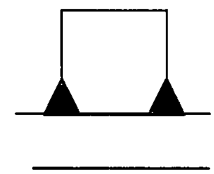
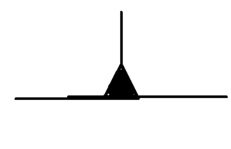
Weld	Location	**Type of Weld**	**Inspection**	**Figure**
S_7	Handling Element: Outer Shell and Trunnions.	Fillet Weld 10 mm Apothem	Dye-penetrant 100%	
S_8	Handling Element: Outer Shell and Handling Lugs	Fillet Weld 10 mm Apothem	Dye-penetrant 100%	

TABLE 0.8

CHEMICAL COMPOSITION OF THE MAIN MATERIALS OF THE PACKAGING

Material	Density (kg/m^3)	Composition (%)
Stainless Steel	7850	Cr: 18 Fe: 72 Ni: 10
Lead	[redacted]	[redacted]
Plywood	500	H: 7 C: 36 O: 57
"F" Resin	[redacted]	[redacted]
Air	1.2	O: 80 N: 20

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

FIGURE 0.1

DIAGRAM OF TN 106 PACKAGING

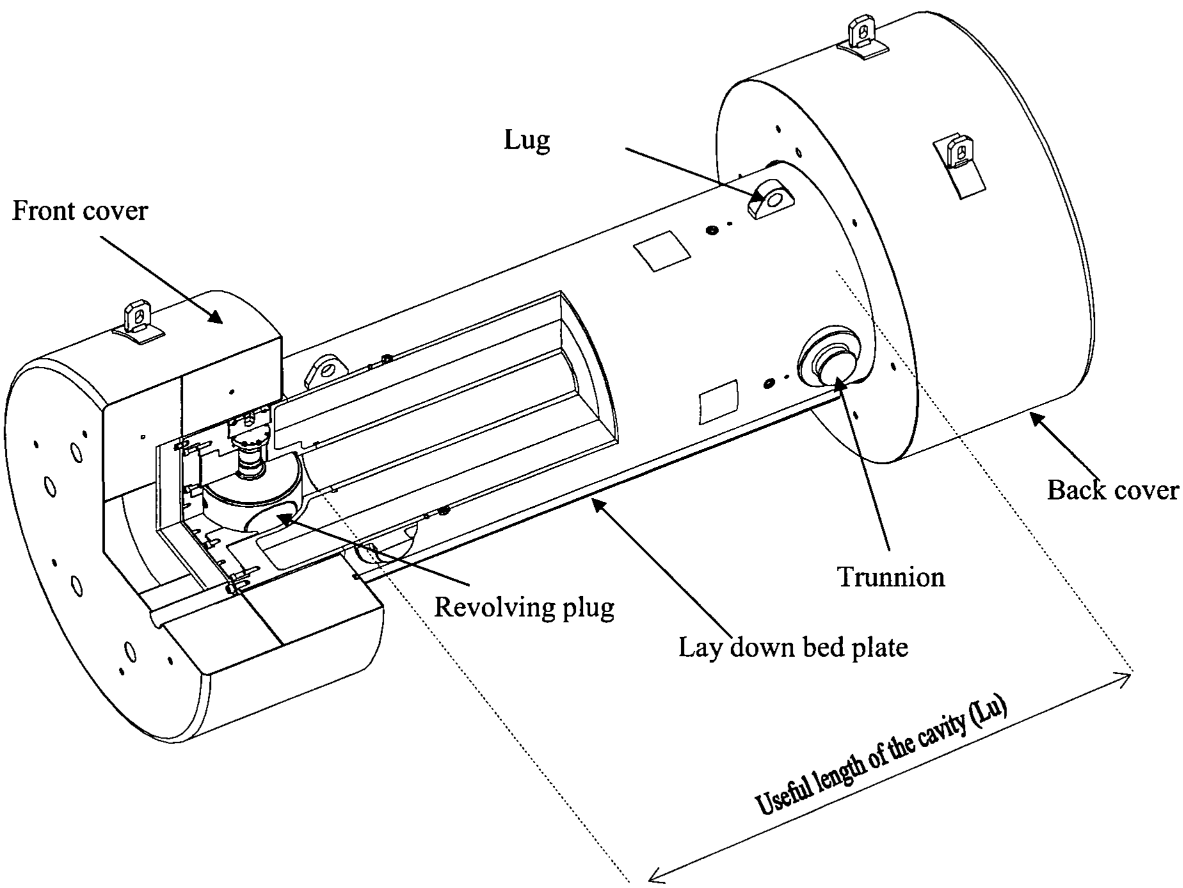
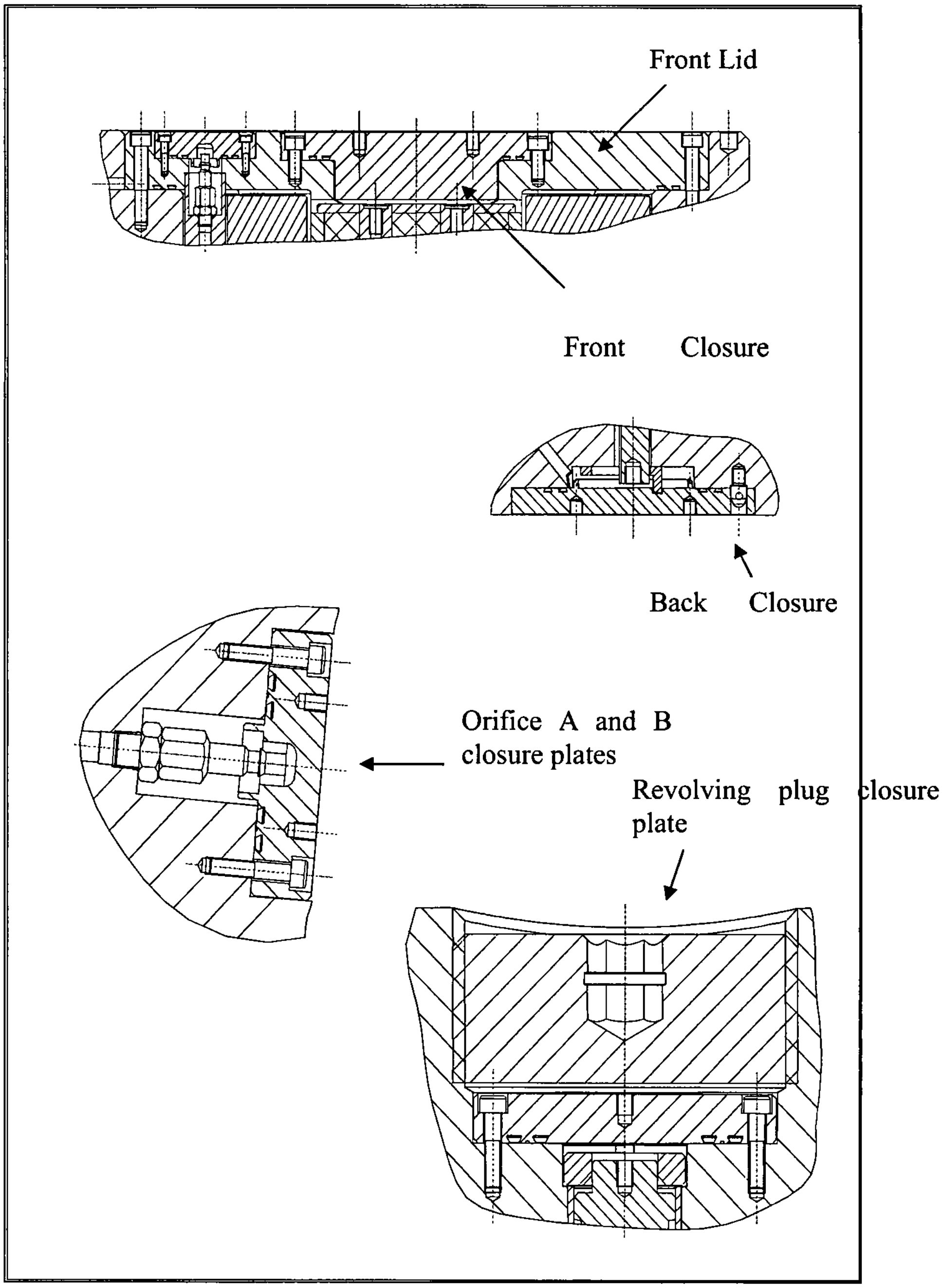


FIGURE 0.2

DIAGRAM OF THE PACKAGING ORIFICES



CONCEPT DRAWING OF TN 106 PACKAGING

Reference	Index	Format	Title
5573-04	F	A0	Concept Drawing – TN 106 Packaging

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-0-1E			
-	07/07/99	Ind. A: Drawing first issue	
-	09/06/00	Ind. B: Enlargement of the surface upon which the packaging is set down Increase of the effective diameter of the trunnions Revolving plug rotation stop over 90° integrated in the lower pivot Rotation bearing of the revolving plug with the clamps Central protective boss of the seals on all closure plates Addition of regulatory plates Addition of the value of the effective safety gaps Identification and marking of the weld beads Additional views for clarification	
-	03/08/00	Ind. C: Standardisation of the screws Increase of the diameter of the axes of the lugs of the covers	
0	28/12/00	Ind. D: Addition of valves on the covers Modification of the definition of the Poral pellet supports	L. MARIETTE/ HANSEL
Ref. : DOS-08-00126114-021			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT
1	02/13	Ind. E : Update of the useful length of the cavity Ind. F : Update of the drawing (correction of mistakes) **(applicable version)**	R. BAHOU / D. HONDAGNEU

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

F	[illegible]	[illegible]	E. [illegible]	[illegible]	[illegible]
E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
REV	DATE	[illegible]	[illegible]	[illegible]	OBSERVATIONS

TN INTERNATIONAL

AREVA

5573-04

TN 106 PACKAGING
CONCEPT DRAWING

EMBALLAGE TN 106
PLAN DE CONCEPT

A0

ECHELLE SCALE 1/10

Previous reference: 5573-Z-0A

DESCRIPTION OF INTERNAL CONSTITUENTS AND CONTENT AUTHORISED IN THE TN 106 PACKAGE MODEL

CONTENTS

REVISION STATUS

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-0A			
0	01/01	Document first drawn up	L. MARIETTE/ L. HANSEL
1	04/01	Increase of the burn-up rate for UO_X and MOX fuel types. Clarification on oxide contents Addition of plenums for contents of type UO_X, MOX and Fast Neutron Reactor. Addition of contents in the form of solid uraniferous material (MTR, NUGG types). Clarification on the envelope reference contents for calculating the release of activity used in Chapter 3A.	L. MARIETTE/ C. VALLENTIN
2	11/01	Incorporation of comments from TRANSNUCLEAIRE fax DRP/SCA/01-0171 of 25/09/01	L. MARIETTE/ C. VALLENTIN
Ref. : DOS-08-00126114-030			
00	11/08	New document reference New formalism Account takenConsideration of the new authorised weightsmasses of material, linked to the change from a homogeneous model to a to a heterogeneous one in safety-criticality calculations and modification of the heavy metal weightsmasses, following the consideration of release through permeation. Presentation of the new rule for uranium and plutonium mixtures. Presentation of the maximum number of broken rods transportable (following consideration of the possible radiolysis phenomenon in broken rods which could contain water). Reduction in the maximum weightmass of hydrogenated (resin type) products admissible. Update of the maximum masses of heavy metal linked to the new release calculations. Update of the maximum masses of fissile material linked to the new criticality calculations.	S.CHEVET/ JC. BOTT

		Integration of reduced thermal loadings. Consideration of the update of mechanical calculations made in Chapter 5573-Z-1A Rev.1. Content 8 type 2 becomes content 3 type 2.	
01	06/11	Translation of the documents DOS-06-00032898-005 rev 5 Integration of the fissile contents n°21, 22 and non-fissile contents 23, 24, 25 type 1 and/or type 2 Integration of a new internal arrangement of diameter 110 mm for content 21 Integration of the fissile content n°26 Numbering of the non-fissile contents from 13 to 20	B. GSIB/ C. GRANDHOMME
02	12/12	Translation of the documents DOS-06-00032898-005 rev 8. Displacement of the calculation of the release activities in the chapter 3A and appendices. Modification of the thermal powers. Deletion of the contents n°7 and n°21. Addition of a specific type for the contents N°1, n°2, n°3 and n°5. Tables update to take into account the results of the new release calculations. Precision concerning the maximum masses's acceptable punishing character of contents according to the thicknesses of the internal arrangements for the criticality purposes. Modification of the mass's definition of hydrogenated products authorized in the cavity. Put in coherence the definition of the contents with the approval certificates.	R. BAHOU / D. HONDAGNEU

1. INTRODUCTION

The objective of this chapter is to present the content authorised to be transported in the TN 106 package.

The following paragraphs successively describe:

- the characteristics common to all content (geometry, mass, thermal power, activity),
- the physicochemical and nuclear characteristics of each content,
- the internal fittings.

The characteristics given here are those used to justify the safety of the package model TN 106. In all cases, the transport must be performed dry.

2. CHARACTERISTICS COMMON TO ALL CONTENT

2.1 Geometry

The maximum section of content must come within a circle of a diameter of 203 mm.

2.2 Mass

The maximum acceptable mass applicable to all the content (including internal fittings) is 254 kg/m of cavity.

2.3 Activity

The activity of loading will be such that, given the nature and energy of the radiation emitted, the acceptable dose rate limits around the package will not be exceeded.

Furthermore, compliance with maximum combustion rates, minimum cooling time and maximum enrichment time, or activities and masses of gas participating in release, specified for each content and on which the release study is based, can ensure that the regulatory criteria for the release of activity under normal and accidental transport conditions will not be exceeded.

Furthermore, this activity must be less than 75 x L_u (in PBq) where L_u is the length of the cavity in metres.

2.4 Maximum mass of hydrogenated products

With the exception of water which may be contained in the failed rods, the total mass of hydrogenated products (resin type) according to the mass percentage of hydrogen present in the compound must comply with the following values (see chapter 3A):

Mass percentage P_H of hydrogen	$P_H \leq 5\%$	$5\% < P_H \leq 10\%$	$10\% < P_H \leq 11\%$
Mass of hydrogenated products authorised (in g)	$\leq 6.48 \times V_L^{(1)}$	$\leq 3.24 \times V_L^{(1)}$	$\leq 2.94 \times V_L^{(1)}$

(1): V_L: free volume of the cavity if the internal fitting is not gas tight, or free volume of the internal fitting if it is gas tight (in m^3)

The contents that may transport these masses are the contents n° 1 to 6, n° 8 to 20 and n° 23.

2.5 Maximum number of failed rods transportable

Before transport, in case there are any failed rods present which may contain water, the maximum number of rods transportable in the package TN 106 is 22 (see chapter 3A).

The content that these rods may transport are the contents n°1 to 3, 6, 8 to 15 and 17 to 20.

2.6 Limit on the maximum acceptable mass of sodium

In case sodium is present, the package cavity must be made inert using nitrogen and if the material is placed in one or more internal fittings, these must not be leaktight or they must be made inert in the same way as the cavity. The mass of sodium in the cavity must be less than 50 g.

Furthermore, loading must be done dry and the presence of failed rods that may contain water is prohibited. Furthermore, in case of unloading underwater before transport, it is necessary to dry the cavity before loading.

The contents that may present sodium are the contents n°1 to 6 and 8 to 20 and 26.

2.7 Loading conditions

Heavy water is not authorised in the package TN 106.

2.8 Thermal power

For powders and pellets, the linear thermal power is obtained by relating the total power to the total length of the internal fitting (box, sheath,...) containing the material.

3. DESCRIPTION OF AUTHORISED FISSILE CONTENT

3.1 Content n°1 (types 1, 2, 3, 4 and 5): Fuels, irradiated or not in PWR, BWR, MTR or FNR, based on uranium oxide

Physical nature

Fuels composed of uranium oxide UO_2, irradiated or not, alone or in inert matrices (excluding graphite and beryllium), and in any form whatsoever.

If material is in the form of irradiated powder, it must come from milling irradiated pellets and any cladding that they may have.

The free volume in the cavity must be greater than 37.4 litres for contents n°1 type 1 to 4. The free volume in the cavity must be greater than 52.1 litres for the content n°1 type 5.

The oxide may be of any density.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The masses of uranium 235 and total uranium before irradiation must be less than or equal to the values defined in the table below according to the maximum initial enrichment (e_{max} expressed as a mass percentage) in ^{235}U present in the cavity and according to diameter D of the internal fitting for purposes of criticality. The term "No limitation" indicates that as much uranium as possible may be transported within the internal diameter in question.

- Case of fuels irradiated in Fast Neutron Reactors (FNR) content 1 type 4:

Enrichment in ^{235}U in %	D=60 mm		D= 120 mm		Cavity without internal fitting provided for purposes of criticality	
	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)
$e_{max} \leq 20$	0.8	4	0.64	3.2	0.072	0.36

- Other cases (fuels irradiated in BWR, PWR or MTR):

Enrichment in ^{235}U in %	D=60 mm	D= 120 mm		Cavity without internal fitting provided for purposes of criticality	
	Mass of ^{235}U and U_{tot} (kg)	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)
$e_{max} \leq 93$	No limitation	≤ 2.9	≤ 290 / e_{max}	≤ 0.56	≤ 56 / e_{max}
$e_{max} \leq 50$	No limitation	≤ 7	≤ 700 / e_{max}	≤ 0.65	≤ 65 / e_{max}
$e_{max} \leq 10$	No limitation	No limitation	No limitation	≤ 0.97	≤ 97 / e_{max}
$e_{max} \leq 5$	No limitation	No limitation	No limitation	≤ 2.33	≤ 233 / e_{max}
$e_{max} \leq 4$	No limitation	No limitation	No limitation	No limitation	No limitation

Mixing content 1 irradiated in FNR with other contents or with fuels, irradiated or not, of the present content is prohibited.

<u>Maximum thermal power of contents</u>

- Thermal loading applied to contents 1 types 1, 2, 4 and 5:

▪ *Applicable to enclosures that are welded or fitted with seals*

The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	Total linear power (W/m)	Linear power per enclosure (*) (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*) enclosure welded or fitted with seals

- *Other case:*

  Total linear thermal power ≤ 300 W/m

  Where

  Total power in the cavity ≤ 100 W

- Thermal loading applied to content 1 type 3:
  Total power in the cavity ≤ 100 W

Rates of combustion, cooling time, maximum quantity of fuel

The rates of combustion, the cooling time and the quantities of heavy metal before irradiation, and the characteristics of the filling gas, must comply with the values given in the following tables for the following contents:

- Content n°1 type 1: table 0A.1
- Content n°1 type 2: table 0A.1
- Content n°1 type 3: table 0A.3
- Content n°1 type 4: table 0A.1
- Content n°1 type 5: table 0A.15

3.2 Content n°2 (types 1, 2, 3 and 4): Fuels, whether irradiated or not in PWR, BWR or MTR, based on plutonium oxide, or mixed oxide or carbide of plutonium and uranium.

Physical nature

Fuels composed of plutonium oxide or mixed oxide or carbide of uranium and plutonium, whether irradiated or not, alone or in inert matrices (excluding graphite and beryllium) in any form whatsoever.

The free volume in the cavity must be greater than 37.4 litres for contents n°2 type 1 to 3. The free volume in the cavity must be greater than 52.1 litres for the content n°2 type 4.

Maximum oxide density: 11.

Maximum quantity of fissile material for compliance with safety-criticality criteria

- Fissile material based on plutonium alone

The isotopic vector of plutonium may be any.

The maximum mass of plutonium before irradiation must comply with the values defined in the table below according to the diameter D of the internal fitting provided for purposes of criticality:

	D=60 mm	**D=120 mm**	**Cavity without internal fitting provided for purposes of criticality**
Mass of Pu (kg)	4	3.2	0.36

- Fissile material based on oxide mixed with plutonium with natural or depleted uranium

The maximum mass of plutonium before irradiation must comply with the values defined in the following table according to the diameter D of the internal fitting provided for purposes of criticality:

Content in Pu_{total} in %	**Isotopic content of Pu before irradiation**	**Mass of Pu (kg) D=60 mm**	**Mass of Pu (kg) D=120 mm**	**Mass of Pu (kg) Cavity without internal fitting provided for purposes of criticality**
≤ 100	Any	4	3.2	0.36
≤ 50	Any	No limitation	6	0.38
≤ 12.5	$^{240}Pu/Pu_{total} \geq 0.17$ $^{241}Pu/^{240}Pu \leq 0.647$ $^{242}Pu/^{241}Pu \geq 0.091$	No limitation	No limitation	1.03

The uranium must not be dissociated from the plutonium.

In case of the mixture of different types of fuels as defined in the tables above, the maximum acceptable mass of plutonium for the whole of the content is the most restrictive limit mass defined for each type of fuel separately.

- Fissile material based on plutonium with enriched uranium

  The maximum masses of plutonium and uranium (expressed in kg), before irradiation, must comply with the values defined in the following table according to the diameter D of the internal fitting provided for purposes of criticality and the maximum enrichment in uranium 235:

D = 60 mm	**D = 120 mm**	**Cavity without internal fitting provided for purposes of criticality**
$\frac{m(Pu_t)}{4} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{5200}{e_{max}}$	$\frac{m(Pu_t)}{3,2} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{290}{e_{max}}$	$\frac{m(Pu_t)}{0,36} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{56}{e_{max}}$

The parameter e_{max} corresponds to the enrichment, in uranium 235, of the most enriched material transported.
With e_{max} expressed as a mass percentage, for example, for an enrichment of 3%, $e_{max} = 3$.
m(Pu), m(Ut) and $m(U)_{max}$ must be expressed in kg.

Maximum thermal power of contents

- Thermal loading applied to contents 2 types 1, 2 and 4:

  ▪ *Applicable to enclosures that are welded or fitted with seals*

  The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	**Total linear power (W/m)**	**Linear power per enclosure (*) (W/m)**
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*)enclosure welded or fitted with seals

  ▪ *Other case:*

  Total linear thermal power ≤ 300 W/m
Where
  Total power in the cavity ≤ 100 W

- Thermal loading applied to content 2 type 3:

  Total power ≤ 100 W

Rates of combustion, cooling time and maximum quantity of fuel

The rates of combustion, the cooling time and the quantities of heavy metal before irradiation, and the characteristics of the filling gas, must comply with the values given in the following tables for the following contents:

- Content n°2 type 1: table 0A.1
- Content n°2 type 2: table 0A.1
- Content n°2 type 3: table 0A.3
- Content n°2 type 4: table 0A.15

3.4 Content n°3 (types 1, 2, 3, 4 and 5): Fuel, whether irradiated or not, in FNR, based on plutonium and uranium such as Pu_{tot} / (U+Pu) ≤ 45% or experimental materials

Physical nature

Fuels, whether irradiated or not, composed of oxides, nitrides, carbides or mixed uranium and plutonium metals, alone or in inert matrices (excluding graphite and beryllium) and in any form whatsoever.

The experimental fuels are specific elements enclosing a set of containers, each containing, before irradiation, actinide isotope compounds (U, Th, Np, Pu, Am, Cm) or products of fission or boron.

The free volume in the cavity must be greater than 37.4 litres for the content 3 types 1, 2 and 3. The free volume in the cavity must be greater than 52.1 litres for the content n°3 type 4 and 5.

Maximum oxide density: 11
Maximum density of carbides: 13.63
Maximum density of nitrides: 14.38

Maximum quantity of fissile material for compliance with safety-criticality criteria for content n° 3 of type 1, 2 and 3

The quantities presented here (content in Pu, isotopic and mass compositions) must be complied with for the non-irradiated fuel, with the exception of the case of the transport of fertile materials where these quantities are to be considered after irradiation.

Fissile materials or fertile materials:

The mixture of fissile and fertile materials is not authorised.

The maximum mass of plutonium (in kg) with the natural or depleted uranium must comply with the values defined in the table below according to the nature of the fuel, the maximum total plutonium content and the diameter D of the internal fitting provided for purposes of criticality:

			Maximum mass of Pu (Kg)		
Nature	**Content in Pu_{total} in %**	**Isotopic composition**	**D=60 mm**	**D=120 mm**	**Cavity without internal fitting provided for purposes of criticality**
Mixed oxide	≤ 45	$^{240}Pu/Pu_{total} \geq 0.17$ $^{241}Pu/^{240}Pu \leq 0.647$ $^{242}Pu/^{241}Pu \geq 0.091$	No limitation	37.69	0.75
	≤ 5.15	Any(1)	No limitation	No limitation	0.26
	≤ 4	Any(1)	No limitation	No limitation	0.28
Nitride and/or carbide	≤ 23	$^{240}Pu/Pu_{total} \geq 0.12$ $^{241}Pu/^{240}Pu \leq 0.25$	No limitation	No limitation	0.70
Any	≤ 30	Any(2)	0.36		

(1): All content (particularly fertile)
(2): excluding fertile coverage

The uranium must not be dissociated from the plutonium.

In case of the mixture of different types of fuels as defined in the table above, the maximum acceptable mass of plutonium for the whole of the content is the most restrictive limit mass defined for each type of fuel separately.

Fissile materials with fertile materials:

In the case of fissile materials with the presence of fertile materials based on natural or depleted uranium, the maximum mass of plutonium and natural or depleted uranium (in kg) in the fissile material and the maximum mass of natural or depleted uranium (in kg) in the fertile material must comply with the values defined in the table below:

Fissile materials				Irradiated fertile materials (fissile materials)			
Nature	**Content in Pu_{total} in %**	**Isotopic composition**	**Maximum mass of (U+Pu) (kg)**	**Nature**	**Content in Pu_{total} in %**	**Isotopic composition**	**Maximum mass of U+Pu (kg)**
Oxide	≤ 45	$^{240}Pu/Pu_{total} \geq 0.17$ $^{241}Pu/^{240}Pu \leq 0.647$ $^{242}Pu/^{241}Pu \geq 0.091$	1.234	Oxide	≤ 6	Any	0.617
Nitride or carbide	≤ 30	Any	0.930	Nitride or carbide	≤ 6	Any	0.270

Experimental materials with fertile materials

The maximum total mass of isotopes of compounds contained in the set of containers in experimental materials must be less than 1 g.

The fertile materials are composed of natural or depleted uranium in the form of an oxide. The mass of uranium before irradiation in the fertile materials must be less than or equal to 0.160 kg. The Pu content in the fertile materials after irradiation must be less than 6%.

Maximum thermal power of contents

- Thermal loading applied to content 3 types 1 to 5:
  - *Applicable to enclosures that are welded or fitted with seals*

    The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	**Total linear power (W/m)**	**Linear power per enclosure (*) (W/m)**
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*)enclosure welded or fitted with seals

▪ *Other case:*

Total linear thermal power ≤ 300 W/m

Or total power in the cavity ≤ 100 W

Rates of combustion, cooling time, maximum quantity of fuel

The rates of combustion, the cooling time and the quantities of heavy metal before irradiation, and the characteristics of the filling gas and thermal powers, must comply with the values given in the following tables for the following contents:

- Content n°3 type 1: table 0A.1
- Content n°3 type 2: table 0A.1
- Content n°3 type 3: table 0A.1
- Content n°3 type 4: table 0A.15
- Content n°3 type 5: table 0A.15

3.5 Content n°5 (types 1, 2, 3, 4, 5 and 6): fuels, whether irradiated or not, in MTR or UNGG, based on uranium-bearing solids

Physical nature

The fuels, in any solid form, are compounds of uranium isotopes in metallic, oxide, carbide or nitride forms, alone or associated with metals. They come:

- either from MTR research reactors (excluding TRIGA elements)

- or from systems of the UNGG and/or heavy water type. In this case, the cavity must be made inert with a neutral gas (nitrogen, argon,... with the exception of helium) before shipping and precautions must be taken when opening the package.

The free volume in the cavity must be greater than 37.4 litres for content n°5 type 1, 2, 3 and 4. The free volume in the cavity must be greater than 52.1 litres for content n°5 type 5 and 6.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The maximum masses of uranium 235 and total uranium before irradiation must be less than or equal to the values defined in the table below according to the maximum initial enrichment (e^{max} expressed as a mass percentage) in ^{235}U present in the cavity and according to diameter D of the internal fitting provided for purposes of criticality:

Enrichment in ^{235}U (in %)	D=60 mm	D=120 mm		Cavity without internal fitting provided for purposes of criticality	
	Mass of ^{235}U and U_{tot}	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)	Mass of ^{235}U (kg)	Mass of U_{tot} (kg)
$e_{max} \leq 93.5$	No limitation	$m \leq 2.9$	$M \leq (290 / e_{max})$	$m \leq 0.56$	$M \leq (56 / e_{max})$
$e_{max} \leq 50$	No limitation	$m \leq 7$	$M \leq (700 / e_{max})$	$m \leq 0.65$	$M \leq (65 / e_{max})$
$e_{max} \leq 10$	No limitation	No limitation	No limitation	$m \leq 1.0$	$M \leq (100 / e_{max})$
$e_{max} \leq 5$	No limitation	No limitation	No limitation	$m \leq 1.5$	$M \leq (150 / e_{max})$
$e_{max} \leq 4$	No limitation	No limitation	No limitation	$m \leq 2$	$M \leq (200 / e_{max})$
$e_{max} \leq 3$	No limitation	No limitation	No limitation	No limitation	No limitation

The term "No limitation" indicates that as much uranium as possible may be transported within the internal diameter in question, the limit being fixed by the density of the uranium metal.

Rates of combustion, cooling time, maximum quantity of fuel

The rates of combustion, the cooling time and the quantities of heavy metal before irradiation must comply with the values given in the following tables for the following contents:

- Content n°5 type 1: table 0A.1
- Content n°5 type 2: table 0A.1
- Content n°5 type 3: table 0A.1
- Content n°5 type 4: table 0A.1
- Content n°5 type 5: table 0A.15
- Content n°5 type 6: table 0A.15

Maximum thermal power generated by content n°5 all types

- Maximum thermal loading (contents 5 all types):

  - *Applicable to enclosures that are welded or fitted with seals*

    The total linear thermal power of the content and the linear thermal power per enclosure must comply with the limits given in the following table according to the dimensions of the internal fitting present and the perimeter P_e (in m) of the smallest section of the first enclosure that is welded or fitted with a seal for content n° 5 present in the cavity:

		Dimensions of the internal fitting		
Maximum acceptable thermal power	**No fitting, (for purposes of criticality, neither shovel or sleeve)**	**160 mm ≤ ϕ < 203 mm**	**120 mm ≤ ϕ < 160 mm**	**60 mm ≤ ϕ < 120 mm**
Linear power acceptable in the cavity in case of distributed thermal loading	$\min\begin{cases}\dfrac{2021{,}5\times p_e}{0{,}92+p_e}\\300\end{cases}$ **W/m**	$\min\begin{cases}\dfrac{495{,}3\times p_e}{0{,}23+p_e}\\300\end{cases}$ **W/m**	$\min\begin{cases}\dfrac{395{,}7\times p_e}{0{,}18+p_e}\\300\end{cases}$ **W/m**	$\min\begin{cases}\dfrac{219{,}3\times p_e}{0{,}10+p_e}\\300\end{cases}$ **W/m**

  - *Other cases*

    Total linear thermal power ≤ 300 W/m

    Or total power in the cavity ≤ 100 W

3.6 Content n°8 (type 1): Fuel, whether irradiated or not, in FNR, based on plutonium and uranium possibly doped with americium, curium and/or neptunium

Physical nature

Fuel, whether irradiated in FNR or not, based on (U, Pu) possibly doped with actinides (Am, Cm, Np or not, in any form whatsoever and any other inert materials.

The free volume in the cavity must be greater than 37.4 litres.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The isotopic vector of plutonium may be any.

All irradiated material coming from fertile covers from fast neutron reactors is to be excluded.

The maximum masses of plutonium and the uranium (natural or depleted) and plutonium assembly, before irradiation, must comply with the values defined in the following table:

Content in Pu_{total} in %	Cavity with or without internal fitting provided for purposes of criticality	
	Mass of Pu (kg)	Mass of U + Pu (kg)
$t_{max}(Pu) \leq 30$	0.257	Minimum $\{2,570; \frac{25,7}{t_{max}(Pu)}\}$

The uranium must not be dissociated from the plutonium.

The masses of actinides (Am, Cm, Np), before irradiation, must be less than the values defined in the following table:

	Np	Am	Cm
Maximum masses of actinides (g)	4	**2.4** including 0.24 g of ^{242m}Am as a maximum	**1.3** including 0.39 g of ^{245}Cm as a maximum

Maximum thermal power of contents

The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	Total linear power (W/m)	Linear power per enclosure (*) (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*) enclosures welded or fitted with seals

Maximum quantity of fuel

The quantities of uranium, plutonium, americium, curium and neptunium before irradiation and the filling gas, according to the maximum combustion rates and minimum cooling times, must comply with the conditions presented in table 0A.5.

3.7 Content n°9 (types 1, 2, 3 and 4): Fuel, whether irradiated or not, in PWR, BWR or MTR, based on uranium oxide, possibly with the presence of thorium and graphite

Physical nature

Fuel composed of uranium oxide, possibly with the presence of thorium and graphite, whether irradiated or not, alone or in inert matrices (excluding beryllium), in any form.

The free volume in the cavity must be greater than 37.4 litres.

Maximum oxide density: 10.96

Maximum quantity of fissile material for compliance with safety-criticality criteria

The maximum masses, before irradiation, of total uranium and total thorium must be less than or equal to the values defined in the table below according to the maximum initial enrichment (e_{max}, expressed as a mass percentage) in ^{235}U present in the cavity:

Enrichment in ^{235}U in %	Mass of U (kg)	Mass of Th (kg)	Mass of graphite (kg)
$e_{max} \leq 93$	0.277	0.243	No limitation

Maximum thermal power of contents

Total power ≤ 100 W

Rates of combustion, cooling time and maximum quantity of fuel

The quantities of heavy metal before irradiation and filling gas, according to maximum combustion rates and minimum cooling times, are given in the table 0A.3.

3.8 Content n°11: fuels, whether irradiated or not, based on uranium oxide or mixed plutonium oxide or mixed plutonium and uranium oxide (mixture of contents 1 and 2)

Physical nature

The fuel is composed of a mixture of uranium oxide and/or uranium oxide or carbide and/or plutonium, irradiated or not, alone or in inert matrices (excluding graphite and beryllium), in any form.

The free volume in the cavity for content n° 11 is 37.4 litres.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The masses (expressed in kg) of total uranium and total plutonium before irradiation must comply with the criteria defined in the following table according to the diameter D of the internal fitting provided for purposes of criticality and the maximum enrichment in uranium 235:

D = 60 mm	D = 120 mm	Cavity without internal fitting provided for purposes of criticality
$\frac{m(Pu_t)}{4} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{5200}{e_{max}}$	$\frac{m(Pu_t)}{3,2} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{290}{e_{max}}$	$\frac{m(Pu_t)}{0,36} + \frac{m(U_t)}{m(U)_{max}} \leq 1$ with $m(U)_{max} = \frac{56}{e_{max}}$

The parameter e_{max} corresponds to the enrichment, in uranium 235, of the most enriched material transported.
With e_{max} expressed as a mass percentage, for example, for an enrichment of 3%, $e_{max} = 3$.
m(Pu), m(Ut) and $m(U)_{max}$ must be expressed in kg.

Maximum thermal power of contents

- Thermal loading applied to the whole of content 11:

  - *Applicable to enclosures that are welded or fitted with seals*

    The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	Total linear power (W/m)	Linear power per enclosure (*) (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*) enclosure welded or fitted with seals

  - *Other case:*
    Total linear thermal power ≤ 300 W/m
    Or total power in the cavity ≤ 100 W

Data relative to confinement

The content is composed of a mixture of contents 1 and 2; each material must comply with one of the sets of characteristics from the tables:

- 0A.1, 0A.3 or 0A.15 according to the materials transported
- or 0A.10 and 0A.11 according to the materials transported

All of the sets must belong to the same table.

Furthermore, the masses (tables 0A.1, 0A.3, or 0A.15) or the activities and volumes of gas (tables 0A.10 and 0A.11) and the thermal powers of the content must be less than or equal to those of the material having the most restrictive values.

3.9 Content n°12: fuels, irradiated or not, based on uranium and plutonium (mixture of contents 1, 2, 3 and 5)

Physical nature

The fuel is composed of a mixture of uranium and/or plutonium in the form of an oxide, of carbide, of nitride and/or metal, irradiated or not, alone or in inert matrices (excluding graphite and beryllium), in any form.

The free volume in the cavity for content n° 11 is 37.4 litres.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The masses (expressed in kg) of total uranium and total plutonium before irradiation must comply with the criteria defined in the following table according to the diameter D of the internal fitting provided for purposes of criticality and the maximum enrichment in uranium 235:

D = 60 mm	D = 120 mm	Cavity without internal fitting provided for purposes of criticality
$\frac{m(Pu_t)}{4}+\frac{m(U_t)}{m(U)_{max}}\leq 1$ with $m(U)_{max}=\frac{5200}{e_{max}}$	$\frac{m(Pu_t)}{3,2}+\frac{m(U_t)}{m(U)_{max}}\leq 1$ with $m(U)_{max}=\frac{290}{e_{max}}$	$\frac{m(Pu_t)}{0,36}+\frac{m(U_t)}{m(U)_{max}}\leq 1$ with $m(U)_{max}=\frac{56}{e_{max}}$

The parameter e_{max} corresponds to the enrichment, in uranium 235, of the most enriched material transported.
With e_{max} expressed as a mass percentage, for example, for an enrichment of 3%, $e_{max} = 3$.
m(Pu), m(Ut) and $m(U)_{max}$ must be expressed in kg.

The presence of fertile materials irradiated in FNR is not authorised. The only materials irradiated in FNR that are authorised in the mixture are defined in the following table, according to the nature of the fuels, the maximum plutonium content and the isotopic composition of the plutonium, before irradiation:

Nature	Content in Pu_{total} in %	Isotopic composition
$(U,Pu)O_2$	≤ 45	$^{240}Pu/Pu_{total} \geq 0.17$ $^{241}Pu/^{240}Pu \leq 0.647$ $^{242}Pu/^{241}Pu \geq 0.091$
(U,Pu)N and/or (U,Pu)C	≤ 23	$^{240}Pu/Pu_{total} \geq 0.12$ $^{241}Pu/^{240}Pu \leq 0.25$

Maximum thermal power of contents

- Maximum thermal loading (applied to all the content 12):

▪ *Applicable to enclosures that are welded or fitted with seals*

The total linear thermal power of the content and the linear thermal power per enclosure are given in the following table according to the diameter of the transported enclosures that are welded or fitted with seals:

ϕ enclosure (*) (mm)	Total linear power (W/m)	Linear power per enclosure (*) (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*) enclosure welded or fitted with seals

▪ *Other case:*

Total linear thermal power ≤ 300 W/m
Or total power in the cavity ≤ 100 W

Data relative to confinement

The content is composed of a mixture of contents 1, 2, 3 and 5; each material must comply with one of the sets of characteristics from the tables:

- 0A.1, 0A.3 and 0A.15
- or 0A.8 and 0A.10 to 0A.12

All of the sets must belong to the same table.

Furthermore, the masses (tables 0A.1, 0A.3 or 0A.15) or the activities and volumes of gas (tables0A.8, 0A.10, 0A.11 and 0A.12) and the thermal powers of the content must be less than or equal to those of the material having the most restrictive values.

3.10 Content n°22: UO_2 with polymer resin present and possibly thoria present

Content 22 is described in appendix 0A-3.

3.11 Content n°26: fuels, irradiated or not, in FNR, based on uranium, plutonium, americium or neptunium in metallic or nitride form, and/or based on metallic technetium.

Physical nature

- Fuel elements (type 1, type 2, type 3, type 4 or type 5), whether or not irradiated in FNR, pressurised or not, composed of uranium, plutonium, americium or neptunium in metallic or nitride form, and/or technetium in metallic form, alone or in inert matrices (for examples Zr), and all other inert materials.

Loading conditions

The free volume in the cavity must be greater than or equal to 37.4 litres.

For the irradiated elements, the absence of risk of radiolysis is guaranteed by the integrity of the cladding and its drying.

Characteristics of the contents:

The elements before irradiation must comply with the characteristics defined in the table below:

	Nominal composition (% by mass)			Maximum enrichment in $^{235}U/U_{tot}$ (% by mass)	Nominal content (% by mass)			
	in Tc	in Am	in Np		Pu/ (Pu+U)*	Pu/ ML*	Am/ML*	Np /ML*
Type 1	-	^{241}Am: 100 %	^{237}Np: 100 %	0.3	45	41	6	4
Type 2				0.3	100	82	19	1
Type 3				0.3	35	27	15	10
Type 4				4.3	97	82	16	-
Type 5	^{99}Tc: 100 %	-	-	-	-	-	-	-

* a variation of +/-2 of the mass of the heavy metal ML, namely (U+Pu+Am+Np), around these values is acceptable for transport

When these elements are irradiated:
- The rates of combustion must be less than or equal to:
  - Element of type 1: 9.3 at%,
  - Element of type 2: 17.4 at%,
  - Element of type 3: 1.7 at%,
  - Element of type 4: 4.5 at%,
  - 28.05 at% for technetium,
- The cooling time must be a minimum of 1 year,
- The total mass of heavy metal per enclosure must be less than or equal to 9.1 grams of (Am + Pu + U + Np+ Tc) per metre of cavity.
- The maximum number of enclosures, welded or fitted with seals, is 5.

The characteristics of the filling gas:
- of an enclosure at 20°C must be less than or equal to 10.13 bar.cm^3.

Maximum quantity of fissile materials for compliance with safety-criticality criteria:

The quantities presented in the table below must be complied with for the fuel considered before irradiation

Fissile material	Characteristics
Chemical form	(U, Pu)(*)
$^{235}U/U_{total}$ (mass %)	≤ 10
Maximum Pu content (% by mass): $Pu_{total}/(U + Pu)_{total}$	≤ 100
Pu isotopic vector	any(**)

(*) presence of americium, neptunium and/or technetium in metallic or nitride form

(**) Any irradiated material coming from the fertile covers of fast-breeder reactors is to be excluded.

The total maximum mass of (U+Pu) for all of the elements is 42 g with presence, before irradiation, of a maximum of 6.2 g of americium and 2.1 g of neptunium.

Maximum quantity of heavy metal for compliance with the release criteria

The maximum mass of heavy metal is $1.1,10^{-1}$ kg in the case of pressurised enclosures.

Maximum thermal power of contents

- Total linear power in the cavity ≤ 300 W/m or 100 W
- Maximum linear power applicable to enclosures that are welded or fitted with seals only (W/m):

  The total linear thermal power of the content and the linear thermal power per enclosure, welded or fitted with seals (*) must comply with the values in the following table according to the diameter of the enclosure that is welded or fitted with seals.

ϕ enclosure (*) (mm)	Total linear power (W/m)	Linear power per enclosure (*) (W/m)
≥ 10 mm	≤ 289	≤ 41.3
≥ 9 mm	≤ 269	≤ 38.5
≥ 8 mm	≤ 249	≤ 35.6
≥ 7 mm	≤ 228	≤ 32.6
≥ 6 mm	≤ 206	≤ 29.5
≥ 5 mm	≤ 183	≤ 26.1

(*) First enclosure welded or fitted with seals

4. DESCRIPTION OF AUTHORISED NON-FISSILE MATERIALS (CONTENTS N°4, N°6, N°10, AND N°13 A 20, N°23, N°24 AND N°25 type 1 and/or type 2)

4.1 Content n°4 (solid, non-fissile radioactive materials)

Physical nature

These are radioactive materials (contaminated and/or activated components, sources sealed or not,...) in solid form. The free volume in the cavity must be greater than 37.4 litres.

Physicochemical characteristics of the material

They are:

- metals (steels, aluminium, copper, tin, lead, tungsten, zinc, zirconium, silver, indium, cadmium, hafnium, dysprosium, titanium, gadolinium, lithium) and their alloys,
- boron, alone, allied with the previous metals or in the form of boron carbide (B_4C).

Furthermore, irradiated boron carbide is likely to contain tritium. The maximum authorised quantity of tritium is 0.1 TBq.

The presence of liquid is excluded.

Fissile material

The quantity of fissile material per package must be less than 15 grams.

Actinides other than isotopes of uranium, plutonium or americium 241 may be present in the form of traces.

Americium 241 has not been subject to separation processing in relation to the other fissile materials.

Maximum thermal power of contents

The maximum acceptable thermal power is 300 W/m of cavity or a total acceptable maximum power in the cavity of 100 W.

4.2 Content n°6 (types 1 and 2): Elements based on americium oxide

Physical nature

These are elements composed of americium AmO_x, alone or in inert matrices (such as spinel $MgAl_2O_4$), possibly with spacer blocks made of UO_2 and in any form.

The free volume in the cavity must be greater than 37.4 litres for content 6 type 1 and 46.2 litres for content 6 type 2.

Maximum quantities of material for compliance with release criteria

The maximum mass of americium before irradiation in the enclosures must comply with the values defined in the table below:

Composition of Am	Maximum mass of Am (g)	Possible presence of spacer blocks in UO_2
Type 1 ^{241}Am: 100 %	8	no
Type 2 ^{241}Am: 95%, ^{243}Am: 5%	4	Yes

The total maximum mass of U in the spacer blocks before irradiation is less than 11 grams. The maximum nominal enrichment in uranium 235 before irradiation in the spacer blocks is 4%.

When the 100% ^{241}Am (type 1) pellets are irradiated, the quantities of isotopes must comply with the values specified in table 0A.7.

When the pellets consisting of 95% ^{241}Am / 5% ^{243}Am (type 2) are irradiated:

- The rate of combustion must be less than or equal to 37 at% for the americium and the UO_2 spacer blocks,
- The cooling time must be a minimum of 6 months,
- The total mass of heavy metal in the cavity must be less than 15.1 grams of (Am+U).

Nature of filling gas: any

The quantity of filling gas for all the enclosures at 20°C must be less than or equal to:

- 200 bar.cm^3 for type 1;
- 100 bar.cm^3 for type 2.

Maximum number of enclosures pressurised: 50

Maximum thermal power of contents

The maximum acceptable thermal power is 300 W/m of cavity or a total acceptable maximum power in the cavity of 100 W.

Non-fissile character of content

- Content n°6 type 1:
  The maximum initial mass of americium 241 is 8 g. The sum total of actinides that are fissile (according to <1>) and potentially fissile (according to <3>) will therefore always be less than 8 g. This content is therefore not fissile in the sense of <1> (because the mass of the fissile material according to <1> is always less than 15 g).

  Among the actinides that are potentially fissile according to <3> and that are not defined in <1>, ^{251}Cf is the one with the lowest critical mass (5 g, see <2>). The total mass of fissile materials generated by an initial 8 g of americium 241 and calculated above is:

  $m_f = 3.37$ g,
  and that of ^{251}Cf is:
  $m_{251Cf} = 1.19{,}10^{-6}$ g.

  This content therefore presents no risk of criticality because the total mass of the actinides that are fissile and potentially fissile (according to <3>) is less than 5 g.

- Content n°6 type 2:
  The maximum initial mass of americium is 4 g. The sum total of actinides that are fissile (according to <1>) and potentially fissile (according to <3>) will always be less than 4 g. Also, the initial maximum mass of UO_2 is 11 g, for a maximum initial enrichment of 4%. This content is therefore not fissile in the sense of <1>, because the mass of the fissile material according to <1> is always less than 15 g.

4.3 Content n°10 (types 1, 2 and 3): Fuel elements, whether irradiated or not, in PWR, BWR or MTR, based on uranium oxide or mixed oxide of plutonium and thorium or mixed oxide or carbide or nitride of plutonium and uranium

Physical nature

Fuels based on uranium oxide or mixed oxide of plutonium and thorium or mixed oxide or carbide or nitride of plutonium and uranium, with possible presence of graphite and beryllium, irradiated or not, alone or in inert matrices, pressurised or not, and in any form.

The free volume in the cavity must be greater than 37.4 litres.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The maximum quantity of fissile materials ($U^{233} + U^{235} + Pu^{239} + Pu^{241}$) in the cavity must be less than 15 g. The quantity of beryllium must be less than 2.5 g.

Maximum thermal power of contents

- Maximum thermal loading (applied to content 10 type 2):
  Total linear thermal power ≤ 300 W/m
  Total power ≤ 100 W

- Low thermal loading (applied to contents 10 types 1 and 3):
  Total power ≤ 100 W

Rates of combustion, cooling time and maximum quantity of fuel

The rates of combustion, the cooling time and the quantities of heavy metal before irradiation must comply with the values given in the following tables for the following contents:

- Content n°10 type 1: table 0A.3
- Content n°10 type 2: table 0A.1
- Content n°10 type 3: table 0A.3

In case of mixing different types of content n° 10, the total masses of heavy metal in the content must comply with the limits of the most restrictive type.

4.4 Contents n°13 to 20

The correspondence between the non-fissile (13 to 20) and fissile contents is presented in the table below:

Fissile content	"Equivalent" non-fissile content
1	13
2	14
3	15
5	16
8	17
9	18
11	19
12	20

However, for the non-fissile contents, the maximum mass of fissile materials (U^{233} + U^{235} + Pu^{239} + Pu^{241}) must be less than 15 grams in the cavity.

4.5 Content n°23: Elements based on americium oxide and uranium oxide

Physical nature:

These are elements, which may or may not be irradiated in FNR, in any form, and pressurised or not, composed of americium oxide, alone or in inert matrices (such as $(Zr, Y)O_2$ or MgO), uranium oxide and all other inert materials. Impurities of the neptunium type may be considered in the form of traces.

Loading conditions:

The free volume in the cavity must be greater than or equal to 55 litres.

For the irradiated elements, the absence of sodium and risk of radiolysis are ensured by the integrity of the cladding, and of it being washed before irradiation and dried after washing.

Characteristics of the contents:

The total mass of americium before irradiation is less than or equal to 6 grams. The nominal composition of the americium in ^{241}Am before irradiation is 100%.

The maximum total mass of uranium before irradiation is less than or equal to 30 grams. The maximum enrichment in ^{235}U before irradiation is 4%.

When these elements are irradiated:
- The rate of combustion must be less than or equal to 23 at% for the americium and less than or equal to 9.25 at% for the uranium,
- The cooling time must be a minimum of 6 months,
- The total mass of heavy metal in the cavity must be less than or equal to 40 grams of (Am +U).

The quantity of filling gas for all the enclosures at 20°C must be less than or equal to 60.8 bar.cm^3.

Maximum quantity of fissile materials for compliance with safety-criticality criteria:

The maximum quantity of fissile materials ($U^{233} + U^{235} + Pu^{239} + Pu^{241}$) in the cavity must be less than 15 g.

Maximum thermal power of contents

- Total power (in W) $\leq$ 100 W,

4.6 Content n°24: Elements based on mixed oxide of plutonium and americium and uranium oxide

Physical nature
These are elements (type 1 or type 2), whether irradiated or not in FNR, in any form, and pressurised or not, composed of mixed oxide of plutonium and americium, alone or in inert matrices (such as MgO), of uranium oxide and any other inert materials. Impurities of the neptunium type may be considered in the form of traces.

Loading conditions

The free volume in the cavity must be greater than or equal to 37.4 litres.

For the irradiated elements, the absence of sodium and risk of radiolysis are ensured by the integrity of the cladding, and of it being washed before irradiation and dried after washing.

Characteristics of the contents:

The elements before irradiation must comply with the characteristics defined in the table below:

	Nominal composition in Am	Nominal content in Am Am/(Pu+Am) (% by mass)
Type 1	^{241}Am: 100 %	50
Type 2	^{241}Am: 100 %	80

The maximum total mass of americium and plutonium for the type 1 before irradiation is less than or equal to 4.45 grams.

The maximum total mass of americium and plutonium for the type 2 before irradiation is less than or equal to 5.05 grams.

The maximum total mass of uranium oxide before irradiation is less than or equal to 23 grams. The maximum enrichment in ^{235}U before irradiation is 6.9%.

When these elements are irradiated:
- The rates of combustion must be less than or equal to:
  - Element of type 1: 8.8 at% for the (americium, plutonium),
  - Element of type 2: 5.7 at% for the (americium, plutonium),
  - 1.82 at% for the uranium
- The cooling time must be a minimum of 6 months,
- The total mass of heavy metal in the cavity must be less than or equal to 44 grams of (Am + Pu + U).

The quantity of filling gas for all the enclosures at 20°C must be less than or equal to 40.52 bar.cm^3.

Maximum quantity of fissile materials for compliance with safety-criticality criteria:

The maximum quantity of fissile materials (U^{233} + U^{235} + Pu^{239} + Pu^{241}) in the cavity must be less than 15 g.

Maximum thermal power of contents

- Total power (in W) ≤ 100 W.

4.7 Content n°25: Elements based on uranium oxide (type 1) and/or uranium oxide and plutonium (type 2) with or without the presence of depleted uranium oxide.

The characteristics of content n° 25 are presented in table 0A.14

Physical nature

These are fuel elements, irradiated or not in PWR, BWR or MTR, in any form, pressurised or not, alone or in inert matrices, composed of a mixture of uranium oxide (type 1) and/or oxide of uranium and plutonium (type 2) with or without the presence of depleted uranium oxide.

These materials undergo a first irradiation in PWR, BWR, or MTR in a first enclosure, which is opened and depressurised before the second irradiation. These materials are then repackaged in new enclosures, pressurised or not, possibly with the addition of depleted uranium oxide, before the second irradiation in PWR, BWR or MTR.

Loading conditions

The free volume in the cavity must be greater than or equal to 37.4 litres.

The absence of radiolysis is ensured by the absence of water in the enclosures in which the material is repackaged after the first irradiation.

Characteristics of the contents:

The maximum rates of combustion in the 1st irradiation and the 2nd irradiation, the minimum cooling time after the 1st irradiation and the 2nd irradiation, the quantities of (U + Pu) before irradiation and the characteristics of the gases for filling the enclosures (pressurised or not) must comply with the values given in table 0A.14.

Whatever the configuration (type 1, type 2 or a mixture of the two types), the maximum total mass of (U + Pu) before irradiation must be less than or equal to 0.0336 kg.

Maximum quantity of fissile material for compliance with safety-criticality criteria

The maximum quantity of fissile materials (U^{233} + U^{235} + Pu^{239} + Pu^{241}) in the cavity must be less than 15 g.

Maximum quantity of heavy metal for compliance with the release criteria

This is the subject of table 0A.14.

Maximum thermal power of contents
- Total linear thermal power in the cavity ≤ 300 W/m
- or a total power ≤ 100 W

5. RELEASABLE ACTIVITY OF CONTENT

This data is presented in the appendices to chapter 3A

6. PACKAGING OF AUTHORISED CONTENT

The content (radioactive material) may be packaged in 2 types of internal fittings:
- the internal fittings have a safety-criticality function and their geometry is retained after normal and accidental transport conditions,
- the internal fittings facilitate loading and unloading the material and/or can avoid contaminating the cavity.

6.1 Internal fittings for the purposes of criticality

The content may be placed in containers or sheaths made of stainless steel of type A (X2CrNi19-11 or equivalent) of cylindrical section, leaktight or not, of variable usable diameter. Loading content in the internal fitting must be performed dry. The presence of water inside this fitting is prohibited.

The sheath is centred in the cavity using spacers. According to the content and the internal diameter of 60, 110 or 120 mm, these sheaths must comply with the following thicknesses:

Maximum mass of content, m in kg/m of cavity			Minimum thickness in mm			Maximum thickness in mm		
Fitting of internal diameter D (mm)								
60 mm	110 mm	120 mm	60 mm	110 mm	120 mm	60 mm	110 mm	120 mm
12	50	64	3	3	3	23		
21	68	87	5	4	4			
30	86	108	7	5	5			
32	104	130	8	6	6			

Also, the total mass of the content must not exceed 120 kg.

A plan of these internal fittings is presented in appendix 0A-1. The sheaths are centred directly in the cavity.

The maximum acceptable masses of content presented in the table above are penalising in relation to the maximum acceptable masses calculated in chapter 1A.

The distance separating two spacers must be a maximum of 300 mm. These spacers must be made of stainless steel of type A (X2CrNi19-11 or equivalent) and comply with the minimum thicknesses presented below:

<table>
<tr><th></th><th>Internal diameter 120 mm</th><th>Internal diameter 110 mm</th><th>Internal diameter 60 mm</th></tr>
<tr><td>Thickness of spacer in mm</td><td colspan="3">21</td></tr>
</table>

6.2 Internal fittings facilitate loading and unloading the material and/or can avoid contaminating the cavity

The content may be placed in the internal fittings made of aluminium and or/stainless steel and/or bronze.

7. REFERENCES

<1> Applicable AIEA regulations: see chapter 00.

<2> AMERICAN NUCLEAR SOCIETY, American National Standard for Nuclear Criticality Control of Special Actinide Elements, ANSI/ANS-8.15-1981 (reaffirmed 1987), ANS, New York (1981).

<3> IAEA Safety Standards Series – Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material – Safety Guide – No. TS-G-1.1 (ST-2)

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CHARACTERISTICS OF CONTENTS N°1, 2, 3, 5 AND 10 AT MAXIMUM THERMAL POWER (300 W/m)

Type of reactor			PWR, BWR, MTR			
Type of fuel			UO_2 (***)		PuO_2, MOX or (U,Pu)C or (U,Pu)N	
Enrichment in ^{235}U: e%			≤ 10%	≤ 20%	≤ Unat	≤ Unat
Content in Pu %			/	/	≤ 12.5%	≤ 16%
Maximum combustion rate (MWj/t heavy metal)			≤ 100,000	≤ 104,000	≤ 80,000	≤ 90,000
Minimum cooling time (months)			≥ 3	≥ 6	≥ 3	≥ 6
Name of content			**Content 1 Type 1**	**Content 1 Type 2**	**Content 2 Type 1**	**Content 2 Type 2**
Irradiation in PWR then MTR			authorized	authorized	authorized	authorized
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 6.87	≤ 9.89	≤ 27.34	≤ 45.6
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Mass of heavy metal per enclosure (*) (kg)	≤ 0.172	≤ 0.247	≤ 0.684	≤ 1.14
Content that does not have a pressurised enclosure	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with/without water)	m1 + 2 x m2 ≤ 0.363 / m1 + 2 x m2 ≤ 0.686	m1 + 2 x m2 ≤ 0.718 / m1 + 2 x m2 ≤ 0.988	m1 + 2 x m2 ≤ 1.31 / m1 + 2 x m2 ≤ 2.73	m1 + 2 x m2 ≤ 4.2
Content that does not have a pressurised enclosure	Materials partly in enclosures that are welded or fitted with seals	Mass of heavy metal per enclosure (*) (kg)	≤ 0.172	≤ 0.247	≤ 0.684	≤ 1.14
Content that does not have a pressurised enclosure	**Number of enclosures**		**≤ 40**			
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 6.87	≤ 9.89	≤ 27.34	≤ 45.6
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Mass of heavy metal per enclosure (*) (kg)	≤ 0.344	≤ 0.494	≤ 1.367	≤ 2.28
Content that does not have a pressurised enclosure	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with/without water)	m1 + 2 x m2 ≤ 0.363 / m1 + 2 x m2 ≤ 0.686	m1 + 2 x m2 ≤ 0.718 / m1 + 2 x m2 ≤ 0.988	m1 + 2 x m2 ≤ 1.31 / m1 + 2 x m2 ≤ 2.73	m1 + 2 x m2 ≤ 4.2
Content that does not have a pressurised enclosure	Materials partly in enclosures that are welded or fitted with seals	Mass of heavy metal per enclosure (*) (kg)	≤ 0.343	≤ 0.494	≤ 1.31 / ≤ 1.367	≤ 2.28
Content that does not have a pressurised enclosure	**Number of enclosures**		**≤ 20**			
Content that does not have a pressurised enclosure	Other cases	Total mass of heavy metal in the cavity (kg) (with/without water)	≤ 0.363 / ≤ 0.686	≤ 0.718 / ≤ 0.988	≤ 1.31 / ≤ 2.73	≤ 4.2
Content that does not have a pressurised enclosure	Number of enclosures		Any			

(*) First enclosure welded or fitted with seals

(**) with **m1**: mass of materials outside enclosures welded or fitted with seals and **m2** mass of materials present in the 2 enclosures welded or fitted with seals that contain the most materials, or in the enclosure that is welded or fitted with seals (if there is only one).

(***) Plate fuel elements are not authorised

TABLE 0A.1 (2/4)
CHARACTERISTICS OF CONTENTS N°1, 2, 3, 5 AND 10 AT MAXIMUM THERMAL POWER (300 W/m or 100 W)

Type of reactor			PWR, BWR, MTR			
Type of fuel			UO_2 (***)		PuO_2, MOX or (U,Pu)C or (U,Pu)N	
Enrichment in ^{235}U: e%			≤ 10%	≤ 20%	≤ Unat	≤ Unat
Content in Pu %			/	/	≤ 12.5%	≤ 16%
Maximum combustion rate (MWj/t heavy metal)			≤ 100,000	≤ 104,000	≤ 80,000	≤ 90,000
Minimum cooling time (months)			≥ 3	≥ 6	≥ 3	≥ 6
Name of content			**Content 1 Type 1**	**Content 1 Type 2**	**Content 2 Type 1**	**Content 2 Type 2**
Irradiation in PWR then MTR			authorized	authorized	authorized	authorized
Content having at least one pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 6.45	≤ 9.62	≤ 25.36	≤ 45.8
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.161	≤ 0.241	≤ 0.634	≤ 1.145
	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with/without water)	m1 + 2 x m2 ≤ 0.233 / m1 + 2 x m2 ≤ 0.320	m1 + 2 x m2 ≤ 0.543 / m1 + 2 x m2 ≤ 0.667	m1 + 2 x m2 ≤ 0.796 / m1 + 2 x m2 ≤ 1.14	m1 + 2 x m2 ≤ 3 (with water)
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.161	≤ 0.241	≤ 0.634	≤ 1.145
	Number of enclosures		**≤ 40**			
	Materials exclusively in one of the enclosures that are welded or fitted with seals	≤ 6.45	≤ 9.62	≤ 25.36	≤ 45.8	
		≤ 0.322	≤ 0.482	≤ 1.268	≤ 2.28	
	Materials partly in enclosures that are welded or fitted with seals	m1 + 2 x m2 ≤ 0.233 / m1 + 2 x m2 ≤ 0.320	m1 + 2 x m2 ≤ 0.543 / m1 + 2 x m2 ≤ 0.667	m1 + 2 x m2 ≤ 0.796 / m1 + 2 x m2 ≤ 1.14	m1 + 2 x m2 ≤ 3 (with water)	
		≤ 0.233 / ≤ 0.320	≤ 0.482	≤ 0.796 / ≤ 1.14	≤ 2.28	
	Other cases	≤ 0.233 / ≤ 0.320	≤ 0.543 / ≤ 0.667	≤ 0.796 / ≤ 1.14	≤ 3	
	Number of enclosures		**≤ 20**			
	Characteristics of gas for filling an enclosure (*) at 20°C (in bar.cm³)		≤ 700			
	Nature of filling gas		Any			

(*) First enclosure welded or fitted with seals

(**) with **m1**: mass of materials outside enclosures welded or fitted with seals and **m2** mass of materials present in the 2 enclosures welded or fitted with seals that contain the most materials, or in the enclosure that is welded or fitted with seals (if there is only one).

(***) Plate fuel elements are not authorised

TABLE 0A.1 (3/4)
CHARACTERISTICS OF CONTENTS N°1, 2, 3, 5 AND 10
AT MAXIMUM THERMAL POWER (300 W/m or 100 W)

Type of reactor			PWR, BWR, MTR	FNR		
Type of fuel			$(Th,Pu)O_2$	UO2	(U,Pu) oxide, carbide, nitride or metal	
Enrichment in ^{235}U: e%			/	≤ 20%	≤ Unat	≤ Unat
Content in Pu %			≤ 11.5%	/	≤ 45%	≤ 30%
Max rate of combustion (MWj/t heavy metal)			≤ 60,000	≤ 35,000	≤ 150,000	≤ 70,000
Minimum cooling time (months)			≥ 10	≥ 6	≥ 4	≥ 6
Name of content			**Content 10 Type 2**	**Content 1 Type 4**	**Content 3 Type 1 and 3**	**Content 3 Type 2**
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 8.64	≤ 2.42	≤ 5.16	≤ 6.53
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.216	≤ 0.0484	≤ 0.129	≤ 0.163
	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg (**) (with/without water)	m1 + 2 x m2 ≤ 14.96	m1 + 3 x m2' ≤ 0.155 / m1 + 2 x m2' ≤ 0.188	m1 + 2 x m2 ≤ 0.48 (with water)	m1 + 2 x m2 ≤ 0.6 (with water)
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.216	≤ 0.0484	≤ 0.129	≤ 0.163
	Number of enclosures (*)		≤ 40	≤ 50	≤ 40	
	Other cases	Total mass of heavy metal in the cavity (kg) (with/without water)	≤ 14.96	≤ 0.155 / ≤ 0.188	≤ 0.48	≤ 0.6
	Number of enclosures (*)		Any			
Content having at least one pressurised enclosure	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 6.72	≤ 2.42	≤ 5.1	≤ 6.36
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.168	≤ 0.0484	≤ 0.128	≤ 0.159
	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with/without water)	m1 + 2 x m2 ≤ 12	m1 + 3 x m2' ≤ 0.155 / m1 + 2 x m2' ≤ 0.188	m1 + 2 x m2 ≤ 0.336 (with water)	m1 + 2 x m2 ≤ 0.42 (with water)
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.168	≤ 0.0484	≤ 0.128	≤ 0.159
	Other case	Total mass of heavy metal in the cavity (kg) (with/without water)	≤ 12	≤ 0.155 / ≤ 0.188	≤ 0.336	≤ 0.42
	Characteristics of gas for filling an enclosure (*) at 20°C (in $bar.cm^3$)		≤ 700			
	Nature of filling gas		Any			
	Number of enclosures (*)		≤ 40	≤ 50	≤ 40	

(*) *First enclosure welded or fitted with seal*

(**) with **m1**: mass of materials outside enclosures welded or fitted with seals and **m2** mass of materials present in the 2 enclosures welded or fitted with seals that contain the most materials, or in the enclosure that is welded or fitted with seals (if there is only one),
m2' mass of materials present in the 3 enclosures welded or fitted with seals containing the most materials, or in the 2 or in the enclosure welded or fitted with seals (if there are only 2 or 1).

TABLE 0A.1 (4/4)
CHARACTERISTICS OF CONTENTS N°1, 2, 3, 5 AND 10 AT MAXIMUM THERMAL POWER (300 W/m or 100 W)

Type of reactor		MTR			UNGG
Type of fuel		Uranium			
Name of content		**Content 5 Type 1**	**Content 5 Type 2**	**Content 5 Type 3**	**Content 5 Type 4**
Maximum combustion rate (MWj/t heavy metal)		≤ 680,000	≤ 120,000	≤ 91,650	≤ 9,500
Enrichment in ^{235}U: e%		≤ 93.5%	≤ 19.65%	≤ 50%	≤ 1.65%
Minimum cooling time		≥ 1 year	≥ 75 days	≥ 6 months	≥ 15 years
Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of U in the cavity (kg)	≤ 7.2	≤ 2.5	≤ 46.1	≤ 68.4
	Total mass of U per enclosure (*) (kg)	≤ 0.18	≤ 0.05	≤ 1.16	≤ 68.4
	Number of enclosures (*)	≤ 40	≤ 50	≤ 40	Any
Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with/without water)	m1 + 2 x m2 ≤ 3.36,10^{-1} with water	m1 + 3 x m2' ≤ 5.57,10^{-2} / m1 + 3 x m2' ≤ 1.5,10^{-1}	m1 + 2 x m2 ≤ 4.69 / m1 + 2 x m2 ≤ 6.47	≤ 68.4
	Total mass of heavy metal per enclosure (*) (kg)	≤ 0.18	≤ 0.05	≤ 1.16	≤ 68.4
	Number of enclosures (*)	≤ 40	≤ 50	≤ 40	Any
Other cases	Total mass of heavy metal in the cavity (kg) (with/without water)	≤ 3.36.10^{-1}	≤ 5.57,10^{-2} / ≤ 1.5,10^{-1}	≤ 4.69 / ≤ 6.47	≤ 68.4
Pressurisation		Non-pressurised			

(*) First enclosure welded or fitted with seal

(**) with **m1**: mass of materials outside enclosures welded or fitted with seals or leaktight

m2 mass of materials present in the 2 enclosures welded or fitted with seals or leaktight containing the most materials or in the enclosure welded or fitted with seals or leaktight (if there is only one).

m2' mass of materials present in the 3 enclosures welded or fitted with seals containing the most materials, or in the 2 or in the enclosure welded or fitted with seals (if there are only 2 or 1).

TABLE 0A.3 (1/2)
CHARACTERISTICS OF CONTENTS N°1, 2, 9 AND 10
AT REDUCED THERMAL POWER (100 W)

Type of reactor			PWR, BWR, MTR					
Type of fuel			UO_2 (***)					
Enrichment in ^{235}U: e%			≤ 93%		≤ 10%	≤ 20%	≤ 93%	≤ 93%
Content in Pu %			/		/	/	/	/
Maximum combustion rate (MWj/t heavy metal)			≤ 120,000		≤ 100,000	≤ 104,000	≤ 120,000	≤ 60,000
Minimum cooling time (months)			≥ 96 (8 years)		≥ 3	≥ 6	≥ 96 (8 years)	≥ 264 (22 years)
Presence of thorium			/		no	no	no	Yes
Name of content			**Content 1 Type 3**		**Content 9 Type 1**	**Content 9 Type 2**	**Content 9 Type 3**	**Content 9 Type 4**
Irradiation in PWR then MTR			authorized		authorized	authorized	authorized	prohibited
Content that does not have a pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 18.8		≤ 7.92,10^{-2}	≤ 2.28,10^{-2}	≤ 3.48,10^{-1}	≤ 9.6
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.47	≤ 0.94	≤ 1.58,10^{-3}	≤ 4.56,10^{-4}	≤ 8.7,10^{-3}	≤ 0.192
	Number of enclosures (*)		≤ 40	≤ 20	≤ 50	≤ 50	≤ 40	≤ 50
	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with water)	ml + 2xm2 ≤ 0.72		ml + 3xm2' ≤ 0.145	ml + 3xm2' ≤ 4.56,10^{-1}	ml + 2xm2 ≤ 7.08,10^{-1}	ml + 3xm2' ≤ 14.4
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.47	≤ 0.72	≤ 1.58,10^{-3}	≤ 4.56,10^{-4}	≤ 8.7,10^{-3}	≤ 0.192
	Number of enclosures (*)		≤ 40	≤ 20	≤ 50	≤ 50	≤ 40	≤ 50
	Other cases	Total mass of heavy metal in the cavity (kg)	≤ 0.72		≤ 1.59,10^{-1}	≤ 4.56,10^{-1}	≤ 7.08,10^{-1}	≤ 14.4
	Number of enclosures (*)		Any					
Content having at least one pressurised enclosure	Materials exclusively in one of the enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg)	≤ 18.8		≤ 7.92,10^{-2}	≤ 2.28,10^{-2}	≤ 3.48,10^{-1}	≤ 9.6
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.47	≤ 0.94	≤ 1.58,10^{-3}	≤ 4.56,10^{-4}	≤ 8.7,10^{-3}	≤ 0.192
	Materials partly in enclosures that are welded or fitted with seals	Total mass of heavy metal in the cavity (kg) (**) (with water)	ml + 2xm2 ≤ 0.72		ml + 3xm2' ≤ 1.45,10^{-1}	ml + 3xm2' ≤ 4.56,10^{-1}	ml + 2xm2 ≤ 7.08,10^{-1}	ml + 3xm2' ≤ 14.4
		Mass of heavy metal per enclosure (*) (kg)	≤ 0.47	≤ 0.72	≤ 1.58,10^{-3}	≤ 4.56,10^{-4}	≤ 8.7,10^{-3}	≤ 0.192
	Number of enclosures		≤ 40	≤ 20	≤ 50	≤ 50	≤ 40	≤ 50
	Other cases	Total mass of heavy metal in the cavity (kg) (with water)	≤ 0.72		≤ 1.59,10^{-1}	≤ 4.56,10^{-1}	≤ 7.08,10^{-1}	≤ 14.4
	Number of enclosures		Any					
	Characteristics of gas for filling an enclosure (*) at 20°C (in bar.cm^3)		≤ 700					
	Nature of filling gas		Any					

(*) *First enclosure welded or fitted with seals*
(**) with **ml**: mass of materials outside enclosures welded or fitted with seals and **m2** mass of materials present in the 2 enclosures welded or fitted with seals that contain the most materials, or in the enclosure that is welded or fitted with seals (if there is only one),
m2' mass of materials present in the 3 enclosures welded or fitted with seals containing the most materials, or in the 2 or in the enclosure welded or fitted with seals (if there are only 2 or 1).
(***) *Plate fuel elements are not authorised*

TABLE 0A.3 (2/2) CHARACTERISTICS OF CONTENTS N°1, 2, 9 AND 10 AT REDUCED THERMAL POWER (100 W)

<table>
<tr><td colspan="3">Type of reactor</td><td colspan="3">PWR, BWR, MTR</td></tr>
<tr><td colspan="3">Type of fuel</td><td>PuO_2, MOX or (U,Pu)C</td><td>UO2</td><td>MOX</td></tr>
<tr><td colspan="3">Enrichment in ^{235}U: e%</td><td>≤ 83%</td><td>≤ 16.7 %</td><td>≤ Unat</td></tr>
<tr><td colspan="3">Content in Pu %</td><td>≤ 26%</td><td>/</td><td>≤ 45%</td></tr>
<tr><td colspan="3">Max rate of combustion (MWj/t heavy metal)</td><td>≤ 165,000</td><td>≤ 160,000</td><td>≤ 150,000</td></tr>
<tr><td colspan="3">Minimum cooling time (months)</td><td>≥ 228 (19 years)</td><td>≥ 100 days</td><td>≥ 4</td></tr>
<tr><td colspan="3">Name of content</td><td>**Content 2 Type 3**</td><td>**Content 10 Type 1**</td><td>**Content 10 Type 3**</td></tr>
<tr><td colspan="3">Irradiation in PWR then MTR</td><td>authorized</td><td>-</td><td>-</td></tr>
<tr><td rowspan="8">Content that does not have a pressurised enclosure</td><td rowspan="2">Materials exclusively in one of the enclosures that are welded or fitted with seals</td><td>Total mass of heavy metal in the cavity (kg)</td><td>≤ 36</td><td>$\leq 1.2{,}10^{-1}$</td><td>$\leq 5.28{,}10^{-1}$</td></tr>
<tr><td>Mass of heavy metal per enclosure (*) (kg)</td><td>≤ 0.72</td><td>≤ 0.0024</td><td>$\leq 1.056{,}10^{-2}$</td></tr>
<tr><td colspan="2">Number of enclosures (*)</td><td colspan="3">≤ 50</td></tr>
<tr><td rowspan="2">Materials partly in enclosures that are welded or fitted with seals</td><td>Total mass of heavy metal in the cavity (kg) (**) (with water)</td><td>m1 + 3x m2' ≤ 1.6</td><td>m1 + 3x m2' $\leq 2.4{,}10^{-1}$</td><td>m1 + 3x m2' ≤ 1.06</td></tr>
<tr><td>Mass of heavy metal per enclosure (*) (kg)</td><td>≤ 0.72</td><td>≤ 0.0024</td><td>$\leq 1.056{,}10^{-2}$</td></tr>
<tr><td colspan="2">Number of enclosures (*)</td><td colspan="3">≤ 50</td></tr>
<tr><td>Other cases</td><td>Total mass of heavy metal in the cavity (kg)</td><td>≤ 1.6</td><td>$\leq 2.4{,}10^{-1}$</td><td>≤ 1.06</td></tr>
<tr><td colspan="2">Number of enclosures (*)</td><td colspan="3">Any</td></tr>
<tr><td rowspan="8">Content having at least one pressurised enclosure</td><td rowspan="2">Materials partly in enclosures that are welded or fitted with seals</td><td>Total mass of heavy metal in the cavity (kg)</td><td>≤ 36</td><td>$\leq 5.28{,}10^{-2}$</td><td>$\leq 5.28{,}10^{-1}$</td></tr>
<tr><td>Mass of heavy metal per enclosure (*) (kg)</td><td>≤ 0.72</td><td>$\leq 1.056{,}10^{-3}$</td><td>$\leq 1.056{,}10^{-2}$</td></tr>
<tr><td rowspan="2">Materials exclusively in one of the enclosures that are welded or fitted with seals</td><td>Total mass of heavy metal in the cavity (kg) (**)</td><td>m1 + 3x m2' ≤ 1.6</td><td>m1 + 3x m2' $\leq 1.06{,}10^{-1}$</td><td>m1 + 3x m2' ≤ 1.06</td></tr>
<tr><td>Mass of heavy metal per enclosure (*) (kg)</td><td>≤ 0.72</td><td>$\leq 1.056{,}10^{-3}$</td><td>$\leq 1.056{,}10^{-2}$</td></tr>
<tr><td>Other case</td><td>Total mass of heavy metal in the cavity (kg) (with water)</td><td>≤ 1.6</td><td>$\leq 1.06{,}10^{-1}$</td><td>≤ 1.06</td></tr>
<tr><td colspan="2">Characteristics of gas for filling an enclosure (*) at 20°C (in $bar.cm^3$)</td><td colspan="3">≤ 700</td></tr>
<tr><td colspan="2">Nature of filling gas</td><td colspan="3">Any</td></tr>
<tr><td colspan="2">Number of enclosures (*)</td><td colspan="3">≤ 50</td></tr>
</table>

(*) First enclosure welded or fitted with seal
(**) with **m1**: mass of materials outside enclosures welded or fitted with seals and
m2' mass of materials present in the 3 enclosures welded or fitted with seals containing the most materials, or in the 2 or in the enclosure welded or fitted with seals (if there are only 2 or 1).

TABLE 0A.5
CHARACTERISTICS OF CONTENT N°8
(ENCLOSURES WELDED OR FITTED WITH SEALS)
Integral or non-integral elements without water

	Content with at least one pressurised enclosure (**)	Content with no pressurised enclosure (**)
Maximum thermal power in the cavity	300 W/m or 100 W	
Maximum combustion rates (MWj/t heavy metal)	120,000	
Minimum cooling time (months)	6	
Total mass of heavy metal in the cavity (kg)	≤ 5.1	
Total mass of Am in the cavity (g)	≤ 2.43	
Total mass of ^{242m}Am in the cavity (g)	≤ 0.24	
Total mass of Cm in the cavity (g)	≤ 1.31	
Total mass of ^{245}Cm in the cavity (g)	≤ 0.39	
Total mass of Np (*) in the cavity (g)	≤ 4.05	
Mass of heavy metal per enclosure (**) (kg)	≤ 0.255	
Mass of Am per enclosure (**) (g)	≤ 1.05	
Mass of Cm per enclosure (**) (g)	≤ 0.24	
Mass of Np (*) per enclosure (**) (g)	≤ 1.77	
Number of enclosures (**)	20	Variable
Characteristics of gas for filling enclosures(**) at 20°C (in bar.cm^3)	≤ 5000	0

(*) any isotopy
(**) enclosure welded or fitted with seals

CHARACTERISTICS OF CONTENT N°8
(OTHER CASES)
Non-integral elements with water

	Content with at least one pressurised enclosure (**)	Content with no pressurised enclosure (**)
Maximum thermal power in the cavity	300 W/m or 100 W	
Maximum combustion rates (MWj/t heavy metal)	120,000	
Minimum cooling time (months)	6	
Total mass of heavy metal in the cavity (kg)	≤ 0.26	
Number of enclosures (***)	20	Any
Total mass of Am in the cavity (g)	≤ 1.07	
Total mass of ^{242m}Am in the cavity (g)	≤ 0.247	
Total mass of Cm in the cavity (g)	≤ 0.247	
Total mass of ^{245}Cm in the cavity (g)	≤ 0.4	
Total mass of Np (*) in the cavity (g)	≤ 1.8	
Characteristics of gas for filling enclosures(***) at 20°C (in bar.cm^3) (**)	≤ 5000	0

(*) any isotopy
(**) In the case where at least one of the elements is pressurised
(***) enclosure welded or fitted with seals

TABLE 0A.6

PARTS LIST FOR THE INTERNAL FITTING FOR PURPOSES OF CRITICALITY

Mark	Title	Quantity	Material
1	Central tube	1	Stainless steel Type A(4)
2	Flange	1	Stainless steel Type A(4)
3	Base	1	Stainless steel Type A(4)
4	Spacer	((Lu(2)-90)/300) (3) min.	Stainless steel Type A(4)
5	Anti-friction pad	((Lu(2)-90)/300) (3) min.	Cupro-Nickel, or Cupro-Aluminium
6	Plug	1	Stainless steel stainless steel Type A(4), Cupro-Nickel(5), or Cupro-Aluminium(5)
7	Locking nut (1)	1	Stainless steel, Cupro-Nickel, or Cupro-Aluminium
7Bis	Base shimming system(6) (for bottom not attached to push device)	1	Stainless steel, Cupro-Nickel, or Cupro-Aluminium

(1): only in the case where the internal fitting is screwed onto the push device.
(2): Lu: usable length of the cavity in the package (in mm)
(3): value to be rounded to the higher integer
(4): See chapter 0
(5): In this case, the cupro-nickel or the cupro-aluminium used must have an elastic limit at least equivalent to that of stainless steel Type A
(6): Only in the case where the internal fitting is not screwed onto the push device.

TABLE 0A.7

MAXIMUM ACTIVITIES OF MAIN ISOTOPES OF CONTENT N°6 TYPE 1

Isotope	Activity (in TBq)
Products of fission	
Zr95	1.08
Nb95	2.13
Ru106	2.71
Rh106	2.71
Cs134	0.61
Ce144	2.56
Pr144	2.56
Actinides	
Cm242	25.08
U233	$1.71{,}10^{-11}$
U235	$2.31{,}10^{-10}$
Np237	$9.73{,}10^{-09}$
Pu238	0.85
Pu239	$5.48{,}10^{-4}$
Pu240	$1.56{,}10^{-3}$
Pu241	0.44
Pu242	$5.70{,}10^{-5}$
Am241	$7.96{,}10^{-4}$
Am242m	$1.89{,}10^{-5}$
Am243	$2.21{,}10^{-3}$
Cm243	$6.55{,}10^{-2}$
Cm244	2.10
Cm245	$3.85{,}10^{-4}$
Cm247	$4.59{,}10^{-9}$
Cf249	$3.30{,}10^{-7}$
Cf251	$7.03{,}10^{-8}$
Gas	
H3	$1.54{,}10^{-3}$
Kr85	$1.59{,}10^{-2}$
I129	$1.14{,}10^{-7}$
I131	$1.04\ .10^{-6}$

TABLE 0A.8 (1/2)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 3
NOT HAVING ANY PRESSURISED ENCLOSURE, AT MAXIMUM THERMAL POWER (300 W/m)

	Content 3 type 2		Content 3 type 1	
	Materials exclusively in one of the enclosures that are welded or fitted with seals	Other cases	Materials exclusively in one of the enclosures that are welded or fitted with seals	Other cases
Type of reactor	FNR		FNR	
Maximum combustion rate (MWj/tU)	115,000		Any	
Maximum number of enclosures (*)	40	Variable	40	Variable
Values to comply with	Per enclosure (*)	In the cavity	Per enclosure (*)	In the cavity
Aerosols activity (A_2)	806.455	$2.964,10^{3}$	$6.37,10^{2}$	$2.371,10^{3}$
Total activity of gases (A_2)	$1.89,10^{-3}$	$6.96,10^{-3}$	$1.50,10^{-3}$	$5.57,10^{-3}$
Activity Kr85 (A_2)	$1.41,10^{-3}$	$5.18,10^{-3}$	$1.11,10^{-3}$	$4.15,10^{-3}$
Activity H3 (A_2)	$4.15,10^{-4}$	$1.52,10^{-3}$	$3.28,10^{-4}$	$1.22,10^{-3}$
Total STP volume of fission gases (l)	0.617	2.27	$4.87,10^{-1}$	1.81

(*) first enclosure welded or fitted with seal, without considering containers of experimental materials.

TABLE 0A.8 (2/2)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 3
WITH AT LEAST ONE PRESSURISED ENCLOSURE, AT MAXIMUM THERMAL POWER (300 W/m)

	Content 3 type 2		Content 3 type 1	
	Materials exclusively in one of the enclosures that are welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals	Materials exclusively in one of the enclosures that are welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals
Type of reactor	FNR		FNR	
Maximum combustion rate (MWj/tU)	115,000		Any	
Maximum number of enclosures (*)	40	Variable	40	Variable
Values to comply with	Per enclosure (*)	In the cavity	Per enclosure (*)	In the cavity
Aerosols activity (A_2)	$7.85,10^{2}$	$2.075,10^{3}$	$6.30,10^{2}$	$1.660,10^{3}$
Total activity of gases (A_2)	$1.84,10^{-3}$	$4.87,10^{-3}$	$1.48,10^{-3}$	$3.90,10^{-3}$
Activity Kr85 (A_2)	$1.37,10^{-3}$	$3.63,10^{-3}$	$1.10,10^{-3}$	$2.90,10^{-3}$
Activity H3 (A_2)	$4.04,10^{-4}$	$1.07,10^{-3}$	$3.24,10^{-4}$	$8.53,10^{-4}$
Total STP volume of fission gases (l)	0.601	1.59	$4.82,10^{-1}$	1.27
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)			

(*) first enclosure welded or fitted with seal, without considering containers of experimental materials.

TABLE 0A.10 (1/3)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 1
NOT HAVING ANY PRESSURISED ENCLOSURE, WITH MAXIMUM POWER OF 300 W/m

	Content 1 type 1			Content 1 type 2		
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals	
Type of reactor	PWR, BWR, MTR					
Maximum combustion rate (MWj/tU)	≤ 100,000			≤ 104,000		
Maximum number of enclosures (*)	40	Any		40	Any	
Values to comply with	Per enclosure (*)	In the cavity with water	In the cavity without water	Per enclosure (*)	In the cavity with water	In the cavity without water
Aerosols activity (A_2)	389.8725	$8.24,10^{2}$	$1.56,10^{3}$	$2.20,10^{2}$	$6.40,10^{2}$	$8.80,10^{-1}$
Total activity of gases (A_2)	$8.64,10^{-3}$	$1.83.\ 10^{-2}$	$3.45,10^{-2}$	$3.68,10^{-3}$	$1.07,10^{-2}$	$1.47,10^{-2}$
Activity Kr85 (A_2)	$1.77,10^{-3}$	$3.74,10^{-3}$	$7.07,10^{-3}$	$3.29,10^{-3}$	$9.55,10^{-3}$	$1.31,10^{-2}$
Activity H3 (A_2)	$2.16,10^{-4}$	$4.57,10^{-4}$	$8.64,10^{-4}$	$3.71,10^{-4}$	$1.08,10^{-3}$	$1.48,10^{-3}$
Total STP volume of fission gases (l)	0.5151126	1.09	2.06	$8.25,10^{-1}$	2.39	3.29
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)					

(*) first enclosure welded or fitted with seal

TABLE 0A.10 (2/3)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 1
HAVING AT LEAST ONE PRESSURISED ENCLOSURE, AT A MAXIMUM POWER OF 300 W/m

	Content 1 type 1			Content 1 type 2		
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals	
Type of reactor	PWR, BWR, MTR					
Maximum combustion rate (MWj/tU)	≤ 100,000			≤ 104,000		
Maximum number of enclosures (*)	40			40		
Values to comply with	Per enclosure (*)	In the cavity with water	In the cavity without water	Per enclosure (*)	In the cavity with water	In the cavity without water
Aerosols activity (A_2)	$3.66,10^{2}$	$5.29,10^{2}$	$7.26,10^{2}$	$2.14,10^{2}$	$4.84,10^{2}$	$5.94,10^{2}$
Total activity of gases (A_2)	$8.11,10^{-3}$	$1.17,10^{-2}$	$1.61,10^{-2}$	$3.58,10^{-3}$	$8.09,10^{-3}$	$9.94,10^{-3}$
Activity Kr85 (A_2)	$1.66,10^{-3}$	$2.40,10^{-3}$	$3.30,10^{-3}$	$3.20,10^{-3}$	$7.22,10^{-3}$	$8.87,10^{-3}$
Activity H3 (A_2)	$2.03,10^{-4}$	$2.94,10^{-4}$	$4.03,10^{-4}$	$3.61,10^{-4}$	$8.15,10^{-4}$	$1.00,10^{-3}$
Total STP volume of fission gases (l)	0.484	6.99,10-1	$9.60,10^{-1}$	8.02,10-01	1.81	2.22
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)					

(*) first enclosure welded or fitted with seal

TABLE 0A.10 (3/3)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 1
HAVING AT LEAST ONE PRESSURISED ENCLOSURE, AT A REDUCED POWER OF 100W

	Content 1 type 3	
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals
Type of reactor	FNR	
Maximum combustion rate (MWj/tU)	Any	
Maximum number of enclosures (*)	50	
Values to comply with	Per enclosure (*)	In the cavity with water
Aerosols activity (A_2)	$2.30,10^{2}$	$3.53,10^{2}$
Total activity of gases (A_2)	$5.31,10^{-3}$	$8.14,10^{-3}$
Activity Kr85 (A_2)	$5.31,10^{-3}$	$8.14,10^{-3}$
Activity H3 (A_2)	0	0
Total STP volume of fission gases (l)	$9.63,10^{-3}$	$1.48,10^{-2}$
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)	

(*) first enclosure welded or fitted with seal

TABLE 0A.11 (1/3)

MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 2
NOT HAVING ANY PRESSURISED ENCLOSURE, WITH MAXIMUM POWER OF 300 W/m

	Content 2 type 1			Content 2 type 2	
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals
Type of reactor	PWR, BWR, MTR				
Maximum combustion rate (MWj/tU)	≤ 80,000			≤ 90,000	
Maximum number of enclosures (*)	40	Any		40	Any
Values to comply with	<u>Per enclosure (*)</u>	<u>In the cavity with water</u>	<u>In the cavity without water</u>	<u>Per enclosure (*)</u>	<u>In the cavity</u>
Aerosols activity (A_2)	$7.833,10^{3}$	$1.501,10^{4}$	$3.129,10^{4}$	$3.409,10^{3}$	$1.256,10^{4}$
Total activity of gases (A_2)	$2.73,10^{-2}$	$5.23,10^{-2}$	$1.09,10^{-1}$	$7.41,10^{-3}$	$2.73,10^{-2}$
Activity Kr85 (A_2)	$3.00,10^{-3}$	$5.75,10^{-3}$	$1.20,10^{-2}$	$5.43,10^{-3}$	$2.00,10^{-2}$
Activity H3 (A_2)	$8.07,10^{-4}$	$1.55,10^{-3}$	$3.22,10^{-3}$	$1.96,10^{-3}$	$7.22,10^{-3}$
Total STP volume of fission gases (l)	1.57	3.01	6.275	2.93	10.79
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)				

(*) first enclosure welded or fitted with seal

TABLE 0A.11 (2/3)

MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 2
HAVING AT LEAST ONE PRESSURISED ENCLOSURE, AT A MAXIMUM POWER OF 300 W/m

	Content 2 type 1			Content 2 type 2	
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals
Type of reactor	PWR, BWR, MTR				
Maximum combustion rate (MWj/tU)	≤ 80,000			≤ 90,000	
Maximum number of enclosures (*)	40			40	
Values to comply with	Per enclosure (*)	In the cavity with water	In the cavity without water	Per enclosure (*)	In the cavity
Aerosols activity (A_2)	$7.266,10^{3}$	$9.12,10^{3}$	$1.306,10^{4}$	$3.424,10^{3}$	$8.970,10^{3}$
Total activity of gases (A_2)	$2.53,10^{-2}$	$3.18,10^{-2}$	$4.55,10^{-2}$	$7.44,10^{-3}$	$1.95,10^{-2}$
Activity Kr85 (A_2)	$2.78,10^{-3}$	$3.49,10^{-3}$	$5.00,10^{-3}$	$5.45,10^{-3}$	$1.43,10^{-2}$
Activity H3 (A_2)	$7.48,10^{-4}$	$9.39,10^{-4}$	$1.35,10^{-3}$	$1.97,10^{-3}$	$5.16,10^{-3}$
Total STP volume of fission gases (l)	1.46	1.83	2.62	2.94	7.71
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)				

(*) first enclosure welded or fitted with seal

TABLE 0A.11 (3/3)

MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 2
HAVING AT LEAST ONE PRESSURISED ENCLOSURE, AT A REDUCED POWER (100W)

	Content 2 type 3	
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals
Type of reactor	PWR, BWR, MTR	
Maximum combustion rate (MWj/tU)	Any	
Maximum number of enclosures (*)	50	
Values to comply with	Per enclosure (*)	In the cavity
Aerosols activity (A_2)	$2.570,10^3$	$5.712,10^3$
Total activity of gases (A_2)	$2.62,10^{-3}$	$5.82,10^{-3}$
Activity Kr85 (A_2)	$2.62,10^{-3}$	$5.82,10^{-3}$
Activity H3 (A_2)	0	0
Total STP volume of fission gases (l)	$4.74,10^{-3}$	$1.05,10^{-2}$
Total thermal power (W)	100	
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)	

(*) first enclosure welded or fitted with seal,

TABLE 0A.12 (1/1)
MAXIMUM ACTIVITY AND VOLUME OF FISSION GASES FOR CONTENT 5
AT MAXIMUM THERMAL POWER (300W/m)

	Content 5 type 1		Content 5 type 2			Content 5 type 3			Content 5 type 4
	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals	Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed exclusively in enclosures welded or fitted with seals	Materials not placed in enclosures welded or fitted with seals		Materials placed in enclosures welded or fitted with seals or not
Type of reactor	PWR, BWR, MTR								
Maximum combustion rate (MWj/tU)	≤ 700,000		≤ 700,000			≤ 700,000			≤ 700,000
Maximum number of enclosures (*)	40		50			40			Any
Values to comply with	Per enclosure (*)	In the cavity	Per enclosure (*)	In the cavity with water	In the cavity without water	Per enclosure (*)	In the cavity with water	In the cavity without water	In the cavity
Aerosols activity (A_2)	$1.260,10^{3}$	$2.352,10^{3}$	$9.555,10^{2}$	$1.064,10^{3}$	$2.87,10^{3}$	$2.754,10^{3}$	$1.121,10^{4}$	$1.55,10^{4}$	$1.231,10^{4}$
Total activity of gases (A_2)	$1.48,10^{-2}$	$2.76,10^{-2}$	$1.4,10^{-1}$	$1.55,10^{-1}$	$4.19,10^{-1}$	$1.84,10^{-2}$	$7.50,10^{-2}$	$1.04,10^{-1}$	$3.07,10^{-2}$
Activity Kr85 (A_2)	$1.48,10^{-2}$	$2.76,10^{-2}$	$1.00,10^{-3}$	$1.11,10^{-3}$	$3.00,10^{-3}$	$1.82,10^{-2}$	$7.41,10^{-2}$	$1.02,10^{-1}$	$3.07,10^{-2}$
Activity H3 (A_2)	0	0	0	0	0	0	0	0	0
Total STP volume of fission gases (l)	3.96	7.40	1.09	1.22	3.28	3.92	$1.59,10^{1}$	$2.20,10^{1}$	$6.06,10^{-2}$
Characteristics of filling gas at 20°C (in bar.cm^3)	≤ 700 per enclosure (*)								

(*) first enclosure welded or fitted with seal.

TABLE 0A-14
CHARACTERISTICS OF CONTENT N°25 type 1 UOX and / or type 2 MOX with or without presence of depleted uranium oxide
THERMAL POWER (300 W/m)

UOX or MOX elements:

Type of reactor	1st irradiation or not in PWR, BWR or MTR then 2nd irradiation or not in PWR, BWR or MTR	
Type of fuel(*)	**Type 1** U oxide	**Type 2** (U. Pu) oxide
Maximum enrichment in ^{235}U: e%	≤ 5%	< U natural
Content in Putot Pu/(U+Pu)%	-	≤ 10%
Maximum combustion rate of 1st irradiation (MWj/t_{ML})	≤ 89,995	≤ 69,987
Minimum cooling time between the 1st and the 2nd irradiation (years)	≥ 1	
Maximum combustion rate of the 2nd irradiation (MWj/t_{ML})	≤ 42	
Minimum cooling time after the 2nd irradiation (hours)	≥ 12	
Total mass of U +Pu of UOX or MOX elements in the cavity (kg)	≤ 0.0336	

(*) Elements based on $_{depleted}$ U, undergoing only the 2nd irradiation of UOX or MOX elements, not included.

Mixing types 1 and 2 is authorised.

Elements based on $_{depleted}$ U:

Type of reactor	Irradiation or not in PWR, BWR or MTR
Type of fuel	U oxide
Maximum enrichment in ^{235}U: e%	< U natural
Maximum combustion rate of the irradiation (MWj/t_{ML})(**)	≤ 42
Minimum cooling time after the irradiation (hours) (**)	≥ 12
Total mass of U of the elements in $U_{depleted}$ in the cavity (kg)	≤ 0.0336

(**) This irradiation corresponds to the second irradiation of UOX or MOX elements

The characteristics of the gas for filling the enclosures at 20°C must be less than 1500 bar.cm^3.

TABLE 0A.15 (1/2)
CHARACTERISTICS OF CONTENTS N°1 TYPE 5, N°2 TYPE 4, N°3 TYPE 4 and 5, N°5 TYPE 5 AND 6 AT MAXIMUM THERMAL POWER (300 W/M)

Type		Content 1 type 5 Section irradiated in a PWR or BWR and re-irradiated in a CEA reactor	Content 2 type 4 Section irradiated in a PWR or BWR and re-irradiated in a CEA reactor	Content 3 type 4 and 5 Section irradiated in a PWR or BWR and re-irradiated in a CEA reactor
Maximum combustion rate (GWj/t of ML)		100	80	150
Cooling time minimum		3 months	3 months	4 months
Number of enclosures		≤ 40		
Maximum fissile content before irradiation		10% of ^{235}U	12.5% of Pu_{total}	45% of Pu_{total}
In the presence of sound elements pressurised elements	Mass of heavy metal in the cavity (kg) (*)	71	49	15
	Mass of heavy metal per enclosure (*)	1.775	1.225	0.375
In the presence of non-pressurised elements, non-integral without water	Mass of heavy metal in the cavity (kg) (*)	27	32	2.6
	Mass of heavy metal per enclosure (*)	0.675	0.8	0.065

(*): the mass of heavy metal is defined as the sum of the masses of uranium and plutonium.

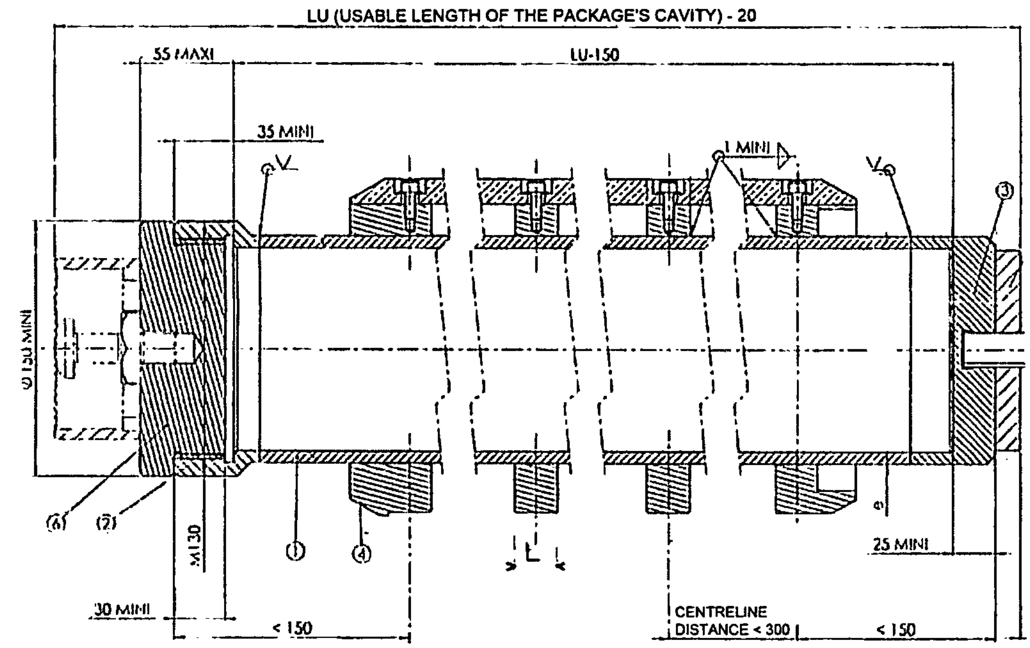
TABLE 0A.15 (2/2)
CHARACTERISTICS OF CONTENTS N°1 TYPE 5, N°2 TYPE 4, N°3 TYPE 4 and 5, N°5 TYPE 5 AND 6 AT MAXIMUM THERMAL POWER (300 W/M)

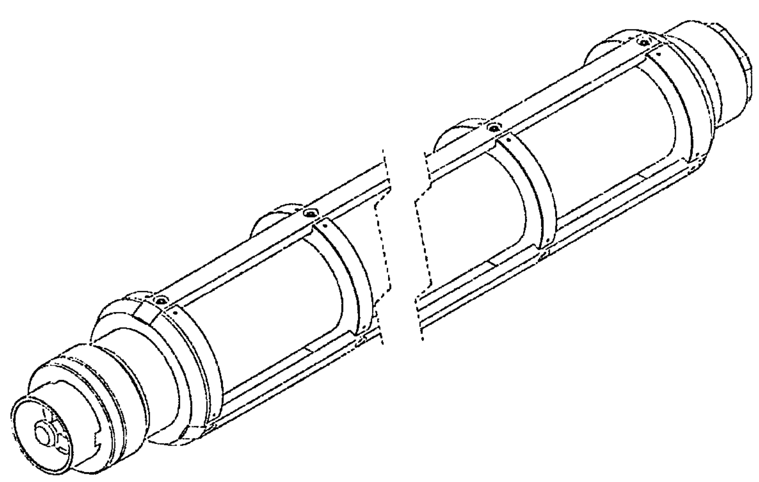
Type		Content 5	
		type 5 Section irradiated in a PWR or BWR and re-irradiated in a CEA reactor	type 6 Section irradiated in a PWR or BWR and re-irradiated in a CEA reactor
Maximum combustion rate (GWj/t of ML)		120	680
Cooling time minimum		75 days	1 year
Number of enclosures		≤ 40	
Maximum fissile content before irradiation		19.65% of ^{235}U	93.5% of ^{235}U
In the presence of sound elements Non-pressurised elements	Mass of heavy metal (*) in the cavity (kg)	276	609
	Mass of heavy metal per enclosure (*)	6.9	15.225
In the presence of non-pressurised elements, non-integral without water	Mass of heavy metal (*) in the cavity (kg)	13	105
	Mass of heavy metal per enclosure (*)	0.325	2.625

(*): the mass of heavy metal is defined as the sum of the masses of uranium and plutonium.

FIGURE 0A.1

DIAGRAM OF A SHEATH PROVIDED FOR PURPOSES OF CRITICALITY





INTERNAL ARRANGEMENTS DRAWING FOR THE PURPOSE OF CRITICITY

Reference	Index	Format	Title
5573-75	E	A1	Case Concept Drawing – TN 106 Packaging

REVISION STATES

Rev	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-0A-1E			
0	06/03	Ind. A: Drawing first issue	L. MARIETTE / C. VALLENTIN
Ref. : DOS-08-00126114-031			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT
01	06/11	New case concept drawing index	B. GSIB/ C. GRANDHOMME
2	02/13	Deletion of the content maximal acceptable masses Insertion of the screw thread insertion depth of the plug	R. BAHOU / D. HONDAGNEU

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

REV.	DATE	DESSINE / DRAWN	VERIFIE / CHECKED	APPROUVE / APPROVED	MODIFICATIONS
E	04/05/12	A.BIGUET	E.GAUTBOF	J-A. [illegible]	MODIFICATIONS SUIVANT DMAM PQA-08-00117278-001-00
D	12/06/08	A.BIGUET	S ESPERBE	C.GRANDHOMME	MODIFICATIONS SUIVANT DMAM PQA-08-00112278-000-00

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N° PLAN / DRAWING REFERENCE: 5573-075

EMBALLAGE TN 106
PRINCIPE DE L'ETUI

FORMAT A1

ECHELLE / SCALE 1:2

PACKAGING STRUCTURAL STRENGTH

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1E			
0	06/00	Document first drawn up	F. PETIT / L. HANSEL
Ref. : DOS-08-00126114-100			
00	08/08	New document reference New formalism Update appendix	S. CHEVET / JC. BOTT
1	02/13	Translation of the document DOS-06-00032898-100 Rev 0. References and appendices update.	R. BAHOU / D. HONDAGNEU

SUMMARY

Purpose:

The purpose of this chapter is to analyse the mechanical strength of the TN 106 packaging design and to show that it meets the requirements of the regulations which apply to type B packages loaded with fissile materials.

Essential Parameters and their Sources:

The dimensions, masses and properties of the materials are taken from Chapter 0.

The temperatures of the various elements are taken from Chapter 2.

Results and Conclusions:

This chapter shows that TN 106 packaging complies with IAEA regulations <1> for type B packages and for packages which contains fissile materials with particular regard to protection from radiation, the containment, and nuclear safety.

Subsequent Use of the Results Obtained:

This chapter makes it possible to define a damaged package used in Chapter 3A for the analysis of the containment, in Chapter 4A for protection from radiation and in Chapter 5A for the nuclear safety analysis of the package.

1. PURPOSE

The purpose of this chapter is to analyse the mechanical strength of the TN 106 package design and to show that it meets the regulatory requirements concerning B type packages loaded with fissile materials. In addition, this chapter demonstrates that it withstands the mechanical loads of conditions of transport and handling and that the packaging complies with CODAP <2> requirements.

2. REQUIREMENTS RELATING TO B(U) TYPE PACKAGINGS

Appendix 2 of Chapter 00 shows the correspondence between all the requirements relating to B type packages loaded with fissile materials and this safety analysis report.

3. STRUCTURAL STRENGTH OF THE PACKAGING IN NORMAL CONDITIONS OF HANDLING AND TRANSPORT

The demonstration of the mechanical strength of the shock absorbing covers, the base plate and the handling points and the tie-down in normal conditions of transport is made in the Appendix 2 and 3 of this chapter. The temperatures used for the analysis are taken from Chapter 2-1.

4. STRUCTURAL STRENGTH OF THE PACKAGING IN ACCIDENT CONDITIONS OF TRANSPORT

Appendix 4 of this chapter determines the length of the model upon which tests are performed which are representative of normal and accident conditions of transport as well as the test load used. It also defines all drop tests designed to guarantee that the package is undergoes maximum damage to the safety components to be tested.

The appendix 7 of this chapter determines the appropriate frequencies the packaging TN 106.

These drop tests were performed on a ½ scale model of the packaging, shown in Appendix 9. The similarity of which to the full-scale model is demonstrated in Appendix 10.

The drop tests report, its analysis so the complimentary measures realized on the model are presented on the appendix 11 on this chapter.

The demonstration of the mechanical strength of the package during accident conditions of transport is demonstrated in Appendices 12 and 13 of this chapter.

5. REQUIREMENTS RELATING TO THE CODAP CODE

The compliance of the packaging containment, closure plates and lid with requirements of the CODAP Code <2> is demonstrated in Appendix 1 of this chapter.

6. CONCLUSION

This chapter and these appendices set out the mechanical analysis of the packaging and in particular:

- The resistance of the packaging to statutory pressures (see Appendix 1-1),
- The resistance of the structures (see Appendix 1-2),
- The mechanical strength of the tie-down and handling points of packaging TN 106 (see Appendix 1-3),
- The resistance to drop tests (see Appendices 1-4 to 1-13),

This chapter also shows that the packaging TN 106 complies with the IAEA regulations <1> which apply to type B packages and packages of fissile materials with particular regard to the following points:

- No risk of brittle fracture,
- Resistance to test pressure in normal conditions and to pressure due to immersion in water in accident conditions and for packages containing irradiated nuclear fuel,
- Resistance to the normal and transport accident condition test sequences defined in IAEA regulations <1>, and in particular, with regard to criteria concerning the loss and dispersion of radioactive contents, protection from radiation and nuclear safety.

7. REFERENCES

<1> Regulation IAEA applicable: see chapter 00.

<2> CODAP, 1995 Edition, (30 June 1995) - Revision 97-12: 1st January 1997 - SNCT - AFIAP.

LIST OF APPENDICES

RESISTANCE OF TN 106 PACKAGING TO REGULATORY PRESSURES

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-1E			
0	12/00	Document first drawn up	L. MARIETTE / L. HANSEL
Ref. : DOS-08-00126114-101			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT
01	02/13	Translation of the document DOS-06-00032898-101 Rev. 0 Update of the maximal temperatures reached by the packaging.	R. BAHOU / D.HONDAGNEU

SUMMARY

This appendix shows the verification of the resistance to pressure of TN 106 packaging. In particular, this analysis is used to define the maximum allowable internal pressure and the resistance to the external test pressures.

Objectives:

- To determine the maximum allowable internal pressure,
- To determine the resistance to external test pressure,
- To set the test pressure of the packaging.

Essential Parameters and their Sources:

The dimensions, masses and properties of the materials of the packaging components are taken from Chapter 0.

The temperatures of various elements are taken from Chapter 2.

Assumptions and Methods Used:

The requirements concerning the pressure in the containment system are:

1. Calculation of the maximum allowable internal pressure in accordance with the CODAP 95 regulations <2>,

2. Immersion in water test (Section 729 of <1>): resistance to an external gauge pressure of at least 150 kPa = 1.5 bar,

3. Immersion in water test for packages containing irradiated nuclear fuel (Section 730 of <1>): Resistance to an external gauge pressure of at least 2 MPa = 20 bars.

The verification of Point 3, immersion in water test for packages containing irradiated nuclear fuel, is carried out by means of analytical calculation. This verification envelops Point 2.

Results and Conclusions:

1. This calculation shows that the allowable internal pressure is 24 bars in normal conditions of service and 43 bars in exceptional conditions of service,

2. An external pressure of 20 bars is acceptable.

Subsequent Use of the Results Obtained:

The test pressure is set at 11 bars, which is compatible with the results of the calculation of the maximum allowable internal pressure and the different pressures to which the package is subjected during exploitation.

1. PURPOSE

This calculation note sets out the verification of the allowable pressure inside and outside the containment system of TN 106 packaging in accordance with CODAP 95 <2>.

2. CALCULATION OF THE CONTAINMENT SYSTEM SUBJECTED TO INTERNAL PRESSURE

The e/De ratio (thickness of the cylindrical envelope over the external diameter of the containment system) equals 23.5/[redacted] = 0.09, so that it is less than 0.16. Chapter C2.1 of <2> is therefore applicable.

The relative allowable pressure in the cavity can be deduced from the C2.1.4.1 general formula:

$$P = \frac{efz}{R_i + 0.5e}$$

Where:

- P: pressure in the cavity,
- e: thickness of the cylindrical wall,
- f: calculation nominal stress,
- R_i: inner radius of cylindrical envelope,
- z: welding coefficient defined in Table C.1.8.

Normal Conditions of Service:

The stress is given in Table C1.7.2 for austenitic stainless steels.
We set the criterion $f_3 = \max\left(\frac{\sigma_r}{3.5}\ ;\ \frac{\sigma_e}{1.66}\right)$.

Where:

- σ_r: Tensile strength of steel type A at 200 °C =360 MPa
- σ_e: Yield strength of steel type A at 200 °C =118 MPa

N.B.: The maximum temperature reached by the inner shell in normal conditions of transport is 91.9 °C. The use of mechanical properties of the steel at 200 °C ensures a conservative approach because it produces a lower allowable stress.

So $f_3 = \max\left(\frac{360}{3.5}\ ;\ \frac{118}{1.66}\right) = 103$ MPa.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

Exceptional Conditions of Service:

The stress is given in Table C1.7.4 for austenitic stainless steels.

$$f = \frac{\sigma_r}{2}$$

Where:

- σ_r: Tensile strength of steel type A at 200 °C = 360 MPa

N.B.: The maximum temperature reached by the inner shell in accident conditions of transport (fire) is 152,8 °C. The use of the steel mechanical characteristics' at 200°C is penalizing because it drives to a weaker acceptable constraint

$$f = \frac{360}{2} = 180 \text{ MPa.}$$

- z: Weld coefficient defined in Table C1.8.

Given the nature of the elements transported, the construction category of the TN 106 is B.

Coefficient z is equal to 0.85 taking account of the harsh manufacturing acceptance criteria. In exceptional conditions of service, there is no reason to take a welding coefficient into account, so we must take z = 1.

- R_i: Internal radius of the cylindrical envelope = 101.5 mm.

We therefore calculate the allowable pressures according to CODAP 95:

Normal Conditions of Service

$$P = \frac{23.5 \times 103 \times 0.85}{101.5 + 0.5 \times 23.5} = 18 \text{ MPa}$$ which is **180 bars**.

Exceptional Conditions of Service

$$P = \frac{23.5 \times 180 \times 1}{101.5 + 0.5 \times 23.5} = 37.3 \text{ MPa}$$ which is **373 bars**.

3. CALCULATION OF THE CONTAINMENT SYSTEM SUBJECTED TO INTERNAL PRESSURE AND OTHER LOADS

This verification is the subject of Chapter C2.4 of <2>. According to this chapter, the verification is to be carried out for the following additional load cases:

- Force exerted along the axis of the packaging,
- Bending moment exerted on a plane containing the envelope axis,
- Torsional moment around the axis of the envelope value.

None of these loads are present in normal conditions of service. In exceptional conditions of service, load due to being dropped is not added to the effects of internal pressure.

4. CALCULATION OF THE BOLTED CIRCULAR LIDS SUBJECTED TO INTERNAL PRESSURE ONLY

This calculation is dealt with in Chapter C3.3 of <2>.

First, the minimum thickness for the situation of the gasket seat is calculated. This thickness must be less than the thickness of the lid. Next, the allowable pressure is determined based on the real thickness of the lid.

Section C3.3.4, calculation rules for lids with internal gaskets at the bolt circle, is applied.

The minimum thickness of the lid is given by the relation:

$$e = \max \left\{ (e_A) ; (e_P) \right\}$$

in the situation of the gasket seat:

$$e_A = \sqrt{\frac{3(C-D_j)F'_A}{\pi D_j \quad f_A}} \quad \text{(formula C3.3.4a1)}$$

- C: diameter of the bolt circle,

- D_j: Diameter of the circle supporting the gasket,

- F'_A: Tensile force exerted on the bolts in the situation of the gasket seat defined in Section C6.1.4.

$$F'_A = \frac{nS_r + S}{2} f_{b;A} \quad \text{(formula C6.1.4e)}$$

Where n: number of bolts.

- S_r: Tensile stress area of a bolt.

- S: Minimum cross-section required for all n bolts.

$$S = \frac{F_A}{f_{b,A}}$$

- F_A: Minimum stress to be exerted by the n bolts in the situation of the gasket seats equal to 0 for the EPDM gaskets according to Section C 6.A4.

Thus, $F_A = 0$ and $S = 0$.

- $f_{b;A}$: Nominal stress used in the calculation of the bolts for the pressure of the gasket seats defined in Table C1.7.2 for bolts made from non alloy or austenitic alloy steel (general case).

$$f_{b;a} = \min\left(\frac{\sigma_e}{3};\frac{\sigma_r}{5}\right)$$

Where:

- σ_e: Yield strength of the carbon steel used for the screws at 20 °C;
    - $\sigma_e = 640$ MPa for class 8.8 screws;
    - $\sigma_e = 900$ MPa for class 10.9 screws;

- σ_r = Tensile strength of the carbon steel used for the screws at 20 °C;
    - $\sigma_r = 800$ MPa for the class 8.8 screws;
    - $\sigma_r = 1000$ MPa for class 10.9 screws.

- f_A: Nominal stress used in the calculation of the lid material in the situation of the gasket seat.

This stress is given in Table C1.7.2 for austenitic stainless steels.

We set the criterion $f_a = \max\left(\frac{\sigma_r}{3.5};\frac{\sigma_e}{1.66}\right)$

Where:

- σ_e: Tensile strength of steel type A at 20 °C, equal to 175 Mpa for steel type A and 450 Mpa for steel type B;
- σ_r: Yield strength of steel at 20 °C, equal to 450 Mpa for steel type A and 650 Mpa for steel type B.

So $f_a = 129$ MPa for the steel type A.
$f_a = 271$ MPa for the steel type B.

The results of the calculation of the minimum thickness of the lids at the situation of the gasket seats e_A and the value of the real thickness of the lids e_R are set out in the table at the end of this section. This calculation can be used to check that the real thickness of the lids e_R is greater than e_A.

Note: To the right of the quick-connect coupling (central part of the closure plate), the drainage and vent closure plates have a recess of diameter 20 mm and depth 17 mm. The thickness of closure plate at the level of the recess is reduced to 13 mm which is less than the minimum thickness required at the situation of the gasket seats (15.2 mm). However, the standard thickness of these closure plates is 30 mm. The localised thinning at the centre of the closure plates over a surface of less than 5% of their total surface is largely offset by the standard thickness whose value is double than that required by the calculation.

<u>In a situation under pressure:</u>

$$e_p = \sqrt{\left[\frac{3(3+\upsilon)}{32}D_j^2+3\left(\frac{D_j}{4}+2J_E m\right)(C-D_j)\right]\frac{P}{f}} \quad \text{(formula C3.3.4a2)}$$

Where $2J_Em$ = Ym/P = 0 for the EPDM gaskets according to Section C6.A4, so, the allowable pressure for each closure is equal to:

$$P = \frac{e_p^{\ 2} \text{ x } f}{\frac{3(3+\upsilon)}{32}D_j^2+3\left(\frac{D_j}{4}\right)(C-D_j)}$$

- e_p: Thickness of the sheet metal of the lid = e_R

  The drainage and venting closure plate possess a recess to the right of the quick-connect coupling, the thickness used is, therefore, the thickness at the recess, which is e_R – 17 mm.

- f : Nominal stress used in the calculation of the base material for the situation under pressure considered. As the material from which the lid and base of packagings are made is type A steel, the stress is the same as that determined in §2. This thus leads to the following equation:

  f = 103 MPa in normal conditions of service;
  f = 180 MPa in exceptional conditions of service.

- υ : Poisson coefficient of the steel = 0.30 (see Table C1.6.6).

This calculation, therefore, gives us the maximum allowable pressure for each lid.

For the front lid, the calculation is carried out assuming the plate to be entire. First of all, however, we check that this hypothesis produces a maximum stress which is more than it would be if the hole drilled for the front closure plate were taken into account.

In order to do this, the ratio of the maximum observable stresses in the front lid is calculated in cases 2e and 10b of Table 24 in <3>. These cases correspond to the front closure plate with (case 2e) or without (case 10b) the hole.

Calculation of the ratio of the maximum stress:

$$\frac{\sigma_{max}(2e)}{\sigma_{max}(10b)} = \frac{M_{max}(2e)}{M_{max}(10b)}$$

Where

- $M_{max}(2e) = qa^2\left(L_{17} - \frac{C_7}{C_4}L_{14}\right)$

- $M_{max}(10b) = qa^2/8$

So:

- $L17 = \frac{1}{4}\left\{1 - \frac{1-\nu}{4}\left[1 - \left(\frac{r_0}{a}\right)^4\right] - \left(\frac{r_0}{a}\right)^2\left[1 + (1+\nu)\ln\frac{a}{r_0}\right]\right\}$

- $L14 = \frac{1}{16}\left[1 - \left(\frac{r_0}{a}\right)^4 - 4\left(\frac{r_0}{a}\right)^2 \ln\frac{a}{r_0}\right]$

- $C4 = \frac{1}{2}\left[(1+\nu)\frac{b}{a} + (1-\nu)\frac{a}{b}\right]$

- $C7 = \frac{1}{2}\left(1-\nu^2\right)\left[\frac{a}{b} - \frac{b}{a}\right]$

With: r_0 = b = 111 mm (corresponds to the area of bearing of the pressure on the front closure plate)
a = 340 mm (corresponds to the radius of the front lid screws)
υ = 0.3

Which gives:

- L17 = 0.14 L14 = 0.03

- C4 = 1.28 C7 = 1.25

Thus giving:

$$\frac{\sigma_{max}(2e)}{\sigma_{max}(10b)} = 8\left(L_{17} - \frac{C_7}{C_4}L_{14}\right) = \mathbf{0.88}$$

This means that for an equal loading, the maximum stress in the entire lid is greater than the maximum stress in the lid without the front closure plate. This justifies the fact that the lid is assumed to be entire for the calculation of maximum allowable pressure.

All the results (e_A and P) are summarised for the lid and each closure plate in the following table:

Element	C	Dj	Bolts			e_A	e_R	Max Allowable P Normal Condition	Max Allowable P Exceptional Condition
			n	Sr	$f_{b;A}$				
	mm	mm		mm²	MPa	mm	mm	(bars)	(bars)
Front Lid	680	604	24	157	160	16.8	60	25	43
Front closure plate	300	222	12	157	160	19.9	26	24	43
Back closure plate	260	172	12	157	160	24.0	30	45	79
Revolving plug closure plate	130	83	8	37	200	11.2	24	117	205
Drainage Closure Plate	100	49	8	37	200	15.2	30	66*	116*
Vent Closure Plate	100	49	8	37	200	15.2	30	66*	116*

* With recess: e_R – 17 mm = 13 mm.

5. CALCULATION OF THE CONTAINMENT SYSTEM SUBJECTED TO EXTERNAL PRESSURE ONLY

The cylindrical shell of the containment system is verified in accordance with CODAP 95. The calculation for the front closure plates and the front lid is carried out using formulas taken from <3>.

5.1 Calculation of the Cylindrical Shell

This calculation is dealt with in Chapter C4.1 of <2>.

Section C4.1.5 is applied in order to determine the maximum allowable pressure for a cylindrical envelope. This pressure is determined by the following relation:

$$P_a = \frac{4\,B}{3\,D_c / e} K \quad \text{(Formula C4.1.5.1.d)}$$

Where

- B: coefficient determined using chart C4.9.2
- De: external diameter of the cylindrical envelope
- e: Thickness of the envelope
- K: coefficient equal to:
  - 1 for normal conditions of service
  - 1.35 for exceptional conditions of service

Let e=23.5 mm is the thickness of the cylindrical envelope.

The ratio $\frac{D_e}{e}$ $(\frac{250}{23.5}=10,6)$ is greater than 10 so Section C4.1.5.1 is applicable.

The length of the envelope ranges between 2200 mm and 2400 mm.

The ratio $\frac{L}{D_e}$ ranges between 8.8 and 9.6.

The ratios $\frac{D_e}{e}$ and $\frac{L}{D_e}$ calculated above can be used to determine coefficient A using chart C4.9.1.

- For L = 1000 mm; A = 0.013.
- For L = 3200 mm; A = 0.011.

Coefficient B is determined using chart C4.9.2-13: Cr-Ni low carbon and Cr-Ni low nitrogen carbon types of austenitic steels for a temperature of 205 °C.

The lowest value of A produces the lowest value of B which minimises the allowable pressure. In a penalizing way, we consider the coefficient A equal to 0,011.

We obtain B = 60 (for A = 0.011).

The maximum allowable pressure is, therefore, according to the above formula:

For normal conditions of service, K =1

$$P_a = \frac{4\,x\,60\,x\,1}{3\,x\,\frac{250}{23.5}} = 7.5\,MPa \quad \text{(which is 75 bars)}$$

For exceptional conditions of service, K = 1.35

$$P_a = \frac{4\,x\,60\,x\,1.35}{3\,x\,\frac{250}{23.5}} = 10.1\,MPa \text{ (which is 101 bars)}$$

So, the thickness of the cylindrical containment system envelope is sufficient, according to CODAP 95, to withstand an external pressure of 2MPa (20 bars).

5.2 Calculation of the Lids

The calculation of the lids is carried out using the formula taken from <3>, and corresponding to the calculation of circular plates of constant thickness, uniformly loaded over the whole plate, fixed periphery (case 10b in Table 24).

The moment is greatest at the periphery of the plate: $M_{max} = q\ a^2/8$.

The maximum bending stress is therefore: $\sigma_{max} = 6\ q\ a^2/\ (8\ e_R^2)$.

Where:

- q: Pressure applied to the lid: q = 2 MPa,
- a: Radius of the bolt circle equal to C/2,
- e_R: Thickness of the lid.

The allowable limit for maximum stress is taken as being equal to the yield strength at 150°C of the material considered. Accepted the front closure plate, all the closure plates and the lid are made from type A stainless steel. The yield strength of this steel is: σ_e = 130 MPa at 150°C. The front closure plate is made from type B stainless steel witch has a yield strength equal to 335 MPa at 150°C.

The results of the calculation are set out in the following table:

Element	a mm	e_R mm	σ_{max} MPa
Front lid	340	60	49
Front closure plate	150	26	50
Back closure plate	130	30	29
Revolving plug closure plate	65	24	11
Drainage closure plate	50	13*	23
Vent closure plate	50	13*	23

* To ensure a conservative approach, the thickness of the closure plate at the recess is used.

For each closure plate and lid, the maximum stress is lower than the yield strength. Therefore, the thickness of the lids is sufficient to withstand an external pressure of 2 MPa (20 bars).

6. SATURATING VAPOUR PRESSURE

As the TN 106 packaging can be loaded or unloaded under water, it should be checked that the saturating vapour pressure remains lower than the maximum allowable pressure in normal conditions of service.

The maximum temperature of the walls of the cavity in normal transport conditions is 91.9 °C (see chapter 2). The saturating vapour pressure is equal to 0.756 bars and is thus much lower than 24 bars (minimum value of Section 4) when the cavity is immersed in water.

The test pressure shall be arbitrarily set at 11 bars.

7. CONCLUSION

All of the results are summarised in Table 1-1.1.

The maximum allowable internal pressure for the containment system is equal to 24 bars in normal conditions of service and 43 bars in exceptional conditions of service. The test pressure is set at 11 bars, which is compatible with the results of the calculation of the maximum allowable internal pressure. Furthermore, the external pressure of 20 bars is allowable and does not produce any deformation of the packaging.

8. REFERENCES

<1> Regulations applicable IAEA: see chapter 00

<2> CODAP, 1995 Edition, (30 June 1995) - Revision 97-12: 1st January 1997 - SNCT - AFIAP.

<3> Roark's Formulas for Stress and Strain, 6th Edition (1989).

<4> Handbook of Chemistry and Physics - The Chemical Rubber Company - 73rd Edition, 1992 - 1993 - 70 Cleveland, Ohio, USA.

LIST OF TABLES

TABLE 1-1.1

SUMMARY OF THE RESULTS

CODAP CHAPTER	COMPONENT CHECKED	PURPOSE OF CALCULATION	NORMAL CONDITION (bars)	EXCEPTIONAL CONDITION (bars)
C2.1.4	Shell	Calculation of the containment system subjected to internal pressure only	180	373
C3.3	Lids	Front Lid	25	43
		Front closure plate	24	43
		Back closure plate	45	79
		Revolving Plug Closure Plate	117	205
		Drainage Closure plate	66	116
		Vent Closure plate	66	116
C4.1	Shell	Calculation of the containment system subjected to external pressure only	75	101
		ALLOWABLE PRESSURE	**24**	**43**

MECHANICAL STRENGTH OF AUXILIARY STRUCTURES

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-2E			
0	12/00	- Document first drawn up	L. MARRIETTE / L. HANSEL
Ref. : DOS-08-00126114-102			
00	08/08	- New document reference - New formalism	S. CHEVET / JC. BOTT
01	02/13	- Translation of the document DOS-06-00032898-102 Rev. 0. - Update of the cavity's useful length's range [2200 mm - 2400 mm] and the materials' mechanical characteristics limits.	R. BAHOU / D. HONDAGNEU

SUMMARY

This appendix justifies the dimensioning, in normal conditions of handling and normal conditions of transport, of the packaging auxiliary structures as described in Chapter 0 and in the drawings of Appendix 1, Chapter 0.

Purpose:

In the case of TN 106 packaging, these structures are the shock-absorbing cover, handling points and the base plate. Verification therefore concerns the following:

- Resistance to overpressure in the shock-absorbing cover due to a hypothetical gaseous release from the wood in normal conditions of transport. This pressure is taken as being equal to 0.1 bar,
- The resistance of the shock absorbing covers to shocks in normal conditions of transport. Verification is carried out with an acceleration of 2 g,
- The resistance of the handling points of the lid, of the revolving plug and shock absorbing covers is verified for accelerations of 2 g to take account of snatch lifting,
- The strength of the base plate when the loaded package is set down. We realize the verification is carried out with an acceleration of 2 g,
- Determination of the maximum pressure on the ground when the package without shock absorbing covers rests on the base plate in the horizontal position or on the back flange in the vertical position when it is full of water.

Essential Parameters and their Sources:

The dimensions, masses and properties of the materials are taken from Chapter 0.

The temperatures of the various elements are taken from Chapter 2.

Assumptions and Methods Used:

The stresses are calculated for a differential pressure P = 0.1 bar = 0.01 MPa (internal overpressure) taking account of the low level of any hypothetical release of gas from the wood in normal conditions of transport.

The calculation is carried out for the external metal envelope of the shock absorbing cover only; the stiffeners are not calculated as they are not subjected to differential pressure.

Verification is made by analytical calculation.

Results and Conclusions:

The maximum stress in the auxiliary structures of the packaging in normal conditions of handling and normal conditions transport is [redacted] MPa. This value is obtained on the top sheet of the shock absorbing cover (513) when subjected to a differential pressure of 0.1 bars. This stress is lower than the limit of [redacted] MPa for type A steel.

The maximum pressure exerted on the ground is [redacted] t/m^2 for the package in the horizontal position and [redacted] t/m^2 for the package in the vertical position filled with water.

Subsequent Use of Essential Parameters:

Taking into account the results in normal configuration of transport, the shock absorbing cover complies with the assumptions made for the analysis of accident conditions.

In the horizontal position, the package can only be placed on the ground on the base plate on a structure which will withstand at least a load to the ground of 11 t/m^2.

In the vertical position, the package can only be placed on the ground on a structure which will withstand at least a load of 21 t/m^2.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

1. PURPOSE

This appendix justifies the dimensioning, in normal conditions of handling and normal conditions of transport, of the packaging auxiliary structures as described in Chapter 0 and in the drawings of Appendix 0, Chapter 1.

With respect to TN 106 packaging, these structures are the shock-absorbing cover, handling points and the base plate. Verification therefore concerns the following:

- The resistance to overpressure in shock-absorbing cover,
- The resistance of the shock absorbing cover to shocks in normal conditions of transport,
- The strength of the handling points of the front lid, the revolving plug and the shock absorbing covers,
- The strength of the base plate when the package is set down,
- Determining the maximum pressure exerted on the ground.

The dimensioning of the tie-down and handling devices is justified in Appendix 3 of Chapter 1 of the safety analysis report.

The mechanical properties of the welding filler materials are at least equal to those of the assembled materials. In addition, the welds are not subject to specific verification.

2. SHOCK-ABSORBING COVER: RESISTANCE TO DIFFERENTIAL PRESSURE

2.1 Assumptions

The shock-absorbing cover consists of a type A stainless steel envelope (see Chapter 0) filled with balsa and plywood. It is fixed to the body by means of 6 CHC M20 screws. The metal envelope comprises radial stiffeners which are also made from stainless steel.

We calculate the stress for a differential pressure P = 0.1 bar = 0.01 MPa (internal overpressure) taking account of the low level of any hypothetical release of gas from the wood in normal conditions of transport. In excess of this pressure, the valves allow outgassing of the shock absorbing covers.

The metal containment is fitted with fusible plugs (see description in Chapter 0) to ensure a good behaviour in the event of fire.

The chapter 2 shows that the maximum temperature obtained in normal conditions of transport is lower than 80°C at the external surface level of the packaging body.

Also, by considering the yield strength at 20°C for the steel type A of the shock absorbing covers presented in the chapter 0 and the yield strength at 100°C presented in the standard < 2 >, we can calculate by interpolation the yield strength at 80°C which corresponds to the stress criterion not to be exceeded for the steel type A of the shock absorbing covers, that is 161 MPa.

The calculation of resistance to the differential pressure is carried out for the external metal envelope of the shock absorbing cover only, the stiffeners are not calculated as they are not subjected to differential pressure (the pressure is the same on both sides of the plates).

The top inner shell (514) and the bottom inner shell (503) have smaller diameters than the outer shell (501), the verification of their strength is enveloped by the calculation of the outer shell (501).

The bottom plate under the shock absorbing cover (502) is of a similar shape to the top sheet (513), but its free surface is smaller, the strength of this plate is therefore enveloped by the calculation of the top sheet (513).

The verification, therefore, concerns the following elements:

- The outer shell (501),
- The intermediate plate (506),
- The puncture protection plate (509),
- The top sheet of the shock absorbing covers (513).

2.2 Outer Shell (501)

The outer shell is uniformly welded to radial stiffeners (510), the calculation is carried out taking a sector between two stiffeners as a flat plate which ensures a very conservative approach.

The calculations are in accordance with case 1a of Table 26 of <1>, corresponding to a rectangular plate supported on all 4 sides.

The developed length of the arc of the circle is:

$$a = \frac{\pi.D}{n_S}$$

Where:

- D: diameter of the shock absorbing cover = 1,458 mm
- n_S: sector number = 6

We obtain

$$a = \frac{\pi \times 1458}{6} = 764\ mm$$

The width of the plate is equal to the height of the outer shell which is:

- b = 725 mm

Which is the ratio a/b:

$$\frac{a}{b} = \frac{764}{725} = 1.05$$

Based on case 1a of Table 26 of <1> and for a maximum ratio a/b = 1 we determine:

- $\beta = 0.2874$

The maximum stress is calculated by means of the following relation:

$$\sigma = \frac{\beta.q.b^2}{t^2} = \frac{0,2874 \times 0,01 \times 725^2}{4^2} = 94 \text{ MPa}$$

Where:

- t: Thickness of the sheet = 4 mm

This value is below the criterion of 161 MPa for type A steel.

2.3 Intermediate Plate (506)

This disc sits directly on the lid of the packaging body. Vertical displacement of the outer edges of the disc is prevented by the screws fixing the shock-absorbing cover to packaging body. Thus, this disc directly transfers the stress due to pressure onto the lid:

$$\sigma = p = 0.01 \text{ MPa}$$

2.4 Puncture Protection Plate (509)

The central disc is assumed to be fixed to the outer edge (formula 10b from Table 24 of <1>). The maximum bending moment corresponding to pressure exerted over the total surface area of the disc is given by the following relation:

$$|M_r| = \frac{q.a^2}{8}$$

Where:

- q: Pressure applied to the disc = 0.01 MPa
- a: External radius of the plate = 425 mm

The associated stress is:

$$\sigma = \frac{6.M}{t^2}$$

So $\sigma = \frac{6.q.a^2}{8.t^2}$

Where:

- t: Thickness of the sheet = 16 mm

$$\sigma = \frac{6 \times 0.01 \times 425^2}{8 \times 16^2} = 5.3 \text{ MPa}$$

This value is below the criterion of 161 MPa for type A steel.

2.5 Top Sheet of the Shock absorbing cover (513)

The top disc is assumed fixed to the periphery (formula 2h from Table 24 of <1>). The maximum bending moment corresponding to pressure exerted over the total surface area of the disc is given by the following relation:

$$M = K_M.q.a^2$$

Where:

- q: Pressure applied to the disc = 0.01 MPa
- a: external radius of the plate = 729 mm

The associated stress is:

$$\sigma = \frac{6.M}{t^2}$$

So $\sigma = \frac{6.K_M.q.a^2}{t^2}$

Where:

- t: Thickness of the plate = 4 mm
- K_M: Coefficient defined in the introduction of Case 2 and given in the table of Case 2.h.

For the ratio b/a:

$$\frac{b}{a} = \frac{246}{729} \cong 0.3$$

- b: external radius of the plate = 246 mm
- K_{Mrb} = -0.0570
- K_{Mra} = -0.0347

$$|K_{Mrb}| > |K_{Mra}|$$

In order to calculate the most conservative case, we use $K_M = K_{Mrb}$

- K_M = -0.057

We obtain

$$\sigma = \left| -\frac{6 \times 0.057 \times 0.01 \times 729^2}{4^2} \right| = 114 \text{ MPa}$$

This value is below the criterion of 161 MPa for type A steel.

3. SHOCK-ABSORBING COVER: RESISTANCE TO SHOCKS DURING TRANSPORT

3.1 Assumptions

The shock-absorbing cover is made up of a stainless steel outer shell filled with wood (balsa and plywood), as defined in Chapter 0 and in the drawings in Appendix 1 of Chapter 0.

Radial or axial shocks of 2 g are considered liable to occur in normal conditions of transport. The mass of the shock absorbing covers is taken as being equal to 700 kg (695kg in Table 0.6 of the chapter 0)

These shocks involve a load exerted by the wood and the steel on the surfaces of the envelopes against the direction of movement. It is assumed that the corresponding force of the pressure is uniformly distributed over these faces.

3.2 Axial Shock of 2g

- Metal envelope of the shock-absorbing cover

  Only the verification of the areas upon which greatest stress is exerted is shown.

  The case of axial shock exerts maximum stress on the steel sheets perpendicular to the axis of the shock. In fact, these sheets work in flexion and not only in traction.

Among these sheets, the most conservative ratio (mass/thickness of the resisting sheet) is reached on the bottom plate under the shock absorbing cover (502), when it is loaded by the greatest height of balsa and a metal disc.

The surface mass of this assembly is:

$$m_S = \rho_{acier} \times h_{acier} + \rho_{balsa} \times h_{balsa}$$

Where:

- ρ_{steel}: Density of the steel = 7,850 kg/m^3 according to Table 0.8 of the chapter 0.
- h_{steel}: height of steel corresponding to the sheets (502), (507) and (513) = 4 mm each
- ρ_{balsa}: Density of the balsa wood = 120 kg/m^3 according to Table 0.8 of the chapter 0.
- h_{balsa}: Height of the balsa wood taken into account, which is 715 mm

$$m_S = 7{,}850\cdot10^{-9}.\ (4 + 4 + 4) + 120\cdot10^{-9}\cdot\ 715$$

$$m_S = 180\cdot10^{-6}\ \text{kg/mm}^2$$

This surface mass subjected to an acceleration of 2 g produces a pressure p on the sheet such that:

$p = m_S.2.g = 180.10^{-6} \times 2 \times 9.81 = 0.004$ MPa.

According to the assumption of calculation of this value, this is the maximum pressure which can be exerted on all the surfaces of the shock-absorbing cover in the event of 2 g axial shock.

This value is lower than the design pressure (0.01 MPa) considered above. This section verifies the strength of all the sheets of the metal envelope. Thus, the stresses generated in the metal envelope of the shock absorbing cover resulting from an axial shock of 2g are also lower than the criterion of 161 MPa.

- Fixing screws (519)

The shock absorbing cover is fixed to the packaging body by six (6) class 10.9 CHC M20 screws (Table 0.1 of Chapter 0).

For an axial acceleration of 2 g the stress per screws is:

$$F_{acc} = \frac{2.M_{cover}.g}{N_{screw}}$$

- M_{cover}: Total mass of the shock-absorbing shock absorbing cover = 695 kg

- N_{screw}: Number of screws (519) fastening the shock absorbing cover to the body = 6

$$F_{acc} = \frac{2 \times 695 \times 9.81}{6} = 2273 \text{ N}$$

The screws tightening torque of shock-absorbing covers is 380 N.m.
The minimum preload in screws Fst min is 70476 N (see chapter 1-13).
We thus have Fst min > Facc

This ensures that the shock-absorbing cover remains held firmly against the body of the packaging and that the screws are sufficiently dimensioned.

3.3 Radial Shock of 2 g

Only the verification of the cylindrical envelope under average radial pressure is presented. The design and the proportions of the shock absorbing cover are such that the other areas are only subjected to very small mechanic loads.

Having taken account of the shape of the shock-absorbing cover and the distribution of the wood, the maximum pressure which can be exerted on the outer shell is due to the ring of balsa placed above the lid (505 and 511).

To ensure a conservative approach, the bottom inner shell (503) and the outer shell (501) are also taken into account.

For these components, the pressure exerted on the external containment when subjected to an acceleration of 2 g is:

$$p = (\rho_{steel} . e_{steel} + \rho_{balsa} . h_{balsa}).2.g$$

Where:

- ρ_{steel}: Density of the steel = 7,850 kg/m^3 according to Chapter 0

- e_{steel}: Thickness of the steel corresponding to the shells (501) and (503), which is 4 mm each.

- ρ_{balsa}: Density of the balsa wood = 120 kg/m^3 according to Chapter 0

- h_{balsa}: Thickness of the balsa wood taken into account = 1458/2 - 492/2 = 483 mm

$$p = [\ 7\ 850.10^{-9} \text{ x } (4 + 4) + 120 \cdot 10^{-9} \text{ x } 483\ ] \text{x } 2 \text{ x } 9.81 = 0.0024 \text{ MPa}$$

According to the calculation hypothesis p = 0.0024 MPa, this is the maximum pressure which can be exerted on all surfaces of the shock-absorbing cover in the event of a radial shock of 2 g.

This value is lower than the design pressure (0.01 MPa) considered in the precedent section. This section verifies the strength of all the sheets of the metal envelope. Thus, the stresses generated in the metal envelope of the shock absorbing cover resulting from a radial shock of 2 g are also lower than the criterion of 161 MPa.

4. HANDLING POINTS

For all elements handled, a coefficient of 2 is used to take account of snatch lifting. The minimum engaged length is taken as equal to 10 mm for the tappings used for handling and the calculations are carried out based on handling at one point. The absence of threaded inserts in the calculation ensures a conservative approach as the diameter of the tapping is therefore smaller and the stress exerted on the screw thread greater.

4.1 Assumptions

The chapter 2 shows that the maximum temperature obtained in normal conditions of transport is:

- Lower than 80°C at the external surface level of the packaging body,
- Lower than 93°C in elements constituting the packaging body.

Also, by considering the yield strength at 20°C for the steel type A presented in the chapter 0 and the yield strength at 100°C presented in the standard < 2 >, we can calculate by interpolation:

- The yield strength at 80°C which corresponds to the stress criterion not to be exceeded for the steel type A of the shock absorbing cover lifting lugs, that is 161 MPa.
- The yield strength at 93°C which corresponds to the stress criterion not to be exceeded for the steel type A of the front lid and the front revolving plug, which is 150 MPa.

4.2 Handling of the Front Lid

The front lid, with a total mass taken as equal to 242.5 kg (mass of the lid, the front closure plate and the orifice A closure plate) is handled using M16 tappings.

The shear stress of the screw thread is:

$$\tau = \frac{F}{\pi . d_2 . h / 2}$$

Where:

- h: Engaged length = 10 mm
- d_2 = Effective diameter = 14.7 mm for a M16.

Maximum stress during handling is therefore:

- $F = m.\gamma = 242.5{\cdot}2{\cdot}9.81 = 4758$ N

We obtain

$$\tau = \frac{4758}{14.7\pi.10/2} = 21 \text{ MPa}$$

This value is lower than the criterion of 161 MPa for the steel type A.

4.3 Handling of the Revolving Plug

The revolving plug, whose total mass is taken as equal to 200 kg is handled by means of M16 tappings. The calculation of the front lid therefore covers that of the revolving plug.

4.4 Shock absorbing cover Lifting Lugs

The shock absorbing cover is handled by means of a lifting lug.

The stress exerted on the lifting lug is therefore:

$$F = m.\gamma = 700{\cdot}2{\cdot}9.81 = 13734 \text{ N rounding to } 13800 \text{ N}$$

The weakest section upon which stress is exerted is that of the articulation axis of the lifting lug clevis pin (see Figure 1-2.1).

The diameter (d) of the axis is 12 mm, which is tensile stress area (S) of 113 mm^2.

In a clevis-pin arrangement, 2 sections are loaded in parallel during shearing, hence the stress (τ):

$$\tau = \frac{F}{2.S} = \frac{13800}{2\times113} = 62 \text{ MPa}$$

Which gives:

$$\sigma_{eq} = \sqrt{3}.\tau = 106 \text{ MPa}$$

The handling axis is made from type A stainless steel whose yield strength is $\sigma_e = 161$ MPa for the steel type A.

5. BASE PLATE: RESISTANCE TO THE WEIGHT OF THE PACKAGE

5.1 Assumptions

The base plate is made from a 10 mm thick stainless steel sheet, as defined on the drawings in Appendix 0-1. The length of the base plate is equal to that of the cavity less 100 mm.

The maximum weight of the loaded package is taken from Chapter 0 and varies between 11620 and 12300 kg.

The package is considered subject to an acceleration of 2 g in order to take account of shocks when being set down.

5.2 Compression Strength

The compression stress of the base plate is given by the following relation:

$$\sigma = \frac{2.M.g}{2.L.e}$$

Where:

- M: The mass of the package considered, which is 11620 kg and 12300kg
- g: Gravitational acceleration equal to 9.81 m/s 2
- L: The length of the base plate
- e: Thickness of the base plate, which is 10 mm

The following table sets out the results:

	Mass of the package (kg)	Length of the base plate (mm)	Compressive stress (MPa)
Package with an effective cavity length of 2200 mm	11620	2100	11
Package with an effective cavity length of 2400 mm	12300	2300	11

These values are lower than the yield strength of type A steel.

5.3 Resistance to Buckling

We use the model of a plate supporte in its extremities (formula 1a, table 15.2 < 1 >). The critical buckling stress is given by:

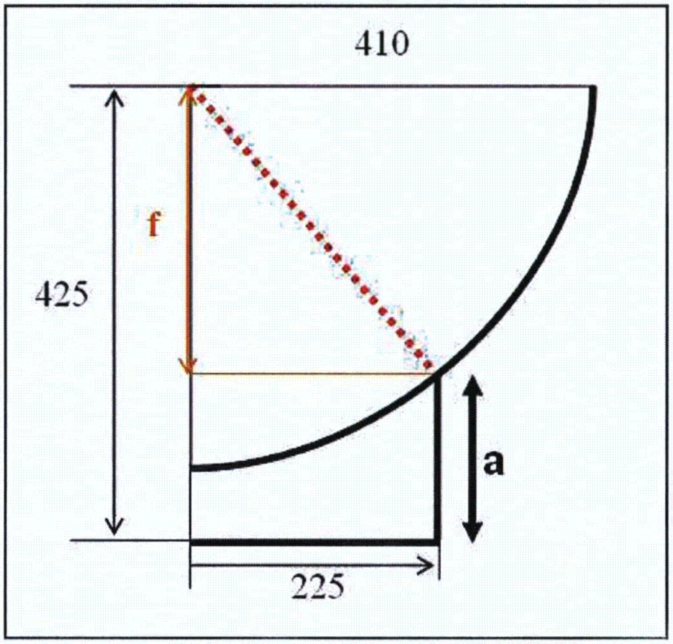
$$\sigma = K \frac{E}{1-\nu^2}\left(\frac{e}{L}\right)^2$$

Where:

- e: Thickness of the base plate taken into consideration, which is 10 mm
- L: Length of the base plate
- E: Young's modulus, in a penalizing way equal to 189 GPa at 100°C according to <3>
- ν : Poisson coefficient equal to 0.3
- K: Constant stemming of <1> and determined by the ratio a/L where
  - L: Length of the base plate which varies from 2100 mm to 2300 mm.
  - a: Height of the base plate which is given by :

$$f = 225 \times \tan\left(A\cos\left(\frac{225}{410}\right)\right) = 342,7 \text{ mm.}$$

$$h_{semelle} = 425 - f = 82,3 \text{ mm.}$$



The following table sets out the results:

	Mass of the package (kg)	Length of the base plate (mm)	Value of K	Critical stress in MPa
Package with an effective length of cavity of 2200 mm	11620	2100	6.92	32
Package with an effective cavity length of 2400 mm	12300	2300	6.92	27

These values are greater than the maximum compressive stress of the package, which is 6 MPa, so there is no risk of buckling.

6. PRESSURE EXERTED ON THE GROUND

6.1 Assumptions

In the horizontal position, the package rests on the base plate which is not fitted with the shock absorbing covers. The base plate is considered to distribute the total weight of the package uniformly over the contact surface between the base plate and the ground.

In the vertical position, the package is not fitted with its shock absorbing covers and may be filled with water.

The maximum mass of the charged package is stemming of the chapter 0 and varies from 11620 to 12300 kg. The mass of each cover is 695 kg. We shall hold for the continuation of the study the maximum masses of the package without cover varying from 10230 to 10910 Kg.

6.2 Calculation of the Pressure Exerted on the Ground, package in the Horizontal Position

The maximum pressure exerted on the ground is obtained by the following relation:

$$P_{ground} = M/L.l \qquad \text{in } t/m^2$$

Where:

- M: Mass of the package considered
- L: Length of the base plate
- l: Width of the base plate, which is 450 mm.

The following table sets out the results:

	Mass of the package (kg)	Length of the base plate (mm)	Pressure exerted on the ground (t/m^2)
Package with an effective cavity length of 2200 mm	10 230	2 100	11
Package with an effective cavity length of 2400 mm	10 910	2 300	11

6.3 Calculation of the Pressure Exerted on the Ground, Package in the Vertical Position

This pressure is calculated taking into account the package loaded with its contents, filled with water and without shock absorbing covers.

The volume liable to be taken up by water is taken as being equal to the volume of the cavity to which the volume of the cavity of the revolving plug is added. To ensure a conservative approach, the volume occupied by the contents and any internal arrangements is not taken into account.

The volume of water in the package is therefore:

$$V_{water} = \pi \times (D_c/2)^2 \times (Lu + L_{revolving\ plug})$$

Where:

- Dc: Diameter of the cavity which is equal to 203 mm
- Lu: Cavity length ranging from 2200 to 2400 mm
- $L_{revolving\ plug}$: Revolving plug cavity length which equals 370 mm

The volume of water in the package is therefore:

$$m_{water} = \rho_{water} \times V_{water} \qquad \text{where } \rho_{water} = 1000 \text{ kg/m}^3$$

The maximum pressure exerted on the ground is obtained by the following relation:

$$P_{ground} = (M + m_{water}) / [\pi(D/2)^2] \quad \text{in t/m}^2$$

Where:

- M: Mass of the package considered
- m_{water}: mass of water in package
- D: Diameter of the back flange upon which the package loaded with water equal to 820 mm rests.

The results are set out in the following table:

	Mass of the package without covers (kg)	**Mass of the water (kg)**	**Pressure exerted on the ground (t/m^{2})**
Package with an effective cavity length of 2200 mm	10 230	84	20
Package with an effective cavity length of 2400 mm	10 910	90	21

7. CONCLUSION

The maximum stress in the auxiliary structures of the packaging in normal conditions of handling and normal conditions of transport is 114 MPa. It is obtained on the top sheet of the shock absorbing cover (513) when it is subjected to a differential pressure of 0.1 bars. This stress is lower than the limit of 161 MPa for type A steel.

In the horizontal position, the maximum pressure exerted by the package of effective cavity length 2200 mm and 2400 mm on the ground is 11 t/m^2..

In the vertical position, the maximum pressure exerted by the package of cavity effective length 2200 mm and 2400 mm on the ground is 20 t/m^2 and 21 t/m^2 respectively.

8. REFERENCES

<1> Formulas for Stress and Strain J. ROARK and Warren C. YOUNG, Fifth Edition. Mc Graw Hill Book Company.

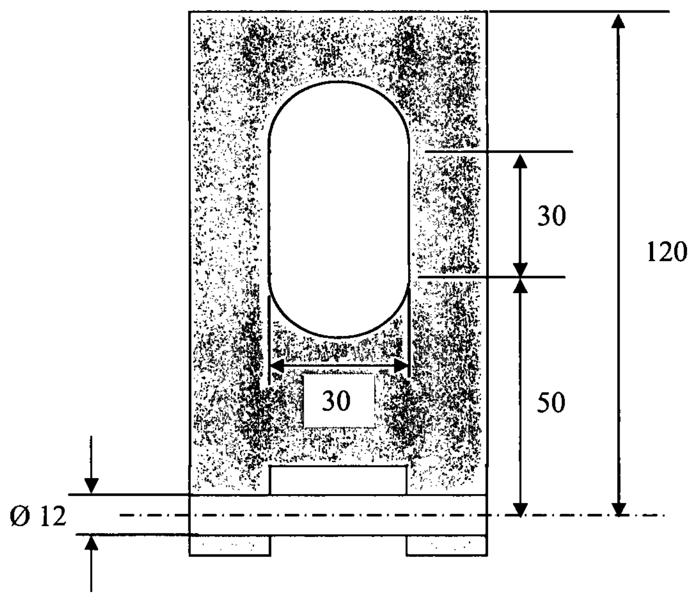
<2> Standard NF EN 10028-7 of August 2008.

<3> ASME IID Subpart 2.

LIST OF FIGURES

FIGURE 1-2.1

DIAGRAM OF THE SHOCK ABSORBING COVER LIFTING LUG



Thickness: 22 mm

MECHANICAL STRENGTH OF TIE-DOWN AND HANDLING DEVICES

TABLE OF CONTENT

REVISION STATUS

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-3E			
0	04/00	Document first drawn up	F. PETIT / T. MASSIA
Ref. : DOS-08-126114-103			
00	08/08	New document reference New formalism Taken the stress due to the seaway transport into account.	S. CHEVET / JC. BOTT
1	02/13	Translation of the document DOS-06-00032898-103 Rev. 0 Change to the method for calculating fatigue in the trunnions. Change of the accelerations considered. Rework the vertical forces for two of the four trunnions. Adding of the external shell and the base plate as tie-down components. Change of the maximum mass of the package (change to a maximum usable cavity length of 2400 mm)	R. BAHOU / D. HONDAGNEU

SUMMARY

Objectives:

The purpose of this appendix is to check the correct mechanical strength of pacakage tie-down and handling devices. The handling devices are composed of two trunnions and two lugs, welded to the shell. The tie-down devices are composed of four trunnions, the base plate and the external shell of the TN106 package.

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials are taken from chapter 0.

The temperatures of the various elements are taken from chapter 2.

Hypotheses and methods used:

For the trunnions, the static calculation is done with the I-DEAS software and with a model representing a section of the package and the trunnion. The criterion is that the elastic limit is not exceeded.

For the lugs, the base plate and the external shell, the static check is done using analytical calculation.

The analysis of fatigue in the trunnions, the external shell, the base plate and the handling lugs is performed according to the following method:

- The intensity of the stress is calculated by combining the results of the numeric calculations with a spectrum of accelerations for transport and handling.
- From resistance-to-fatigue curves taken from ASME <1> and calculated stresses, it is then possible to determine the damage suffered by each element for all of these stresses.
- Lastly, the number of cycles acceptable is determined from damage calculated according to the Palmgren-Miner cumulative damage rule.

Results and Conclusions:

The number of cycles acceptable is limited by the strength of the handling lugs and is 84,745 cycles (543 years). Also, we consider that the trunnions, the handling lugs, the external shell and the base plate are dimensioned for the total estimated lifespan of the package (40 years).

Subsequent use of the results obtained:

Given the results of the fatigue analysis, the tie-down and handling devices (trunnions, lugs, external shell and base plate) are dimensioned for the total estimated lifespan of the package.

1. PURPOSE

The purpose of this appendix is to check the correct mechanical strength of the devices the package tie-down and handling devices. The handling devices are composed of two trunnions and two lugs, welded to the shell. The tie-down devices are composed of four trunnions, the base plate and the external shell of the TN106 package.

2. CHARACTERISTICS OF THE PACKAGE

2.1 Calculation mass

The masses used for calculations are presented in the following table. They correspond to the loaded package of maximum length (usable cavity length of 2400 mm) with the maximum mass content as defined in chapter 0.

Calculated elements	Stowing	Handling
Trunnions	12,300	12,300
Lugs	-	With frame Increased to 16,000 kg
External shell	With frame Increased to 16,000 kg	-
Demounting base plate	12,300	-

2.2 Temperature

Chapter 2 shows that the maximum temperature obtained under normal transport conditions is less than 93°C in the components of the package body.

2.3 Characteristics of the materials

By considering the mechanical characteristics at 20°C of the steels Type A and B presented in chapter 0 and the mechanical characteristics at 100% presented in the standard <9>, we can determine, by interpolation, the mechanical characteristics of steels Type A and B at 93°C to be used for the calculation of criteria under stress.

Material	Mechanical characteristics at 93°C	
	$Re_{0.2}$ (MPa)	R_m (MPa)
Steel Type A	150	414
Steel Type B	368	596

The external shell, the base plate and the filler material for welding the trunnions and the lugs are made of stainless steel of type A (see chapter 0).

The trunnions and lugs are made of stainless steel of type B (see chapter 0).

3. CRITERIA

The justification of the static mechanical strength of the external shell, the base plate, the trunnions and the handling lugs is performed using a conventional "strength of materials" approach.

Concerning fatigue calculations, the number of cycles acceptable is determined from cumulated damage calculated according to the Palmgren-Miner cumulative damage rule.

For each of the bodies analysed, the table specifies the codes used and the acceptance criteria.

Elements	Static		Fatigue
	Criteria		Standard
	Stowing	Handling	Transport
Trunnion	$\sigma <$ Re (T) (1)	$\sigma <$ Re (T) (1)	ASME <1>
External shell	$\sigma <$ Re (T) (1)	-	ASME <1>
Base plate	$\sigma <$ Re (T) (1)	-	ASME <1>
Handling lug	-	$\sigma <$ Re (T) (1)	ASME <1>

(1) conventional "strength of materials" approach, with Re (T): the elastic limit of the material at 93°C.

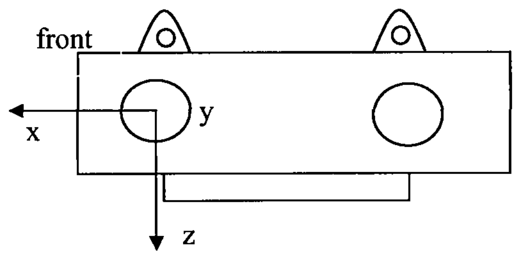
4. METHOD FOR ANALYSING FATIGUE

The analysis of fatigue in the trunnions, the external shell, the base plate and the handling lugs is performed according to the following method:

- The intensity of the stress is calculated by combining the results of the numeric calculations with a spectrum of accelerations for transport and handling.
- From resistance-to-fatigue curves taken from ASME <1> and calculated stresses, it is then possible to determine the damage suffered by each element for all of these stresses.
- Lastly, the number of cycles acceptable is determined from damage calculated according to the Palmgren-Miner cumulative damage rule.

5. DEFINITION OF STRESSES

The definition of directions is as follows:



- the package is secured by four trunnions and/or the base plate and the external shell. In a penalising manner, the vertical forces will only be divided over two of the four trunnions.

- the package is handled by a minimum of two trunnions. To tilt the package, it is also possible to use one lug.

5.1 Static

5.1.1 Transport conditions

The accelerations considered under transport conditions are summarised in the table below:

Direction	Modes of transport		
	Road	Rail	Maritime
X	2 g	2	2
Y	1 g	2	2
Z	2g upwards 4g downwards	3	3

The combination of accelerations is taken into account when the component resumes the forces in several directions, namely:

- for the trunnions, combination of longitudinal accelerations (according to the direction X) and vertical accelerations (direction Z) divided over two trunnions. The transversal component (direction Y) does not apply force to the trunnions because it tends to compress its base.

- for the external shell, combination of vertical accelerations upwards (direction Z) and transversal accelerations (direction Y),

- for the base plate, vertical acceleration downwards (direction Z).

5.1.2 Handling conditions

Under handling, an acceleration of 2 g is considered (taking into account sudden and jerky lifting), divided over two trunnions.

5.2 Fatigue

5.2.1 Land transport

To justify the fatigue resistance of the tie-down during land and rail transport, we take, as a reference, the levels of accelerations and the number of cycles measured in <3> while transporting an NTL 8 package by road (mass of 36 tonnes) over a distance of 1600 km.

By combining this information with the stresses, it is possible to determine the cumulative damage calculated according to the Palmgren-Miner cumulative damage rule and the number of cycles acceptable.

5.2.2 Maritime transport

The fatigue resistance of the tie-down components in case of maritime transport must be determined taking into account the forces to which the package is subject for common sea conditions with an average of force 6 on the Beaufort scale, and severe sea conditions up to force 11.

Calculation of fatigue resistance requires knowing the acceleration to which the package is subject, its frequency and duration. The calculations of these three parameters are explained in <8>.

The number of fatigue cycles for sea conditions of an average of force 6 and up to force 11 depends on the period of the swell and the number of days spent by the ship under such conditions. For the calculations <8>, an estimated package lifetime of 40 years is used. The following table gives the number of acceleration cycles according to the sea state:

Sea force F	Acceleration (g)	Wave period (s)	Duration at sea (days)	Number of cycles (ni)
F≤6	0.4	6	7300	1.10^8
6<F≤11	0.6	9.2	440	4.10^6

The acceleration spectrum is given in table 1-3.1 for an estimated package lifetime of 40 years.

The following parameters are used to calculate the fatigue resistance of the trunnions:

- sea conditions of an average of force 6 represent 1.10^8 acceleration cycles at ±0.4g (corresponding to a period of 6 s applied over 20 years, representing 50% of the life of the package),

- severe sea states up to force 11 represent 4.10^6 acceleration cycles at ±0.6g (corresponding to a period of 9.2 s applied over 11 days/year for 40 years, representing 11x40 = 440 days).

The number of fatigue cycles for sea conditions of force 11 is penalising because it considers that during these 440 days of wind greater than force 7, the ship will suffer maximum stress for sea conditions of force 11. However, the ship will not suffer 440 days of winds under the extreme conditions of force 11.

5.2.3 Handling

In a penalising manner, we consider that the package is handled and loaded with its frame and its covers.

The note in reference <4> recommends the following cycles for each handling operation:

- 1 acceleration cycle ± 1 g corresponds to static loading and unloading,
- 5 acceleration cycles between ± 0.2 g correspond to handling jolts (variation between 0.8 g and 1.2 g).

Conservatively, we consider 5 acceleration cycles at ± 1.2 g.

6. CALCULATION FOR TRUNNIONS

The stresses used for justifying the static strength and fatigue resistance of trunnions are taken from a finite element calculation.

6.1 Static calculation

6.1.1 Assumptions

Field of study: static, elastic and small distortions.

The load is distributed over a total angle of 45° and over a height of 25 mm according to a sinusoidal distribution located as near as possible to the fillet radius at the end.

The external shell is modelled and a weld bead is considered at the periphery of the trunnion.

The trunnion is simply placed on the external shell. Only the weld joins the trunnion to the shell. In the compression zone, the nodes between the shell and the trunnion are common.

6.1.2 Modelling

Modelling is performed using the I-DEAS V6.0 <5> software. The mechanical analysis uses the finite element method.

The calculation model is representative of the trunnion as defined by the design plans, presented in appendix 1 of chapter 0. The calculations are performed by considering an external diameter of 128 mm instead of 130 mm, in order to take into account possible resurfacing operations on the bearing part of the trunnions during maintenance.

The geometries of the trunnion and the complete model are respectively represented in figures 1-3.1 and 1-3.2.

For reasons of load symmetry and geometry, only half of the model is analysed. Hexahedral quadratic volume elements were used and the meshing is presented in figure 1-3.3.

The characteristics of the different materials used for this model are presented in the following table:

Materials	Modulus of elasticity E (MPa)	Poisson coefficient ν
Steel	185,000	0.3
Resin	3,000	0.3
Lead	42,000	0.44

Figure 1-3.4 presents the limit conditions applied to the model:

- all of the perpendicular translations in the symmetrical plane are blocked,
- on the services that are perpendicular to the axis of the package, all of the translations are blocked, thus representing either side of the trunnion being embedded.

6.1.3 Loading

The forces Fx and Fz are unitary forces taken arbitrarily at 10,000 N. The axial force Fx and the force perpendicular to the axis Fz are modelled by a pressure applied to the surface delimited by the 45° and the height of 25 mm.

The pressures stemming from loads according to X and Z are applied as near as possible to the fillet radius at the extremity, over a radius of 0.064 m. The calculation of the pressure, detailed in appendix 1-3.1, leads to 12.68 MPa.

The table below presents the modelled loads:

Direction	Value of the force
X	10,000 N
Z	10,000 N

Namely a force resulting from: $F = 10\,000.\sqrt{2} \approx 14142$ N

6.1.4 Type of calculation

A static linear calculation is made with the I-DEAS <5> software. Results of finite element calculation

The main results obtained are presented in the table below and archived in <6>. The figures 1-3.6, 1-3.7 and 1-3.8 respectively present the Von Mises stresses in the complete model, the trunnion and the external shell.

TN106 Packaging	Maximum values in MPa (Von Mises stress)
Trunnion	10.2
External shell (weld)	3.6

6.1.5 Calculating the maximum stresses for the tie-down and handling configurations

The maximum stresses for the tie-down and handling configurations may be determined from the following relationship:

$$\sigma_{\mathrm{VM\,T\,or\,M}} = \frac{\sigma_{\mathrm{VM}} . M_{\mathrm{T\,or\,M}} \times g \times \gamma_{equ}}{n \times F}$$

Where:

- σ_{VM}: Von Mises equivalent stress in the trunnion and the shell taken from the digital calculation (see paragraph 6.1.5),
- $M_{\mathrm{T\,ou\,M}}$: mass of the package considered in tie-down or handling configuration (T or M, corresponding respectively to tie-down and handling),
- g: acceleration due to gravity, g = 9.81 m/s²,
- γ_{eq}: equivalent acceleration, $\gamma_{equ} = \sqrt{\gamma_X{}^2 + \gamma_Z{}^2}$, the accelerations γ_Z and γ_x are taken from paragraph 5.1,
- F: force resulting from loading the digital model (see paragraph 6.1.3), F = 14,142 N,
- n: number of trunnions to which force is applied (n = 2 whatever the configurations and the directions of the accelerations).

The results of the equivalent Von Mises stresses in the trunnion and the shell for the static load when tie-down and handling are presented in the following table:

	Stowing	**Handling**
M (kg)	12300	12300
γ_{eq} (g)	4.47	2
Von Mises stress in a trunnion (MPa)	194	87
Trunnion criterion (MPa)	368	368
Von Mises stress in external shell (weld) (MPa)	69	31
Create external shell (weld) (MPa)	150	150

The maximum stresses in the trunnions and in the external shell (weld near the trunnions) in the handling and tie-down configuration are less than the limit criteria.

6.2 Fatigue calculation

6.2.1 Combinations of accelerations

During transport, the package is subject to force in its three main axes. In this study, we only consider the axes that cause flexion stresses in the axis of the trunnion, namely the longitudinal axis X and the vertical axis Z. The fatigue study will be carried out by combining the flexion stresses resulting from the forces applied to each of these two axes.

The histograms of the results of the accelerometer measurements when transporting the NTL8 package by road taken from <3> are presented in appendix 3 of the present document. For a defined range of acceleration, these histograms give a number of measured cycles. Thus, in the vertical axis, we see in range [01], 504640 cycles, which signifies that the levels of acceleration for each of these cycles are between 0.2 and 0.4 g. Conservatively, we will take the maximum value of the acceleration interval, so for our example, 0.4 g.

The table 1-3.1 gives, for each maximum level of acceleration, the number of cycles deduced from <3> and the histograms presented in appendix 3.

The maximum acceleration measured according to axis Z is greater than that measured according to axis X. The principle of combination will therefore consist of selecting the levels of acceleration in decreasing order, to always combine the maximum acceleration values between each other.

First we take the maximum acceleration according to the axis Z and we combine it with the maximum acceleration according to axis X, then with the following levels (in decreasing order) if all the cycles according to axis Z have not already been combined. This will be done until all the cycles for an acceleration according to the vertical axis are combined with the longitudinal acceleration levels.

When we move to a following vertical level of acceleration, we do not take into account the cycles according to the longitudinal axis that have already been previously combined.

So, if we have 10 cycles at 2 g according to axis Z and for axis X, we have 4 cycles at 1.8 g and 8 cycles at 1.6 g, the combination would give:

- 4 cycles with 2 g according to axis Z and 1.8 g according to axis X
- 6 cycles with 2 g according to axis Z and 1.6 g according to axis X

The non-combined two cycles at 1.6 g according to axis X will be associated with the lower level of acceleration according to axis Z.

For the levels of acceleration at 0.6 g and 0.4 g according to axis Z, the cycles according to axis X are missing. We then consider that the levels of acceleration that remain to be combined according to the X axis to be 0.2 g.

The table 1-3.1 presents this combination of accelerations.

6.2.2 *Intensity of stresses*

For each of the acceleration pairs γ_x and γ_z determined in paragraph 6.2.1, it is possible to determine the intensities of the corresponding stresses using the formula:

$$\sigma_{\mathrm{VM\,T\,or\,M}} = \frac{\sigma_{\mathrm{VM}} \times M_{\mathrm{T\,or\,M}} \times g \times \gamma_{equ}}{n \times F}$$

Where:

- σ_{VM}: Von Mises equivalent stress in the trunnion and the shell taken from the digital calculation (see paragraph 6.1.5),
- $M_{T\ or\ M}$: mass of the package considered in tie-down or handling configuration (T or M, corresponding respectively to tie-down and handling),
- g: acceleration due to gravity, g = 9.81 m/s²,
- γ_{eq}: equivalent acceleration, $\gamma_{equ} = \sqrt{\gamma_X{}^2 + \gamma_Z{}^2}$, and γ_z and γ_x , the accelerations for each pair in the fatigue calculation spectrum (constructed from the vertical and horizontal spectrums of table 1-3.1),
- F: force resulting from loading the digital model (see paragraph 6.1.3), F = 14,142 N,
- n: number of trunnions to which force is applied (n = 2 whatever the configurations and the directions of the accelerations).

The results of the intensities of the stresses thus calculated are presented in appendix 1-3.2.

6.2.3 *Trunnion calculation*

The figure I-9.5M from reference <1> presents the fatigue-resistance curve for the trunnions.

By using the formula given below (taken from <1>), which allows the results to be interpolated, we obtain the number of cycles acceptable for a given stress.

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{\frac{\log\left(\frac{S_i}{S}\right)}{\log\left(\frac{S_i}{S_j}\right)}}$$

<u>*For land transport:*</u>

Appendix 1-3.2 presents the damage calculations for one instance of transport and handling from the calculation spectrum in table 1-3.1 and the stress intensities determined previously.

We obtain:

For one instance of transport: $n / N = 3.09{,}10^{-6}$

For one instance of handling: $n / N = 0$

Concerning the forces applied to the trunnions, the table 1-3.2 shows that a transport cycle may be composed of a maximum of 3 instances of transport and 4 instances of handling; therefore the damage $D_{transport}$ for a transport cycle is:

$$D_{transport} = (3 \times 3.09{,}10^{-6}) + (4 \times 0) = 9.27{,}10^{-6}$$

Transport is no longer possible when the damage equals 1. Wear by fatigue, due to land transport, therefore allows 107874 transport cycles.

For maritime transport:

The stress to be considered for fatigue analysis during maritime transport is produced under vertical loading. The number of fatigue cycles n_i for the two levels of acceleration studied (0.4 and 0.6 g) are given in the table in paragraph 5.2.2. From this, we deduce the maximum number of cycles acceptable N_i by using the fatigue-resistance curve I-9.5M from the reference <1>, then the fatigue damage for a level of acceleration. The total fatigue damage is calculated by applying Miner's law.

The table below gives the values for fatigue damage corresponding to both levels of acceleration: 0.4 g (force 6) and 0.6 g (force 11).

Acceleration	**0.4 g**	**0.6 g**
Intensity of the geometrical stress σ_i (Mpa) (*)	17.4	26.1
Number of cycles: n_i	1.10^8	4.10^6
Maximum number of cycles: N_i	∝	∝
Damage: $d_i = \frac{n_i}{N_i}$	0	0

The stresses undergone by the package during maritime transport are sufficiently low to not cause fatigue damage to the trunnions.

Conclusion:

The total number of transport cycles authorised, limited by the fatigue analysis related to road transport, therefore remains 107874. Assuming a maximum of three transport cycles per week (representing up to 9 transport operations because 3 transport operations are provided per cycle, see appendix 1-3-2), the lifetime L of the trunnions would be:

$$L = \frac{107874}{52 \times 3} = 691 \text{ years}$$

We therefore consider that the trunnions are dimensioned for the total estimated lifetime of the package.

6.2.4 Calculation for the external shell (weld near the trunnions)

The same reasoning used for the fatigue calculation for the trunnions (see paragraph 6.2.2) applies for the shell.

Bearing in mind that the acceleration spectrum is identical, the level of stress is less in the external shell than in the trunnions and the fatigue resistance curve for the material of which the shell is composed (Figure I-9-2.1 of the reference <1>) is identical to that of the material for the trunnions, the fatigue calculation for the trunnion encompasses that of the external shell (weld near the trunnions).

6.2.5 Conclusion

As the calculation for the trunnions encompasses that of the external shell (weld near the trunnions), the number of transport cycles acceptable, limited by analysing fatigue during land transport, is 107874. The lifetime of the trunnions (691 years) largely encompasses the estimated lifetime of the package (40 years).

7. CALCULATION FOR THE EXTERNAL SHELL

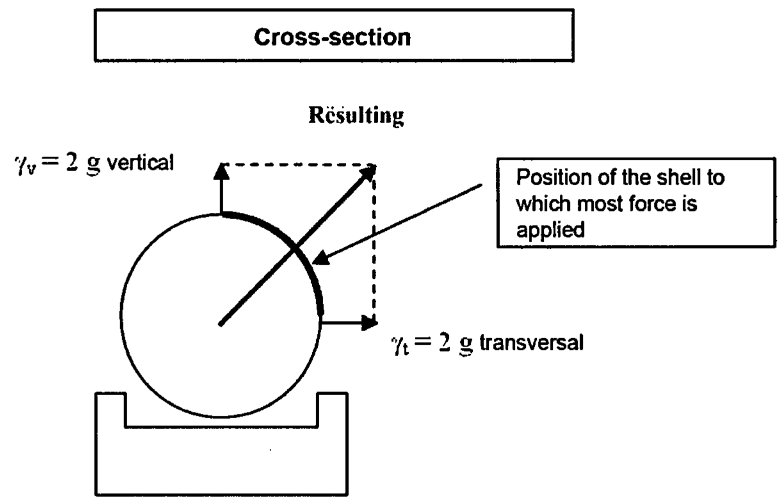
The stresses used for justifying the static strength and fatigue resistance of the external shell are calculated analytically.

7.1 Static calculation

7.1.1 Loading

The objective of this demonstration is to check that the external shell does not shear under the effect of straps under routine transport conditions.

Force is applied to the external shell vertically and transversely. The result of the stresses applied to this element via the tie-down components during transport is defined as follows:



The resulting acceleration is therefore equal to: $\gamma_r = \sqrt{\gamma_Z^2 + \gamma_Y^2} = 2\sqrt{2}g$

7.1.2 Permissible limit

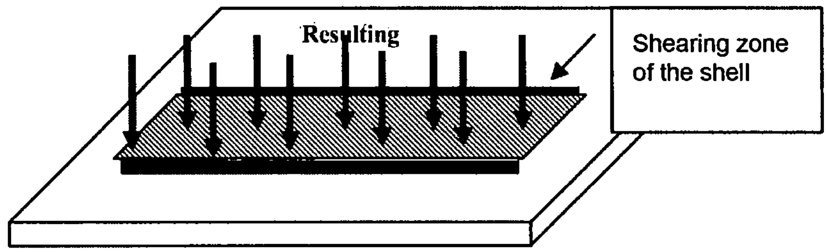
It is the conventional limit for the rules on the strength of materials: $\sigma_{VM} \leq \sigma_e$

7.1.3 Calculation of maximum stresses

The following assumptions are used:

- all of the force is taken by a single strap, considering a contact zone equal to a quarter of the exterior perimeter of the external shell,
- the force is identical at all points on the surface and equal to the maximum force calculated above,

- the force induced is similar to a shearing stress on the shell near the edges of the zone of contact between the strap and the shell.



The shearing surface is therefore: $S = 2 \times Ep_{virole} \times \pi/2 \times R_{virole}$

With: $R_{shell} = 410$ mm,

$Ep_{shell} = 20$ mm, according to the plan in the appendix 0-1

Let $S = 2.57{,}10^4$ mm^2

The maximum shearing stress in transport is therefore:

$$\tau_{max} = \frac{M \times 2\sqrt{2}g}{S} = \frac{16000 \times 2\sqrt{2}g}{2{,}57.10^4} = 18 \text{ MPa}$$

$$\sigma_{eq} = \sqrt{3}.\tau = 31 \text{ MPa}$$

The external shell is made of stainless steel type A. The criterion of 150 MPa (see paragraph 2.3) is complied with.

7.2 Fatigue calculation

For land transport:

According to <3>, the spectrum of accelerations recorded along longitudinal axis X encompasses the spectrum of transversal accelerations recorded along the Y axis. Considering the pairs of accelerations γ_x and γ_z for the fatigue calculation for the external shell is therefore penalising

For each of the acceleration pairs γ_x and γ_z determined in paragraph 6.2.1, it is possible to determine the intensities of the corresponding stresses using the formula:

$$\sigma = \frac{\sigma_{eq} \times \gamma_{eq}}{2\sqrt{2}}$$ where,

- σ_{eq}: equivalent stress in the external shell, representing 31 MPa,

- γ_{eq} : equivalent acceleration, $\gamma_{equ} = \sqrt{\gamma_X^2 + \gamma_Z^2}$, and γ_z and γ_x , the accelerations for each pair in the fatigue calculation spectrum (constructed from the vertical and horizontal spectrums of table 1-3.1),

From the fatigue resistance curve for the external shell presented in figure I-9-2.1 of reference <1> and by using the formula given below (taken from <1>), which allows the results to be interpolated, we obtain the number of cycles acceptable for a given stress.

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{\frac{\log\left(\frac{S_i}{S}\right)}{\log\left(\frac{S_i}{S_j}\right)}}$$

The maximum equivalent acceleration γ_{eq} (2.84 g) leads to a maximum stress intensity σ of 31 MPa. The acceptable number of cycles is unlimited.

Therefore, all of the pairs of accelerations presented in table 1-3.1 lead to an unlimited acceptable number of cycles.

For maritime transport:

As the accelerations to be considered for maritime transport (0.4 g and 0.6 g) are lower than the maximum acceleration considered above, they also lead to an unlimited acceptable number of cycles.

Conclusion:

The mechanical strength of the external shell is assured. The number of transport operations authorised is not limited.

8. CALCULATION OF THE DEMOUNTING BASE PLATE

We check the strength of the demounting baseplate by analytical calculation.

8.1 Static calculation

8.1.1 Assumptions

The package rests on the tie-down device via the intermediary of the base plate. The base plate is made of stainless steel sheet metal 10 mm thick, as defined in the plans in appendix 0-1. The length of the baseplate is equal to that of the cavity less 100 mm.

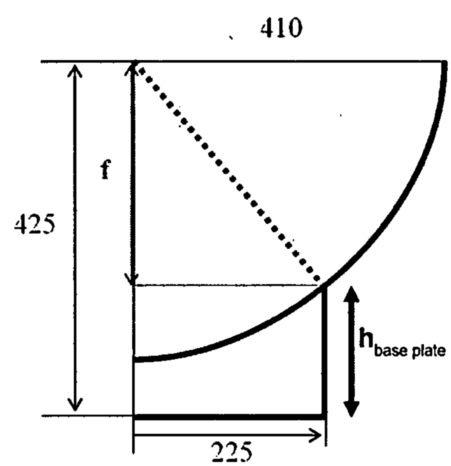
We consider the package to be subject to a vertical acceleration of 4 g downwards.

The maximum mass of the loaded package is taken from chapter 0 and varies from 11620 to 12300 kg.

The height of the base plate $h_{base\ plate}$ is calculated as follows:

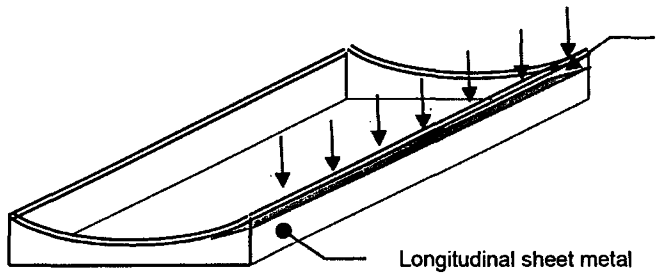
$$f = 225 \times \tan\left(A\cos\left(\frac{225}{410}\right)\right) = 342.7 \text{ mm}$$

$$h_{base\ plate} = 425 - f = 82.3 \text{ mm}$$



8.1.2 Vertical acceleration

Resistance to compression



The compression stress on the base plate is given by the following relationship:

$$\sigma_c = \frac{M \times \gamma_Z}{2 \times L \times e}$$ where,

M: mass of the package

γ_Z : vertical acceleration of 4 g

L: the length of the base plate

e: thickness of the base plate, representing 10 mm

The following table presents the results:

	mass of the package (kg)	**length of the base plate (mm)**	**stress σ_c (MPa)**
Package with a usable cavity length of 2,200 mm	11,620	2,100	11
Package with a usable cavity length of 2,400 mm	12,300	2,300	11

The demounting base plate is made of stainless steel type A. The criterion of 150 MPa (see paragraph 2.3) is complied with.

Resistance to buckling

We use the model of a plate supported at its extremities (formula 1a, table 15.2 <10>). The critical buckling stress is given by:

$$\sigma_c = K.\left(\frac{E}{1-v^2}\right).\left(\frac{e}{L}\right)^2$$

with:

E: Young's modulus for the material considered in a penalising manner at 100°C, representing 189 GPa according to <11>,

v: Poisson coefficient equal to 0.3,

L: The length of the base plate,

e: thickness considered of the base plate, representing 10 mm

K: factor taken from <10> determined by the relationship $h_{base\ plate}$ / L with

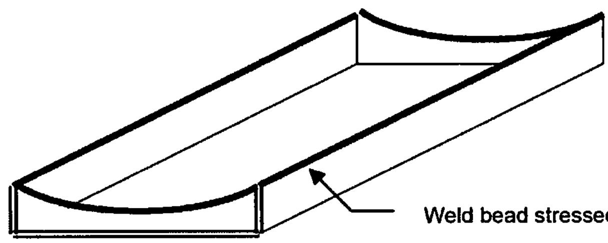
L: length of the base plate, varying from 2100 mm to 2300 mm

The following table presents the results:

	mass of the package (kg)	**length of the base plate (mm)**	**value of K**	**Critical stress (MPa)**
Package with a usable cavity length of 2,200 mm	11,620	2,100	22.2	104
Package with a usable cavity length of 2,400 mm	12,300	2,300	22.2	87

The critical buckling stresses are greater than the maximum compression stress for the longitudinal sheet metal, namely 11 MPa; there is therefore no risk of elastic buckling.

8.1.3 Weld shearing



Whatever the direction of the force and the angle formed by the assembled sides, the CM66 rules <7> require that:

$$\sigma_e \geq \frac{M \times \gamma_{xyz}}{0{,}75 \times a \times \alpha \times l_{weld}}$$

with:

σ_e: elastic limit of the base metal,

e: thickness considered of the base plate, representing 10 mm

M: mass of the package,

γ_Z : vertical acceleration of 4 g

a: apothem of the weld, a = 0.7 × e = 7 mm,

α: reduction coefficient, $\alpha = 0.8\ (1 + 1/a) = 0.914$

l_{weld}: length of the base plate's weld $l_{weld} = 2 \times (L + l_{arc})$,

with:

L: The length of the base plate,
l_{arc}: length of the arc of the lateral sheet metal.

$$l_{arc} = 410 \times 2 \times A\sin\left(\frac{225}{410}\right) = 476 \text{ mm}$$

The results are given in the following table:

	mass of the package (kg)	length of the base plate (mm)	stress σ_{weld} (MPa)
Package with a usable cavity length of 2,200 mm	11,620	2,100	19
Package with a usable cavity length of 2,400 mm	12,300	2,300	19

The filler material for the weld is stainless steel of type A. The criterion of 150 MPa (see paragraph 2.3) is complied with.

8.2 Fatigue calculation

For land transport:

The maximum vertical acceleration to which the base plate and its weld are subject is 2.2 G according to <3>.

The intensity of the corresponding stress is 6 MPa and 11 MPa, respectively for the base plate and the weld.

From the fatigue resistance curve for the external shell presented on figure I-9-2.1 of reference <1>, we obtain an unlimited acceptable number of cycles.

For maritime transport:

As the accelerations to be considered for maritime transport (0.4 g and 0.6 g) are lower than the maximum acceleration considered above, they also lead to an unlimited acceptable number of cycles.

Conclusion:

The mechanical strength of the base plate is assured. The number of transport operations authorised is not limited.

9. CALCULATION FOR HANDLING LUGS

This is an analytical calculation to check the strength of the lug and its weld. The lug is diagrammed in figure 1-3.10.

9.1 Static calculation

9.1.1 Loading

The mass of 16,000 kg is applied to one lug under an acceleration of 2 g (to take into account sudden and jerky lifting).

The force in the lug is therefore:

$F = m\,\gamma = 16{,}000 \times 2 \times 9.81 = 313{,}920$ N

9.1.2 Permissible limit

It is the conventional limit for the rules on the strength of materials: $\sigma_{VM} \leq \sigma_e$

9.1.3 Calculating the maximum stresses for the handling configurations

Calculation for the weld:

Whatever the direction of the force and the angle formed by the assembled sides, the CM 66 rules in reference <7> require that:

$$\frac{F}{0{,}75 \times a\alpha \times 2 \times L} < \sigma_e \quad \text{(rule 4.132-2)}$$

where,

F = 313,920 N

a = 10 mm

α = Coefficient of reduction, dependant on the thickness 'a' (in mm) of the weld, which takes the value:

$\alpha = 0.8\ (1 + 1/a) = 0.88$; $a.\alpha = 8.8$

L = 160 mm: length of the weld

We obtain:

$$\sigma = \frac{313920}{0{,}75 \times 8{,}8 \times 2 \times 160} = 149 \text{ MPa}$$

The filler material for the weld is stainless steel of type A. The criterion of 150 MPa (see paragraph 2.3) is complied with.

Calculation for the lug:

The lug must resist dual shearing:

$$\tau = \frac{F}{2 \times l \times h}$$

where,

F = 313,920 N

l = 55 mm: thickness of the lug

h = 52.5 – (55/2) = 25 (see figure 1-3.10)

We obtain: $\tau = \frac{313\,920}{2 \times 55 \times 25} = 115$ MPa

$\sigma_{eq} = \sqrt{3}.\tau = 198$ MPa

The lug is made of stainless steel of type B. The criterion of 368 MPa (see paragraph 2.3) is complied with.

9.2 Fatigue calculation

9.2.1 Assumptions

Conservatively, we consider 5 acceleration cycles at ± 1.2 g (see chapter 5.2.3).

9.2.2 Intensity of stress

The stress in the weld, resulting from paragraph 9.1.3, is equal to:

$\sigma = 149$ MPa

The shearing stress in the lug, resulting from paragraph 9.1.3, is equal to:

$\sigma_{eq} = \sqrt{3}.\tau = 198$ MPa

The shearing intensity corresponds to an acceleration cycle of ± 1.2 g calculated as follows:

$$\Delta\sigma = \frac{\sigma \times 1{,}2}{2}$$

Acceleration Δa	**1.2 g**
Stress intensity in the weld	90 MPa
Shearing stress intensity in the lug	119 MPa

9.2.3 *Calculation for the lug*

The number of cycles acceptable by the lug is determined from the table 1-9.5M (curve for a steel of type B corresponding to the material of which the lug is made) of reference <1>.

By using the formula given below (taken from <1>), which allows the results to be interpolated, we obtain the number of cycles acceptable for a given stress.

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{\frac{\log\left(\frac{S_i}{S}\right)}{\log\left(\frac{S_i}{S_j}\right)}}$$

Acceleration Δa	**1.2 g**
Stress intensity: σ_i (Mpa)	119
Number of cycles per operation: n_i	5
Maximum number of cycles: N_i	$4.26,10^{6}$
Damage: $d_i = \frac{n_i}{N_i}$	$\mathbf{1.18,10^{-6}}$

The table 1-3.2 indicates that a transport cycle may be composed of a maximum of 10 handling operations, therefore the damage $D_{transport}$ for a transport cycle is:

$D_{transport} = (10 \times 1.18,10^{-6}) = 1.18,10^{-5}$

Transport is no longer possible when the damage equals 1. Wear by fatigue, due to land transport, therefore allows 84745 transport cycles.

Based on a maximum of three transport cycles per week (representing up to 9 transport operations because 3 transport operations are planned per cycle, see table 1-3-2), the lifetime L of the lug would be:

$$L = \frac{84745}{52 \times 3} = 543 \text{ years}$$

We therefore consider that the lugs are dimensioned for the total estimated lifetime of the package.

9.2.4 *Calculation of the weld for the lug*

The same reasoning as for the fatigue calculation for the lugs (see paragraph 9.2.3) applies for the welds.

Bearing in mind that the acceleration spectrum is identical, that the stress level is less in the welds than in the lug and that the fatigue resistance curve for the material composing the weld (Figure I-9-2.1 of the reference <1>) is identical to that of the material for the lug, the fatigue calculation for the lug is encompassed by that of the welds.

9.2.5 *Conclusion*

The number of transport cycles acceptable, limited by the fatigue analysis under handling, is 84745. The lifetime of the handling lugs (543 years) largely encompasses the estimated lifetime of the package (40 years).

10. SUMMARY OF RESULTS

The table below presents the results of the tie-down and handling configurations:

	Element		**Static**		**Fatigue**
	Element		**Von Mises stress (MPa)**	**Criteria (MPa)**	**Number of cycles acceptable**
§ 6	**Trunnions**	**Stowing**	194	368	107874
		Handling	87	368	
	External shell	**Stowing**	69	150	
		Handling	31	150	
§ 7	**External shell**	**Stowing**	54	150	∝
§ 8	**Base plate**	**Stowing**	11	150	∝
	Weld for the base plate	**Stowing**	19	150	∝
§ 9	**Handling lugs**	**Handling**	198	368	84745
	Welds for the lugs	**Handling**	149	150	

11. CONCLUSION

The number of cycles acceptable is limited by the strength of the handling lugs and is 84,745 cycles (543 years). Also, we consider that the trunnions, the handling lugs, the external shell and the base plate are dimensioned for the total estimated lifespan of the package (40 years).

Shunting with humps is prohibited during rail transport and indicated by placing manoeuvring label n° 15 from RID (see chapter 6A).

12. REFERENCES

<1> ASME Boiler and Pressure Vessel Code, An American National Standard, Section III, Division I, 1995 edition.

<2> "Advisory Material for the AIEA Regulations for the Safe Transport of Radioactive Material", SAFETY GUIDE No. TS-G-1.1 (ST-2).

<3> "Measurement of the acceleration undergone by the trunnions of irradiated fuel transport flasks during normal use". D. PUJET, Nuclear Transport Limited Paris - P. MALESYS, TRANSNUCLEAIRE PARIS - PATRAM 89, June 11, 16 1989, WASHINGTON DC, USA

<4> Experimental and analytical evaluation of dynamic loads on shipping cask trunnions, W. Botzem (NUKEM) - B. GÜNTHER (Bundesamtalt für Material Forschung und prüfund) - PATRAM 89. June 11, 16 1989, WASHINGTON, D.C., USA.

<5> Software for finite element calculations I-DEAS Master Series V6.0 developed by SDRC.

<6> File archiving:

[ARCHIVE_A5573]/[ARCHIVE_mecanique]/[5573B22R2]		
File name.unv	**FE model**	**Content**
tn106_rev2	Contact zone compression – load 2	Calculation of trunnion under loading 2 with common nodes trunnion/shell in the compression zone

<7> CM calculation rules – Calculation rules for steel constructions (12^{th} edition 1996 - Additives from 80 included).

<8> COGEMA Logistics letter S/03-045, Transport of radioactive materials, Generic subjects, Strength of tie-down lugs under maritime transport, 28 May 2003.

<9> Standard NF EN 10028-7 of August 2008

<10> Formulas for stress and strain J. ROARK and Warren C. YOUNG seventh edition Mc Graw Hill Book Company

<11> ASME IID Subpart 2

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix number	Rev.	Title	Number of pages
1-3-1	A	Details of the load corresponding to the force in the trunnion	1
1-3-2	C	Details of the calculation on damage for the trunnions	1
1-3-3	A	Histograms of accelerations during transport according to <3>	2
Total			**4**

TABLE 1-3.1
SPECTRUMS USED FOR THE FATIGUE ANALYSIS

NUMBER OF CYCLES PER RANGE OF ACCELERATION FOR LAND TRANSPORT (<3>)

Range of accelerations		±2.2 g	±2 g	±1.8 g	±1.6 g	±1.4 g	±1.2 g	±1 g	±0.8 g	±0.6g	±0.4 g
Number of cycles	Vertical	7	9	14	27	50	160	580	3862	38765	505578
	Longitudinal			6	20	69	268	834	2098	4975	12289

COMBINATION OF ACCELERATIONS FOR LAND TRANSPORT

Axial accelerations	γ_v (g) Vertical axis	±2.2	±2.2	±2	±1.8	±1.8	±1.6	±1.4	±1.4	±1.2
	γ_h (g) Longitudinal axis	±1.8	±1.6	±1.6	±1.6	±1.4	±1.4	±1.4	±1.2	±1.2
Number of cycles		6	1	9	10	4	27	38	12	160

Axial accelerations	γ_v (g) Vertical axis	±1	±1	±0.8	±0.8	±0.8	±0.6	±0.6	±0.6	±0.4
	γ_h (g) Longitudinal axis	±1.2	±1	±1	±0.8	±0.6	±0.6	±0.4	±0.2	±0.2
Number of cycles		96	484	350	2098	1414	3561	12289	22915	505578

HANDLING CONFIGURATION SPECTRUM (<4>)

Range of accelerations	± 1.2 g
Number of ni cycles per transport operation	100

MARITIME TRANSPORT CONFIGURATION SPECTRUM (<8>)

Range of accelerations	± 0.4 g	± 0.6 g
Number of ni cycles per transport operation	1.10^8	4.10^6

TABLE 1-3.2
COUNT OF THE NUMBER OF TIMES FORCE IS APPLIED DURING A TRANSPORT CYCLE

operation	handling	handling	handling	transport
	1 lug	2 lugs	2 trunnions	2 trunnions
1- package resting on its frame	departure position			
2- placed on the lorry (package + frame)		1		
3- transport				1
4- removal from lorry (package + frame or package alone)		1		
5- transfer to cell				
case of horizontal loading		1		
case of vertical loading	1 (place the block under the package)		1	
6- load the content				
7- transfer to frame or table				
case of horizontal loading		1		
case of vertical loading	1 (place the block under the package)		1	
8- place on the lorry (package + frame or package alone)		1		
9-transport				1
10- remove from the lorry (package + frame or		1		
package alone)				
11- transfer to cell				
case of horizontal loading		1		
case of vertical loading	1 (place the block under the package)		1	
12- unload content				
13- transfer to frame or table				
case of horizontal loading		1		
case of vertical loading	1 (place the block under the package)		1	
14- place on the lorry (package + frame or package alone)		1		
15-transport				1
16- removal of lorry		1		
17- package at rest on its frame	arrival position			
TOTAL				
Total if no vertical loading:	**0**	**10**	**0**	**3**
Total if 1 vertical loading operation:	**2**	**8**	**2**	**3**
Total if 2 vertical loading operations:	**4**	**6**	**4**	**3**
encompassing total	**4**	**10**	**4**	**3**
	handling	**handling**	**handling**	**transport**
	1 lug	**2 lugs**	**2 trunnions**	**2 trunnions**

FIGURE 1-3.1

GEOMETRY OF THE TRUNNION CALCULATION MODEL

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.2

GEOMETRY OF THE MODEL

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.3

MODEL GRID

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.4

LIMIT CONDITIONS FOR THE CALCULATION FOR THE TRUNNION

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.5

LOADING TRUNNIONS

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.6

VON MISES STRESSES IN THE COMPLETE MODEL (PA)

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.7

VON MISES STRESSES IN THE TRUNNION (PA)

Proprietary information withheld pursuant to 10 CFR 2.390

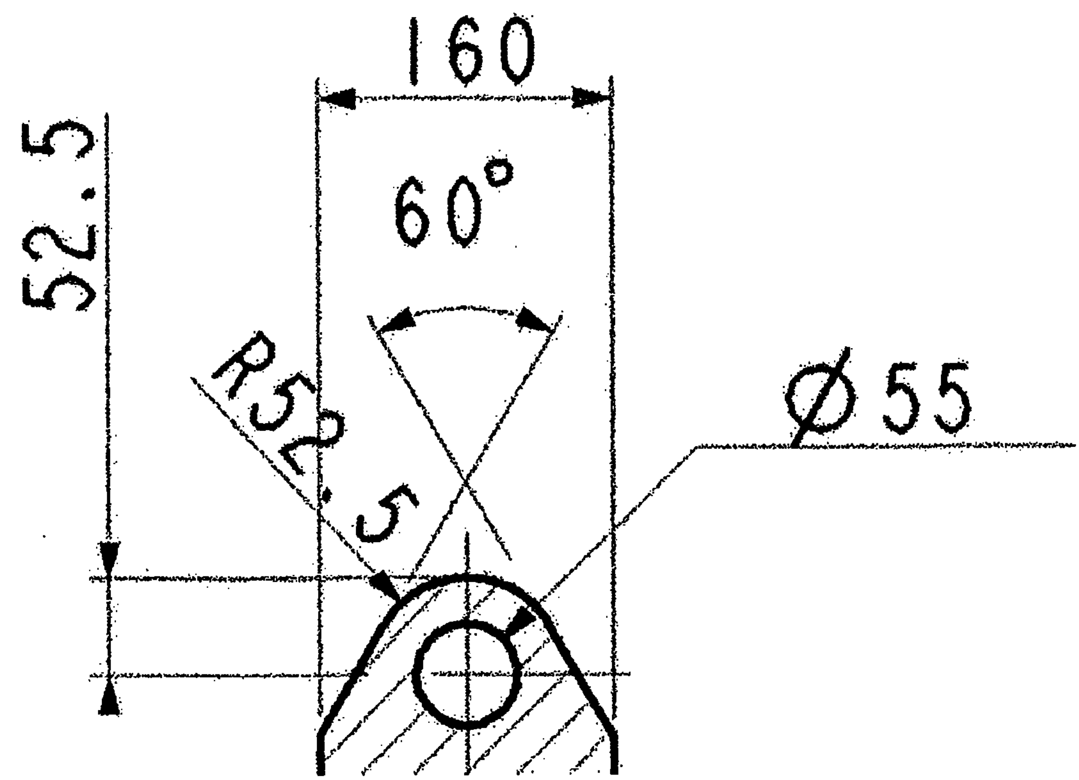
FIGURE 1-3.8

VON MISES STRESSES IN THE SHELL (PA)

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-3.10

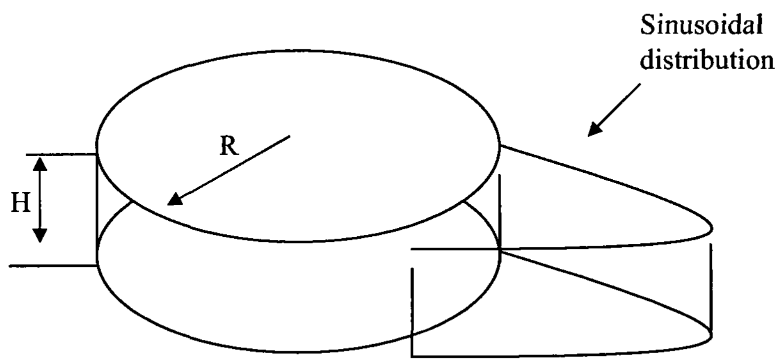
DIAGRAM OF THE HANDLING LUG



APPENDIX 1-3-1

DETAILS OF LOADING CORRESPONDING TO FORCES IN THE TRUNNION

The load corresponding to forces during transport is distributed over the total angle of 45° and over a height of 25 mm according to a sinusoidal distribution presented in the following figure:



From a total force F, the pressure to be applied on the surface may be calculated from the following equation:

$$F = \int_{-\pi/8}^{\pi/8} dF_z \cdot d\theta \quad = 10{,}000\ \text{N}$$

$$dF_z = H \cdot R \cdot p(\theta) \cdot \cos\theta \cdot d\theta$$

where,

$$p(\theta) = p_{\max} \cdot \cos(4\theta)$$

For an angle of distribution of 45° and from the above equations, the pressure is determined by the following equation:

$$p_{\max} = \frac{15 \cdot F}{8H \cdot R \cdot \sin(3\pi/8)}$$

Where:

R = 0.064 m
H = 0.025 m
F = 10,000 N

We obtain,

P_{max} = 12.68 MPa

APPENDIX 1-3-2

DETAILS OF THE CALCULATION OF DAMAGE FOR THE TRUNNIONS

For land transport:

Proprietary information withheld pursuant to 10 CFR 2.390

For one handling operation:

Proprietary information withheld pursuant to 10 CFR 2.390

For a maritime transport operation:

There is no damage due to maritime transport (see paragraph 6.2.2).

APPENDIX 1-3-3 (1/2)

HISTOGRAMS OF ACCELERATIONS DURING TRANSPORT ACCORDING TO <3>

Proprietary information withheld pursuant to 10 CFR 2.390

APPENDIX 1-3-3 (2/2)

HISTOGRAMS OF ACCELERATIONS DURING TRANSPORT ACCORDING TO

Proprietary information withheld pursuant to 10 CFR 2.390

DETERMINATION OF MODEL LENGTH AND DROP CONFIGURATIONS

TABLE OF CONTENT

REVISION STATES

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SUMMARY

Purpose:

This document determines the model length for which the tests representing normal and transport accident conditions are to be performed. It also defines the drops orientations which ensure that the package safety test components are subjected to maximum damage.

Basic Data:

- The size and the masses of packaging component parts are taken from Chapter 0 and Appendix 0-1. The masses of the empty packaging (Me) and the full packaging (Mt) can be expressed, as a function of the effective length of the cavity (Lu). in the following approximate manner:

  $Me \approx 3.0 \times Lu + 3910$,
  $Mt \approx 3.26 \times Lu + 3910$.

  Where M is expressed in kg and Lu in mm,

- The acceleration and the residual deformation obtained in the case of the lateral drop, as a function of the length of the packaging and the angle of drop, are calculated using finite elements in Appendices 1-5 and 1-6.

Assumptions and Methods Used:

- In the case of the axial drop, each component upon which stress is exerted is studied, that is to say:

  - The cover (crushing),
  - Revolving plug axis,
  - The revolving plug fixing clamps,
  - The revolving plug (deformation),
  - The front lid and its closure plate,
  - The back closure plate,
  - The inner shell (buckling and compression due to the creep of the lead),
  - The lead (settlings).

  Analytical calculation are used to find the optimum configuration of the packaging, i.e. the mass of the packaging (the effective length), the mass of the contents and the orientations of drop (onto the top or onto the base), which results in the maximum damage in each case.

- In the case of the drop onto a corner, only the following elements are studied, also by means of analytical calculation, as the stress exerted on the others is greater during the other drop cases:

  - The cover (crushing),
  - The screws which hold the lid and closure plate in place on the side of impact,
  - The fixing screws of the cover on the side of impact,

  - The revolving plug (opening).

- In the case of the lateral drop, the elements upon which loads are exerted are as follows:

  - The covers (crushing),
  - The cover screws,
  - The containment (deformation),
  - The revolving plug closure plate.

  The case of a drop leading to maximum damage is estimated by calculations using the finite elements method. A first study (Appendix 1-5) calculates the acceleration rates as a function of the length of the packaging and the drop angle. A second study (Appendix 1-6) calculates the stress and the residual deformation after drops for the worst cases as predicted by the acceleration calculations.

In the case of drops onto a puncture bar, only the zones likely to be affected are studied: the outer shell and the top closure plate.

The drop model characteristics are set based on these results which cover the majority of the most damaging cases; the other cases are verified by calculation.

Results and Conclusion:

The most conservative length for:

- Determining maximum deformation of the containment and the packaging,
- Validating the dimensioning of the covers,
- Validating the strength of the revolving plug axes and holding clamps.

is the maximum length.

Therefore, the drop tests were performed using a model with the longest maximum effective length and the maximum mass of contents.

Additional calculations are necessary, however, to check the preload stress in the closure plate fixing screws.

1. PURPOSE

Packaging TN 106 loaded with its contents is a type B(U) package for fissile materials. For this reason, its capacity to withstand regulatory drop tests in normal and accident conditions of transport must be demonstrated in compliance with <1> and <1'>.

This is accomplished by means of drop tests. The purpose of this document is to define the characteristics of the test specimen, as well as all of the drops which ensure that the safety elements of the package are subjected to worst possible loads.

2. REGULATORY DROP REQUIREMENTS

According to regulatory document <1> and <1'>, for a B(U) type package for fissile material, the drop tests which must be performed on the specimen are as follows:

2.1 Tests to demonstrate the capacity to withstand normal transport conditions.

Free fall drop test: 622a from <1> and 722a from <1'>: The specimen must fall on the target in the way which will cause it maximum damage. The drop height for the TN 106 (mass ranging approximately between 6,900 and 14,400 kg) must be 0.9 for the model representing the shortest package (mass < 10,000kg) and 0.6 m for the model representing the longest package (mass ≥ 10,000 kg).

Given the fissile contents foreseen in the package, each of these drops must be preceded by a 0.3 m drop on each quarter of each of the circular edges (only Art. 622b of <1>).

The penetration test using a bar (with a hemispherical end of 3.2 cm diameter and a mass of 6 kg required by Article 624 of <1> and 724 of <1'>) is not performed as it is of no consequence for this package taking account of the robustness of the accessible outer envelope of the package.

2.2 Tests to demonstrate the capability to withstand transport accident conditions.

The following sequence of tests must be performed on the specimen:

- A 9 m drop on a flat target (Art. 627a of <1> and 727a of <1'>),
- A 1 m drop on to a puncture bar (Art. 627b of <1> and 727b of <1'>).

The order in which the specimen is subjected to these two tests must cause the maximum damage during the thermal tests which will follow.

Articles 553 of <1> and 660 of <1'> stipulate a sequence of drop tests comprising the sequence of the tests of the 2 last paragraphs. In the light of the capacity to withstand the package drops, the drops from heights of 0.3 and 0.6 m do not affect its capacity to withstand the following drops from a height of 9 m. The drops relating to normal conditions of transport and those relating to the fissile aspect of the package are not performed.

3. PURPOSE OF THE DROP TESTS

These drops must make it possible:

- To establish that the same geometric model is preserved for the thermal, shielding and criticality calculations in normal transport conditions and transport accident conditions,
- To establish that the containment is preserved in order to ensure that release is lower than 10^{-6} A_2/h after the tests of Section 2.1, and lower than 1 A_2/week following the tests from Section 2.2.

4. CHARACTERISTICS OF THE PACKAGE MODEL

The TN 106 is a package design for which the cavity length may range from 1,000 to 3,200 mm. The mass of the packaging with covers as a function of the length is as follows:

Cavity Length (mm)	1,000	3,200
Total length of the packaging (mm)	2,400	4,600
Total mass of the packaging (kg) (1)	6,900 (2)	14,400 (3)

(1) envelope values
(2) empty
(3) Loaded to the maximum, based on a maximum allowable mass of 254 kg/m in the cavity.

Notation:

The notations used for the calculations set out in the rest of this note are:

- Lu: Effective length of the cavity,
- Ma: Mass of the lid or the front closure plate,
- Mb: Mass of the revolving plug,
- Mc: Mass of the contents (Mc = ml x Lu, M in kg and Lu in mm),
- Me: Mass of the empty package (Me ≈ 3.0 x Lu + 3910),
- Mt: Total mass of the package with contents (Mt = Me + Mc ≈ 3.26 x Lu + 3910),
- σ: Crushing stress of the wood,
- S: Wood crush area,
- ml: maximum linear mass in kg/m.

The maximum mass of the contents, Mc max., depends on the length of the cavity and the maximum mass (ml) is therefore defined in Kg/m.

The maximum linear mass of the contents is set at 0.254 kg/mm.

5. METHOD

For each drop case, the optimum configuration of the packaging is found, which is to say the mass of the packaging (the effective length), the mass of the contents and the direction of drop (onto the top or onto the base) which cause maximum damage.

The characteristics of the drop model are established based on these results covering the majority of the most damaging cases, the other cases are verified by calculation.

6. DROPS REPRESENTATIVE OF ACCIDENT CONDITIONS OF TRANSPORT

The drops to be taken into consideration are the 9 m (axial, lateral and corner) drops and the drops onto a puncture bar.

6.1 Axial Drops

The elements upon which stress is exerted during an axial drop are:

- The cover,
- The revolving plug axis,
- The revolving plug fixing clamps,
- The revolving plug (deformation),
- The front lid and its closure plate,
- The back closure plate,
- The inner shell (buckling and compression due to the creep of the lead),
- The lead (settling).

The vent closure plate is only subjected to its own weight during the axial drop so there is no reason to check its very minor bending or shear stress.

6.1.1 Crushing of the cover

In order to ensure that the cover is sufficiently capable of absorbing the shock of maximum mass of the package, that is to say, in order to ensure that the maximum crushing rate of the wood is never exceeded, the **maximum length and the maximum mass of the contents** must be chosen. The orientation of the package is **immaterial.**

6.1.2 Strength of the Revolving Plug Axis

Increasing the packaging length produces two opposing effects on the revolving plug axis when loaded by the contents. It reduces the acceleration applied and it increases the mass of the contents covered by the revolving plug. This section determines the dominant parameter.

The force applied to the revolving plug axis is F= M.γ

Where: M = Mc + Mb γ = σ .S/Mt and Mb = 175 kg

Therefore F = σ.S (Mc + Mb)/Mt = σ.S (Mc + Mb)/(Mc + Me)

As the stress and the crushing surface of the wood are constant for the axial drops, the envelope case is that for which (Mc + Mb)/(Mc + Me) is greatest. This expression has 2 independent parameters which are the mass of the contents and that of the empty packaging.

Since the mass of the contents is equal to a maximum 6% of that of the packaging, we can say:

- (Mc + Mb)/(Mc + Me) ≈ (Mc + Mb)/Me

So, for a fixed length, the stress will be the greatest for the greatest mass of contents.

The (Mc + Mb)/(Mc + Me) ratio has been shown in the Figure 1-4.1 as a function of the length and for several values of linear mass, the mass of the contents is fixed at its maximum value in accordance with what is set out above.

This curve shows that the value of the length which increases the (Mc + Mb)/(Mc: + Me) ratio depends on the linear mass. For a linear mass greater than 136 kg/m, the optimum is obtained for the maximum length.

So, in our case, the **maximum length and the mass of the maximum contents** must be chosen. The package must be positioned **top end first.**

6.1.3 Strength of the Clamp and Deformation of the Revolving Plug

The same reasoning can be applied so the **maximum length and the mass of the maximum contents** must be chosen. The package must be positioned **top end first.**

6.1.4 Strength of the Lid and the Front Closure Plate

The maximum force applied to the lid or the closure plate is F= Ma. γ.

Thus, F = σ.S.Ma/Mt.

Since the mass of each element is constant whatever the effective length, the stress applied will be greatest for the mass of the smallest package, so the **shortest length and the smallest mass of contents** must be chosen. With respect to the orientation of the package, it should be positioned **top end first**

because the diameters of the screw inserts are greater than those of the flanges.

In general, when the mass of a component does not depend on the length of the package and it does not support anything, the most conservative case is obtained for maximum acceleration and therefore the minimum mass (and the effective length) of the package.

6.1.5 *Strength of the Back Closure Plate*

We aim to show that the mechanical strength of the back closure plate is covered by the mechanical strength of the front closure plate. (Both closure plates are made from the same material).

- Shearing of the screws:

$$\tau = \frac{F}{S} = \frac{\sigma.S'}{Mt}\frac{M}{(\pi.D.e - n.D_{screw}.e)}$$

Where:

- σ: Crush stress of the wood
- S': Crush area of the wood
- M: Mass of the closure plate
- Mt: Total mass of the package
- D: Diameter of the screw inserts
- e: Thickness of the closure plate

So, we can say: $\tau = K \frac{M}{(\pi.D.e - n.D_{screw})}$

- K: Constant

If:

- τ1: Shear stress applied to the back closure plate
- τ2: Shear stress applied to the front closure plate

$$\frac{\tau_1}{\tau_2} = \frac{M_1.(\pi.D_2.e_2 - n_2.D_{screw2}.e_2)}{M_2.(\pi.D_1.e_1 - n_1.D_{screw1}.e_1)} = \frac{16\times(\pi\times 300\times 32 - 12\times 16\times 32)}{32\times(\pi\times 260\times 30 - 12\times 16\times 30)} = \mathbf{0.64}$$

$\frac{\tau_1}{\tau_2} < 1$, so the resistance to shear stress of the back closure plate is enveloped by that of the front closure plate.

- Bending moment at the screws:

$$\frac{\sigma_1}{\sigma_2}=\frac{M_1}{M_2}\left(\frac{e_2}{e_1}\right)^2$$

Where:

- M: Maximum bending moment at the screws

According to <2> (Case 10b of Table 24):

$$M_1 = -\frac{q_1 a_1{}^2}{8} \text{ : back closure plate}$$

$$M_2 = -\frac{q_2 a_2{}^2}{8} \text{ : front closure plate}$$

Where:

- a: Radius of the screw inserts
- $a_1 = 130$ mm
- $a_2 = 150$ mm

And $\frac{q_1}{q_2} = \frac{e_1}{e_2}$

Therefore:

$$\frac{\sigma_1}{\sigma_2}=\frac{M_1}{M_2}\left(\frac{e_2}{e_1}\right)^2=\frac{q_1 a_1^2 e_2^2}{q_2 a_2^2 e_1^2}=\frac{a_1^2 e_2}{a_2^2 e_1}=\frac{130^2\times 32}{150^2\times 30}=\mathbf{0.8}$$

$\frac{\sigma_1}{\sigma_2} < 1$ so the resistance to the bending of the back closure plate is enveloped by that of the front lid

The above demonstrates that the strength of the back closure plate is enveloped by the strength of the front lid.

6.1.6 The Resistance of the Inner Shell to the Compression of the Lead

The lead is compressed during the axial drop. This axial compression produces radial compression of the inner shell and therefore circumferential compressive stress in this shell.

The compression stress in the lead is:

$$\sigma_{comp} = \frac{F}{S} = \frac{S.h.\rho.\gamma}{S} = h \, . \, \rho \, . \, \gamma$$

Where:

- S: Radial cross-section of the lead
- h: Height of the lead
- ρ: Density of the lead
- γ: Acceleration

According to <3>, the value of the radial pressure exerted by the lead on the shell is:

$$q = \frac{\nu_{pb}}{\frac{d}{2e} \times \frac{E_{pb}}{E_a} \times (1 - \nu_{pb})} \times \sigma_{comp}$$

- d: Internal diameter of the shell

- e: Thickness the shell

Therefore the value of the circumferential stress is:

$$\sigma_\theta = \frac{q.d}{2e}$$

So we can say: $\sigma_\theta = K \, . \, h \, . \, \gamma$

- K: Constant

- $h \approx Lu$

$$\gamma = \frac{\sigma.S}{Mt}$$

So, $\sigma_\theta = K' \frac{Lu}{Mt} = K' \frac{Lu}{Me + Mc}$

So, the envelope case corresponds to maximum Lu/(Mc + Me):

The Lu/(Mc + Me) ratio is shown in Figure 1-4.2 as a function of the length and the mass of the contents.

We observe that **the maximum length and the minimum mass of the contents** must be chosen.

With reference to the orientation of the package, it should be positioned **top end first** in order also to consider the strength of the top flange whose shape is complex and is also loaded by the lead.

6.1.7 Resistance of the Inner Shell to Buckling

The critical bending stress is inversely proportional to the square of the packaging length: $Fc = K/Lu^2$.

The value of the compressive force is: $F = Md.\gamma = (Md/Mt)\ \sigma.S$.

Where Md: The mass of the top part of the packaging likely to come to rest on the inner shell in the event of axial drop.
So, the most conservative case corresponds to maximum F/Fc, which is $(Lu^2\ Md)/(Mc + Me)$ maximum.

Therefore, as above, the **maximum length and the minimum mass of contents** must be chosen.

With reference to the orientation of the package, because the front and back parts have equivalent masses (approximately 1092 kg and 1025 kg respectively), the orientation of the package is unimportant.

6.1.8 Settling of the Lead

We have seen in Section 5.1.6 that the circumferential stress of the shell is proportional to the compressive stress in lead.

The reasoning is therefore the same and the **maximum length and the minimum mass of the contents** must be chosen. The orientation of the package is unimportant.

6.1.9 *Conclusion*

The results obtained can be summed up in the following table:

Element	Section	Conservative Length	Conservative Mc	Conservative drop orientation	Justification by Calculation Possible?
Cover	6.1.1	Maximum	Maximum	Unimportant	Yes
Revolving plug, revolving plug axis and clamps	6.1.2 and 6.1.3	Maximum	Maximum	Top	Yes
Lid, front closure plate and back closure plate	6.1.4 and 6.1.5	Minimum	Minimum	Top	Yes
Containment	6.1.6 and 6.1.7	Maximum	Minimum	Top	No
Lead settling	6.1.8	Maximum	Minimum	Unimportant	Yes

We can make the following groups:

- Cover and revolving plug axis since the side of impact can vary for the cover,
- Settlement of the lead, containment and revolving plug axis: only the Mc value is different between these two configurations. It can be demonstrated that going from Mc = 0 to Mc max has little impact on the strength of the containment and the settlement of the lead.

We have seen in 6.1.6 that: $\sigma_\theta = K.\gamma$

Thus:

$$\frac{\Delta\sigma_\theta}{\sigma_\theta} = \frac{\Delta\gamma}{\gamma}$$

Now, Lu =[3200]mm, γ (Mc=0) =[redacted] g

γ (Mc max) =[redacted] g

Thus, $\frac{\Delta\gamma}{\gamma}$ =[redacted]%

The mass of the contents has, therefore, little influence on the loading of the inner shell and on the settlement of the lead.

So, the axial drops can be grouped as follows:

Element	Conservative Length	Conservative Mc	Conservative side of impact
Cover **Revolving plug axis** **Clamp** **Containment** **Settlement of the lead**	Maximum	Maximum	Top
Front lid **Front closure plate** **Back closure plate**	Minimum	Minimum	Top

If we choose a model with the maximum length and the maximum mass of contents, the leaktightness preservation tests for the front lid and the closure plates are not verified using the harshest conditions since the stress applied to the lids and the closure plates is proportional to mass and acceleration.

The solution lies in completing the drop test by means of the following analytical calculations:

- Resistance of the closure plates to shearing and bending,

- Non-separation of the closure plates by analysing the pre-load of the closure plate fixing screws.

These calculations will be carried out with the acceleration obtained during the axial drop balanced by the ratio of the model mass to the lightest packaging.

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6.2 Drops from a Height of 9 m onto the Corner

The most conservative drop configuration can be determined by analytical calculation. The case of the drop onto the corner is such that the centre of gravity is aligned with the point of impact. The vertical then forms an angle θ with the axis of the packaging and the centre of gravity is taken as the geometric centre of the packaging.

Since the effective length varies from 1,000 to 3,200 mm, the position of the centre of gravity in relation to the height of the packaging (fitted with the covers) ranges from 1,200 to 2,300 mm and the angle θ ranges from 31 to 17°.

So, we will calculate the crushing and acceleration for several effective lengths. Each effective length corresponds to a minimum mass m_1 (without contents), a maximum mass m_2 (with envelope contents) and drop angle θ.

The maximum force of impact is $E = m_2.g.h$

The crushing force of the shock absorbing cover is determined by the relation:

$$E_c = \sigma_\theta \int S(x)dx$$

Where: x is the crushing height of the cover
σ_θ is crushing stress of the wood for the angle θ :

$$\sigma_\theta = \frac{\sigma\perp \times \sigma//}{\sigma\perp \times \sin^n \theta + \sigma// \times \cos^n \theta}$$

Where: $\sigma//$: crushing stress parallel to the grain,
$\sigma\perp$: crushing stress perpendicular to the grain.

The surface S(x) can be expressed as follows (see Figure 1-4.3):

$$S(x) = \frac{R^2}{\cos\theta}\left(\frac{\pi}{2} - \text{arc } \sin v - v\sqrt{1-v^2}\right)$$

Where: $v = 1 - \dfrac{x}{R\sin\theta}$

The integration of the force formula gives:

$$E_c = \sigma_\theta R^3 \operatorname{tg}\theta \left[-\frac{\pi}{2}v + v \arcsin v + \sqrt{1-v^2} - \frac{(1-v^2)^{\frac{3}{2}}}{3} \right]$$

Since $E_c = E$, v can be determined, then the crushing d:

$$d = x = R \sin\theta \ (1 - v)$$

Where acceleration is concerned, by only taking the wood into account, it is given by:

$$\gamma = \frac{\sigma_\theta \times S}{m_1 \times g}$$

In addition, the contribution of force and acceleration of the metal parts of the lid (steel sheeting, gusset plates) is minor given their buckling (due to bending). The sheets are in fact very thin: from 2 to 4 mm.

Thus, for h = 9 m:

Effective L (mm)	θ (°)	m1 (kg)	m2 (kg)	Acceleration (g)	Maximum compression
1000	31	6900	7200	[redacted]	89%
1600	25	8700	9200	[redacted]	84%
2200	22	10500	11100	[redacted]	83%
3200	17	13500	14500	[redacted]	78%

The acceleration values are lower than those obtained during vertical and horizontal drops with a maximum at[70]g.

The values of the maximum compression are sometimes greater than the maximum allowable of 80%. This excess is however small and localised being calculated between the point of impact and the edge of the packaging. In addition, the structures of the cover involved in the crushing have not been taken into account.

Most Conservative Drop Configuration:

The drop onto the edge primarily makes it possible to:

- Check the maximum crushing of the shock absorbing cover for this type of drop,
- Apply a load on the lid fixing screws and the closure plate screws on the side of impact,
- Apply a load on the fixing screws of the cover on the side of impact,
- Apply a load on the opening of the revolving plug.

Greater load is placed on the other packaging elements by the other drop cases given the maximum acceleration rates obtained here.

With respect to the stress exerted on the screws, taking into account that:

- The masses of the lid and of the closure plate are fixed for any value of Mt,

- The maximum acceleration is obtained for the maximum length and the minimum mass of the contents, (because the angle of drop between the vertical and the packaging axis is smaller for a long packaging and the surface area of the wood impacted increases),

- Stress is not exerted on the closure plates or the lid by the contents, in fact, the impact of the contents is borne either by the revolving plug or the back flange,

it is the configuration with the maximum length and minimum mass of the contents which gives the envelop value.

With respect to the crushing rate, it has been demonstrated that the deviation between the maximum length (78% crush) and the length minimum (89% crush) is small. The relative deviation is, therefore, 14% whereas it reaches 100% in cases of axial and lateral drops.

The configuration with the maximum length and minimum mass of the contents therefore gives the envelope value. As in section 6.1.9, going from the minimum mass of contents to the maximum mass of contents does not significantly modify acceleration.

Therefore, the most enveloping case in terms of crush and acceleration is the **maximum length and maximum mass of contents, with the package up side down.**

6.3 Lateral Drop

The purpose of a lateral drop is to:

- Check the dimensioning of the shock absorbing covers (maximum crush, no impact of the trunnions),
- Check that there is no shearing of the shock absorbing cover screws,
- Exert deformation stress on the packaging, in particular the containment,
- Exert stress on the revolving plug closure plate.

The worst case drop is estimated by calculations which use the finite elements method.

Appendix 1-5 calculates the acceleration rates at three points on the inner shell (top, centre and base) as a function of the following parameters: The length of the packaging and the angle of drop.

This study is completed by calculation of the stresses and residual deformation after the drops set out in Appendix 1-6 for the most conservative cases defined by acceleration calculations. We define these configurations for a given length based on the maximum acceleration to which the top of the packaging (for lengths of [redacted] and [redacted] mm) and the level of the centre of the shell (for lengths of [redacted] and [redacted] mm) are subjected.

Reading the table of results in Appendix 1-5, the cases used are:

- Maximum acceleration from the top of the packaging:

- Lu = [redacted] mm, angle of drop nil,
- Lu = [redacted] mm, angle of drop nil,
- Lu = [redacted] mm, 10 ° angle (1st impact on the base).

- Maximum acceleration rates at the centre of the shell:

- Lu = [redacted] mm, 10 ° angle (1st impact on the top),
- Lu = [redacted] mm, angle of drop nil.

6.3.1 *Shock absorbing covers*

Maximum crushing of the shock absorbing covers will be obtained for the maximum mass of the packaging and therefore for the maximum length and the maximum mass of the contents.

The maximum crushing obtained in Appendix 1-5 and Appendix 1-6 with the effective length of 3,200 mm and the maximum mass of contents is:

Horizontal packaging: 112 mm

Packaging angled at 10°: 135 mm

6.3.2 *Deformation of the Packaging*

Residual deformation of the top flange and the steel shell taken from Appendix 1-6 are set out in Figures 1-4.4 and 1-4.5.

- **Top flange:**

First of all, Figure 1-4.4 shows that the maximum residual plastic deformation varies little between the different cases calculated (from 0.66% to 1.1%). The maximum value is obtained for a length of 3,200 mm and an angle of drop of 10°. The case of the horizontal drop presents greater residual deformation of the inner shell but the value of 0.66% corresponds, according to the tensile curve used for the calculations, to a stress of 135 MPa which, in turn,

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corresponds to negligible plastic deformation (σe = 130 MPa and σr = 380 MPa).

- **Shell:**

Appendix 1-6 and Figure 1-4.5 show that with regard to the inner and outer shells, plastic deformation is greatest for length 3,200 mm and a horizontal drop: The maximum value for the inner shell is 1.05% with a maximum stress of 150 MPa. The same packaging dropped from an angle of 10° presents a maximum plastic deformation for the inner shell of 0.5%.

6.3.3 Revolving Plug Closure Plate

The closure plate is verified by calculation as are the top closure plates (see 6.3.4).

6.3.4 Conclusion:

The calculation set out in Appendix 1-6 shows that the maximum residual deformation will be 1.05% with a maximum stress of 150 MPa for the case of the length of 3200 mm and a horizontal drop. These values show that the plastic deformation is minor in relation to allowable limits: 5% deformation of the internal cavity and 380 MPa (tensile strength).

With respect to the top flange, it is the case of length 3200 mm and drop angle 10° which produces the greatest deformation.

The drop configuration used is the packaging of **maximum length, a drop orientation of 10° above horizontal and with maximum mass of contents** because:

- Increasing the deformation of the covers ensures a more conservative approach,
- This choice also causes maximum deformation of the supports of the leaktight seals of the front flange.

The tests are completed by calculations to check the pre-load stress of the closure plate fixing screws by:

- Measurement of the accelerations during drop tests,
- Theoretical calculation of the ratio between the maximum acceleration of this element and that of the drop configuration,
- Calculation of maximum acceleration based on the two above points,
- Verification of the correct dimensioning of the closure plate and tappings and of the pre-load value of the closure screws.

6.4 Drops onto a puncture bar

The elements to be checked during a drop onto a puncture bar are:

- Outer shell of the body of the packaging,
- Top lid,
- Top closure plate,
- Closure plate A (venting orifice),
- Revolving plug control closure plate.
- Closure plate B (filling/drainage orifice),
- Base closure plate.

The Case of the Top Lid, the Top Closure Plate, Closure Plate A and the Base Closure Plate:

They are covered by a single drop on the top closure plate, in fact:

- The top lid and closure plate A are better protected by the cover,

- The base and top closure plates (which are made from the same material) have equivalent resistance. In fact, the bending, radial and tangential moments for a circular plate recessed around its outer edges and subjected to a uniform load distributed at the centre of the plate (force due to the puncture bar) are calculated in the following way (in accordance with <2>, Table 24):

  $M_r = -\frac{W}{4\pi}$ and $M_t = -\frac{\upsilon \times W}{4\pi}$, as these moments are calculated for the recessing of the plates.

  The stresses associated with these moments are expressed as: $\sigma = \frac{6M}{t^2}$ and therefore do not depend on the thickness of the flange.

  The thicknesses of the flanges of the front and back closure plates are 32 and 30 mm respectively. The stress levels in these closure plates are therefore equivalent.

Case of the Revolving Plug Control Closure Plate:

A drop onto a puncture bar on the closure plate is not significant because:

- The closure plate is protected by a 60 mm thick steel plug having an acme thread, ϕ 170,
- There is a 3 mm clearance between the closure plate and the stopper,
- The plug is protected by the shock-absorbing cover.

The force exerted on the packaging upon impact can be estimated in the following way:

A package will be dropped onto a vertical puncture bar whose axis is not in the projection of the packaging's centre of gravity where W is the absorbance of the total force of impact, this absorbance depends on the geometry of the packaging.

Energy of impact: Ei = m g h

The force thus transmitted is not the total force but a part of the force of impact corresponding to:

$$E = m\,g\,h.\ [1 - \frac{m\,l^2}{I_G + m(l^2 + d^2)}\ ]$$

where:

- l = Distance from the axis of the spike to the centre of gravity of the packaging,
- d = Distance from the point of impact on the inner shell of the packaging to the axis of the packaging,
- m = 15,000 kg,
- $g = 9.81\ m.s^{-2}$,
- h = 1 m,
- l = 4000/2 – 270 = 1.73 m,
- d = 820/2 = 0.41 m.

$$I_G = m\left[\frac{R^2}{4} + \frac{L^2}{12}\right]$$

Where

- R = 0.41 m: Radius of the packaging,
- L = 4.0 m: Length of the body of the packaging (without covers).

So: **E = 50,000 J**

We disregard the presence of the cover and evaluate the force absorbed by the protective plate. For this calculation case, the steel shell is considered to be infinitely rigid.

The shear force Ec absorbed by the thickness of the steel plate is given by:

$$Ec = \frac{\sigma_R}{\sqrt{3}}\ A\ e = \frac{450}{\sqrt{3}}\ x\ (\ \pi\ x\ 170\ x\ 60/2)\ x\ 30\ x\ 10^{-3}$$

The ultimate stress σR for stainless steel at 20 °C is:

σR = 450 MPa.

- e: Threaded height which is half of the thickness of the plate,
- A: Shear section.

Ec = 125,000 J

The shear force Ec in the thickness of the plate absorbs the drop force onto bar E=50,000 J, without the plate shearing.

Case of closure plate B:

A drop onto a puncture bar on this closure plate is not necessary as the closure plate is installed in a way that prevents it from being impacted by the puncture bar.

- Its diameter is 120 mm,
- It is embedded in the base flange at a minimum depth of 40 mm,
- It is covered by the cover.

The drop programme therefore includes the **2** following **drops onto a puncture bar:**

- 1 drop on the top closure plate,
- 1 drop on the outer shell.

In both cases, the force of impact and therefore the mass of the package must be the maximum to ensure maximum damage is caused. So, the **maximum length and the maximum mass of the contents** must be chosen.

7. CONCLUSION

7.1 Drop Model characteristics

The results obtained for the different types of drops in terms of effective length and mass of contents are set out in the following table:

	Drop Case		Length	Content Mass
Drops onto a Flat Target	**Axial Drop**	**Maximum Deformation**	Maximum	Maximum
		Maximum Stress on the Closure Plate	Minimum	Minimum
	Drop on the Corner		Maximum	Maximum
	Lateral Drop	**Maximum Deformation**	Maximum	Maximum
		Maximum Stress on the Closure Plate	Intermediate	Minimum
Drops onto a puncture bar			Maximum	Maximum

It is observed that the most conservative length for:

- Determining the maximum deformation of the containment and the packaging,
- Validating the dimensioning of the covers,
- Validating the strength of the revolving plug axes and holding clamps

is the maximum length.

This length is only conservative for the elements which remain unchanged when the length of the packaging varies, namely, the front lid and the closure plates. These elements are those which support the leaktightness seals. The choice of maximum length makes it possible to test the installation of these elements (maximum deformation of the support), the strength of these elements will be verified by means of calculation, using the method set out in Section 6.

So it is decided to perform the drop tests using a model with the **longest maximum effective length and maximum content mass.**

7.2 ORIENTATION OF THE MODEL

We have seen that for each type of 9 m drop a single orientation is sufficient; for the drops onto a puncture bar, 2 positions must be tested:

Drop Case		**Orientation**
Drops onto a Flat Target	**Axial Drop**	Top End
	Drop on the Corner	Top End
	Lateral Drop	Angle of 10°, 1st impact base end
Drops on to a puncture bar		1 on the top closure plate, vertical 1 on the outer shell, angle of impact 30°

8. REFERENCES

<1> IAEA Safety Series No. 6. Regulations for the Safe Transport of Radioactive Material –1985 Edition – (Revised in 1990).

<1'> Regulation of the Transportation of Radioactive Materials. IAEA Safety Standard No. ST1 (1996 Edition)

<2> ROARK and W.C. Young "ROARK's Formulas for Stress and Strain", fifth edition, McGraw-Hill Book Company.

<3> Strength of Materials - Timoshenko - Tome 1 (dunod)

LIST OF FIGURES

FIGURE 1-4.1

STRESS EXERTED ON THE REVOLVING PLUG AXIS

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-4.2

CIRCUMFERENTIAL STRESS IN THE INNER SHELL

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-4.3

CRUSHING OF THE COVER WHEN DROPPED ON THE CORNER

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Crushing surface:

$$S = \frac{R^2}{\cos\theta}\left(\frac{\pi}{2} - \arcsin_v - v.\sqrt{1-v^2}\right)$$

where $v = 1 - \dfrac{x}{R\sin\theta}$

Crushing force:

$$E = \sigma \int_0^x s\,dx$$

$$= \sigma R^3 \tan\theta \left(-\frac{\pi}{2}v + v.\arcsin_v + \sqrt{1-v^2} - \frac{1}{3}\left(1-v^2\right)^{\frac{3}{2}}\right)$$

FIGURE 1-4.4

RESIDUAL DEFORMATION OF THE TOP FLANGE FOR THE EFFECTIVE LENGTH OF 3200 MM - HORIZONTAL DROP AT A 10° ANGLE

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-4.5

RESIDUAL DEFORMATION OF THE INNER SHELL FOR THE EFFECTIVE LENGTH OF 3200 MM - HORIZONTAL DROP AT A 10° ANGLE

Proprietary information withheld pursuant to 10 CFR 2.390

CALCULATION OF TN 106 PACKAGING IN THE CASE OF A 9 M HEIGHT LATERAL DROP

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-5E			
0	02/00	Document First drawn up	F. PETIT / T. MASSIA
Ref. : DOS-08-00126114-105			
00	08/08	New document reference New formalism Insertion of the effect study of Young's modulus of the lead	S. CHEVET / JC. BOTT

SUMMARY

Purpose:

This appendix makes it possible to determine the most conservative configuration (cavity length/angle of drop), from the point of view of acceleration, for the packaging in the case of a lateral drop from a height of 9 m. This appendix also allows to study the effect of Young's modulus of the lead on TN 106 packaging acceleration with a length of 3200 mm, during a 9 m height lateral drop.

Basic Data:

The dimensions and masses of the packaging components are taken from Chapter 0 and Appendix 0-1.

Assumptions and Methods Used:

The body of the packaging is considered deformable.

The structure is studied in a flexible body for angles of impact ranging from -20° to +20°.

Given the structural symmetry, only half a model is made.

The package falls on the handling lug side. The handling lugs are modelled in the 3,200 mm version (maximum mass) in order to check that they do not impact.

The plate of the shock absorbing cover in the symmetrical drawing is modelled and is considered, dimensionally, as being unable to buckle.

The screwed connections between the shock absorbing covers and the packaging, in addition to the different contacts and gaps (apart from the one between the shell and the intermediate cover and the one between the inner shell and the mass of the contents) are not represented. The connections are considered total.

The revolving plug and all areas situated on the top and bottom of the packaging are modelled by their mass.

The contents are modelled by a steel bar.

Based on these assumptions, the acceleration is measured at three (3) points on the structure (on top, at the centre and at the base of the packaging) and for three (3) cavity lengths (3,200 mm, 2,200 mm and 1,000mm).

The different acceleration curves obtained in this way are filtered at 1,000 Hz. Appendix 1-7 justifies this value.

Results and Conclusions:

- The maximum accelerations at the top of the packaging are obtained for the following configurations:
  - Length 1,000 mm and horizontal drop case,
  - Length 2,200 mm and horizontal drop case,
  - Length 3,200 mm and case of the drop at an angle of 10° (1st impact on the base).

- The maximum accelerations at the centre of the packaging shell are obtained for the following configurations:
  - Length 1,000 mm and the case of the drop at an angle of 10° (1st impact on the top),
  - Length 2,200 mm and the case of the drop at an angle of 10° (1st impact on the top),
  - Length 3,200 mm and horizontal drop case.

The handling lugs do not impact as the thicknesses of crushed wood are less than the height of these lugs.

Subsequent Use of the Results Obtained:

The drop angle which maximises the accelerations can be determined from these results in the case of each cavity length.

Conservative configurations are used in Appendix 1-6 in order to determine the stress and deformation of the packaging.

Moreover, the effect of Young's modulus of the lead is inconsiderable with regard to the deformation and acceleration energies suffered by the collar (<5%). The Young's modulus of the lead also has no effect on the most disadvantageous angle of drop.

1. PURPOSE

The purpose of this appendix is to determine, in the case of a lateral drop from a height of 9 m, the most disadvantageous configuration (cavity length/drop angle) for TN 106 packaging, which is to say, the configuration which maximises residual deformation at the top, the centre and the base of the package. This appendix also contains the study of the effect of Young's modulus of the lead on TN 106 packaging acceleration whit a length of 3200 mm, during a 9 m height lateral drop.

2. APPROACH

The stages of the study are as follows:

- Calculation of the acceleration rates at three points on the structure (on top, at the centre and at the base of the packaging) and for three cavity lengths (3,200 mm, 2,200 mm and 1,000 mm). These results are then used to determine the drop angle which maximises the acceleration obtained at the centre and at the top for each cavity length,
- The filtering frequency of the acceleration curves will be evaluated in Appendix 1-7 in order to justify the choice of 1,000 Hz in this study,
- Once the maximum acceleration rates have been determined, the whole of the structure of the cases used is studied in Appendix 1-6 in order to determine the level of stress and residual deformation at the centre and at the top of the shell.

3. ASSUMPTIONS

- The body of the packaging is considered deformable,
- The structure is studied in a flexible body for angles of impact ranging from -20° to +20°,
- Only half a model is produced on account of the structural symmetry,
- The package falls onto the handling lug side. The handling lugs are modelled in the 3,200 mm version (maximum mass) in order to ensure that they do not impact,
- The plate of the cover in the symmetrical drawing is modelled and is considered, dimensionally, as being unable to buckle,
- The screwed connections between the covers (top and bottom) of the packaging and the different contacts and gaps (apart from the one between the shell and the intermediate cover and the one between the inner shell and the mass of the contents) are not represented. The connection is considered total (common nodes),
- The revolving plug, as well as all other areas situated on the top and bottom of the packaging, are modelled by their mass,
- The contents are modelled by a steel bar,
- The filtering frequencies of the acceleration curves shall be taken as 1,000 Hz (for reference, the acceleration recording no-filtered and filtered at 1,000 Hz are explained in the 5573-C-19 note)
- Two valors of the Young's modulus of the lead are studied in the 3,200 mm version (see to paragraph 4.2) in order to treat the effect of the temperature (decrease of the Young's modulus under heat).

4. MODELING

Modelling is carried out in accordance with the finite elements method using I-DEAS <1> software, calculations and post-processing are performed using LS-DYNA and LS-TAURUS <2> software.

4.1 Mesh

The geometry of the model is taken from <3>.

The elements used, described in the following table, are:

- Shock-absorbing covers: wood (Figure 1-5.1) and sheet steel (Figure 1-5.2),
- Base (with lifting lugs for the 3,200 mm package): lead, resin and steel (Figure 1-5.3),
- Top (with lifting lugs for the 3,200 mm package): lead, resin and steel (Figure 1-5.4),
- Centre: lead, resin and steel (Figure 1-5.5) where "L" is the variable length of the packaging,
- Mass (of the contents): steel (Figure 1-5.6) where "L" is the variable length of the packaging,
- Hence the different package models: 3,200 mm (Figure 1-5.7), 2,200 mm
- (Figure 1-5.8), and 1,000 mm (Figure 1-5.9).

Subassembly	**Characteristics of the Elements**		
	Size	**Nature**	**Type**
Body, top and base (steel)	Volume	Deformable (elasto-plastic)	LS-DYNA type 24
Covers made from balsa wood (top and base)	Volume	(elasto-plastic) honeycomb	LS-DYNA type 26
Plywood	Volume	Deformable (resilient)	LS-DYNA type 1
Contents	Volume	Deformable (resilient)	LS-DYNA type 1
Gusset plates of the covers	Plate	Deformable (elasto-plastic)	LS-DYNA type 24
Interface contacts	Plate	deformable (resilient)	LS-DYNA type 1
Resin	Volume	Deformable (resilient)	LS-DYNA type 1
Lead	Volume	Deformable (resilient)	LS-DYNA type 1

The characteristics of the materials used are given in Section 4.2.

4.2 Materials

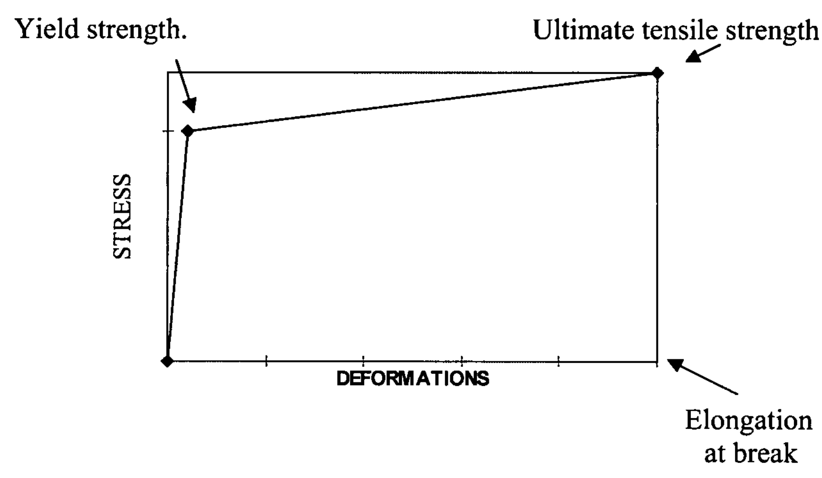
The characteristics of the materials (except the wood) used are:

Material	Young's Modulus (GPa)	Poisson Coefficient	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation at break (%)	Density(*) (kg/m³)
Steel (at 150 °C)	200	0.3	130	380	45	7850
Lead (at 20 °C)	[redacted] (**)	[redacted]	-	-	-	[redacted]
Resin	[redacted]	[redacted]	-	-	-	[redacted]

(*) These densities are modified in order to integrate the mass of the different un-modelled components as well as geometrical simplifications.
(**) value from <5>

The decrease of the Young's modulus is higher than that expected of the lead of TN 106 packaging in the normal conditions of transport. Thus, the impact study done in this chapter covers the normal conditions of transport.

The law of elasto-plastic behaviour used is bilinear as described below and corresponds to material 24 of LS DYNA 3D:



Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

The properties of the materials (wood) used are:

Properties	Balsa Wood
Young's modulus of the compacted material - E (in GPa)	35
Yield strength of the compacted material - R_{pe} (in MPa)	350
Poisson coefficient - ν	0.3
Density - ρ (in kg/m^3)	189
Young's modulus (in GPa) E_{grain} E_{tang}	 3.150 0.014
Shear module (in GPa) G_{grain} G_{tang}	 0.002 0.233
Crushing stress in the direction of the grain (in MPa)	11
Crushing stress perpendicular to the direction of the grain (in MPa)	1.5
Maximum crushing (Final volume / initial volume)	10%

4.3 Boundary Conditions

4.3.1 Initial Speed

The packaging is released with no initial speed from a height of 9 meters. This corresponds to an impact speed of V_0 = 13.3 m/s.

4.3.2 Angle of Impact

The drop angle θ is taken into consideration between the horizontal surface of impact and the axis of the packaging. This angle is nil for a flat drop, positive for a first impact on the base and a second on the top and this angle is negative for a first impact on the top and a second on the base. The positioning varies from an angle of 20° (Figure 1-5-10) to an angle of -20° (Figure 1-5-11).

4.3.3 Friction

The contact between the structure and the target is taken into account with a friction coefficient of 10%.

5. RESULTS

The results shown are taken from archived files <4>.

Figures 1-5.12 to 1-5.16 show a drop sequence of the 3,200 mm packaging with an initial impact on the base for a drop angle of -10°.

The calculations are used to establish the angles of incidence which produce the maximum acceleration rates in the structure (top, centre and base). The following table presents the vertical acceleration rates for three zones (points A, B and C Figure 1-5.24) of the structure:

- A point at the base of the packaging situated on the inner shell made from steel used to evaluate the acceleration due to the impact of the base. The node numbers used are 15,314 (3,200 mm package) and 31,148 (2,200 mm and 1,000 mm package),
- A point at the top of the packaging situated on the inner shell made from steel used to evaluate acceleration due to impact of the top. The node numbers used are 30,475 (3,200 mm package) and 41,306 (2,200 mm and 1,000 mm packages),
- A point at the centre of the packaging situated on the inner shell made from steel used to evaluate the acceleration near the centre of gravity (CDG) of the structure. The node numbers used are 45,768 (3,200 mm package), 13,896 (2,200 mm package) and 12,053 (1,000 mm package),
- Filtering at [redacted] Hz was performed to try to limit interference phenomena which could make the reading of maximum acceleration difficult (see Appendix 1-7). However, non-physical and unrealistic acceleration peaks will not be taken into account.

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The results can be found in Figures 1-5.18, 1-5.19 and 1-5.20 for the various packages with the various angles given in the table below:

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The italic writing value are resulted of the calculation which take the low value of the Young's modulus of lead into account

Figures 1-5.17 et 1-5.27 show these accelerations filtered at 1000 Hz, at the front, center of gravity and back for the most disadvantageous angle (10°).

Figures 1-5.28 show the accelerations at the front, center of gravity and back for the most disadvantageous angle (10°) and the low value of the Young's modulus of the lead.

Figures 1-5.21, 1-5.22 and 1-5.23 show the thicknesses of crushed wood for the horizontal drops in each packaging length through iso-displacement. For lengths 3,200 mm, 2,200 mm and 1,000 mm, the compacted thicknesses are 112 mm, 101 mm and 66 mm respectively.

The energy absorbed by the lead for a drop angle of 10° is showed on the figure 1-5.25. We can infer from that :

$$\frac{\text{internal energy of the lead}}{\text{internal energy of the half packaging}} = \frac{0{,}22}{5{,}58} = 0{,}36\%$$

The energy absorbed by the lead for a angle drop of 10° with the low value of the Young's modulus of the lead is showed on the figure 1-5.26. We can infer from that :

$$\frac{\text{internal energy of the lead}}{\text{internal energy of the half packaging}} = \frac{0{,}47}{5{,}58} = 0{,}85\%$$

6. CONCLUSIONS

The results shown in the above table show that the cases used for the study in Appendix 1-6 are:

- To maximise the maximum acceleration of the top of the packaging:
    - Length 1,000 mm and horizontal drop case,
    - Length 2,200 mm and horizontal drop case,
    - Length 3,200 mm and case of the drop at an angle of 10° (1st impact on the base).

- To maximise acceleration at the centre of the packaging shell:
    - Length 1,000 mm and case of the drop at an angle of 10° (1st impact on the top),
    - Length 2,200 mm and case of the drop at an angle of 10° (1st impact on the top),
    - Length 3,200 mm and horizontal drop case.

From the thickness of wood crushed, we can conclude that the handling lugs do not impact.

Moreover, the effect of Young's modulus of the lead is insignificant with regard to deformation and acceleration energies suffered by the collar (<5%). The Young's modulus of the lead also has no effect on the most disadvantageous angle of drop.

7. REFERENCES

<1> Finite elements calculation software: I-DEAS Master Series V4.0 developed by SDRC.

<2> Finite elements calculation software: LS-DYNA V940 1.a developed by LSTC.

<3> Design drawing of TN 106 packaging: 5573-04 Ind. A

<4> Archiving files: /z5573001/Dynamique/

Chute 1.arc
*1.unv
CH3200 AN*
CH2200 AN*
CH1000 AN*

<5> "Mechanical characteristicc of the lead and of these alloys" note, Information Center of the Lead

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FIGURE 1-5.1

COVER: WOOD

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FIGURE 1-5.2

COVER: STEEL SHEET

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FIGURE 1-5.3

BASE OF THE PACKAGING

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FIGURE 1-5.4

TOP OF THE PACKAGING

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.5

CENTER OF THE PACKAGING

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.6

MASS OF CONTENTS

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FIGURE 1-5.7

PACKAGING MESH FOR LENGTH 3,200 MM

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.8

PACKAGING MESH FOR LENGTH 2,200 MM

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.9

PACKAGING MESH FOR LENGTH 1,000 MM

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FIGURE 1-5.10

DROP ANGLE OF 20°. 1ST IMPACT ON THE BASE

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FIGURE 1-5.11

DROP ANGLE OF -20°. 1ST IMPACT ON THE TOP

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FIGURE 1-5.12

SIMULATION OF IMPACT AT T = 0 ms

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FIGURE 1-5.13

SIMULATION OF IMPACT AT T = 16.8 ms

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.14

SIMULATION OF IMPACT AT T = 32 ms

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.15

SIMULATION OF IMPACT AT T = 44.8 ms

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FIGURE 1-5.16

SIMULATION OF THE IMPACTED PACKAGE

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FIGURE 1-5.17

ACCELERATIONS OF PACKAGING OF LENGTH 3,200 MM
FOR A DROP ANGLE OF 10°, 1ST IMPACT ON THE BASE

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FIGURE 1-5.18

ACCELERATION EVOLUTION CURVES
FOR THE 1,000 MM PACKAGE AS A FUNCTION OF THE ANGLE

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FIGURE 1-5.19

ACCELERATION EVOLUTION CURVES FOR THE 2,200 mm PACKAGE AS A FUNCTION OF THE ANGLE

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.20

**ACCELERATION EVOLUTION CURVES
FOR THE 3,200 mm PACKAGE AS A FUNCTION OF THE ANGLE**

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FIGURE 1-5.21

THICKNESS OF CRUSHED WOOD FOR THE 3,200 MM PACKAGE DROPPED HORIZONTALLY

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FIGURE 1-5.22

THICKNESS OF CRUSHED WOOD FOR THE 2,200 MM PACKAGE DROPPED HORIZONTALLY

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.23

THICKNESS OF CRUSHED WOOD FOR THE 1,000 MM PACKAGE
DROPPED HORIZONTALLY

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.24

LOCATION ON THE STRUCTURE OF THE POINTS WHERE THE ACCELERATION READINGS WERE TAKEN

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FIGURE 1-5.25 (1/2)

ABSORBED ENERGY BY THE LEAD FOR A DROP ANGLE OF 10°

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FIGURE 1-5.25 (2/2)

ABSORBED ENERGY BY THE LEAD FOR A DROP ANGLE OF 10°

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.26 (1/2)

ABSORBED ENERGY BY THE LEAD FOR A DROP ANGLE OF 10° (WITH THE DISADVANTAGEOUS MECHANICAL CHARACTERISTICS OF THE LEAD).

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FIGURE 1-5.26 (2/2)

ABSORBED ENERGY BY THE LEAD FOR A DROP ANGLE OF 10° (WITH THE DISADVANTAGEOUS MECHANICAL CHARACTERISTICS OF THE LEAD).

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FIGURE 1-5.27 (1/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10°

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FIGURE 1-5.27 (2/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10°

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.27 (3/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10°

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.28 (1/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10° (WITH THE LEAD DISADVANTAGEOUS MECHANICAL CHARACTERISTICS).

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FIGURE 1-5.28 (2/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10° (WITH THE LEAD DISADVANTAGEOUS MECHANICAL CHARACTERISTICS).

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-5.28 (3/3)

ACCELERATIONS AT THE FRONT, CENTER OF GRAVITY AND BACK FOR THE ANGLE 10° (WITH THE LEAD DISADVANTAGEOUS MECHANICAL CHARACTERISTICS).

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ADDITIONAL STUDY OF TN 106 PACKAGING BEHAVIOUR IN THE CASE OF A 9 M HEIGHT LATERAL DROP

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-6E			
0	02/00	Document first drawn up	F. PETIT / T. MASSIA
Ref. : DOS-08-00126114-106			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT

SUMMARY

Purpose:

The purpose of this additional appendix to Appendix 1-5 is to evaluate stress and deformation in the drop test cases considered to be the harshest for the structure for the different lengths of the packages studied.

Basic Data:

The dimensions and the masses of the packaging components are taken from Chapter 0 and Appendix 0-1.

The cases used for this analysis are taken from Appendix 1-5.

Assumptions and Methods Used:

The calculation assumptions are the same as those in Appendix 1-5.

The level of stress and residual deformation of the steel shell is determined based on each of the conservative cases used in Appendix 1-5.

Results and Conclusions:

The maximum stresses in the packaging, for any effective length of the cavity, in the case of lateral drops from a height of 9 meters and any angle of drop, is [redacted] MPa. The maximum residual plastic deformation is [redacted]%.

Subsequent Use of the Results Obtained:

The results are used in Chapter 1 to determine the configuration of the damaged package.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

1. PURPOSE

The purpose of this additional appendix to Appendix 1-5 is to evaluate stress and deformation in the drop test cases considered to be the harshest for the structure for the different lengths of the packages studied.

The most disadvantageous cases used for this analysis taken from Appendix 1-5 are:

- Length 3,200 mm for a drop angle of 10° (1st impact on the base),
- Length 3,200 mm for a horizontal drop,
- Length 2,200 mm for a horizontal drop,
- Length 2,200 mm for an angle of drop of -10° (1st impact on the top),
- Length 1,000 mm for a horizontal drop.

The drop at an angle of −10° for the length of 1,000 mm, will not be dealt with since the maximum acceleration is situated in the centre of the shell and it is clear that the residual stress and deformation at the centre will, in any case, be greater for the case of 3,200 mm (length and maximum mass).

2. APPROACH

The stages of the study are:

- Reworking of the calculation model from Appendix 1-5,
- Determining of the levels of stress and residual deformation of the steel shell,
- Comparing the crushing rate of the top/base covers in respect of the 3,200 mm packaging for a drop at an angle of 10° and a horizontal drop,
- Evaluating of the maximum crushing rate of the covers (wood only without sheeting) in order to compare it to an equivalent analytical solution for the 3,200 mm packaging for a horizontal drop.

3. ASSUMPTIONS

The body of the packaging is considered deformable.

Given the structural symmetry, only a half-model is made.

The plate of the shock absorbing cover in the symmetrical drawing is modelled and is considered, dimensionally, as being unable to buckle.

The screwed connections between the shock absorbing covers (top and bottom) and the different contacts and gaps (apart from the one between the shell and the shock absorbing cover and the one between the inner shell and the mass of the contents) are not represented. The connection is considered total (common nodes).

The revolving plug, in addition to all the areas situated on the top and bottom of the packaging, are modelled by their mass.

The contents are modelled by a shell of equivalent mass.

4. MODELING

Modelling is carried out in accordance with the finite elements method using I-DEAS software <1>, the calculations and post-processing are performed using LS-DYNA and LS-TAURUS software <2>.

4.1 Mesh

The geometry of the model is taken from Appendix 1-5.

SUBASSEMBLY	CHARACTERISTICS OF THE ELEMENTS		
	Dimension	**Nature**	**Type**
Body, top and base (steel)	Volume	Deformable (elasto-plastic)	LS-DYNA type 24
Shock absorbing covers made from balsa wood (top and base)	Volume	Honeycomb (elasto-plastic)	LS-DYNA-type 26
Plywood	Volume	Deformable (resilient)	LS-DYNA-type 1
Contents	Plate	Deformable (resilient)	LS-DYNA-type 1
Gusset plates of the shock absorbing covers	Plate	Deformable (elasto-plastic)	LS-DYNA-type 24
Interface contacts	Plate	Deformable (resilient)	LS-DYNA-type 1
Resin	Volume	Deformable (resilient)	LS-DYNA-type 1
Lead	Volume	Deformable (elasto-plastic)	LS-DYNA-type 3

The characteristics of the materials used are given in Section 4.2.

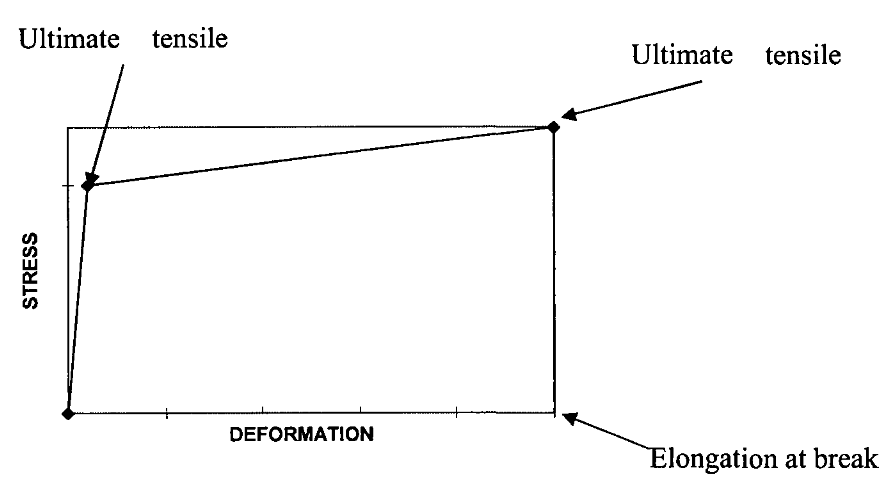
4.2 Materials

The characteristics of the materials (except the wood) used are:

Material Name	Young's Modulus (GPa)	Poisson Coefficient	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation at Break (%)	Density(*) (kg/m³)
Steel at 150 °C	200	0.3	130	380	45	7850
Lead at 20 °C	[redacted]	[redacted]	[redacted]	[redacted] (**)	-	[redacted]
Resin	[redacted]	[redacted]	-	-	-	[redacted]

(*) These densities are modified in order to integrate the mass of the different un-modelled components as well as geometrical simplifications.
(**) Plastic module.

The law of elasto-plastic behaviour used is bilinear as described below and corresponds to material laws 24 and 3 of LS DYNA 3D:



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The characteristics of the materials (wood) used are:

Characteristics	Balsa Wood
Young's modulus of the compacted material - E (GPa)	35
Yield strength of the compacted material - R_{pe} (MPa)	350
Poisson coefficient - ν	0.3
Density - ρ (kg/m^3)	189
Young's modulus (GPa) E_{grain} E_{tang}	 3.150 0.014
Shear module (GPa) G_{grain} G_{tang}	 0.002 0.233
Crushing stress in the direction of the grain (MPa)	9
Crushing stress perpendicular to the direction of the grain (MPa)	1.5
Maximum crushing (Final volume /initial volume)	10%

4.3 Boundary Conditions

4.3.1 Initial Speed

The packaging is released with no initial speed from a height of 9 meters. This corresponds to an impact speed of $V_0 = 13.3$ m/s.

4.3.2 Case of Calculations

The following calculation cases are considered:

- Model of the packaging of length 3,200 mm with an angle of drop of 10°,
- Model of the packaging of length 3,200 mm with a horizontal drop,
- Model of the packaging of length 2,200 mm with a horizontal drop,
- Model of the packaging of length 2,200 mm with an angle of drop of -10°,
- Model of the packaging of length 1,000 mm with a horizontal drop.

4.3.3 Friction

The contact between the structure and the target is taken into account with a friction coefficient of 10%.

5. RESULTS

The results are taken from archived Files <3>.

Figures 1-6.1 to 1-6.5 represent the configurations after impact for the 5 drop cases.

Figures 1-6.6 to 1-6.8 represent the acceleration curves for the drop cases:

- 1,000 mm packaging – horizontal drop,
- 2,200 mm packaging – horizontal drop,
- 3,200 mm Packaging – Drop from an angle of 10° - 1st Impact on the bottom end.

The maximum stresses and residual deformation are shown in Table 1-6.1. Figures 1-6.9 to 1-6.12 show these stresses and deformations for the most disadvantageous case used in this study, which is packaging 3,200 mm, flat drop.

Figures 1-6.14 to 1-6.17 contain maximum crushing values of the wood:

- Figure 1-6.13 shows the referencing of the nodes which will serve for the determination of the crushing of the shock absorbing covers for the 3,200 mm packaging,

- Figure 1-6.14 shows the difference in displacement of the nodes on the angle of the base shock absorbing cover at the point of impact with crushing of 185 mm,

- Figures 1-6.15 and 1-6.16 show the difference in displacements of the nodes with crushing of 85 mm and of 135 mm respectively,

- Figure 1-6.17 represents the iso-displacement of the base shock absorbing cover of the 3,200 mm packaging in a horizontal drop without sheets to contain the wood with crushing of 236 mm.

6. CONCLUSIONS

The maximum stress in the packaging for any effective cavity length for the lateral drops from a height of 9 meters and for any angle of drop is [redacted] MPa. The maximum residual plastic deformation is [redacted]%.

7. REFERENCES

<1> Finite elements calculation software: I-DEAS Master Series V4.0 developed by SDRC.

<2> Finite Elements Calculation Software: LS-DYNA developed by LSTC.

<3> Archiving files: /z5573001/Dynamique/

CH3200AN10C1
CH3200AN0C1
CH2200AN0C1
CH2200Anm10C2
CH1000AN0C1

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LIST OF TABLES

LIST OF FIGURES

TABLE 1-6.1

MAXIMUM STRESS AND RESIDUAL DEFORMATION

CASE Length (mm) / angle	σ_{max} Von Mises	$\varepsilon_{rés.}$ max. on the shell	$\varepsilon_{rés.}$ max. on top or base	$\varepsilon_{rés.}$ max. at the centre of the shell
	Values (MPa)	Values (%)	Values (%)	Values (%)
1000 0°	Proprietary information withheld pursuant to 10 CFR 2.390			
2200 0°				
2200 -10°				
3200 0° (3)				
3200 10°				

(1): Outer shell/inner shell.
(2): Outer Shell
(3): See Figures 1-6.9 to 1-6.12

FIGURE 1-6.1

1000 MM PACKAGING - HORIZONTAL DROP

CONFIGURATION AFTER IMPACT

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.2

2200 MM PACKAGING - HORIZONTAL DROP

CONFIGURATION AFTER IMPACT

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.3

2200 MM PACKAGING - DROP AT AN ANGLE OF - 10° - 1ST IMPACT ON THE TOP END

CONFIGURATION AFTER IMPACT

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.4

3200 MM PACKAGING - HORIZONTAL DROP

CONFIGURATION AFTER IMPACT

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FIGURE 1-6.5

3200 MM PACKAGING - DROP AT AN ANGLE OF 10° - 1ST IMPACT ON THE BOTTOM END

CONFIGURATION AFTER IMPACT

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.6

1000 MM PACKAGING - HORIZONTAL DROP

ACCELERATION CURVES OF THE STEEL SHELL

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.7

2200 MM PACKAGING - HORIZONTAL DROP

ACCELERATION CURVES OF THE STEEL SHELL

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.8

3200 MM PACKAGING - DROP AT AN ANGLE OF 10° - 1ST IMPACT ON THE BOTTOM END

ACCELERATION CURVES OF THE STEEL SHELL

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FIGURE 1-6.9

3200 MM PACKAGING - HORIZONTAL DROP

VON MISES STRESSES IN THE STEEL SHELL

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FIGURE 1-6.10

3200 MM PACKAGING - HORIZONTAL DROP

RESIDUAL ISO-DEFORMATION IN THE STEEL SHELL

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FIGURE 1-6.11

3200 MM PACKAGING - HORIZONTAL DROP

RESIDUAL ISO-DEFORMATION IN THE STEEL SHELL
SHELL AT THE ENDS

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1-6.12

3200 MM PACKAGING - HORIZONTAL DROP - INNER SHELL

RESIDUAL ISO-DEFORMATIONS IN THE STEEL SHELL
AT THE CENTRE

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FIGURE 1-6.13

LOCATION OF THE NODES FOR EVALUATING
THE CRUSHING OF THE WOOD ON THE 3200 MM MODEL

CRUSHING OF THE WOOD COVERS

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FIGURE 1-6.14

DIFFERENCE IN DISPLACEMENT OF NODES 108/208

CRUSHING OF THE WOOD COVERS

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FIGURE 1-6.15

DIFFERENCE IN DISPLACEMENT OF NODES 91/99

CRUSHING OF THE WOOD COVERS

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FIGURE 1-6.16

DIFFERENCE IN DISPLACEMENT OF NODES 6001/6009

CRUSHING OF THE WOOD COVERS

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FIGURE 1-6.17

ISO-DISPLACEMENT OF THE BASE COVER WITHOUT CONTAINMENT SHEETS OF THE 3200 MM PACKAGING FOR A HORIZONTAL DROP

CRUSHING OF THE WOOD COVERS

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MODAL ANALYSIS OF TN 106 PACKAGING

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-7E			
0	02/00	First issue	F. PETIT / T. MASSIA
Ref. : DOS-08-00126114-107			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT

SUMMARY

Purpose:

The purpose of this study is to evaluate the eigen modes and frequencies associated with TN 106 package in the unsupported configuration (free/free) for the following versions of the package.

Packaging version 3,200 mm without source,
Packaging version 3,200 mm with source,
Packaging version 2,200 mm with source,
Packaging version 1,000 mm without source,
Packaging version 1,000 mm with source,
Model of packaging TN106 version 3,200 mm (½ scale) without source,
Model of packaging TN106 version 3,200 mm (½ scale) with source.

A packaging with source is a loaded packaging.

Basic Data:

The dimensions and masses of the packaging components are taken from Chapter 0 and Appendix 0-1.

Assumptions and Methods Used:

The domain of validity of this study is limited to elastic phenomena and small displacements.

We are concerned here only with phenomena linked to flexion of the packaging following a package drop axis.

Only a ½ structure following the axis of the package is modelled.

The covers are taken as part of the mass.

Results and Conclusions:

Whatever the effective length of the packaging cavity, whether it is loaded or not, the first eigen vertical bending frequencies are less than [redacted] Hz.

Subsequent Use of the Results Obtained:

The results are used in Appendices 1-5, 1-6 and 1-11 to justify filtering frequency.

1. PURPOSE

The purpose of this appendix is to evaluate the eigen modes and frequencies associated with TN 106 package in the unsupported configuration (free/free) and the following versions of the package:

Packaging version 3,200 mm without source,
Packaging version 3,200 mm with source,
Packaging version 2,200 mm with source,
Packaging version 1,000 mm without source,
Packaging version 1,000 mm with source,
Model of packaging TN106 version 3,200 mm (½ scale) without source,
Model of packaging TN106 version 3,200 mm (½ scale) with source.

A packaging with source is a loaded packaging.

2. ASSUMPTIONS

The domain of validity of this study is limited to elastic phenomena and small displacements.

We are concerned here only with phenomena linked to flexion of the packaging following a single axis (corresponding to a package drop axis). For this reason, only a ½ structure following the axis of the package is modelled.

The shock absorbing covers are considered part of the mass.

3. MODELING

The study is carried out in accordance with the finite elements method using I-DEAS software <1>.

3.1 Mesh

The geometry of the model is taken from the design drawing found in Chapter 0-1.

The elements used shown in Figure 1-7.1 are of 2 types:

- Solid elements representing the package,
- Shells representing the shock absorbing cover (masses).

3.2 Materials

The mechanical properties of the material used are as follows:

Material	E (MPa)	ν	ρ (kg/m^3) (*)
Steel	[redacted]	[redacted]	[redacted]
Resin	[redacted]	[redacted]	[redacted]
Lead	[redacted]	[redacted]	[redacted]
Shock absorbing covers	-	-	185450
Source	200000	0.3	7850

(*): The density of the materials was adjusted to produce a coherent distribution of mass.

3.3 Limit Conditions

The limit conditions are broken down into support conditions on the symmetrical drawing shown in Figure 1-7.2.

4. RESULTS

The following results are taken from archived file <2>. The different types of modes are shown in Figure 1-7.3.

The modes set out in the following table are the eigen modes for the structure in "free/free" conditions.

Version of Package	Frequency (in Hz)	No. Mode	Frequency (in Hz)	No. Mode	Frequency (in Hz)	No. Mode	Frequency (in Hz)	No. Mode
(½ scale) Model without source								7
(½ scale) Model with source	179							7
Version 3200 mm without source	106							7
Version 3200 mm with source	105				Proprietary Information Withheld Pursuant to 10 CFR 2.390			7
Version 2200 mm with source	172							7
Version 1000 mm without source	387							7
Version 1000 mm with source	389							7

Modes 1, 2 and 3 are the so-called "rigid" modes (frequency = 0 for a mass equal to 100%).

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5. CONCLUSION

The 1st frequencies relating to the 1st mode of the structure are for each version of the packaging:

<table>
<tr><td>(½ scale) model without source</td><td rowspan="7">Proprietary Information Withheld Pursuant to 10 CFR 2.390</td></tr>
<tr><td>(½ scale) model with source</td></tr>
<tr><td>Version 3200 mm without source</td></tr>
<tr><td>Version 3200 mm with source</td></tr>
<tr><td>Version 2200 mm with source</td></tr>
<tr><td>Version 1000 mm without source</td></tr>
<tr><td>Version 1000 mm with source</td></tr>
</table>

Whatever the effective length of the packaging cavity, and whether it is loaded or not, the first eigen vertical bending frequencies are below 400 Hz.

6. REFERENCES

<1> Calculation software using the finite elements method: I-DEAS Master Series V4.0 developed by SDRC.

<2> Archiving Cartridge 3648-32 - File:

Modal*.lis, plot106*.pfb and tn106v*.arc

LIST OF FIGURES

FIGURE 1-7.1

MESH

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Capot : Shock absorbing covers
Plomb : Lead
Résine : Resin
Acier : Steel

FIGURE 1-7.2

LIMIT CONDITIONS

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FIGURE 1-7.3

TYPES OF EIGEN MODES

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DRAWINGS OF ½ SCALE MODEL

Proprietary information withheld pursuant to 10 CFR 2.390

REVISION STATES

<table>
<tr><th>Revision</th><th>Date</th><th>Modifications</th><th>Prepared by / Verified by</th></tr>
<tr><td colspan="4">Ref. : 5573-Z-1-9E</td></tr>
<tr><td>0</td><td>17/08/00</td><td>5573-05 ind. C : “as built” update.
Removal of the base lid shoulder.
Correction of the depth of the recessing of all closure plates and lids.
Modification of the lengths of the tappings of the holes for the shock absorbing cover fixing screws. Indication of the dimensions of the different screws used.

5573-19 ind. B : Augmentation of the thickness of the shell of the test loads following request by the Competent Authority.</td><td>L. MARIETTE / HANSEL</td></tr>
<tr><td colspan="4">Ref. : DOS-08-00126114-109</td></tr>
<tr><td>00</td><td>08/08</td><td>New document reference
New formalism</td><td>S. CHEVET / JC. BOTT</td></tr>
</table>

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

Ind		Préparation	Vérification	Projet	Approbation	Observations
C	Nom Date Visa	E. CHAUMET [illegible]	L. [illegible] [illegible]	L. HANSEL 16.08.00	L. HANSEL 16.08.00	MODIFICATIONS SUIVANT DMAN 5573-[illegible] Rev. 0
B	Nom Date Visa	E. CHAUMET [illegible]	P. [illegible] [illegible]	L. HANSEL [illegible]	P. DE BASTIAT [illegible]	MODIFICATIONS SUIVANT DMAN 5573-[illegible] Rev. 0

TRANSNUCLEAIRE

N° Plan TRANSNUCLEAIRE: 5573-05

SEQ: 6

PLAN DE MAQUETTE
EMBALLAGE TN 106
ECHELLE 1/2

FORMAT: A0

Echelle: 1/5

PROPRIETARY AND SECURITY RELATED INFORMATION WITHHELD UNDER 10 CFR 2.390

Ind.		Preparation	Verification	Projet	Approbation	Observations
B	Nom	F. TOMIC	P. NAIGEON	L. HANSEL	S. KANZ	MODIFICATIONS ALONG DMAM 5573-H-2 REV. 0
	Date	02/11/99	02-11-99	02.11.99	02/11/99	
	Visa					
A	Nom	F. TOMIC	P. NAIGEON	L. MICHELS	P. DE BASTIANI	-
	Date	03/05/99	17/05/99	17/05/99	18/05/99	-
	Visa	-	-	-	-	-

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N° Plan TRANSNUCLEAIRE 5573-19 SEQ 6

LEST
MAQUETTE TN 106
ECHELLE 1/2

FORMAT: A3

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SIMILARITIES BETWEEN TN 106 PACKAGING AND THE ½ SCALE MODEL

TABLE OF CONTENT

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Ref. : 5573-Z-1-10E			
0	12/00	First issue	L. MARIETTE / L. HANSEL
Ref. : DOS-08-00126114-110			
00	08/08	New document reference New formalism Justification of the stress representativeness in scale model screws. Taken the uncertainty into account on the friction coefficient and the tightening torques. Impact of the differential expansion on the screwed bonding. Correction of the clerical errors. Taken of the "VYAL B" resin into account.	S. CHEVET / JC. BOTT
1	02/13	Translation of the document DOS-06-00032898-110 Rev. 1. Range update of the cavity's useful length [2200 mm -2400 mm] and the packaging's tightening torque. Deletion of the "VYAL B" resin.	R. BAHOU / D. HONDAGNEU

SUMMARY

Purpose:

The purpose of this appendix is to present the model of TN 106 packaging upon which the drop tests are to be performed and to justify its representativeness.

Essential Parameters and their Sources:

The model is ½ scale and represents a TN 106 packaging of an effective length o 3200 mm at a full scale. This length corresponded to the initial maximum model's useful length of the packaging TN 106. The current maximum model's length of the packaging TN 106 was reduced and is from now on 2400 mm (see chapter 0). The model and its loads are described in the drawings shown in Appendix 9 of Chapter 1.

Results and Conclusions:

The model fitted with its loads is representative of TN 106 packaging of effective length 3200 mm and loaded with the maximum allowable contents.

1. PURPOSE

The purpose of this document is to present the model of TN 106 packaging upon which the drop tests are to be performed and to justify its representativeness. These drop tests are set out in Appendix 11 of Chapter 1.

2. DESCRIPTION OF THE MODEL

The model is ½ scale and represents a TN 106 packaging of an effective length of 3200 mm at full scale. The model covers the existing packaging. The model and its loads are described in the drawings shown in Appendix 9 of Chapter 1.

2.1 Main characteristics of the Drop Test Model

- Manufacture of the drop model with the dimensions and tolerances to the scale of those of the packaging design. The masses of the full and half scale packaging elements are given in Table 1-10.1,
- Specifications for procurement materials are identical to those of the full scale packaging for the lead, resin, steel, screws and wood,
- Identical welding and using of identical materials,
- The installation of the double seal systems and the respective leaktightness check orifices is identical to the installation of the full scale packaging (allowing for scale),
- The containment system welds are covered with a strip of glass wool (on the lead side) in order to improve helium circulation used for checking leaktightness. The glass wool is held by stainless steel staples. A hole is drilled through the outer containment, the layers of insulation and the lead to inject helium directly onto the glass wool,
- The diameter of the screws is divided by 2 and rounded off to the lower standard diameter.
- The table 1-10.3 presents the characteristics of the model's screws and of the packaging.
- The tightening torques applied are shown in the table 1-10.4

The forces between the model and the full scale version are proportional to the square of the scale ratio:

$F_{model} = \eta^2 F_{full\ scale}$ (where here $\eta = ½$)

2.2 Difference between the Drop Test Model and the Full Scale Version

All the differences between the half scale model and the packaging design are set out and justified in Table 1-10.2.

The content is simulated by cylindrical segments comprising a metal envelope and an internal lead cylinder. This test load, whose linear mass is 63.6 kg/m, is described in the drawing shown in Appendix 9 of Chapter 1. The influence of the load on the position of the centre of gravity is negligible. Indeed, the distance between the top and the centre of gravity on the full scale version varies from 2310 mm (packaging fully loaded) to 2305 mm (no-load packaging).

3. NOMENCLATURE

Note: X2CrNi18-9 or X2CrNi19-11 must be read in place of X2CrNi18-9.

Ref.	Description	Quantity	Material
100	**Body**	**1**	
101	Inner Shell	1	X2CrNi19-11
102	Glass Wool	/	Glass Wool
103	Gamma Shielding	1	Lead
104	Neutron shielding	1	Resin F or VYAL B
105	Outer shell	1	X2CrNi18-9
106	Trunnion	4	X2CrNi18-9
107	Lug	4	X2CrNi18-9
108	Support Bracket	4	

Ref.	Description	Quantity	Material
200	**Front Part**	**1**	
201	Front Flange	1	X2CrNi19-11
202	Revolving Plug Control Axis	1	X2CrNi18-9
203	Revolving Plug Stop	1	X2CrNi18-9
204	Revolving Plug Closure Plate	1	X2CrNi18-9
205	M4 Screws + Washers	8	10.9
206	Protective Plug	1	X2CrNi18-9
207	Front Lid	1	X2CrNi18-9
208	M8 Screws + Washers	24	8.8
209	Front Closure Plate	1	X2CrNiMoN22-5-3
210	M8 Screws + Washers	12	8.8
211	Orifice A Closure Plate	1	X2CrNi18-9
212	M4 Screws + Washers	8	10.9
214	Top Sleeve of Axis	1	X2CrNi18-9
215	Bottom Sleeve of Axis	1	X2CrNi18-9
216	Top Clamp	1	X2CrNi18-9
217	M20 Screws + Washer	4	10.9
218	Bottom Clamp	1	X2CrNi18-9

Ref.	Description	Quantity	Material
300	**Back Part**	**1**	
301	Back Flange	1	X2CrNi19-11
307	Back closure plate	1	X2CrNi18-9
308	M8 Screws + Washer	12	8.8

Ref.	Description	Quantity	Material
400	**Revolving Plug**	**1**	
401	Outer Shell	1	X2CrNi18-9
402	Internal Tube	1	X2CrNi18-9
403	Top Plate	1	X2CrNi18-9
404	Bottom Plate	1	X2CrNi18-9
405	Gamma Shielding	1	Lead
406	Top Axis	1	X2CrNiMoN22-5-3
407	Bottom Axis	1	X2CrNiMoN22-5-3
411	Blank	2	X2CrNi18-9

Ref.	Description	Quantity	Material
500	**Shock absorbing cover**	**4**	
501	Outer Shell	1	X2CrNi18-9
502	Bottom Plate	1	X2CrNi18-9
503	Bottom Inner Shell	1	X2CrNi18-9
504	Bottom Gusset Plate	6	X2CrNi18-9
505	Bottom Sector of the Shock Absorber	6	Radially Fibred Balsa Wood
506	Intermediate Plate (6 mm thick)	1	X2CrNi18-9
507	Intermediate Plate (2 mm thick)	1	X2CrNi18-9
508	Wooden Plate	1	Ply Wood
509	Puncture Protection Plate	1	X2CrNiMoN22-5-3
510	Top Gusset Plate	6	X2CrNi18-9
511	Top Sector of the Shock Absorber	6	Axially Fibred Balsa Wood
512	Screw Insertion Tube	6	X2CrNi18-9
513	Top Sheet	1	X2CrNi18-9
514	Top Inner Shell	1	X2CrNi18-9
516	Handling Lug	2	X2CrNi18-9
517	Handling Lug Plate	2	X2CrNi18-9
518	Support Bracket	2	X2CrNi18-9
519/520	M10 Screws + Captive Washers	6	10.9

Ref.	Description	Quantity	Material
600	Internal test load	8 segments	Stainless Steel/Lead

Test plug	Description
A	Orifice A Closure Plate Test Plug (M10)
C	Front Lid Test Plug (M10)
D	Front Closure Plate Test Plug (M10)
E	Back closure plate Test Plug (M10)
F	Cavity Test Plug (M20)
G	Revolving Plug Closure Plate Test Plug (M10)
H	Helium Injection Orifice for Inspection of the Welds (M20)

Seals	Location	Qty/type	Material
J1/J2	Orifice A Closure Plate	3	EPDM
J3/J4	Back closure plate	3	EPDM
J5/J6	Revolving Plug Closure Plate	3	EPDM
J7/J8	Front Closure Plate	3	EPDM
J9/J10	Front Lid	3	EPDM
J11	Orifice Seal M10	3	EPDM
J13	Orifice Seal M20	3	EPDM

4. CONCLUSIONS

The model fitted with its test loads is representative of TN 106 packaging of effective length 3200 mm and loaded with the maximum allowable contents.

LIST OF TABLES

TABLE 1-10.1

MASSES OF TN 106 PACKAGING AND THE MODEL

	Mass of the Full Scale TN 106 (kg)	Mass of the ½ scale TN 106 Model (kg)	TN 106 Masses ½ Scale Model Restored to Full Scale (kg)
Front Lid	208	24	192
Front Closure Plate	32	4.2	33.6
Orifice A Closure Plate	2.5	0.3	2.4
Revolving Plug Closure Plate	3	0.4	3.2
Revolving Plug	168	20.6	164.8
1 Shock-Absorbing Cover	695	72	576
Contents	812(1)	108.8	870.4
Total Mass:	- Lu=3200 mm : **15 020** (1) - Lu=2400 mm : **12 300** (1)	**1,785**	**14,280**

(1) Result stemming of the presented formula into the paragraph 3 of the chapter 0 for a packaging with 3200 mm of effective length.

The useful length being limited to 2400 mm (cf. chapter 0), the model scale ½ is penalizing.

TABLE 1-10.2
Page 1/4

DIFFERENCES BETWEEN TN 106 PACKAGING AND THE DROP TEST MODEL

	TN 106Packaging	Drop test model	Remarks
Back Flange	Machined to receive the pushing device. The diameter of the support surface of the back closure plate is 150 mm.	Machined to the same diameter as the cavity to facilitate access, no pushing device. The diameter of the support surface of the back closure plate becomes 203 mm (full scale). and its thickness goes from 30 to 50 mm	The test load fills the cavity up to the support surface of the back closure plate, the pushing device will be simulated by the contents. No influence as not dropped on the base.
Lead Height Measuring System	Non-existent	8 mm diameter hole with plug, to the right of the lead shell through to the back flange.	No modification of the mechanical strength of the model.
Orifice A	Quick-connect coupling at the end of the duct.	Coupling not modelled	No modification of the mechanical strength of the model.
Orifice B	Closure plate installed in the body at a minimum depth of 40 mm. 2 drainage ducts, one emerging at closure plate B, the other at the back closure plate.	Orifice closure plate and drainage ducts not modelled.	The installation of the closure plate is studied to be rendered inaccessible when dropped onto a puncture bar. The ducts are machined in steel and do not risk loss of leaktightness when dropped.
Thermal Fuses and "Poral" Pellets	Thermal fuses and "Poral" pellets are fitted on the outer shell and on the metal sheets of the cover.	Not modelled	No modification of the mechanical strength of the model.
Valves	One valve per cover	Not modelled	No modification of the mechanical strength of the model.

TABLE 1-10.2
Page 2/4

DIFFERENCES BETWEEN TN 106 PACKAGING AND THE DROP TEST MODEL

	TN 106 Packaging	Drop test model	Remarks
Revolving Plug Control System	Control of the revolving plug axis by means of an intermediate shaft with an anti-dirt seal. This shaft is blocked by means of a polarising device. 2 friction rings are fitted to the top and bottom of the revolving plug axis.	No anti-dirt seal. Rings not modelled.	No impact on the mechanical strength of the model.
Rabbets	Water channels are fitted to the front and back flanges	Rabbets not modelled.	No modification of the mechanical strength of the model.
Front Drainage Tube	Connects the bottom of the revolving plug to orifice A when the packaging is in the horizontal position.	Not modelled	No modification of the mechanical strength of the model, performance of the leaktightness test of the Orifice A closure plate is always possible.
Test Orifices	1 M20 test plug for each inter seal space and 1 on the body, for inspection of the welds of the inner shell.	The test plug on the body is out of line on the packaging shell. Addition of one orifice at the centre of the back closure plate for creating a vacuum and detecting helium in the cavity during leaktightness checks.	No modification of the mechanical strength of the model.
Centring pins	One pin on the back closure plate, the revolving plug closure plate, the back closure plate and on the covers.	No centring pin	No impact on the mechanical strength of the model.

TABLE 1-10.2
Page 3/4

DIFFERENCES BETWEEN TN 106 PACKAGING AND THE DROP TEST MODEL

	TN 106 Packaging	Drop test model	Remarks
Seal Support Surfaces	Support surface designed with overthickness to allow the seal seats to be re-machined.	Seal seats of the model of the dimension which will allow two remachinings (i.e. 0.5 mm ½ scale).	Model representative of the packaging with seal seats remachined
Bottom Plates of the Covers	Drilled with 6 holes of Ø = 26 mm For the insertion of fixing screws	The holes have diameter Ø = 25 mm (full scale).	Provides smaller gap on the model between the screws and the bottom flange than that of the full scale version
Revolving Plug	1 stop limits the rotation of the revolving plug to 90°.	Pin and rabbet on the front flange not modelled.	No impact on the strength or behaviour of the packaging.
Trunnions		Simplified trunnion	Overall dimensions maintained to validate the possible impact for the case of the lateral drop.
Lifting lugs	2 lifting lugs on the 0° centreline.	2 lifting lugs added to the impact centreline	This makes it possible to check the impact of the lugs in the case of the lateral drop.
Holes and Recesses in the Covers	None	Hole drilled in the back cover for the detection of helium and recesses or drilled holes on front and back of the covers for the installation of accelerometers.	No impact on behaviour when dropped.
Tube for inserting the screws in the front and back covers	6 tubes of $Ø_e$ = 76.1 mm and 2 mm thickness.	6 tubes of $Ø_e$ = 76 mm and 3 mm thickness (full scale).	The 47% increase of the radial steel surface of the tubes produces an increase in the total acceleration when dropped axially which is a conservative approach.

TABLE 1-10.2
Page 4/4

DIFFERENCES BETWEEN TN 106 PACKAGING AND THE DROP TEST MODEL

	TN 106 Packaging	Drop test model	Remarks
Cover Lifting Lugs	Hinged	Welded	No impact on behaviour when dropped
Caps on the Quills of the Cover Tubes	Caps are provided for these quills to prevent water retention.	These caps are not represented.	No impact on behaviour when dropped.
Fixing screws	42 mm diameter for the fixing screws of the clamps holding the revolving plug axis.	Screws of diameter 20 mm in stead of 21 mm	20 mm is a standard diameter. This reduction in diameter is conservative.
	All the tappings can be fitted with threaded inserts	No insert tapped	This absence of tapped inserts ensures a conservative approach as the diameter of the tapping is therefore smaller and the stress exerted on the screw thread greater.
	Engaged length	Shorter engaged lengths (Table 1-10.3) except for the back closure plate	In the design of the model, stress is exerted on the back closure plate by the loads. On the packaging, the base closure plate bears only its own weight. The strength of the screws is covered by that of the front closure plate.

TABLE 1-10.3

CHARACTERISTICS OF THE FULL SCALE SCREWS AND THOSE OF THE MODEL

Element	Engaged Length (mm)	
	Full Scale Packaging Model	1/2 Scale Model [(1)]
Shock absorbing covers	35	31
Front Lid	39	29
Front Closure Plate	23	20
Back Closure Plate	23	27
Clamp	82	72
Revolving Plug Closure Plate	21	17
Drainage Closure Plate (Orifice B)	16	-
Vent Closure Plate (Orifice A)	16	13

[(1)] The dimensions of the model are restored to full scale to simplify the comparison with the packaging.

TABLE 1-10.4

TIGHTENING TORQUE OF MODEL'S SCREWS

Reference	Element	Full Scale nominal diameter	Scale Model nominal diameter	Tightening torque of the full scale version screws (voir chapitre 0) (N.m)	Tightening torque of the scale model screws (N.m)
208	Front Lid	M16	M8	105	17.5
210	Front Closure Plate	M16	M8	140	17.5
308	Back Closure Palte	M16	M8	110	17.5
217	Clamp	M42	M20	2100	298
205	Revolving Plug Closure Plate	M8	M4	15	2.5
212	Vent Closure Plate (orifice A)	M8	M4	15	2.5
519	Shock absorbing covers	M20	M10	380	47.5

REPORT AND ANALYSIS OF REGULATORY DROP TESTS

TABLE OF CONTENT

REVISION STATES

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1-11E			
0	27/03/00	First issue	T. MASSIA / F. PETIT
Ref. : DOS-08-00126114-111			
00	08/08	New document reference New formalism	S. CHEVET / JC. BOTT
1	02/13	Translation of the document DOS-06-00032898-111-Rev. 0. Insertion of the covers destruction measures. Update of the applicable regulations.	R. BAHOU / D. HONDAGNEU

SUMMARY

Purpose:

The purpose of this appendix is to present the results of the regulatory drop tests.

A round of tests was performed on a model of TN 106 packaging. The representativeness of the model in relation to TN 106 packaging is described in Appendix 1-10.

The main results of the drops are set out after the description of the model.

Results:

During the regulatory drop sequences, the leaktightness criterion of $6.65 \cdot 10^{-5}$ Pa.m.^{3}.s^{-1} (SLR) checked prior to the drop tests is also complied with after the drop tests.

This series of tests does not alter the radiological protection of the packaging.

The maximum acceleration obtained for the packaging is [160] g.

The maximum radial accelerations obtained for the packaging are:

- [redacted] g on the back flange,
- [redacted] g on the front flange,
- [redacted] g on the shell.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

1. PURPOSE

The purpose of this Appendix is to present the results of regulatory drop tests <1>.

A round of tests was performed on a 1/2 scale model of TN 106 packaging. The representativeness of the model in relation to TN 106 packaging is described in Appendix 1-10.

2. PURPOSE OF TESTS

The purpose of these tests is to show that the loaded packaging withstands regulatory tests in such a way that it is then possible to show that the model meets regulatory requirements <1> relating to Type B(U) packagings and in particular to:

- The structural strength of the containment system,
- Preservation of leaktightness criteria,
- Maintenance of sufficient radiological protection,
- Preservation of the geometry of the cavity and the packaging used in the nuclear safety studies.

The tests were performed in accordance with regulatory provision <1>.

3. MODEL

The drop test model comprises a body, a lid and the shock-absorbing covers of the packaging.

There are two types of cover (1 and 2). The geometry of shock-absorbing covers type 1 and 2 is identical. Only arrangements for instrumentation are made according to the drop configurations.

The back cover used in all tests is type 1. The type 1 front cover is only used for axial drop No. 5; front cover type 2 is used for the other drops.

The real maximum accelerations of the packaging are given by the following formula:

$$\gamma_{emb} = \gamma_{maq} \cdot n = \frac{\gamma_{maq}}{2}$$

Where:

γ_{maq}: acceleration of the model

γ_{emb}: acceleration of the packaging

n: Scale factor = ½

4. TESTS

A detailed account of the tests can be found in the drop test report for the ½-scale TN 106 packaging model 5573-C-19 Rev. 0 of 31/01/00 appended to this document.

Five drop tests were performed in three regulatory sequences.

The accelerations of the model were filtered at [1000] Hz to limit interference phenomena which could make the reading of maximum acceleration difficult. The justification of this filtering is given in Chapter 1-7.

4.1 Sequence 3:

This sequence comprises the axial drop from a height of 9 m onto the top of the model (Drop No. 5)

Results for the Model:

The overall leaktightness of the model remains below $6.65 \cdot 10^{-5}$ Pa.m^{-3}.s^{-1} (SLR).

The accelerations as well as the impact times are set out in Table 1-11.1.

The maximum acceleration obtained for the model is:

γ_{maq} = [redacted] g.

Results for the Packaging:

The overall leaktightness of the packaging remains below $6.65 \cdot 10^{-5}$ Pa.m^{-3}.s^{-1} (SLR).

The maximum acceleration obtained on the packaging is:

γ_{emb} = [redacted] g.

4.2 Sequence 1:

It comprises Drop No.1 followed by Drop No. 2.

Drop No. 1: Oblique drop from a height of 1 m onto a puncture bar with impact on the shell. The axis of the model is at an angle of 29.5° in relation to the horizontal. The centre of gravity is aligned with the axis of the puncture bar (see Figure 2 of the report).

Drop No. 2: Oblique drop from a height of 9 m with the first impact on the base of the model. The axis of the model is angled at 10° from the horizontal. The model drops on the 90° centreline (see Figure 3 of the report).

Results for the model:

No deterioration of the outer shell of the body of the model is observed. Radiological protection is not affected by this sequence.

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The overall leaktightness of the model remains less than $6.65 \cdot 10^{-5}$ $Pa.m^{-3}.s^{-1}$ (SLR).

The accelerations as well as the impact times are set out in Table 1-11.1.

The maximum accelerations obtained on the model (γ_{maq}) during the second drop are:

- [redacted] g on the back flange,
- [redacted] g on the front flange,
- [redacted] g on the shell.

The handling lug on the 90° centreline of the base is crushed. The height between the outer shell and the crushed surface is [40] mm. This deformation does not cause the failure of the outer shell so the neutron protection of the packaging is not affected.

The crushing measured after the oblique drop n°2 is presented on the figure 1-11.1. The heights crushed by balsa wood are presented in the following table:

Measure	Crushed height (mm)
1	[redacted]
2	[redacted]
3	[redacted]
4	[redacted]

<u>Results for the Packaging:</u>

The containment is not damaged.

The overall leaktightness of the packaging remains below $6.65 \cdot 10^{-5}$ $Pa.m^{-3}.s^{-1}$ (SLR).

The maximum accelerations obtained for the packaging (γ_{emb}) during the second drop are:

- [78] g on the back flange,
- [111] g on the front flange,
- [97] g on the shell.

Neither the trunnions nor the feet of the packaging are impacted.

4.3 Sequence 2:

It consists of the Drop No. 3 followed by Drop No. 4.

Drop No. 3: Axial drop from a height of 1 m onto a puncture bar with impact on the shock-absorbing cover. The model is positioned upside down.

Drop No. 4: Oblique drop from a height of 9 m with the first impact on the shock-absorbing cover. The model is at an angle of 18° from the vertical (see Figure 5 of the report <2>).

Results for the Model:

The top cover is punctured and the puncture protection plate is deformed (dent of 27.6 mm).

The revolving plug operates normally.

The inner cavity is not deformed. In fact, cavity diameters measured fall within the tolerance range (101.5 ±0.5).

The overall leaktightness of the model remains below $6.65 \cdot 10^{-5}$ $Pa.m^{-3}.s^{-1}$ (SLR).

The crushing measured after the oblique drop n°4 is presented on the figure 1-11.2 and in the following table:

Measure	Crushed height (mm)
1	[redacted]
2	[redacted]

Results on the Packaging:

The overall leaktightness of the packaging remains below $6.65 \cdot 10^{-5}$ $Pa.m^{-3}.s^{-1}$ (SLR).

The inner cavity is not deformed.

5. REFERENCES

<1> Regulations applicable IAEA: see chapter 00.

<2> Report of drop tests on the model of packaging scale ½ 5573-C-19 Rev 0

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

LIST OF TABLES

LIST OF FIGURES

TABLE 1-11.1

IMPACT TIME AND ACCELERATION OBTAINED DURING DROP TESTS ON THE MODEL

Drop No. 5		
Transducer*	Time (ms)	Acceleration (g)
X1	30	[redacted]
X2	14	[redacted]

Drop No. 2				
	1st Impact		2nd Impact	
Transducer*	Time (ms)	Acceleration (g)	Time (ms)	Acceleration (g)
Y1	14	Proprietary Information Withheld Pursuant to 10 CFR 2.390		
Y2	14			
Y3	-			
Y4	-			

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* The position of the transducers is given in Appendix 1-10.

FIGURE 1-11.1

CRUSH MEASURES AFTER THE OBLIQUE DROP N°2

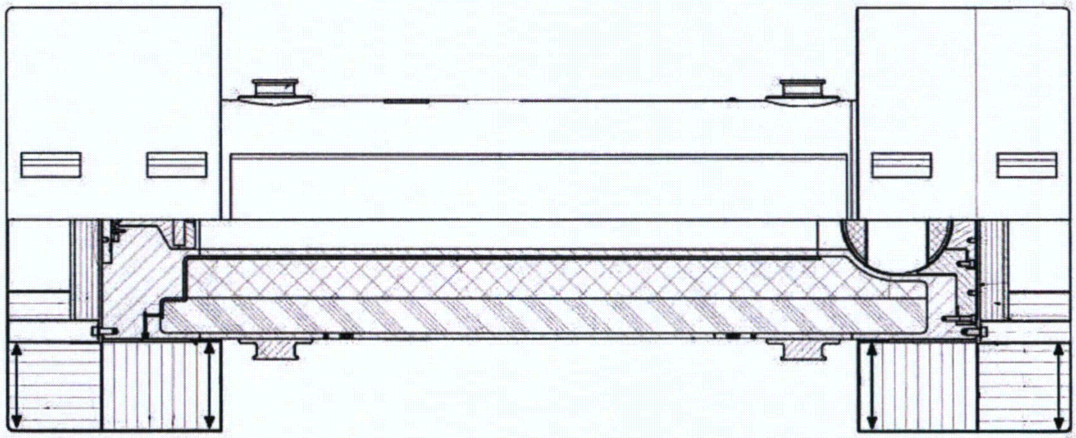
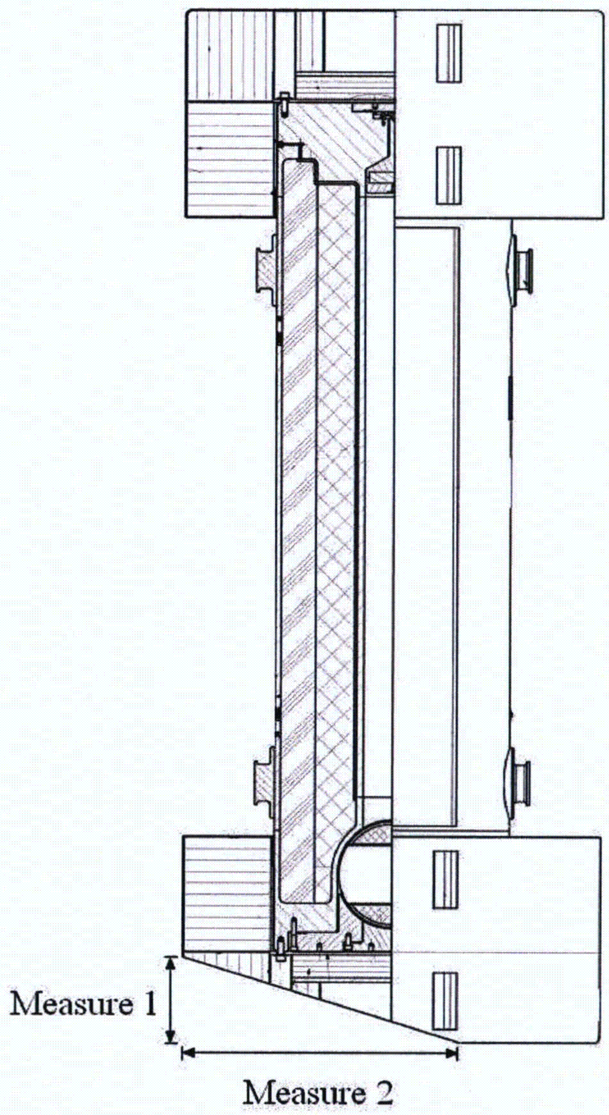


FIGURE 1-11.2

CRUSH MEASURES AFTER THE OBLIQUE DROP N°4



ANALYSIS OF THE BEHAVIOUR OF THE SHOCK-ABSORBING COVERS AND THE STRENGTH OF THE TN 106 PACKAGING IN RELATION TO TEMPERATURE

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RECALIBRATION OF THE TN 106 PACKAGE MODEL

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MECHANICAL STRENGTH OF THE TN 106 PACKAGE MODEL UNDER DROPS OF 9.6 M AT TMAX NCT

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TOP PLATE

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JUSTIFICATION OF THE MECHANICAL STRENGTH OF THE SCREWS FOR THE TN 106 PACKAGE UNDER ROUTINE TRANSPORT CONDITIONS

TABLE OF CONTENT

REVISION STATUS

Revision	Date	Modifications	Prepared by / Checked by
0	02/13	Document first drawn up	R. BAHOU / D. HONDAGNEU

SUMMARY

Objectives:

The objective of this appendix is to check the non-separation of the systems for closing the containment chamber and the correct mechanical strength of the screws for the TN106 package under routine transport conditions.

The screws concerned are as follows:

- screw on the revolving plug closure plate (item 205),
- screw on the front lid (item 207),
- screw on the front closure plate (item 210),
- screw on the orifice A closure plate (item 212),
- screw on the clamp (item 217),
- screw on the back lid (item 308),
- screw on the orifice B closure plate (item 310),
- screws and washers for the cover (item 519/520).

Essential parameters and their origins:

The dimensions, masses and characteristics of the materials are taken from chapter 0.

The temperatures of the various components following normal conditions of transport are encompassed by the temperatures specified in chapter 2.

Hypotheses and methods used:

The calculations for the tightening torque, the stresses in the screws and pressures on the screw heads are performed using the standard <1>.

The screws are not greased and are zinc bichromate plated (or equivalent) (see chapter 0).

The coefficient of friction used is 0.15 with uncertainty of ± 20% <4>.

The stresses considered in this analysis of the screwed assemblies are of two origins:

- the pressure conditions, namely an internal pressure considered in a penalising manner at 11 bars, corresponding to the design internal pressure (see chapter 1-1),
- the accelerations related to routine transport conditions, representing a longitudinal or transversal acceleration of 2 g.

The check on the strength of screws is performed according to the methods of the standard <1> which consists of checking the non-separation of the assembled elements,

while ensuring that the stresses in the screws and the pressures under the heads are acceptable for the materials in question (see chapter 0).

The check on thread shearing is carried out according to <3>.

Results

The non-separation of the front lid , the front closure plate, the base lid, the plug for the conduit seal and the plugs for openings A and B are checked, taking into account accelerations representative of routine transport conditions.

The maximum equivalent stresses undergone by the screws are below the criteria.

There is no risk of shearing the screw threads and the threaded holes.

The stresses due to pressure under their heads for a tightening torque $F_{st\ max}$ are below the criteria.

Conclusion

Given the stresses considered for the calculations on the assembly screws, these are dimensioned to ensure containment and to ensure the mechanical strength of the package under routine transport conditions.

1. OBJECTIVE

The objective of this appendix is to check the non-separation of the systems for closing the containment chamber and the correct mechanical strength of the screws for the package under routine transport conditions. The screws concerned are as follows:

- screw on the revolving plug closure plate (item 205),
- screw on the front lid (item 207),
- screw on the front closure plate (item 210),
- screw on the orifice A closure plate (item 212),
- screw on the clamp (item 217),
- screw on the back lid (item 308),
- screw on the orifice B closure plate (item 310),
- screws and washers for the cover (item 519/520).

The calculations for tightening, stress and pressures under the head are calculated using the standard <1>.

Screw strength verification, carried out according to the method from the standard <1> consists of checking the non-separation of the assembled elements, while making sure that the stresses in the screws, the pressures under the head and the shearing in the threads and threaded holes are acceptable for the materials in question (see chapter 0).

2. NOTATIONS

Symbol	Title	Units
C	Tightening torque	N.m
T_T	Torsional torque undergone by the body of the screw	N.m
d	Nominal diameter of the thread	mm
d_1	$d_1 = d - 1{,}0825 \times p$	mm
d_2	Diameter at the flanks of the thread, $d_2 = d - 0{,}6495 \times p$	mm
d_3	Interior diameter of the exterior thread (diameter at the base of the thread) $d_3 = d - 1{,}2268 \times p$	mm
d_{AS}	Equivalent diameter of the screw in the thread, $d_{As} = d - 0{,}9382 \times p$	mm
d_o	Interior diameter of the supporting surface under the head of the screw	mm
d_h	Exterior diameter of the supporting surface under the head of the screw	mm
F_E	Axial component of the exterior force applied to the assembly	N
$F_{E\ pressure}$	Axial component of the force generated by the package's internal pressure	N
$F_{E\ drop}$	Axial component of the force generated by the drop accelerations	N
F_0	Initial tightness in the screw (pre-load)	N

Symbol	Title	Units
h	Screw thread insertion depth	mm
n	Number of fixing screws for the part in question	
p	Pitch of the thread	mm
A_s	Resistant section of the screw, $A_s = \frac{\pi}{4} d_s^2$ with $d_s = \min\left(\frac{d_2 + d_3}{2}; d_{dec}\right)$	mm²
d_{dec}	Diameter of separation of the shaft of the screw	mm
R_c	Material's resistance to compression, $R_c = \frac{R_e + R_m}{2}$	N/mm²
R_e	Material's elasticity limit	N/mm²
R_m	Material's tensile strength	N/mm²
R_s	Thread strength ratio, $R_s = \frac{R_{m\,pièce}(T)}{R_{m\,vis}(T)} \times \frac{7.d}{6.d_1}$	-
s	Thickness of the wall of the nut	mm
r_m	Average radius of support under head or under nut or under washer, $r_m = \frac{1}{3} \cdot \frac{(d_h^3 - d_0^3)}{(d_h^2 - d_0^2)}$	mm
S_a	Support section under head or under nut or under washer, $S_a = \frac{\pi}{4} \times (d_h^2 - d_0^2)$	mm²
$F_{0\,min}$	Minimum tightness required to maintain the functional characteristics of the assembly in service	N
$F_{0\,max}$	Maximum tightness that may be borne by the assembly in service	N
F_{dil}	Force in the screw due to differential expansion between the assembled parts	N
F_{st}	Total tightening force in the screw, taking into account the thermal expansion effect of the materials	N
ΔC	Uncertainty on the tightening tools	%
μ	Coefficient of friction	-
$\Delta\mu$	Uncertainty on the friction coefficient	%
μ_{min}	Minimum friction coefficient, $\mu_{min} = \mu \times \left(1 - \frac{\Delta\mu}{100}\right)$	
μ_{max}	Maximum friction coefficient, $\mu_{min} = \mu \times \left(1 + \frac{\Delta\mu}{100}\right)$	
σ_C	Compression stress under head of screw	N/mm²
σ_{eq}	Equivalent stress undergone by the screw	N/mm²
σ_t	Tensile stress in the screw	N/mm²
τ_0	Torsional stress in the screw under the effect of tightening	N/mm²
α_{screws}	Average expansion coefficient of the screw	K^{-1}
α_{part}	Average expansion coefficient of the tightened part	K^{-1}
ΔT	Temperature difference	K
T	temperature	K

Symbol	Title	Units
E_{screw}	Modulus of elasticity of the screw at temperature T	Pa
E_{part}	Modulus of elasticity of the part tightened at temperature T	Pa

3. GENERAL ASSUMPTIONS

3.1 Geometry

The geometry used for this analysis is that taken from the plans in appendix 0-1. The dimensions and detailed description of the package are given in chapter 0.

3.2 Loading hypotheses

The stresses considered in this analysis of the screwed assemblies are of two origins: the internal design pressures (see chapter 1-1) and the accelerations related to routine transport conditions. The forces induced by the pressure of the seals are negligible.

3.2.1 Conditions of pressure

In a penalising manner, the calculations are performed considering an internal pressure of 11 bars. This pressure of 11 bars corresponds to the design pressure (see chapter 1-1). Under routine transport conditions, the pressure in the containment chamber is below 11 bars, as demonstrated in chapter 3A.

3.2.2 Accelerations under routine transport conditions

We consider that axial or radial accelerations of 2 g are likely to occur under routine transport conditions.

3.3 Characteristics of the materials

Chapter 2 shows that the maximum temperature obtained under normal transport conditions is less than [redacted]°C in the elements composing the package body.

3.3.1 Steels of Type A and B

Also, by considering the mechanical characteristics at [redacted]°C of the steels Type A and B presented in chapter 0 and the mechanical characteristics at 100% presented in the standard <5>, we can determine, by interpolation, the mechanical characteristics of steels Type A and B at [redacted]°C to be used for the calculation of criteria under stress:

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3.3.2 Steel in the screws

The screws are made of forged steel. The standard <6> indicates that up to typical service temperatures of 150°C, no change that is prejudicial to the mechanical characteristics is observed.

We may therefore consider the mechanical characteristics at 20° presented in chapter 0 for the calculation of criteria under stress at [redacted]°C.

3.4 Tightening tools

The tightening uncertainty is $\Delta C = \pm 10$ %.

3.5 Coefficients of friction

The screws are zinc bichromate plated and are not greased. The friction coefficient is: $\mu = 0.15$ with uncertainty of: $\Delta\mu = \pm 20$ % (<4>).

4. CRITERIA

4.1 Static stress limits applicable to screws

The criterion for the mechanical strength of screws as defined in the standard <1> is the elastic limit R_e at the maximum temperature reached during normal transport conditions, representing:

Material of screws	Elastic limit R_e (MPa)
Steel class 8.8	640
Steel class 10.9	900
Steel class 12.9	1080

4.2 Limit pressure stresses applicable under screw head

To avoid dulling the assembled parts, the maximum compression stresses under the screw heads must not exceed a value that depends on the materials in the parts that are present. This resistance to compression is defined in <4> as the average of the elastic limit at 0.2% (R_e) and the rupture limit of the material in question (R_m) taken at the temperature of normal transport conditions, namely [redacted]°C.

Material under the head	Yield strength R_e (MPa)	Tensile strength R_m (MPa)	Compression limit (MPa)
Austenitic steels type A	150	414	282
Austenitic-ferritic steel type B	368	596	482

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4.3 Limit stresses for shearing threads and threaded holes

The limit stress for calculating threads is defined in paragraph 4.1.

The limit stress for calculating threaded holes is defined in paragraph 4.2.

4.4 Non-separation condition

The non-separation criterion is: $F_{st\,min} > F_{E\,max}$.

Compliance with this criterion ensures that the various plugs and lids do not separate under routine transport conditions.

The results are presented in paragraph 6.1 of this chapter.

5. MECHANICAL ANALYSIS OF THE SCREWS FOR THE COMPONENTS

5.1 Evaluation of the tightening force for a given tightening torque

The pre-stress force for a tightening torque is calculated from the following relationship:

$$F = \frac{C(1 \pm \Delta C)}{0{,}16p + \mu(1 \pm \Delta\mu) \times (0{,}583.d_2 + r_m)}$$

Thus, the maximum pre-stress force is defined by:

$$F_{0\,max} = \frac{C(1 + \Delta C)}{0{,}16p + \mu(1 - \Delta\mu) \times (0{,}583.d_2 + r_m)}$$

Thus, the minimum pre-stress force is defined by:

$$F_{0\,min} = \frac{C(1 - \Delta C)}{0{,}16p + \mu(1 + \Delta\mu) \times (0{,}583.d_2 + r_m)}$$

The torques applied when using the various screws, and the corresponding tightening forces, are presented in table 1-13.3 and in paragraph 6.1.

The variation in the pre-stress due to the differential expansion of components constituting the screwed assembly is defined as follows, taken from <2>:

$$F_{dil} = \frac{(\alpha_{pièce} - \alpha_{vis}).\Delta T \times E_{vis} \times A_s}{1 + \dfrac{A_s \times E_{vis}}{S_a \times E_{pièce}}}$$

Where:

- α_{screw} Average expansion coefficient of the screw at temperature T (K^{-1})

- α_{part} Average expansion coefficient of the tightened part at temperature T (K^{-1})
- ΔT = Tmax CNT – ambient T (K)
- E_{screw} Modulus of elasticity of the screw at temperature T (GPa)
- E_{part} Modulus of elasticity of the tightened part at temperature T (GPa)
- A_s Resistant section of the screw (mm^2)

It should be noted that this force may be positive or negative according to the sign of the factor ($\alpha_{part} - \alpha_{screw}$) and that of the temperature difference ΔT.

The materials for the screwed parts have an expansion coefficient higher than that of the screws (see table 1-13.2) and ΔT being equal to [redacted]°C (= Tmax CNT - 20°C = [93]°C - 20°C), we have $F_{dil\ max} > 0$.

In a penalising manner, we will therefore consider the following as the total tightening force:

$$F_{st\ min} = F_{0\ min}$$

$$F_{st\ max} = F_{0\ max} + F_{dil}$$

The values of the expansion coefficients and the moduluses of elasticity used for calculating the forces due to the expansion of materials are presented in table 1-13.2.

5.2 Evaluation of exterior forces

The exterior forces to be considered are composed of forces due to internal pressure in the confinement chamber and forces due to accelerations undergone by the package model under routine transport conditions:

$$F_E = F_{E\ pression} + F_{E\ acc}$$

These forces are calculated in the table 1-13.4 and the results are presented in paragraph 6.1 for the non-separation analysis.

As the forces induced by the pressure of the seals are negligible compared to the pressure and acceleration forces, they are not considered in the calculation.

5.2.1 Pressure forces

The forces generated by the pressure inside the package are calculated according to the following formula:

$$F_{E\ pression} = \frac{P \times \frac{\pi}{4} \times D_j^2}{n}$$

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Where:

- P = 11 bars: internal design pressure (see chapter 1-1).
- D_j, diameter of the internal seal groove (average diameter of the groove, diameter of opening and tolerances considered) delimiting the surface to which pressure is applied.
- n, the number of screws used to fix the part that is analysed.

5.2.2 Forces due to accelerations under routine transport conditions

The forces generated by accelerations representative of routine transport conditions are calculated by the following formula:

$$F_{E\,acc} = \frac{M \times \gamma}{n}$$

Where:

- M, the mass of the element in question (taken from chapter 0),
- γ, acceleration of 2 g representative of routine transport conditions,
- n, the number of screws used to fix the element.

5.3 Calculation of the stresses in the screws

The results are presented in table 1-13.5 and analysed in paragraph 6.2.

5.3.1 Calculation of the maximum tensile stress in the screw

The maximum tensile stress is:

$$\sigma_t = \frac{F_{st\,max}}{A_S}$$

5.3.2 Calculation of the maximum torsional stress in the screw

The maximum torsional stress is:

$$\tau_0 = \frac{16\, C_{T\,max}}{\pi\, d_{As}^3}$$

Where:

$$C_{T\,max} = F_{st\,max}\,(0{,}16\ p + 0{,}583\,\mu_{min}\ d_2)$$

5.3.3 Calculation of the maximum equivalent stress in the screws during tightening

The maximum equivalent stress is expressed by the following relationship:

$$\sigma_{eq\,max} = \sqrt{\sigma_t^2 + 3\tau_{0\,max}^2}$$

5.4 Calculation of the shearing stress in the threads and threaded holes

The results are presented in table 1-13.5 and analysed in paragraph 6.3.

5.4.1 Shearing stress in the threads

By using the Alexander method <3>, the shearing stress on ISO threads is expressed as:

$$\tau_f = \frac{\mathrm{Max}\{F_E\,;F_{st\,max}\}}{\frac{h}{p}\times\pi\times d_1\times\left(\frac{p}{2}+(d_2-d_1)\frac{1}{\sqrt{3}}\right)\times C_1\times C_2}$$

Where:

$$Rs = \frac{Rm_{pièce}(T)}{Rm_{vis}(T)}\times\frac{7.d}{6.d_1}$$

R_s: thread strength ratio
$R_{m\,screw}(T)$: rupture limit for the material of the screw at temperature T
$R_{m\,part}(T)$: rupture limit for the material of the threaded hole at the temperature T

– C_1: expansion factor for the nut
For $1.4 \leq s/d_o < 1.9$ with s the thickness of the wall
$C_1 = -(s / d_o)^2 + 3.8\,(s / d_o) - 2.61$
otherwise: $C_1=1$

– C_2: flexion factor of the screw's threads
For $1 < R_s < 2.2$: $C_2 = 5.594 - 13.682 \times R_s + 14.107 \times R_s^2 - 6.057 \times R_s^3 + 0.9353 \times R_s^4$
For $R_s \leq 1$: $C_2 = 0.897$

The Von Mises equivalent stress is: $\sigma_{eq} = \sqrt{3}\times\tau$

5.4.2 Stress in the threaded holes

Using the Alexander method <3>, the shearing stress for ISO threaded holes:

$$\tau_t = \frac{\mathrm{Max}\{F_E\,;F_{st\,max}\}}{\frac{h}{p}\times\pi\times d\times\left(\frac{p}{2}+(d-d_2)\frac{1}{\sqrt{3}}\right)\times C_1\times C_3}$$

Where:

– C_3: flexion factor for the threads in the threaded holes (or the nut)
For $0.4 < R_s < 1$: $C_3 = 0.728 + 1.769 \times R_s - 2.896 \times R_s^2 + 1.296 \times R_s^3$
For $Rs \geq 1$: $C_3 = 0.897$

The Von Mises equivalent stress is: $\sigma_{eq} = \sqrt{3} \times \tau$.

5.5 Calculation of the pressure stresses under the screw head for $F_{st\ max}$

The stresses under the screw heads are expressed by the following relationship:

$$\sigma_c = \frac{F_{st\ max}}{S_a}$$

The results are calculated in the table 1-13.5 and the results are analysed in paragraph 6.4.

6. RESULTS

This paragraph presents the results of each analysis. The digital applications used in the calculations are presented in tables 1-13.1 to 1-13.5.

6.1 Verification of non-separation

The following table presents the results of the non-separation analysis of the plugs and lids that ensure the package's containment.

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The non-separation of the front lid , the front closure plate, the base lid, the plug for the conduit seal and the plugs for openings A and B are checked, taking into account accelerations representative of routine transport conditions.

6.2 Equivalent stress in the screw

The equivalent stresses in the screws, considering a force $F_{st\ max}$ or F_E are presented below:

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The equivalent stresses in the screws are below the criterion.

6.3 Shearing stresses in the threads and threaded holes for the screws

The Von Mises equivalent stresses in the threads and threaded holes are presented below:

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For each part, the equivalent stress in the threaded hole and the equivalent stress in the thread for the associated screw comply with the criterion.

6.4 Pressure stresses under the screw head

The stresses under the head of the screw for a tightening torque $F_{st\ max}$ are presented below:

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For each part, the stress under the screw head complies with the criterion.

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7. ANALYSIS OF THE MINIMUM COMPRESSION RATES OF THE SEALS

This paragraph presents the calculation on minimum compression rates for ring leaktightness seals for the containment enclosure for the TN 106 package at -40°C.

7.1 Input data

Ring seals

The volume expansion coefficient for grades of seals made of EPDM that are used (see chapter 0) is taken from <7> for a package model that has already obtained an approval certificate, namely, in an encompassing manner, $5.15{,}10^{-4}\,K^{-1}$.

The dimensions of the seals in question are considered at minimal tolerances: they are given in chapter 0 and are summarised in the table 1-13.6.

Grooves

The volume expansion coefficient for steels of type A and B is taken from <8> and is presented in table 1-13.6.

The dimensions and tolerances of the trapezoidal grooves are taken from chapters 0 and 0-1 and presented in table 1-13.6. The dimensions of the grooves are considered at maximum tolerances.

7.2 Presentation of calculations

The minimum rate of compression is defined by:

$$TC_{min\,i} = 1 - \frac{(H_{max})\,(1+\lambda_g.\Delta T_{min\,i})}{\left[d_{j_{min\,i}}(1+\lambda_j.\Delta T_{min\,i})\right]}$$

With:

- H_{max}: maximum depth of the seal groove H_{max} at the ambient temperature,
- λ_g: linear expansion coefficient of the groove,
- λ_j: linear expansion coefficient of the seal,
- ΔT_{mini} temperature difference between -40°C and the ambient temperature, representing -60°C
- dj_{mini}: minimum diameter of the seal ring.

7.3 Results

Table 1-13.6 presents the minimum rates of compression for ring seals in the trapezoidal grooves at -40°C.

The values calculated ensure the leaktightness of the plugs at the head, openings A and B (Staubli protectors), the conduit seal and the back lid.

The leaktightness of the head cover is demonstrated in chapter 1-12.

8. CONCLUSION

The tightening torques for the screwed assemblies for the TN106 package are such that the acceptability criteria are complied with.

The tightening torques applied to the closure screws for the confinement chamber ensure that the package remains leaktight under routine transport conditions.

The calculations in this appendix have demonstrated that the torques chosen in operation are appropriate. The mechanical strength of the screws and the threaded holes is checked under routine transport conditions.

9. REFERENCES

<1> French standard NF E 25-030-1 of August 1984

<2> S.P Timoshenko – Strength of materials – Volume 1 – Editions Dunod

<3> Alexander's method ("Analysis and Design of Threaded Assemblies" - E. M. Alexander – Society of Automotive Engineers, Inc - 1978 – n° 770420)

<4> French standard NF E 25-030-1 of December 2007

<5> Standard NF EN 10028-7 of August 2008

<6> Standard NF EN ISO 898-1 of June 2009

<7> Letter– ASN – Ref. ASN DGSNR/SD1/D533/2005 of 21 July 2005

<8> ASME IID Subpart 2

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CALCULATION ON MINIMUM COMPRESSION RATES OF RING SEALS FOR MAKING THE TN106 PACKAGE'S CONTAINMENT ENCLOSURE LEAKTIGHT

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TN 106 PACKAGING		Name	Signature	Date
	Prepared by	N. OUKAKI	Signed on the French Version	
5573-C-19 Rev. 0	Checked by	F. PETIT		

Keywords: TN 106
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1. PURPOSE

The purpose of this report is to present the results of reguloatory drop tests <1> and <1□>, from a height of 1 m and 9 m onto a spike, performed on a half scale model of TN 106 packaging.

These tests were performed from 4 to 10 November 1999 at the LAUDUN test station (30).

2. TEST METHOD

2.1. Site

The tests were carried out at the TRANSNUCLEAIRE drop test station at LAUDUN.

The base slab is made, starting from the top level (ground level), from:

– A plate steel:

Grade: E24
Mass: 2800 kg
Thickness: 5 cm
Width and length of the plate: 2 m x 3.5 m

The plate is drilled with 44 holes which allow tie rods to pass through the concrete to the baserock.

The E24 steel tie rods (22 of length 1.5 m and 22 of length 0.6 m) are bent at one end and embedded in the concrete bedrock and threaded at the other for fastening to the plate.

– A concrete baserock

Height ×width ×length: 2 m × 2.5 m × 4 m
Mass of the baserock: 49000 kg

The concrete is reinforced with 14 mm thick steel bars spaced at 17 cm intervals.

The mass of the whole slab is approximately 53 tonnes.

A mechanical dropping hook whose opening is operated by remote control by a cable is used to drop the specimen.

The target used for the regulation 1-metre drop tests onto a spike consists of a solid bar of mild steel with a circular cross-section of diameter 75 ± 2.5 mm (representative of the bar of diameter 150 mm for full scale). The radius of the fillet is 3 mm. This bar is welded vertically to a horizontal steel plate which is fixed to the steel plate of the target described above.

The height of the bar above the steel plate is greater then the length required for penetration of the cavity.

2.2. Equipment Tested

The drop model <2> is made up of the body, the lid and the shock-absorbing covers of the packaging as shown in the drawing in Appendix 1-9.

The back cover used in all tests is type 1. Front cover type 1 is only used for axial drop No. 5; front cover type 2 is used for the other drops.

The geometry of shock-absorbing covers types 1 and 2 is identical. Only arrangements for instrumentation are made according to the drop configurations.

The contents of the model comprise 8 cylindrical loads made from stainless steel filled with lead each with a mass of 13.6 kg. The loads represent the maximum allowable mass per packaging. They are shown in the drawing in Appendix 1-9. The description of the drop model can be found in reference <2>.

3. PERFORMANCE OF THE TESTS

3.1. Test Programme

This drop programme <4> includes three drops from a height of 9 meters and two drops from a height of 1 metre onto a spike.

The tests are performed in the following order:

- **Sequence No. 3**

  * **Drop No. 5**: axial drop from a height of 9 m on the top of the model (Figure 1)

- **Sequence No. 1**

  * **Drop No. 1**: Oblique drop from a height of 1 m onto a spike with impact on the shell. The point of impact and the centre of gravity are aligned. The axis of the model is angled at 30° from the horizontal. The model is positioned with the base downward and drops on the 90° centreline (Figure 2). The height of the spike is 700 mm.

* **Drop No. 2**: Oblique drop from a height of 9 m with the first impact on the base of the model. The axis of the model is angled at 10° from the horizontal. The model drops on the 90° centreline (Figure 3).

- **Sequence No. 2**

  * **Drop No. 3**: Axial drop from a height of 1 m onto a spike with impact on the shock-absorbing cover. The model is positioned upside down. The height of the drop is corrected and is 1.16 m. The height of the spike is 200 mm (Figure 4).

  * **Drop No. 4**: Oblique drop from a height of 9 m with impact on the shock-absorbing cover. The model is positioned upside down. The axis of the model is at angle α in relation to the vertical so that the centre of gravity is aligned with the point of impact. The model drops on the 270° centreline (Figure 5).

The following table shows the correction factor to be taken into account for the drop heights of each of the tests (as per <3>):

	Height of drop H	Factor Correction h	Corrected height of the drop
Drop No. 5	9 m	0.14 m	9.14
Drop No. 1	1 m	0.02 m	1.02
Drop No. 2	9 m	0.18 m	9.18
Drop No. 3	1.16 m	0.02 m	1.18
Drop No. 4	9 m	0.18 m	9.18

3.2. Instrumentation

For drop No. 2, five accelerometers are fixed to the body of the model (Y1; Y2; Y3; Y4; Y5), 2 positioned on the top of the model, 2 on the base and 1 at the centre of the packaging, in the direction of the drop, on the 270° centreline (centreline opposite to impact, Figure 3).

For drop No. 5, two accelerometers (X1; X2) are positioned at the top, diametrically opposed (Figure 1).

3.3. Measurements and Checks

- Tightening to the appropriate torque of the fixing screws of the covers and various closure plates,
- Leaktightness check,
- Verification of accelerometers and measuring system components,
- Post drop dimensional reading (depth and area of crushing),
- Verification of the condition of cover fixing screws,
- Restitution of accelerometric signals to the following filtering frequencies:

600Hz - 1000 Hz - 1500 Hz - 2000 Hz - 3000 Hz - gross (see curves in appendices).

3.4. Test Sequence

- Drop No. 5 was carried out on 05/11/99 (pre and post drop leaktightness inspection, replacement of top cover, measurement of the lead settlement),
- Drops Nos. 1 and 2 were carried out on 08/11/99 (leaktightness inspection between the two drops and after drop No. 2),
- Drop No. 3 was carried out on 09/11/99 (post drop cavity leaktightness check),
- Drop No. 4 was carried out on 10/11/99 (overall leaktightness check).

4. DROP TEST REPORT

4.1. Test Preparation

Acceptance of the model 04/11/99.
Insertion of the loads inside the cavity.
Leaktightness inspection of the seals of the model (see values in Table 1).
Assembly of the type 1 front shock-absorbing cover and the type 1 back shock-absorbing cover on the packaging body.

4.2. Sequence 3:

Drop No. 5: axial drop of 9 m on the top of the model (Figure 1)

4.2.1. Preparation of the Drop

- Installation of the two accelerometers X1 and X2,
- Measurement of the height of the lead, the orifices provided for measuring the settlement of the lead are at 90° and 270°, (Photo 6)
  - Measurement at 90°: 148.7 mm,
  - Measurement at 270°: 146.6 mm.
- Verification of tightening torques,
- The drop height, measured in relation to the point of impact, is 9.14 m,
- Measurement of the ambient temperature: 10° C,

- Weighing of the model: 1785 kg (mass taken into account for the correction of the height (see Section 5.1).

Photo 1 shows the pre-drop position of the model.

4.2.2. *Description of the Drop*

The model falls onto the top cover and comes to rest, after oscillating a few times, in the vertical position.
The post drop position of the model is shown in Photo 2.

4.2.3. *Damage Caused by the Drop*

Photos 3, 4 and 5 show the damage caused by the drop on the model.

4.2.4. *Observations*

- The 6 fixing screws of the cover are intact,
- The welds of the metal envelope of the shock-absorbing cover withstood the drop with the exception of two points located on the upper edge,
- All the screw insert tubes have buckled so access to the screws is difficult.

4.2.5. *Measurements*

Measurement between the back plate of the model and the lead shielding.

Before the drops:
- Measurement at 90° : 147.7 mm
- Measurement at 270° : 144.6 mm

After Drop No. 5:
- Measurement at 90° : 148.7 mm which is a settlement of 1 mm
- Measurement at 270° : 146.6 mm which is a settlement of 2 mm

Leaktightness check after this drop (see Table 1).

The accelerations, filtered at 1000 Hz, on the body of the model are shown in Appendix 1. The maximum accelerations are as follows:

Maximum Accelerations Filtered at 1000 Hz on the Body of the 1/2 Scale Model		
Accelerometer	X1	X2
Axis of acceleration measured	X	X
Impact on the Top of the Packaging	[redacted] g	[redacted] g

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

4.3. Sequence No. 1 – Drop No. 1

Drop No. 1: Oblique drop from a height of 1 m onto a spike with impact on the shell.

4.3.1. Observations

A first drop test was performed however, at the moment of impact, the spike weld failed. So we began the drop test again.

No deformation of the shell was observed during this unfruitful test, the spike was turned 180° for the second test as it was slightly blunt.

4.3.2. Preparation of the Drop

- Replacement of the top shock-absorbing cover,
- Verification of tightening torques,
- The mass and positioning of the centre of gravity were checked. It is located at 689 mm from the front trunnion,
- Measurement of the ambient temperature: 8° C,
- The height measured under the lowest point of the packaging is 1.02 m,
- The angle was checked in relation to the horizontal: 29.5°,
- The alignment of the centre of gravity of the model with the axis of the spike was checked.

Photo 7 shows the pre-drop position of the model.

4.3.3. Description of the Drop

The model bounced off the spike after the first impact, fell onto the spike a second time then hit the floor several times before coming to a standstill.

4.3.4. Damage Caused by the Drop

The damage caused by the drop is shown in photos Nos. 8, 9, 10 and 11. Photo 8 shows the packaging after the drop.

Photo 9 shows the impact of the spike on the shell (both impacts shown).

Photos 10 and 11 show the condition of the spike after the drop.

- Puncture (without rupturing the plate) of the outer shell to the right of the first impact and the second impact on the centreline 90° (Photo 9),

- Buckling of the spike.

4.3.5. *Observations*

The tie-down lug located on the centreline of impact is intact.

4.4. Sequence No. 1 – Drop No. 2

Drop No. 2: Oblique drop from a height of 9 m with the first impact on the base of the model. The axis of the model is angled at 10° from the horizontal. The model drops on the 90° centreline (Figure 3).

4.4.1. *Preparation of the Drop*

The model was not modified between Drops Nos. 1 and 2.

Installation of accelerometers Y1, Y2, Y3, Y4 and Y5.

The centreline of impact of the model is positioned at 90°.

The angle between the packaging and the horizontal, measured for Drop No. 2 is 10.5°, tilted at the bottom end of the packaging.

The drop height, measured in relation to the point of impact is 9.18 m.

Photo 12 shows the pre-drop position of the model.

4.4.2. *Description of the Drop*

The model falls on the base shock-absorbing cover, bounces and hits the top cover. A second impact on the base cover then after several oscillations the model comes to a standstill.

The post drop position of the model is shown in Photo 13.

4.4.3. *Damage Caused by the Drop*

The damage caused by the drop is shown in photos Nos. 14, 15, 16 and 17.

4.4.4. Observations

The 6 fixing screws of the front cover are intact.
The 6 fixing screws of the back cover are intact.
The base cover is sheared over a length of 420 mm and a width of 16 mm, the crushed area is 530 mm x 470 mm (photos 14 -17).
The front cover is not sheared, the crushed area is 490 mm x 360 mm (photos 13 -16).
The handling lug on the centreline 90° base end is crushed (photo 15). The height between the outer shell and the crushed area is 40 mm.

4.4.5. Measurements

Leaktightness check after this drop (see Table 1).

	Accelerations on the 1/2 Scale Model Filtered at 1000 Hz The maximum accelerations are as follows:				
	Accelerometer on the back flange		**Accelerometer on the front flange**		**Accelerometer on the outer shell**
	Y1	**Y2**	**Y3**	**Y4**	**Y5**
Axis of acceleration measured	Y	Y	Y	Y	Y
Impact on base cover	[redacted] g	[redacted] g	[redacted] g	[redacted] g	[redacted] g

The accelerations, filtered at 1000 Hz, on the body of the model are shown in Appendix 2.

4.5. Sequence No. 2 – Drop No. 3

Drop No. 3: Axial drop from a height of 1 m onto a spike with impact on the shock-absorbing cover. The model is positioned upside down. The height of the drop is corrected and is 1.16 m. The height of the spike is 200 mm (Figure 4).

4.5.1. Preparation of the drop

Measurement of the ambient temperature: 9° C

The height measured at the lowest point of the packaging is 1.18m.

Photo 18 shows the pre-drop position of the model.

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

4.5.2. Description of the Drop

The model falls onto the top shock-absorbing cover and comes to a standstill on the spike in the vertical position.

The post drop position of the model is shown in Photos No. 19 and No. 20.

4.5.3. Damage Caused by the Drop

The damage caused by the drop is shown in Photo 21. Perforation of the top cover, the spike hit the anti-puncture plate and deformed it by 27.6 mm (dent).

The spike is slightly blunted (Photo 22).

4.5.4. Observations

- The 6 fixing screws of the shock-absorbing cover are intact.

4.5.5. Measurements

Leaktightness check after the drop (see Table 1).

4.6. Sequence No. 2 – Drop No. 4

Drop No. 4: Oblique drop from a height of 9 m with impact on the shock-absorbing cover.
The model is positioned upside down (Figure 5).

4.6.1. Preparation of the Drop

The model was not modified between drops Nos. 3 and 4.

The centreline of impact of the model is positioned at 270°.

Angle α of inclination, of the packaging axis with the vertical is measured so that the point of impact and the centre of gravity of the model are aligned. The measurement of the angle between the axis of the packaging and the horizontal is 18°.

The drop height, measured in relation to the point of impact, is 9.18 m.

Photo 23 shows the pre-drop position of the model.

4.6.2. Description of the Drop

The model hits the corner of the top end of the cover then bounces and drops again on the centreline of the base end cover. The model comes to a horizontal standstill.

The post drop position of the model is shown in Photo 24.

4.6.3. Damage Caused by the Drop

The damage caused by the drop is shown in photos Nos. 25 and 26.

Crushing of the corner of the shock-absorbing cover to the right of the point of impact.

The sleeves of screws 5 and 6 are completely closed off by the deformation of the cover.

Tearing of the welds of the metal envelope of the notch of the lid on the area of impact.

4.6.4. Observations

The 6 fixing screws of the top shock-absorbing are intact (observed after cutting the part compressed of the shock-absorbing cover).

Photographs No. 27 and No. 28 show the top and base ends of the model, respectively, without covers after the drops with the front and back closure plates removed.

The fixing screws of the lid are intact.

The 4 fixing screws of orifice B closure plate are intact.

The upper edge of the model, on the 90° centreline (centreline of impact), bears no deformation or evidence of impact.

Disassembly of the lid without problem.

Removal of the test loads without problem.

Revolving plug in proper working order.

4.6.5. Measurements

Full leaktightness check after this drop (see Table 1).

Measurement of the diameter of the cavity:

- Base end: 180°-90° ⇒101.4 mm
  0°-270° ⇒101.7 mm

- Top end: 180°-90° ⇒101.4 mm
  0°-270° ⇒101.5 mm

Leaktightness check - see Table 1

5. REFERENCES

<1> IAEA Safety Series No. 6 - Regulations for the Safe Transport of Radioactive Material –1985 Edition – (Revised in 1990).

<1'> International Atomic Energy Agency Regulation for the Safe Transport of Radioactive Materials No. ST-1 (1996 Edition).

<2> TRANSNUCLEAIRE – Description of Drop Model 5573-B-19 rev.0 27/05/99.

<3> TRANSNUCLEAIRE Specification 5573-A-6 rev. 0 of 03/11/99. Specification: Model Packaging Drop Tests.

<4> TRANSNUCLEAIRE Note 5573-P-1 rev. 0 of 27/05/99. Regulatory Drop Test Programme

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix	Index	Description	No. of Pages
1	A	Accelerometric Readings from Drop No. 5	3
2	A	Accelerometric Readings from Drop No. 2	2
TOTAL			**5**

LIST OF PHOTOS

Photos	Index	Description	No. of Pages
1 to 6	A	Sequence 3 – Drop No. 5	
7 to 11	A	Sequence 1 – Drop No. 1	
12 to 17	A	Sequence 1 – Drop No. 2	
18 to 22	A	Sequence 2 – Drop No. 3	
23 to 28	A	Sequence 2 – Drop No. 4	
TOTAL			**14**

TABLE 1
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LEAKTIGHTNESS TESTS

Prior to Dropping		
Location	**Report No.**	**Value in Pa.m.^{3}.s^{-1}**
Cavity Welds	PV 99.11.002.01	6.03×10^{-11}
Revolving Plug Closure Plate	PV 99.11.002.02	2.35×10^{-09}
Orifice A, Top Lid	PV 99.11.002.03	2.41×10^{-10}
Top Lid Closure Plate	PV 99.11.002.04	2.41×10^{-10}
Top Lid	PV 99.11.002.05	2.41×10^{-10}
Base Lid	PV 99.11.002.06	2.41×10^{-10}
After Drop No. 5		
Location	**Report No.**	**Value in Pa.m.^{3}.s^{-1}**
Cavity Weld	PV 99.11.002.07	1.38×10^{-10}
Revolving Plug Closure Plate	PV 99.11.002.12	4.01×10^{-09}
Orifice A, Top Lid	PV 99.11.002.11	6.68×10^{-10}
Top Lid Closure Plate	PV 99.11.002.10	6.68×10^{-10}
Top Lid	PV 99.11.002.09	6.68×10^{-10}
Base Lid	PV 99.11.002.08	1.34×10^{-10}
After Drop No. 1		
Location	**Report No.**	**Value in Pa.m.^{3}.s^{-1}**
Cavity Weld	PV 99.11.002.13	8.54×10^{-11}
Top Orifices	PV 99.11.002.14	2.22×10^{-10}
Bottom Orifices	PV 99.11.002.15	3.33×10^{-10}
After Drop No. 2		
Location	**Report No.**	**Value in Pa.m.^{3}.s^{-1}**
Cavity Weld	PV 99.11.002.16	1.46×10^{-09}
Top Orifices	PV 99.11.002.17	2.74×10^{-09}
Bottom Orifices	PV 99.11.002.18	1.15×10^{-09}

TABLE 1
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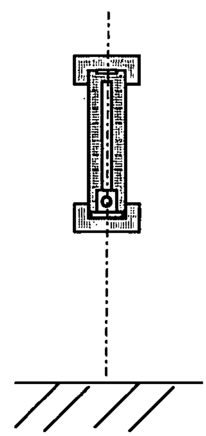
LEAKTIGHTNESS TESTS

After Drop No. 3		
Location	**Report No.**	**Value in $Pa.m.^3.s^{-1}$**
Cavity Weld	PV 99.11.002.19	1.41×10^{-09}
Top Orifices	PV 99.11.002.20	2.64×10^{-09}
Bottom Orifices	PV 99.11.002.21	1.11×10^{-09}
After Drop No. 4		
Location	**Report No.**	**Value in $Pa.m.^3.s^{-1}$**
Cavity Welds	PV 99.11.002.22	7.20×10^{-10}
Revolving Plug Closure Plate	PV 99.11.002.26	1.50×10^{-08}
Orifice A, Top Lid	PV 99.11.002.25	3.40×10^{-09}
Top Lid Closure Plate	PV 99.11.002.24	6.80×10^{-10}
Top Lid	PV 99.11.002.23	6.44×10^{-10}
Base Closure Plate	PV 99.11.002.27	2.15×10^{-09}

FIGURE 1

DROP NO. 5 - AXIAL DROP FROM A HEIGHT OF 9 M ONTO THE TOP OF THE MODEL

POSITION OF THE MODEL



INSTRUMENTATION

2 accelerometers:

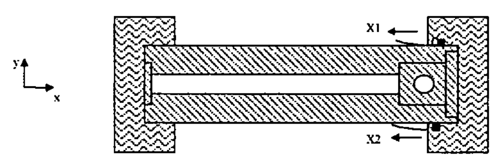
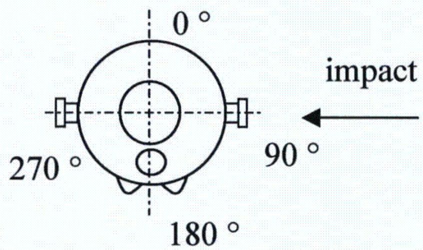
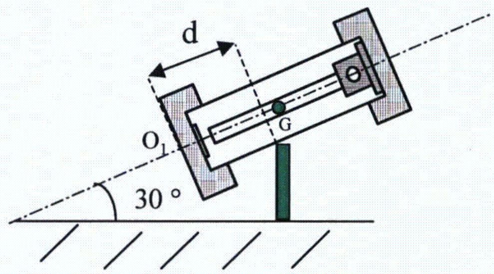


FIGURE 2

DROP NO. 1 - OBLIQUE DROP FROM A HEIGHT OF 1 M ONTO A SPIKE WITH IMPACT ON THE SHELL.

POSITION OF THE MODEL





INSTRUMENTATION

5 accelerometers:

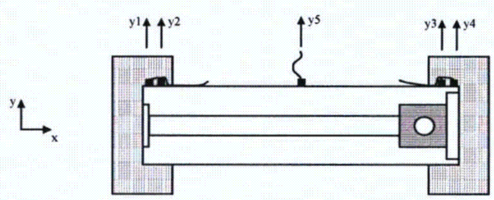
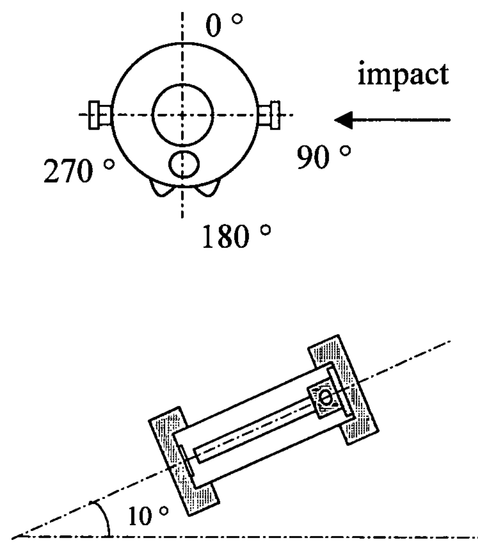


FIGURE 3

DROP NO. 2 - OBLIQUE DROP FROM A HEIGHT OF 9 M WITH THE FIRST IMPACT ON THE BASE OF THE MODEL

POSITION OF THE MODEL



INSTRUMENTATION

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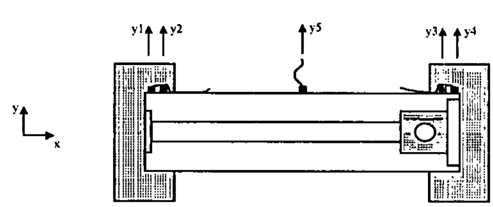
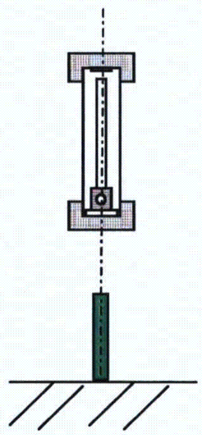


FIGURE 4

DROP NO. 3 - AXIAL DROP FROM A HEIGHT OF 1 M ONTO A SPIKE WITH IMPACT ON THE SHOCK-ABSORBING COVER

POSITION OF THE MODEL



INSTRUMENTATION

5 accelerometers:

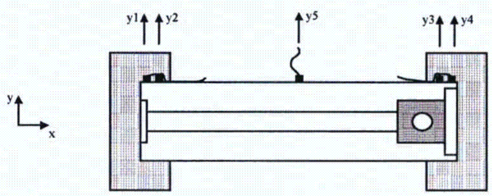
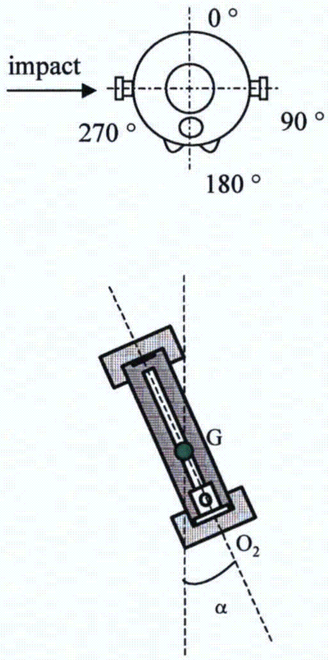


FIGURE 5

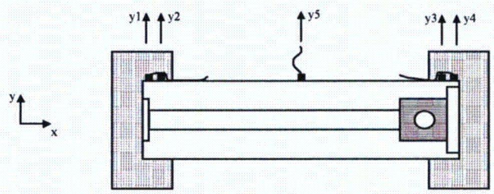
DROP NO. 4 - OBLIQUE DROP FROM A HEIGHT OF 9 M ONTO A SPIKE WITH IMPACT ON THE SHOCK-ABSORBING COVER

POSITION OF THE MODEL



INSTRUMENTATION

5 accelerometers:



APPENDIX 1
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ACCELEROMETRIC READINGS FROM DROP NO. 5

Proprietary information withheld pursuant to 10 CFR 2.390

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ACCELEROMETRIC READINGS FROM DROP NO. 5

Proprietary information withheld pursuant to 10 CFR 2.390

APPENDIX 1
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ACCELEROMETRIC READINGS FROM DROP NO. 5

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APPENDIX 2
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ACCELEROMETRIC READINGS FROM DROP NO. 2

Proprietary information withheld pursuant to 10 CFR 2.390

APPENDIX 2
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ACCELEROMETRIC READINGS FROM DROP NO. 2

Proprietary information withheld pursuant to 10 CFR 2.390

PHOTOGRAPHS

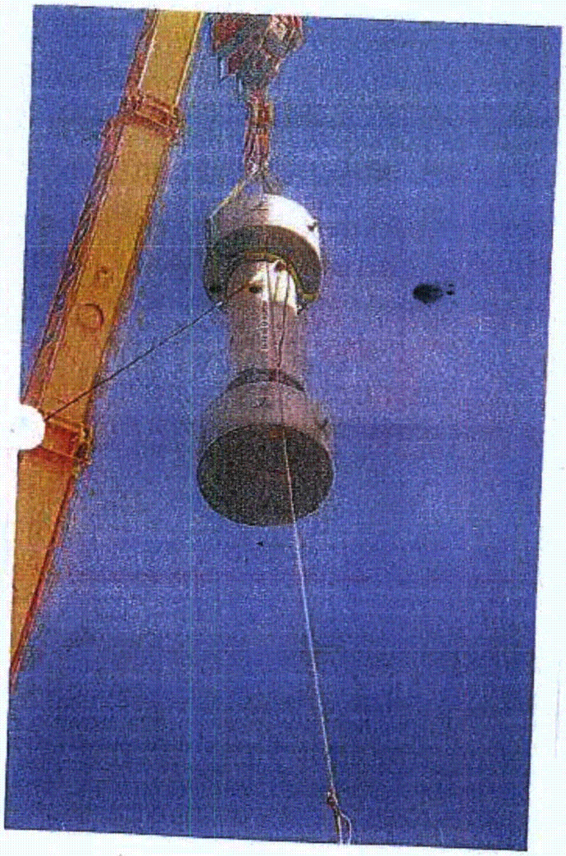

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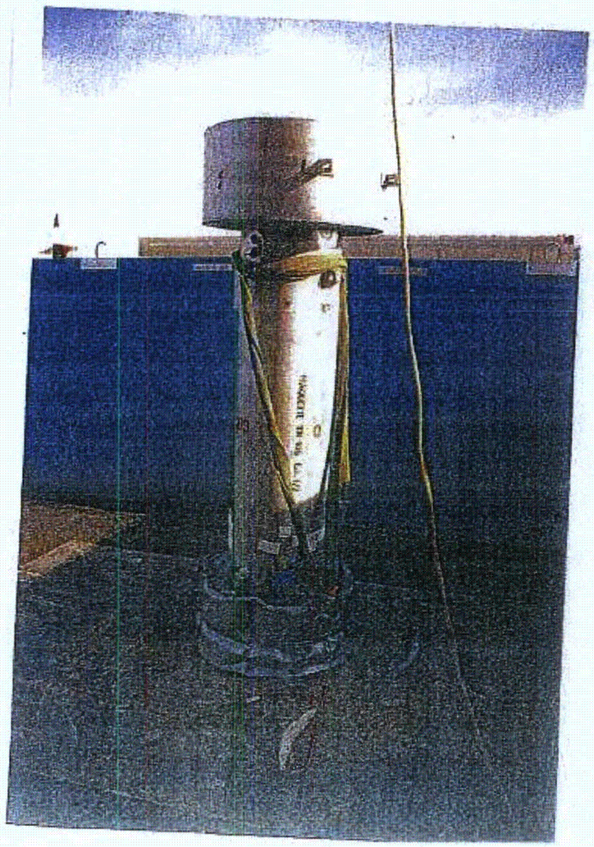
Photo n°2 =>



PHOTOGRAPHS

<= Photo n°3

Photo n°4=>

PHOTOGRAPHS

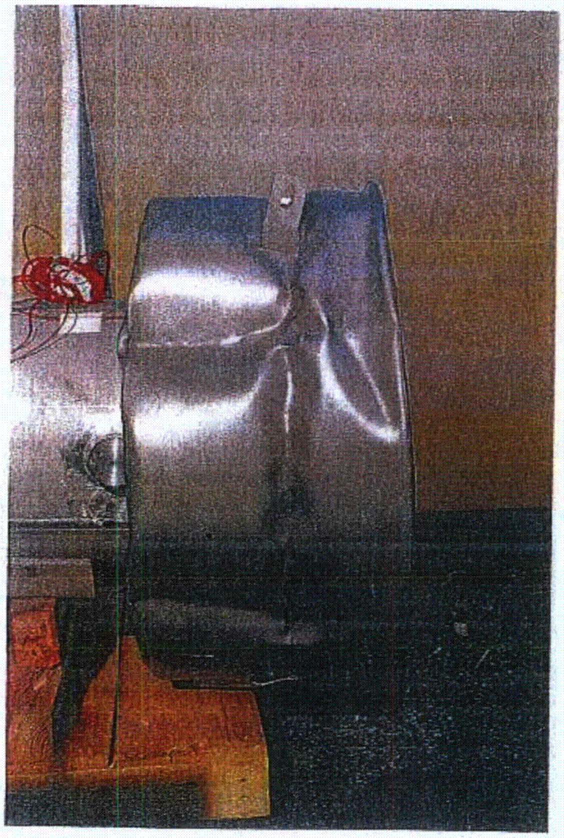


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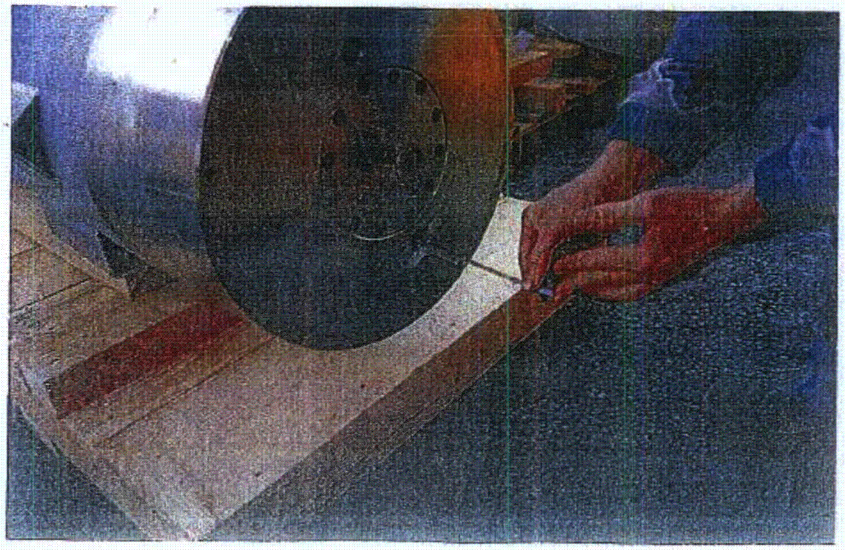
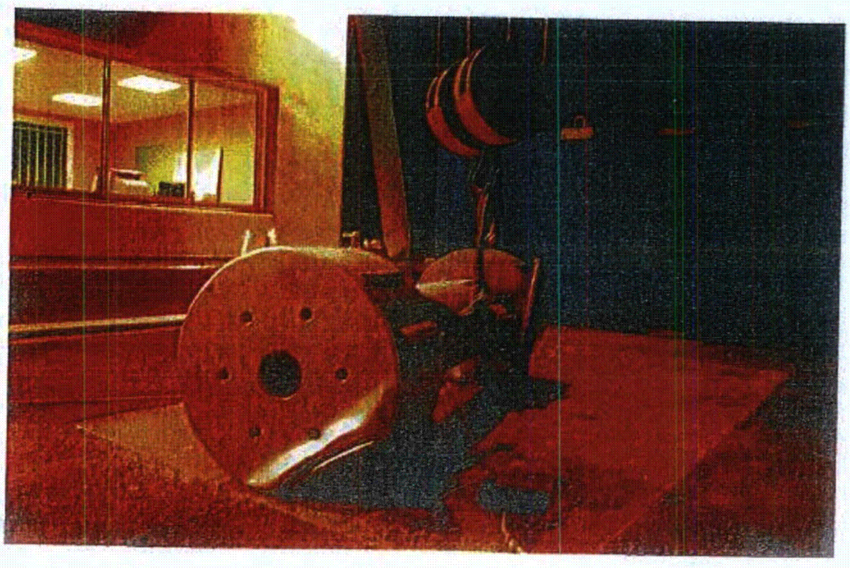
Photo n°6



PHOTOGRAPHS

Photo n°7

Photo n°8



PHOTOGRAPHS

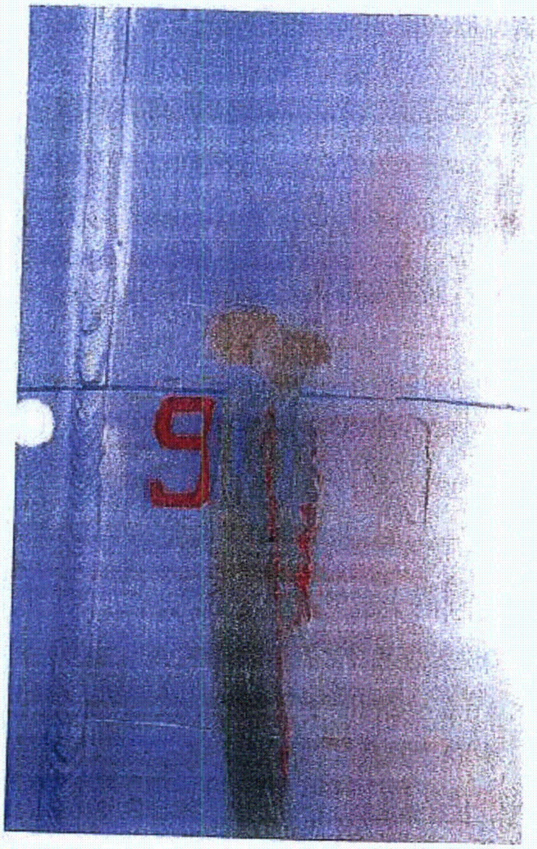


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Photo n°10 =>

PHOTOGRAPHS

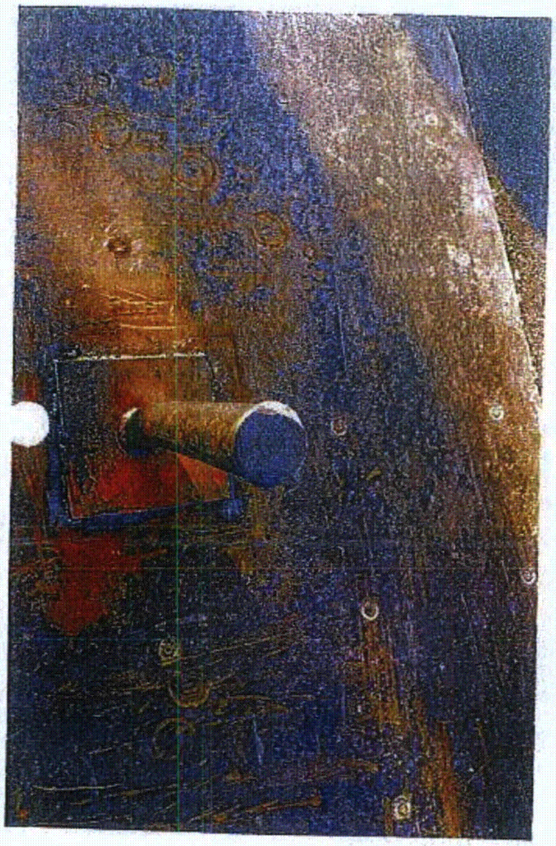

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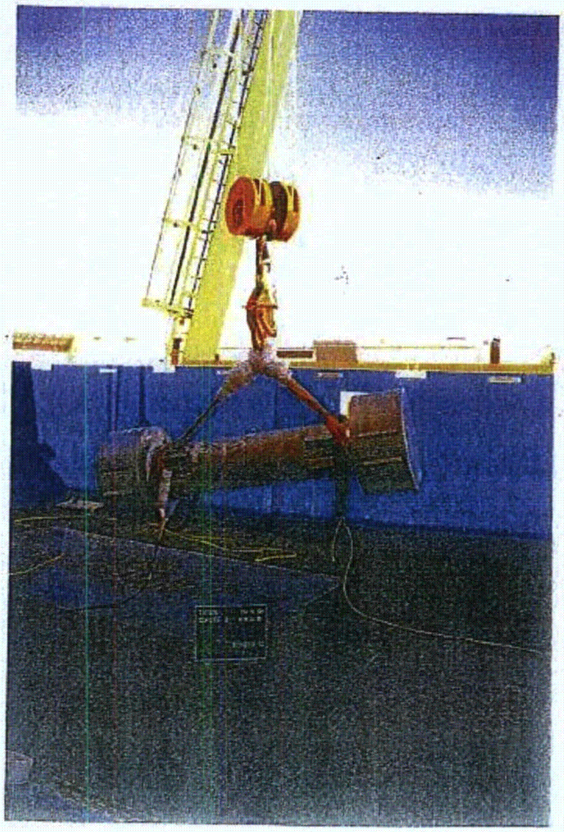
Photo n°12 =>



PHOTOGRAPHS

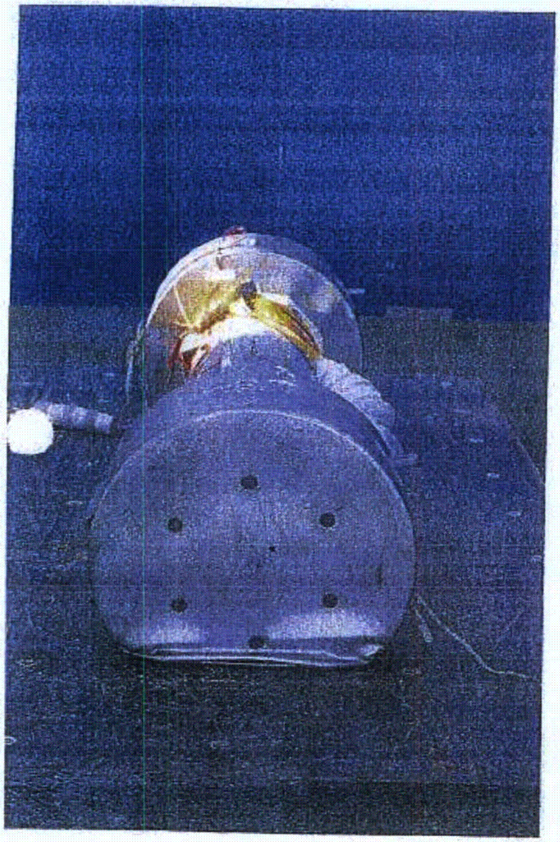


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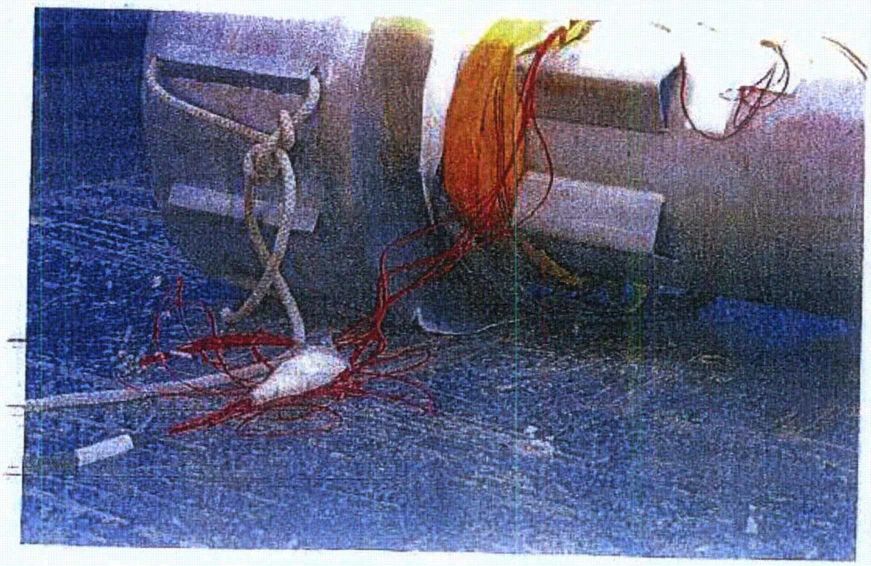
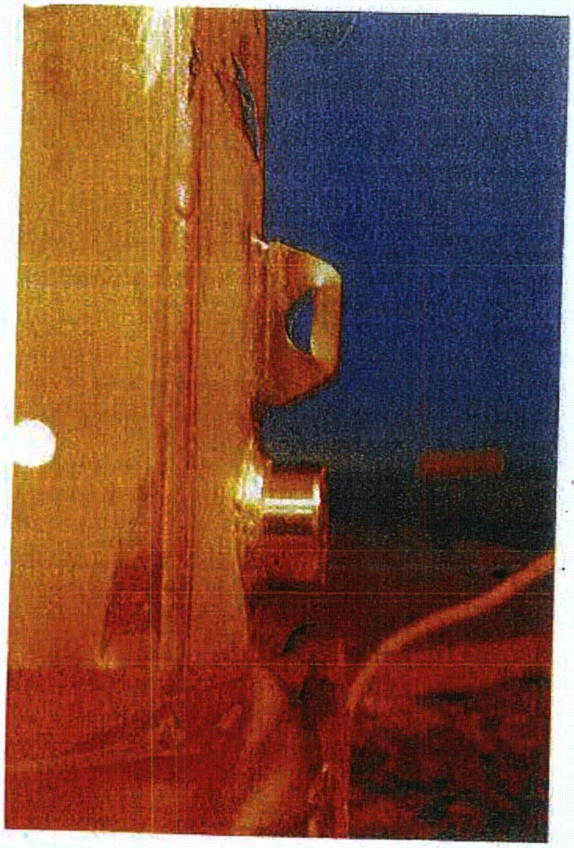
Photo n°14



PHOTOGRAPHS



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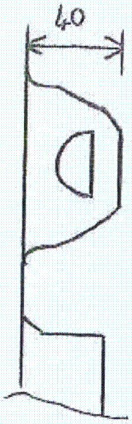
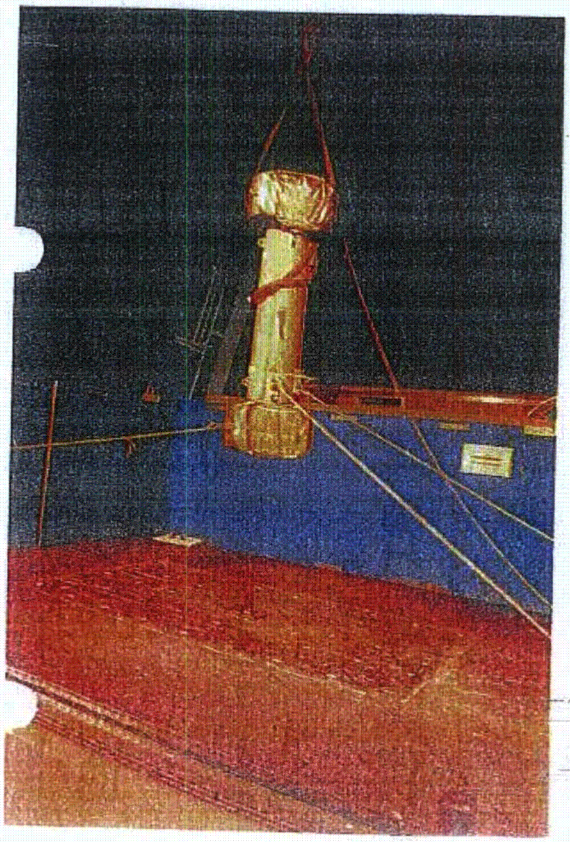


Photo n°16

PHOTOGRAPHS

Photo n°17



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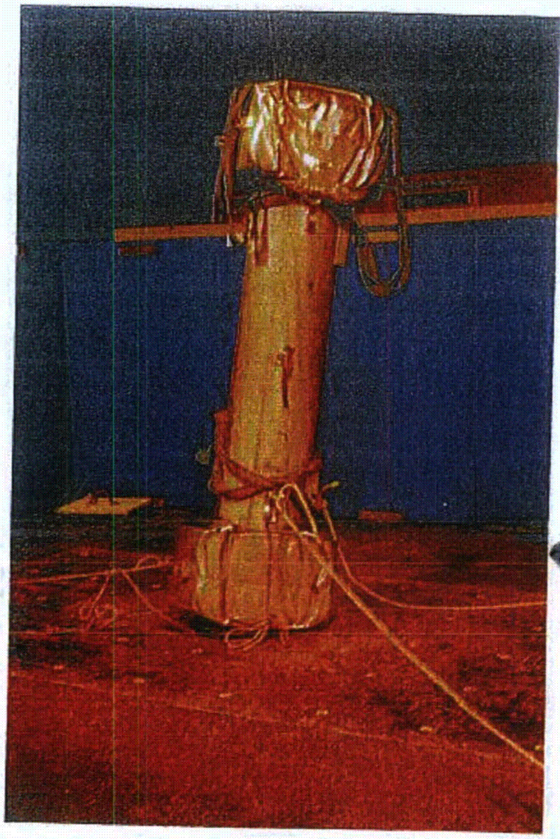

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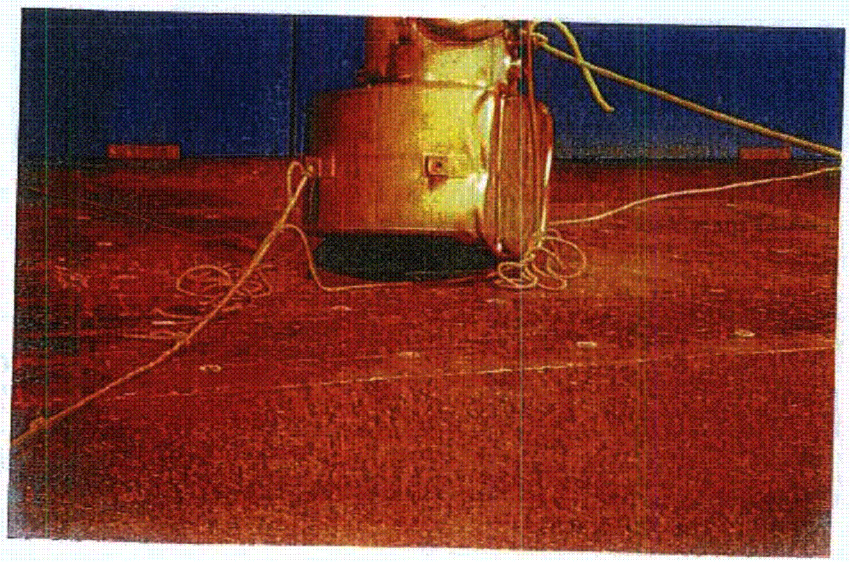

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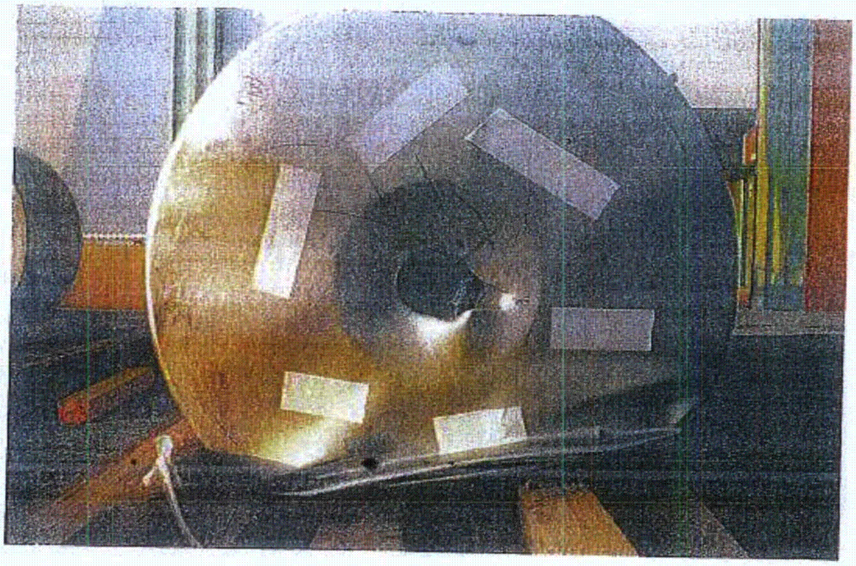

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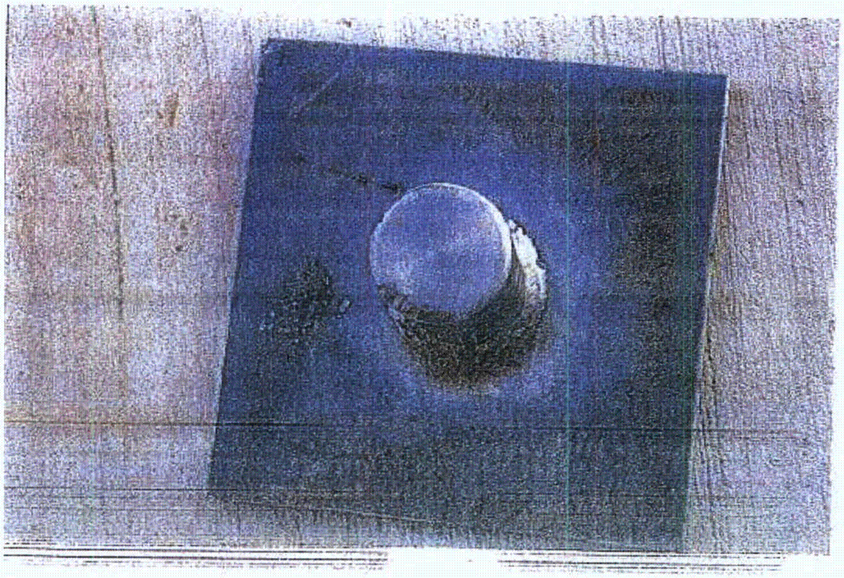

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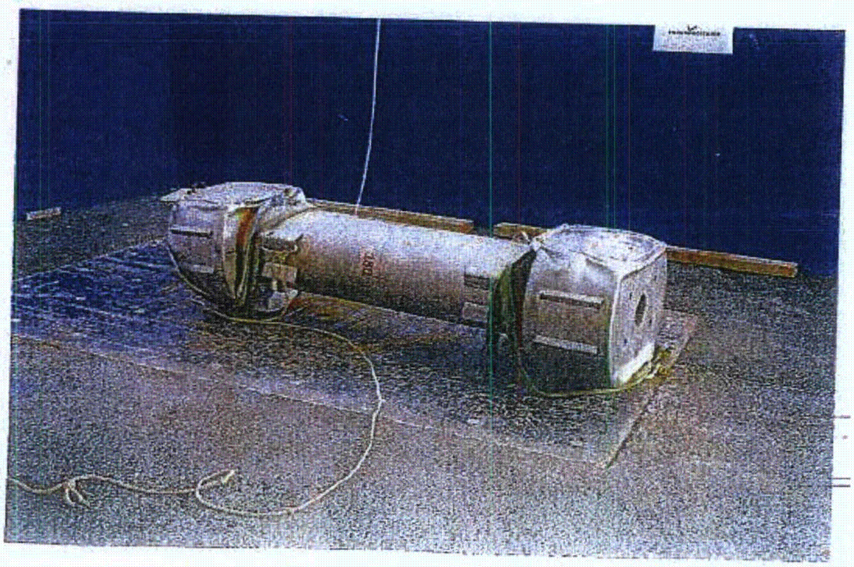

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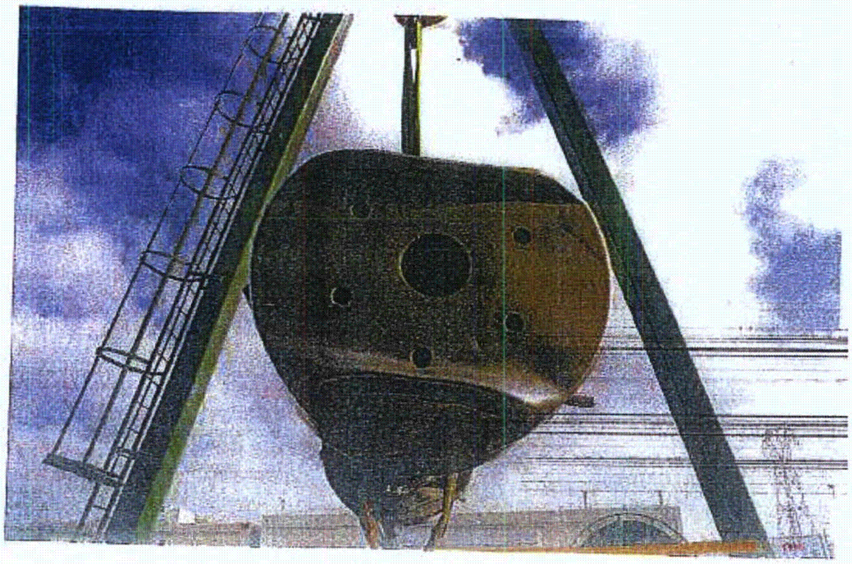

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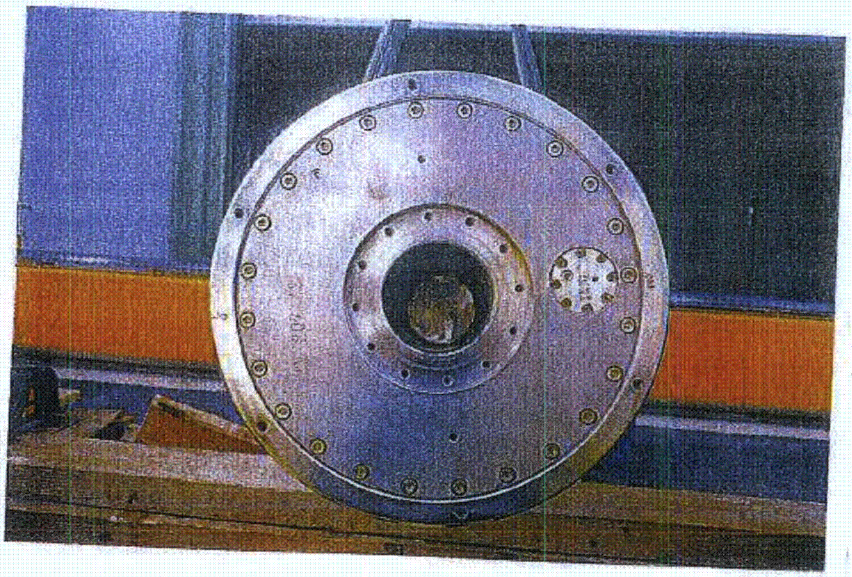

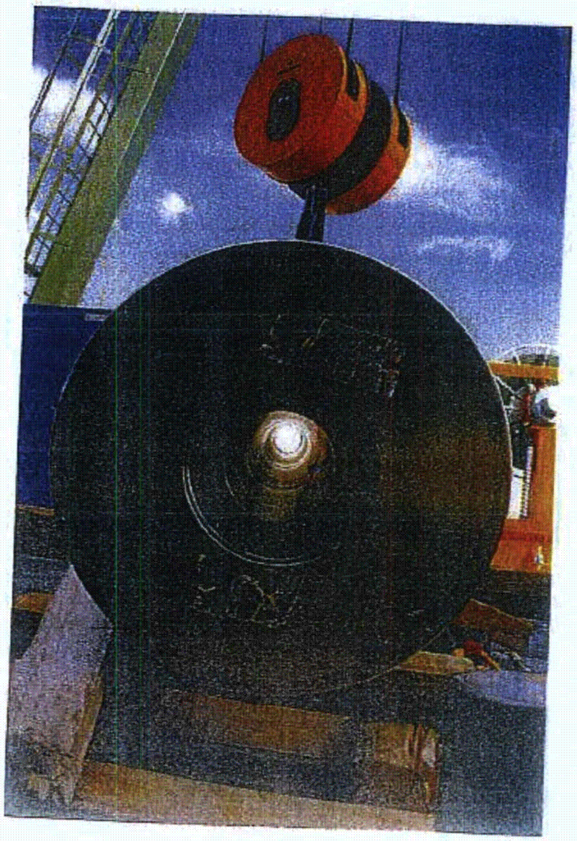

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STRUCTURAL STRENGTH OF INTERNAL ARRANGEMENTS OF TN 106 PACKAGING

TABLE OF CONTENT

REVISION STATES

Rev	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-1AE			
0	06/00	First issue	F. PETIT / L. VIALLON
Ref. : DOS-08-00126114-150			
00	08/08	New document reference New formalism Maximal acceleration calculated in temperature taken into account. Bronze shoes put on the spacer taken into account. Insertion of the study of buckling performance of spacers. Insertion of the study of cutting performance of welds between the spacer and the central pipe.	S. CHEVET / JC. BOTT
01	06/11	Introduction of the internal arrangement diameter (D=110 mm).	B. GSIB/ C. GRANDHOMME
02	02/13	Translation of the document DOS-06-00032898-114 Rev. 2 Range update of the cavity's useful length [2200 mm -2400 mm]. Update of the temperatures and the accelerations undergone by the package model.	R. BAHOU / D. HONDAGNEU

SUMMARY

Purpose:

The purpose of this analysis is to define the minimum thicknesses of the internal arrangements which will guarantee preservation of their geometry in normal and accident conditions of transport.

Essential Parameters and their Source,

The internal arrangements under consideration are steel canisters and can take the diameters taken into consideration in Chapter 0A, which are 120 mm, 110 mm and 60 mm. The mechanical properties of the steel from which the arrangements are made are considered at the temperatures determined based on the maximum linear thermal power (300W/m, Chapter 0A).

Assumptions and Methods Used:

The justification of the mechanical strength of the internal arrangements is based on analytical calculations. These arrangements are centred in the cavity by means of a centring ring and the dimensioning is based on the analysis of the bending strength of the arrangement between the rings.

The acceleration rates under consideration are taken from the packaging drop condition's analysis set out in Appendix 12 of Chapter 1.

This chapter begins with a quote of accelerations suffered by the package in accident conditions of transport just as a calculation of the acceptable maximal weight in different internal arrangements and a calculation of the maximum dynamic factor.

The dimensionning method of the internal arrangements is the following :

1) Dimensionning of the internal arrangement according to the maximum weight which the content withstand in the lateral drop
2) Determination of the natural frequency of arrangements like dimensioned
3) Calculation of the drop stimulation frequency using the impact period which is recorded during the drop simulation.
4) Determination of the maximum dynamic factor which is linked with these frequencies.
5) Checking that the static stress which is increased by the dynamic factor is lower than the steel yield strength at the operation temperature.

Previously, we check the performance of the internal arrangement in the axial drop configuration (compression and buckling)

The dimensioning method of the centring crown (spacer) is the following :

1) Dimensioning of the spacer according to the acceleration withstand during the lateral drop (Appendix 1A.3)
2) Calculation of the buckling critical stress of the spacer during the lateral drop and comparing to the spacer yield strength
3) Calculation of the welding internal stress and checking which is lower than the spacer yield strength.

Finally, we check that shoes are no influence on the internal arrangements behaviour.

Results and Conclusions:

The mechanical calculations of the strength of the internal arrangements (canisters) show that the maximum stresses are lower than the yield strength of the steel concerned. The maximum allowable masses as a function of the thicknesses of the canisters are set out in Table 1A.1. In these conditions, the diameters of the canisters described in Chapter 0A are preserved and can be used for the nuclear criticity safety analysis.

The distance between two spacers must be 300 mm at the maximum. These spacers must be made from steel with a minimum thickness of 21 mm.

1. PURPOSE

The purpose of this chapter is to define the thicknesses of the internal arrangements as defined in Chapter 0A which will guarantee that their geometry is preserved in normal and accident conditions of transport.

2. ACCELERATION TO WHICH THE PACKAGE IS SUBJECTED

Appendix 12 of Chapter 1 sets out the maximum acceleration to be taken into account for the packaging TN106 of an effective cavity length included between 2200 mm and 2400 mm.

- Acceleration according to the axis of the packaging:
  - [redacted] g (axial drop of the packaging of 2200 mm length at T =-40°C)
- Perpendicular acceleration in the axis of the packaging:
  - [redacted] g (lateral drop of the packaging of 2400 mm length in T =-40°C)

3. ACCELERATIONS TO WHICH THE INTERNAL ARRANGEMENTS ARE SUBJECTED

The accelerations to which the internal arrangements are subjected are determined from the accelerations of the package by taking a dynamic amplification coefficient into consideration to take account of the gap between the packaging and the internal arrangement.

This coefficient is calculated as follows:

The dynamic load taken into account is presented in diagram form in Figure 1A.1. We assume that the shock duration is sufficiently short for damping to be negligible.

The dynamic deflection of the sector is according to <1>:

$$x_{(t)} = \frac{P_0}{K}\left[\frac{1}{1-\beta^2}\right](\sin wt - \beta \sin w_s t) \qquad \text{for } 0 < t < T/2$$

and

$$x(t) = \frac{P_0}{K}\left[\frac{-\beta}{1-\beta^2}\right]\left\{\left(1+\cos\frac{\pi}{\beta}\right)\times \sin\left[w_s t - \frac{\pi}{\beta}\right] + \sin\frac{\pi}{\beta}\times\cos\left[w_s t - \frac{\pi}{\beta}\right]\right\} \qquad \text{for } t > T/2$$

Where:

- $\frac{Po}{K}$: corresponds to the deflection for a static load
- w: Excitation pulsation

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- ws: Natural pulsation of the structure

$$\beta = \frac{w}{w_s}$$

- T/2 : impact period (second)

The dynamic amplification coefficient is defined by:

$$D = \left[\frac{1}{1-\beta^2}\right](\sin wt - \beta \sin w_s t) \qquad \text{for } 0 < t < T/2$$

And

$$D = \left[\frac{-\beta}{1-\beta^2}\right]\left\{\left(1+\cos\frac{\pi}{\beta}\right)\times\sin\left[w_s t - \frac{\pi}{\beta}\right] + \sin\frac{\pi}{\beta}\times\cos\left[w_s t - \frac{\pi}{\beta}\right]\right\} \qquad \text{for } t > T/2$$

Figure 1A.1 shows the evolution of the maximum dynamic amplification coefficient D_{max} as a function of β coefficient for the excitation pulsation during the lateral and axial drop.

4. DESCRIPTION OF THE INTERNAL ARRANGEMENTS

The internal arrangements taken into account in this study are canisters or containers made from steel with an effective internal diameter of 120 mm, 110 mm and 60 mm. These canisters are centred in the cavity by centring rings. The overall length of these arrangements is taken as equal to that of the cavity, which is from 2200 mm to 2400 mm.

5. CRITERIA

The criteria used must guarantee the validity of the hypotheses used for the package nuclear safety analysis, which is the preservation of the geometry of the arrangement.

The thicknesses of the internal arrangements are determined in order that the maximum stresses do not exceed the yield strength of the materials at their maximum temperature in normal conditions of transport.

For diameters 120 mm, 110 mm and 60 mm, the temperature of the internal arrangement is taken as 300 °C, 300 °C and 350 °C respectively. The justification of these temperatures is given in Appendix 1A.1.

6. CALCULATION MODEL

6.1 Geometric Model

The geometric model corresponds to an arrangement centred in the cavity and is shown in Figure 1A.2.

6.2 Properties of the Materials

The properties of the materials are set out in the Chapter 0 and summarised below.

		Stainless Steel Type A (304 L or equivalent)
Yield Strength minimum (MPa) at 0.2%	250 °C 300 °C 350 °C	108 100 94
Young's Modulus (MPa)	20 °C 250 °C	198,000 179,000 <5>
Poisson Coefficient	-	0.3
Density (kg/m^3)	-	7,850

7. NORMAL CONDITIONS OF TRANSPORT

Normal conditions of use and transport of the packaging are much less severe than the consequences of the 9 m drops which are analysed in Section 8.

The integrity of the internal arrangements shall be preserved in normal transport conditions from the moment when the demonstration of the strength of these internal arrangements is performed for accident conditions of transport.

8. ACCIDENT CONDITIONS OF TRANSPORT

8.1 Strength of the internal arrangement

8.1.1 Mass allowable by the internal arrangement

The Maximum allowable mass in the cavity is 254 kg/m. For the internal arrangement diameters considered, this maximum allowable mass is reviewed taking a density of 11,500 kg/m^3 into account as the maximum density which can occupy the internal arrangement. This density covers all the contents in the form of oxide. The table below specifies masses of the contents considered in this way.

	Diameter of the cavity 203 mm	Internal diameter 120 mm	Internal diameter 110 mm	Internal diameter 60 mm
Maximum weight (in kg/m)	254	130	109	32

For the rest of the study, the thicknesses of the internal arrangement will be determined as a function of the mass of the contents taking into account the results set out in the above table as maximum value.

8.1.2 Axial Drop Case

In this drop case, the structure of the internal arrangement is loaded only with its own weight. We assume that the internal arrangement is continuous over all the height of the cavity.

The risk of canister deformations is due to compression or buckling.

<u>Internal arrangement strength when compressed:</u>

Natural frequencies of compression of the internal arrangement can be calculated from the following relation:

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{A.E.g}{\omega L^2}} = \frac{K_n}{2\pi}\sqrt{\frac{A.E.g}{A.d.g.L^2}} = \frac{K_n}{2\pi}\sqrt{\frac{E}{d.L^2}} \quad \text{(Table 36 Case 7 of <2>)}$$

Where:

- K_n: Constant equal to 1.57 for the first mode of vibration (Table 36, Case 7 of <2>)
- E: Young's modulus, which is 179,000 MPa
- A: Area of the cross-section in m^2
- g: Gravitational acceleration in m/s^2
- ω: Linear load (natural weight of the arrangement) in N/m
- L: Length of the tube
- d: Density of the arrangement, which is 7,850 kg/m^3

In order to get the use frequency of our system, the impact period which have been measured during the axial drop test of the packaging of 2200 mm of length at T = -40°C (numeral calculation presented in the chapter 1-12), that is 0,025 s.

$T = 2 \times 0.025 = 0.05$ s et $w = \frac{2.\pi}{T} = 126\ s^{-1}$

So, when considering that the length of the arrangement varies from 2200 mm to 2400 mm, we obtain a natural frequency of between 543 Hz and 498 Hz which corresponds to $\beta = 0.037$ and 0.041 respectively.

The frequencies of the internal arrangements calculated above show that no dynamic amplification is liable to intervene. To ensure a conservative approach, the maximum amplification factor got with β variant from 0.019 to 0.095 is accepted, that is $D_{max} = 1.09$.

In order to maximize this stress, we consider in a penalizing way :

- the maximal height of the canister , that is 2400 mm.
- the maximal acceleration (obtained for the packaging of 2200 mm of cavity length), that is [redacted] g.

$\sigma = D_{max} \times F/S = D_{max}\, m\, \gamma/S = D_{max}\, \rho\, S\, h\, \gamma/S = D_{max}\, \rho\, h\, \gamma$.

where:

- h: the maximal height of the canister = 2400 mm.
- γ: the maximal acceleration = [redacted] g.
- d: density of the steel from which the arrangement is made, which is 7,850 kg/m^3.

So $\sigma = D_{max}\, d\, h\, \gamma = 1.09 \times 7{,}850 \times 2.4 \times$ [redacted] $\times 9.81 = 35.9$ MPa

This stress is independent of the cross-section; also, the above calculations are envelope values for all canister diameters and thicknesses. This value is lower than the yield strength of the steel at the temperature of the internal arrangement in normal conditions, which is 94 MPa for steel at 350 °C. The canister withstands the compression in the case of the axial drop.

<u>Resistance to Buckling</u>

We consider that the canister is subjected to a compressive stress $\sigma = D_{max}\rho h\gamma$ applied to each of its ends considered free. This configuration ensures a conservative approach compared with the real load distributed along the tube given its natural weight.

The critical buckling stress for the small tubes is expressed as follows:

$$\sigma=\frac{1}{\sqrt{3}}\frac{E}{\sqrt{1-\nu^2}}\frac{t}{r}$$ (Table 35, Case 15a of <2>)

Where:
- t: thickness
- r: mean radius

So, we should have

$$\frac{1}{\sqrt{3}}\frac{E}{\sqrt{1-\nu^2}}\frac{t}{r} > D_{max}\rho.h.\gamma$$

Which is

$$t \geq \frac{\sqrt{3}.\sqrt{1-\nu^2}.r.D_{max}.\rho.\gamma.h}{E}$$

For a given canister thickness, the conservative configuration for buckling corresponds to a canister of greater diameter, which is 120 mm and of greater length.

The minimum thickness to comply with the above inequation is very small (<<1 mm). So, there is no risk of the canister buckling.

8.1.3 *Lateral drop case*

The maximum acceleration obtained in lateral drop is [redacted] g (see chapter 1-12).

The internal arrangement is centred in the cavity. The risk of deforming the internal arrangement when it is centred is presented by flexion between the supports of this arrangement. In this configuration, the stresses are due to the total allowable mass (contents + arrangement)

The internal arrangement centred in the cavity rests on centring rings spaced at a distance L along the length of the arrangement.

To ensure a conservative approach, the moment is calculated based on a simple two ended supporting beam and is given according to <2>:

$$M = \frac{q\,L^2}{8}$$ in N.m (Table 3, Case 2 of <2>)

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Where:

- L: Length of the inter-spacer span, which is 300 mm
- q: Linear load calculated as follows:

$$q = \gamma.(m_{contents} + \frac{\pi}{4}.(D_e^2 - D_i^2).\rho)$$

Where:

- $m_{contents}$: The mass of the contents in kg/m of the cavity
- D_e: External diameter of the internal arrangement
- D_i: Internal diameter of the internal arrangement
- ρ: Density of the steel from which the arrangement is made, which is 7850 kg/m^3
- γ: Acceleration, which is [redacted] g

The maximum stress is given by:

$$\sigma = \frac{Mv}{I}$$

Where:

- v: Half height, which is $D_e/2$
- I: Moment of inertia calculated as follows:

$$I = \frac{\pi}{64}.(D_e^4 - D_i^4)$$

Based on the above relations, the minimum thickness is determined as a function of the mass of contents in order not to exceed the yield strength of the material at the temperature taken into account. Based on this thickness, the natural frequency associated with this internal arrangement is determined. Then, the β coefficient is calculated taking the impact period into account observed during the lateral drop (numeral calculation presented in the chapter 1-12) is 0,018 s. For this calculation, we consider in a penalizing way an impact duration of 0,022 s

$T = 2 \times 0.022 = 0.044$ s and $w = \frac{2.\pi}{T} = 143\ s^{-1}$

Then, the maximum dynamic factor of the structure is determined and it checks that the increase of the stress seeing by the arrangement, doesn't exceed the yield strength.

$$\sigma_{dynamique} = D_{max} \times \sigma_{statique}$$

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The natural bending frequencies of the internal arrangement can be calculated from the following relation:

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{\omega L^4}}$$ (Table 36, Case 1b of <2>)

Where:
- K_n: Constant of the mode of vibration
- E: Young's modulus in N/m^2
- I: Moment of inertia in m^4
- g: Gravitational acceleration in m/s ^{2}
- ω: Linear load in N/m (weight of the arrangement equipped with his load)
- L: Length of the beam between two supports taken as 400 mm

The constant K_n depends on the boundary conditions of the internal arrangement.

Supported/supported:	$K_n = 9.87$	(Table 36, Case 1b of <2>)
Recessed/recessed:	$K_n = 22.4$	(Table 36, Case 2b of <2>)
Recessed/free:	$K_n = 3.52$	(Table 36, Case 3b of <2>)

For the rest of the study, we shall consider the recessed/free case as it produces the weakest natural frequency of the configurations and is therefore the configuration which meets the amplification maximum.

Table 1A.1 sets out the minimum thicknesses of the internal arrangement made from steel in order to comply with the yield strength criteria as a function of the content mass for the internal diameters of 120 mm, 110 mm and
60 mm.

8.2 Strength of the Spacers

8.2.1 Compression strength during the lateral drop

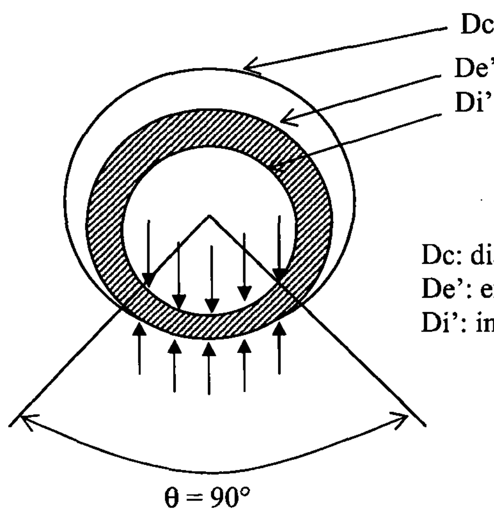
The thickness of the steel spacers is determined for the three diameters of the internal arrangement. This analysis is carried out taking into consideration that the load corresponding to the stresses is distributed over a total angle of 90° degrees over the thickness of the spacer and following a sine curve distribution.

We obtain the minimum thickness of the spacers of 19 mm, 18 mm and 16 mm for the internal arrangements of internal diameters of 120 mm, 110 mm and 60 mm respectively. The details of these calculations are shown in Appendix 1A.2.

To ensure a conservative approach, spacers' thickness is set 21 mm for all the internal arrangements.

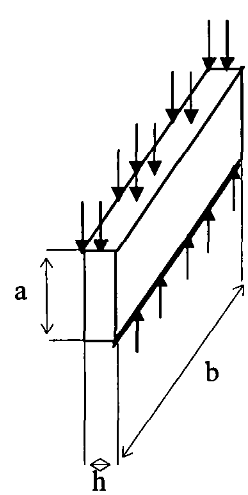
8.2.2 Buckling strength of spacers during the lateral drop

During a horizontal drop, the spacers rest on the cavity. The contact angle is worth 90°. The considered stresses are distributed on the angular sector and the spacer width (seeing the following picture)



Dc: diameter of cavity = 203 mm
De': external diameter of spacer= 200 mm
Di': internal diameter of spacer

To check the buckling strength of the spacer angular sectors, the considered model is a plate of which two opposite sides just are leaned and the two others are fixed (seeing the following picture).



According to <3>, the critical value of the compression stress for the buckling of rectangular plates is given by the relation:

$$\sigma_{cr} = \beta \frac{\pi^2.E.h^2}{12.b^2.(1-\upsilon^2)}$$

With :

- β : Coefficient depending on the ratio a/b (see table 17 of <3>)
  a = (De' – Di')/2 et b = ((Di' + De') / 4) x θ

Whatever the ratio a/b, $\beta \geq 7$. To ensure a conservative approach, β is considered equal to 7.

- E : Young's modulus
- h : spacer thickness = 21 mm
- ν : Poisson's ratio

The following tables show the numerical applications for the buckling stress, as a function of the internal arrangement diameter and the thickness e.

Steel arrangement of internal diameter 120 mm				
Thickness e in mm	**Di' in mm**	**b in mm**	**h mini in mm**	**σ_{px} in MPa**
1	122	126.4	21	31235
1.5	123	126.8	21	31041
3	126	128.0	21	30473
4	128	128.8	21	30102
5	130	129.6	21	29739
6	132	130.4	21	29381
7	134	131.2	21	29030

Steel arrangement of internal diameter 110 mm				
Thickness e in mm	**Di' in mm**	**b in mm**	**h mini in mm**	**σ_{px} in MPa**
3	116	124.1	21	32432
4	118	124.9	21	32025
5	120	125.7	21	31626
6	122	126.4	21	31235
7	124	127.2	21	30850

Steel arrangement of internal diameter 60 mm				
Thickness e in mm	Di' in mm	b in mm	h mini in mm	$\sigma_{p\chi}$ in MPa
3	66	104.5	21	45770
4	68	105.2	21	45090
5	70	106.0	21	44424
6	72	106.8	21	43773
7	74	107.6	21	43137
8	76	108.4	21	42514

The critical buckling stresses are very higher than the yield strength of the considered material. Thus, there is no risk of buckling.

8.2.3 Shear strength of welds between the spacer and the central pipe

Stress

During a axial or lateral drop, the spacer is subjected to his own weight. Whatever being the internal arrangement type (diameter of 60 mm, 110 mm or
120 mm), the envelope mass of a spacer is:

$M_{spacer} = (\pi /4).(De'^2 - Di'^2) \times h \times \rho$

With
- De' : external diameter of spacer = 200 mm
- Di: internal diameter of spacer = 63 mm (minimum)
- h: spacer width = 21 mm
- ρ: density of the steel = 7,850 kg/m^3

$M_{spacer} = 4.7$ kg

The maximum acceleration to take into account during the vertical drop is: $\gamma = 178$ g

So, the total stress applied to the spacer is:

$F = M_{spacer}.\ \gamma = 4.7 \times 178 \times 9.81 = 8208$ N

Resistance of weldings

Weldings correspond to a minimum apothem weld of 1 mm and a minimum length:

$$\ell \approx \pi.Di' = \pi.63$$

The strength inside the spacer welding get by the following formula :

$$\sigma = \frac{F/2}{0.85.\ell.a}$$

The justification of this formula is supplied in Appendix 1A.3.

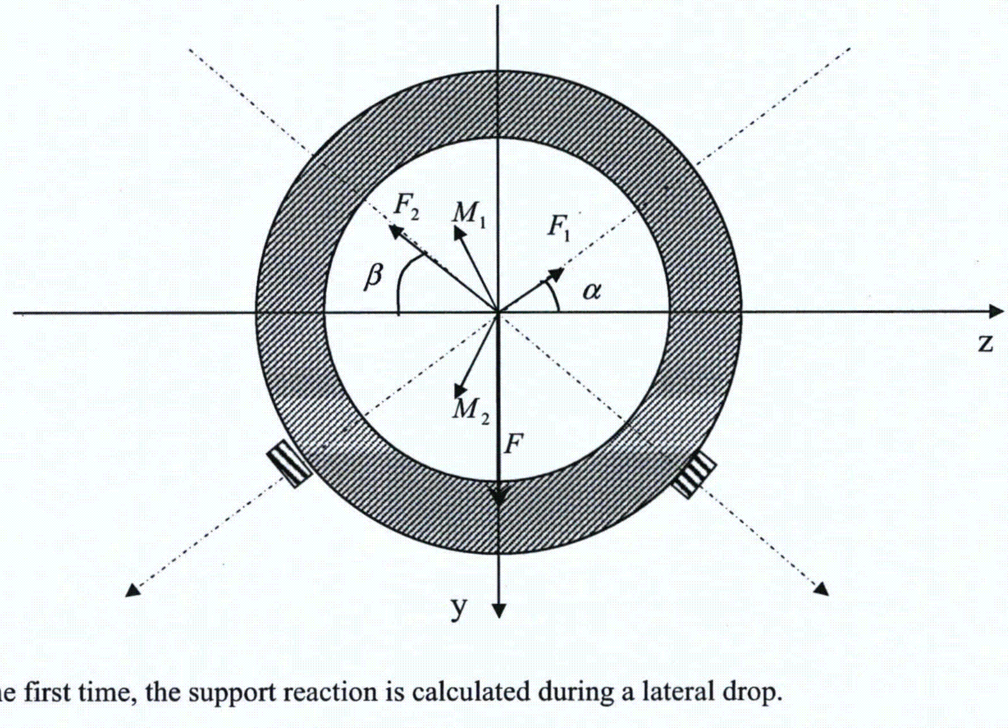
So, the value of the welding stress is :

$$\sigma = \frac{8208/2}{0.85 \times \pi \times 63 \times 10^{-3} \times 1 \times 10^{-3}} = 24.4 \text{ MPa}$$

This stress is lower than the yield strength of the stainless steel type X2CrNi19-11 at the maximum temperature of the case. So, there is no risk of welding shear.

8.3 Shoes effect

Bronze shoes are added on the canister spacers. External strengths on the central pipe act in the different plans which go through the axis of the central pipe. So, the result bending is a compound bending. F is equal to the strength for which the central tube bending is calculated. F_1 and F_2 are the strength on the bronze shoes (support reaction).



In the first time, the support reaction is calculated during a lateral drop.

Strengths projections on y and z:

On y : $F - F_1 \sin\alpha - F_2 \sin\beta = 0$ (1)
On z : $F_1 \cos\alpha - F_2 \cos\beta = 0$ (2)

The equation (2) gives:

$$F_2 = F_1 \frac{\cos\alpha}{\cos\beta}$$

Thus, the equation (1) becomes:

$$F - F_1 \sin\alpha - F_1 \frac{\cos\alpha}{\cos\beta} \sin\beta = 0$$

$$\Leftrightarrow F - F_1 \left(\frac{\cos\alpha \sin\beta + \sin\alpha \cos\beta}{\cos\beta} \right) = 0$$

So:

$$F_1 = F \frac{\cos\beta}{\sin(\alpha+\beta)} \text{ and } F_2 = F \frac{\cos\alpha}{\sin(\alpha+\beta)}$$

Next, the bending moment associated to F_1 and F_2 are projected on the axis (y) and (z):

On y : $-M_1 \cos\alpha + M_2 \cos\beta = M_y$ (3)
On z : $-M_1 \sin\alpha - M_2 \sin\beta = M_z$ (4)

The bending moment M_1 and M_2 are directly proportional to F_1 and F_2 respectively.

So:

$$M_1 = M \frac{\cos\beta}{\sin(\alpha+\beta)} \text{ from (1)}$$

$$M_2 = M \frac{\cos\alpha}{\sin(\alpha+\beta)} \text{ from (2)}$$

To replace M_1 et M_2 in (3) and (4), we have:

$$\begin{cases} M_y = -M \dfrac{\cos\beta \cos\alpha}{\sin(\alpha+\beta)} + M \dfrac{\cos\alpha \cos\beta}{\sin(\alpha+\beta)} = 0 \\ M_z = -M \dfrac{\cos\beta \sin\alpha}{\sin(\alpha+\beta)} - M \dfrac{\cos\alpha \sin\beta}{\sin(\alpha+\beta)} = -M \end{cases}$$

We deduce that the maximum stress associated to the central pipe bending when the canister is on the shoes, is equal to the maximum stress if the arrangement didn't have shoes.

9. CONCLUSION

The mechanical calculations concerning the strength of the internal arrangements (canisters) ensure that the maximum stress is less than the yield strength of the steel considered. The maximum allowable masses as functions of the thicknesses of the canisters are set out in Table 1A.1. In these conditions the diameters of the canisters described in Chapter 0A are preserved and can be used for the nuclear safety analysis.

The distance between two spacers must be 400 mm at the maximum. These spacers must be made from steel.

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<5> ASME IID Subpart 2

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AS A FUNCTION OF THE MASS OF THE CONTENTS

FOR AN INTERNAL DIAMETER OF 120 mm

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TABLE 1A.1 (page 2/3)

MINIMUM THICKNESS OF THE INTERNAL ARRANGEMENT
AS A FUNCTION OF THE MASS OF THE CONTENTS

FOR AN INTERNAL DIAMETER OF 110 mm

Proprietary information withheld pursuant to 10 CFR 2.390

TABLE 1A.1 (page 3/3)

MINIMUM THICKNESS OF THE INTERNAL ARRANGEMENT
AS A FUNCTION OF THE MASS OF THE CONTENTS

FOR AN INTERNAL DIAMETER OF 60 mm

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FIGURE 1A.1 (page 1/2)

DYNAMIC LOADING

(Semi-sine curve)

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EVOLUTION OF THE DYNAMIC AMPLIFICATION COEFFICIENT
FOR THE LATERAL DROP

Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1A.1 (page 2/2)

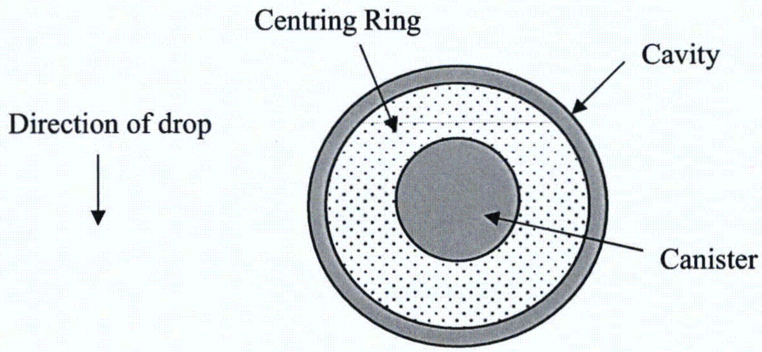
EVOLUTION OF THE DYNAMIC AMPLIFICATION COEFFICIENT
FOR THE LATERAL DROP

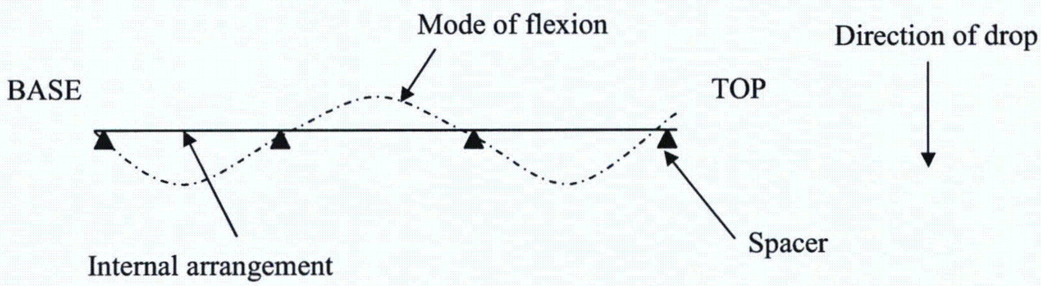
Proprietary information withheld pursuant to 10 CFR 2.390

FIGURE 1A.2

SCHEMATIC DIAGRAM OF AN INTERNAL ARRANGEMENT

CENTRED IN THE CAVITY





APPENDIX 1A-1

CALCULATION OF THE TEMPERATURES OF THE INTERNAL ARRANGEMENT

The calculation in normal conditions of transport produces a maximum packaging cavity temperature of 93°C for a maximum linear thermal power of the contents of 300 W/m (Chapter 2). The temperature of the internal arrangement is determined by taking account of the exchanges by conduction in the air and by radiation.

The temperature is calculated with the following assumptions:
- ✓ Heat exchanges by convection are disregarded,
- ✓ The temperature of the cavity is taken as ambient temperature,
- ✓ Conduction in the internal arrangement is disregarded,

The temperature of the internal arrangement is determined from the following equation:

$$P = \frac{\sigma \pi D\, \varepsilon_1 \varepsilon_2}{\left[1-(1-\varepsilon_2)(1-\varepsilon_1)\right]}(T_2^4 - T_1^4) + \frac{2\lambda_{air}\pi(T_2 - T_1)}{\ln\left(\frac{D_{cavity}}{D}\right)}$$

Index numbers 1 and 2 refer to the cavity and the internal arrangement respectively.

Where:

- λ_{air}=0.025 + 6.86 * 10^{-5}.(T_2+T_1)/2 with T_1 and T_2 expressed in °C.
- D: The internal diameter of the internal arrangement equal to 120, 110 and 60 mm (Chapter 0A)
- D_{cavity}: Internal diameter of the cavity equal to 0.203 m (Chapter 0)
- P: Linear internal power equal to 300 W/m (Chapter 0A)
- ε_i: Emissivity of body, i, which is 0.3 (Chapters 0 and 0A)
- σ: Stefan Bolzmann constant equal to 5.67 * 10^{-8} W/m^2 .K^4
- T_1: Maximum temperature of the internal cavity equal to 93°C (Chapter 2).
- T_2: Temperature of the canister.

Which gives:

	Diameter of 120 mm	Diameter of 110 mm	Diameter of 60 mm
Temperature T_2 of the internal arrangement	257°C	268°C	349°C

For the rest of the study, we will use the characteristics of the internal arrangements at 300 °C for diameters 110 mm and 120 mm, and 350°C for a diameter of 60 mm. The yield strengths at these temperatures are linearly extrapolated based on the characteristics presented in Chapter 0.

APPENDIX 1A.2 (page 1/2)

DETAILED ACCOUNT OF THE LOADING CORRESPONDING TO THE STRESSES IN THE SPACER

The maximum stress in the ring is determined by taking a constant distribution of the stresses over a total angle of 90° into account. To ensure a conservative approach, this stress is calculated for the internal radius of the ring taking into account that the latter is at the temperature of the canister under consideration.

The stress in the spacer is calculated as follows:

$$\sigma = \frac{F}{S} = \frac{F}{\frac{D_e}{2}.H.\theta}$$

where:

- F is calculated as follows:

$$F = (M_1 + M_2) \times \gamma$$

  - M_1: The mass of the canister for the inter-support length, which is

$$M_1 = \frac{\pi}{4}.(D_e^2 - D_i^2).\rho.L$$

  where:

    - D_e: External diameter of the internal arrangement
    - D_i: Internal diameter of the internal arrangement
    - ρ: Density of the steel from which the arrangement is made, which is 7,850 kg/m³
    - L: Distance between 2 supports, which is 300 mm

  - M_2: The mass of the contents, which is

$$M_2 = m_{contenu}.L$$

  where:

    - $m_{contents}$: Maximum mass of the contents for the canister considered

  - γ : acceleration which is [redacted] g

- H: Thickness of the spacer

- θ : The angle of distribution of the load on the ring, which is 90°.

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APPENDIX 1A.2 (page 2/2)

DETAILED ACCOUNT OF THE LOADING CORRESPONDING TO THE STRESSES IN THE SPACER

The minimum thickness of the spacers is determined so that the stress in the ring is less than the yield strength of the steel at the temperature considered:

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APPENDIX 1A.3 (page 1/2)

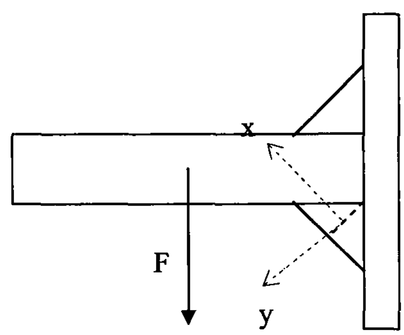
CALCULATION OF THE STRESS IN THE SPACERS WELDINGS

According to the rules CM 66 (reference <4>) :

$$\sqrt{(\sigma^2 + 1{,}8(\tau_\perp^2 + \tau_{//}^2)} \leq \alpha Re \quad \text{equation (1)}$$

with

- α: Coefficient of reduction, according to the weld apothem a (in mm) $\alpha = 1$ for $a \leq 4$ mm
- σ: Component of the average stress perpendicular to the plane bisecting to the weld (x axis)
- $\tau_\perp$: Component of the average stress in the plane bisecting to the weld perpendicular to the weld longitudinal axis (y axis)
- $\tau_{//}$: Component of the average stress, in the plane bisecting to the weld, parallel to the weld longitudinal axis (z axis perpendicular to the sectional drawing). In this particular case, this stress is equal to zero.



F is the strength seing by the spacer during the drop. Each weld endures the strength F/2.

The component of the average stress perpendicular to the plane bisecting to each weld is (in projecting on x axis):

$$\sigma = -\frac{F/2}{a.\ell} \times \frac{\sqrt{2}}{2}$$ where ℓ is the weld length.

The component of the average stress in the plane bisecting to the weld perpendicular to the weld longitudinal axis is (in projecting on y axis)

$$\tau_\perp = \frac{F/2}{a.\ell} \times \frac{\sqrt{2}}{2}$$

APPENDIX 1A.3 (page 2/2)

CLACULATION OF THE STRESS IN THE SPACERS WELDINGS

In replacing in the equation (1), we have:

$$\frac{F^2/4}{a^2.\ell^2}\times\frac{1}{2}+1{,}8\times\frac{F^2/4}{a^2.\ell^2}\times\frac{1}{2}\leq Re^2$$

$$\frac{F^2/4}{a^2.\ell^2}\times\left(\frac{1}{2}+1{,}8\times\frac{1}{2}\right)\leq Re^2$$

$$\frac{F/2}{a.\ell}\times\sqrt{\left(\frac{1}{2}+1{,}8\times\frac{1}{2}\right)}\leq Re$$

So:

$$\frac{F/2}{0{,}85.a.\ell}\leq Re$$

THERMAL ANALYSIS OF THE PACKAGING

CONTENTS

REVISION STATUS

Revision	Date	Modifications	Prepared by / Verified by
Ref. : 5573-Z-2E			
0	10/99	First issue	D. HUILLIER / F. PETIT
Ref. : DOS-08-00126114-200			
00	08/08	New document reference. New formalism. Assessment of the inner shell temperature for a loads with a low thermal power, lower than 2 W. Justification of the resin thickness value disappeared during the ACT. Temperature got with an outer shell emissivity of 0.8 is taken into account. Assessment of the extrusion risk of seals Resin « Vyal B » taken into account. Presentation of temperatures further at the incorporate of the punching around the orifice B closure plate and the revolving plug Presentation of the safety float on temperatures of different packaging components. Appendix 2-3 taken into account: calculation of the intermediate power. Integration of fax CEX-06-00025365 and CEX-06-00033669 : calculation at low and reduced powers	S. CHEVET / JC. BOTT
01	06/11	Translation of the document DOS-06-200032898-200 rev 2 Evaluation of the inner shell temperature for a load with a total thermal power of 5W and a linear power of 70 W/m of cavity length.	B. GSIB/C. GRANDHOMME
02	02/13	Translation of the document DOS-06-200032898-200 rev 3 Decrease in thermal power within the packaging - from 500 to 300 W/m. Integration of minimum localised power of 100 W Removal of low powers (2 & 10 W) and electro-polishing of outer packaging shell. Risk evaluation for self-combustion of cover wood Calculation of seal service lives	R. BAHOU / D. HONDAGNEU

SUMMARY

The TN 106 packaging is designed to dissipate the residual thermal power of radioactive content under normal and accidental transport conditions, while maintaining acceptable temperatures in the packaging.

The thermal analysis of the TN 106 is presented in this chapter according to the regulatory requirements. It consists of:

- determining the maximum temperatures reached by the various components of the packaging under normal and accidental transport conditions.

- checking that, for the maximum acceptable power, the temperature on the surface of the packaging does not exceed 85°C (excluding exposure to sunlight).

Essential parameters :

Several cases of thermal loading are considered:

- loading with linear power of 300 W/m (maximum power),

- localised loading of 100 W (any position).

For a load of a linear power of 70 W/m in the cavity (reduced power), we determine the temperature of the inner shell and the seals from the temperatures obtained for the case of a load with maximum linear power of 300 W/m.

The geometry of the packaging used for the modelling is that of the design plan in appendix 0-1.

The thermal properties of the materials are given in table 0.5 in chapter 0.

The limit conditions are those imposed by regulation <7>.

Hypotheses and methods used:

The packaging is in a horizontal position for all the calculations. This position corresponds to the transport position for normal transport conditions. The justification of the penalising character of this position under accidental transport conditions is given in appendix 2-2.

Under normal and accidental transport conditions, the packaging is placed in free air.

Under accidental conditions, the influence, at the temperatures of the components, of puncturing a cover close to the revolving plug closure plate or orifice B is analysed.

The thermal calculations were carried out using a 3-D calculation model according to a half-structure of the packaging. The revolving plug is modelled by a cylinder with an equivalent volume of air.

The extremities of the packaging may be considered as adiabatic due to the presence of covers.

The calculations for the packaging were performed using the I-DEAS software.

The thermal evaluations under normal transport conditions are presented in appendix 2-1 and in the same chapter (reduced linear power of 70 W/m).

The thermal evaluation under ACT is presented in appendix 2-2.

Results and conclusions:

The thermal behaviour of the TN 106 packaging transporting:

- a load with a linear power of 300 W/m (maximum power) divided over the entire cavity,
- localised loading of 100 W (any position),
- a load of linear power of 70 W/m in the cavity (reduced power),

is acceptable under normal and accidental transport conditions.

In particular, it has been demonstrated that:

- the temperature reached by the seals is acceptable and the confinement of the radioactive material is retained after a fire test,
- the temperature of the lead is below its melt temperature, therefore protection against radiation is retained,
- the temperature on the surface of the packaging, excluding exposure to sunlight, is always below 85°C.

It is also demonstrated that the rate of filling the grooves for the seals in the containment chamber remains limited under NCT & ACT (less than 108%).

1. SUBJECT

The TN 106 packaging is designed to dissipate the residual thermal power of radioactive content under normal and accidental transport conditions, while maintaining acceptable temperatures in the packaging.

The thermal analysis of the TN 106 is presented in this chapter according to the regulatory requirements. It consists of:

- determining the maximum temperatures reached by the various components of the packaging under normal and accidental transport conditions.
- checking that, for the maximum acceptable power, the temperature on the surface of the packaging does not exceed 85°C (excluding exposure to sunlight).

Several cases of thermal loading are considered:

- loading with linear power of 300 W/m (maximum power),
- localised loading of 100 W (any position).

For a load of a linear power of 70 W/m in the cavity (reduced power), we determine the temperature of the inner shell and the seals from the temperatures obtained for the case of a load with maximum linear power of 300 W/m.

2. CALCULATION METHODS

The calculations for the packaging were performed using the I-DEAS <1> and TMG software. This software is widely used throughout the mechanical and thermal fields and is fully qualified.

3. THERMAL LOADING AND ASSUMPTIONS

Under NCT & ACT, several different thermal power cases are studied (see paragraphs below).

3.1 Maximum power: 300 W/m

The maximum linear thermal power of the packaging contents is defined, in Chapter 0A, as 300 W/m. For a worst case scenario, the linear power is applied to the radial cavity walls, giving a surface power of 470.4 W/m². An additional power of 30.5 W is applied to the back and head of the cavity, corresponding to the same surface power imposed on the radial cavity walls.

Loads under normal conditions of transport are studied in Para. 2-1.

Loads under accident conditions of transport are studied in Para. 2-2.

3.2 Intermediate power: 100 W

The total thermal power of the packaging contents is 100 W. This loading is studied under three different configurations:

- Configured with the power towards the back: a power of 100 W is applied to the axial walls (back end) of the cavity in order to maximise the temperatures of the seals in the back of the packaging (back lid, back closure plate and Orifice B),
- Configured with the power towards the front: a power of 100 W is applied to the axial walls (front end) of the cavity in order to maximise the temperatures of the seals in the top of the packaging (front lid, front closure plate, orifice A and revolving plug closure plate),
- Configured with the power towards the centre: a power of 100 W is applied to the central section of the cavity in order to maximise the temperature of the resin.

Loads under normal conditions of transport are studied in Para. 2-1.

Loads under accident conditions of transport are studied in Para. 2-2. This load condition is however covered by the 300 W/m loading.

3.3 Reduced power: 70 W/m

The maximum thermal power for the content is 70 W/m.

Loads under normal conditions of transport are studied in Para. 7-2.

Loads under accident conditions of transport are studied in Para. 8-2.

3.4 Assumptions

3.4.1 Packaging position

The packaging is assumed in a vertical position under NCT & ACT.

In fact, the packaging is transported in a horizontal position and it has been shown (in Appendix 2.2) that this is the worst possible situation for ACT.

3.4.2 Normal Conditions of Transport

3.4.2.1 <u>Exposure to sun</u>

The sunlight exposure is applied to the outer surfaces as per the regulations for the transportation of radioactive materials <7>.

The calculations assume exposure for 12 hours per day as per regulations.

3.4.2.2 <u>Ambient temperature</u>

Ambient temperature under normal conditions of transport is 38°C.

3.4.3 Accident conditions of transport

Under ACT the packaging is originally at the temperature determined under normal conditions as it is directly exposed to the fire: ambient temperature of 800°C for 30 Min with a return to a permanent regime.

The regulatory sunlight exposure (as per <7>) to be applied for 12 hours per day across the whole outer surface of the packaging is 400 W/m² and 200 W/m² for the vertical surfaces.

The calculations assume, for a worst case scenario, sunlight exposure of 24 hours a day during the cooling phase.

Ambient temperature during the cooling phase is 38°C.

The study for ACT is presented in appendix 2-2.

3.4.4 Self-combustion of the wood in the shock absorbing covers

The energy provided by the combustion of the covers is negligible and is thus ignored for the thermal analyses in Chapter 2.2. This assumption is shown by a test presented in the report included in Reference 9, which is representative of the shock absorbing covers fitted to the TN106, as shown in the table below:

	Cover volume (m^3)	**Surface of outer casing (m^2)**	**Ratio of surface area to volume**
Test cover (See <9>)	0.18	2.23	12.54
TN 106	0.97	6.87	7.10

As the surface to volume ratio calculated for the test cover is higher than that of the TN 106 covers, the part of the cover exposed to the heat during thermal testing is larger than on the TN 106 packaging cover.

It has also been shown in <10> that the cover for the thermal test <9> shows more damage than noted during the drop test on the TN 106 packaging.

Moreover, none of the other packaging materials are combustible.

4. THERMAL EXCHANGES

The thermal power of the contents of the packaging is diffused radially, by conduction, through the steel inner shell, the lead lining, the neutron-absorbing resin and finally through the outer steel shell, in so far as the axial surfaces are considered adiabatic, the axial heat exchanges are negligible. In order to study the impact of potential calcination of the resin during the fire test, the [redacted] mm layer of resin is reduced to [redacted] mm for the impact study (See Appendix 2-2).

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The thermal exchanges between outer shell and the environment are by natural convection and radiation.

The thermal power absorbed from the exposure to sunlight is applied to the outer surfaces of the packaging not protected by the covers during ACT & NCT.

5. CALCULATIONS AND MODELLING METHODS

The thermal calculations were carried out using a 3-D calculation model. Just half the structure was modelled, thanks to the symmetrical nature of the packaging.

The geometry of the packaging used for the modelling is that of the concept drawing in appendix 0-1.

The extremities of the packaging may be considered as adiabatic due to the presence of the wooden covers. Under ACT the impact of the puncturing of the wood is included.

The thermal properties of the materials are given in table 0.5 in chapter 0.

6. ACCEPTANCE CRITERIA

The temperatures within the packaging must remain acceptable for the materials used. These temperatures are given in the table 2.1.

If the maximum surface temperature of the packaging (when in shade) exceeds 50°C, the packaging must use dedicated transportation. If this temperature exceeds 85°C a protective barrier must be used to prevent access to to the outer structure of the packaging.

7. THERMAL ANALYSIS UNDER NORMAL CONDITIONS OF TRANSPORT

7.1 Maximum power (300 W/m)

7.1.1 Packaging component temperatures

The presentation of this analysis can be found in Appendix 2.1.

The principal results of this analysis alongside the acceptance criteria can be found in Table 2.2. The conclusion of the analysis is that the TN106 packaging meets all regulatory requirements:

- Maximum seal temperature of 88.4°C; lower than the operational temperature limit of 220°C.
- Maximum resin temperature of [redacted] °C; lower than the operational temperature limit of [redacted] °C.
- Maximum lead temperature of [redacted] °C; lower than the melting point of the lead [redacted] °C).
- The maximum temperature of the outer surface of the TN106 packaging is therefore 79.7°C.

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– The maximum temperature of the inner shell is 91.9°C.

7.2 Reduced power (70 W/m)

This paragraph shows the temperature calculations for the outer surfaces of the packaging with linear power levels of 70 W/m. The regulatory sunlight exposure to be applied for 12 hours per day across the whole outer surface of the packaging is 400 W/m² for curved surfaces.

7.2.1 Calculating the temperature of the outer surfaces T_s

The density of the solar flux hitting the surface is:

$$\varphi_s = a \times E$$

where:

a: solar absorptivity of stainless steel = 0.4

E: solar flux density = 400 W/m²

Hence:

φ_s = 160 W/m^2.

The thermal balance of the packaging when exposed to the regulatory sunlight levels and with a loading of 300 W:m is therefore:

$$\varphi_s + \frac{P_l}{\pi.D} = \sigma.\varepsilon.(T_s^4 - T_e^4) + h.(T_s - T_e)$$

where:

φ_s : solar flux density on surfaces = 160 W/m^2

P_l : linear load power = 70 W/m

D: outer diameter = 820 mm

ε: emissivity of shell steel = 0.3

T_s: Temperature of outer shell

T_e: External temperature = 311 K

σ: Boltzmann Constant ($\sigma = 5.67\times10^{-8}$ W/m².K^4)

h : coefficient of convection for a horizontal cylinder $h = 1.22\ \Delta T^{1/3}$

Solving this equation gives T_s = 342 K or 69 °C.

7.2.2 Calculating the temperature of the inner shell T_{int}

The calculations for the temperature of the inner shell (T_{int}) for a linear power loading of 70 W/m is backd upon:

- The temperature of the outer surface T_s calculated in Paragraph 7.2.1.
- The calculation of the temperature gradient (ΔT) between outer and inner shells for the linear power loading of 300 W/m.

The temperature gradient (ΔT) (by conduction) between the inner and outer shells during NCT for a linear power of 300 W/m (See Appendix 2.1) is:

$$\Delta T = 91.9 - 79.7 = 12.2°C.$$

For a linear power of 70 W/m, this gives:

$$\Delta T' = 12{,}2 \times \frac{70}{300} = 2{,}9 \text{ °C.}$$

The temperature of the inner shell (T_{int}) is therefore:

$$T_{int} = T_s + \Delta T' = 69 + 2.9 = 71.9 \text{ °C}$$

For a worst case scenario we increase the inner shell temperature to 72°C.

In addition, acting conservatively we add the temperature of the packaging seals to that of the inner shell.

7.3 Safety margins for the temperatures of the various component parts of the packaging under NCT

The coefficient of convection used in the analysis for the packaging is h) $1.22.\Delta T^{1/3}$ (in W/m².K). Experience shows that the coefficients of convection for horizontal cylinders are generally around $1.7.\Delta T^{1/3}$ The calculation is therefore harsher in terms of convection-backd heat exchanges.

8. THERMAL ANALYSIS UNDER ACCIDENT CONDITIONS OF TRANSPORT

8.1 Packaging component temperatures

This analysis is presented in appendix 2.2 where a transitional analysis is carried out to evaluate the thermal behaviour of the TN106 during the fire test, as per regulatory requirements <7> (fire at 800°C for 30 min.).

The packaging is modelled without any distortions following the mechanical tests for ACT. This is justified by the mechanical study in Chapter 1.

The packaging is modelled in a horizontal position prior to and after the fire ($h = 1.22.\Delta T^{1/3}$). The fact that this position is harsher than a vertical positioning is proven in Appendix 2.2.

The packaging is initially in a thermal balance situation calculated for NCT. After the fire, the exposure to sunlight is taken into account using conservative hypotheses.

The following analyses are provided:

- Initial analysis with:
  - covers intact,
  - emissivity of outer shell during and after the fire equal to 0.8.
- Second analysis with:
  - the puncturing of a shock absorbing cover around Orifice B closure plate or the revolving plug, caused by a drop onto a bar: in the calculation model the wood is removed from a section of the cover around the closure plate.
- Third analysis with:
  - Calcination of the resin, a thickness of [redacted] mm

These analyses are presented in Appendix 2-2. The results of these calculations show that the puncturing of the shock absorbing back cover in the vicinity of Orifice B (worst case) increases the maximum temperatures in the back cover and the Orifice B seal, without impacting on the maximum temperatures of the other component parts of the packaging.

The maximum temperatures in the packaging and the acceptance criteria are shown in Table 2.3. The conclusion of the analysis is that the temperatures reached within the TN 106 packaging during a fire are acceptable in terms of the resistance of the materials.

In a worst case scenario, the increased temperature of the closure plate & orifice B is used to evaluate the temperature of the revolving plug closure plate if the cover is punctured in the vicinity of the closure plate.

- The maximum seal temperature is 179°C (with puncture - See Appendix 2.2). This value remains below the operational limit of 220°C.
- The maximum temperature of the lead is [redacted]°C in the centre of the packaging. This value remains below the melting point of lead (327°C).
- The maximum temperature of the inner shell is 152.8°C.

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8.2 Temperature of the inner shell for a linear thermal power load of 70 W/m

For a load with a maximum linear power of 300 W/m, the maximum inner shell temperature is 91.9 °C under normal conditions of transport (Table 2-2) and 152.8 °C under accident conditions of transport (Table 2-3). The increased temperature in the inner shell between the two phases is therefore ΔT = 60.9 °C. For a worst case scenario we increase this figure to 61°C.

For a worst case scenario we use this temperature gradient across the inner shell for linear thermal power loads of 70 W/m. The temperature of the inner shell and the seals under normal conditions of transport with such a power is 72 °C (See Para.7.2.2). As a consequence, the temperature of the inner shell and seals under accident conditions of transport reaches a maximum of 72 + ΔT = 133 °C.

Therefore, the temperature of the inner shell and seals is 133 °C.

8.3 Safety margins for the temperatures of the various component parts of the packaging under ACT

During cooling, regulatory sunlight exposure figures should be applied for 12 hours per day. The changes to Appendix 2-2 assumes permanent sunlight exposure.

9. DECREASE IN THE THICKNESS OF THE RESIN FOR ACT

It has been shown, in the test report (Ref. <3>) that, during a fire test to represent ACT, with the inter positioning of a 1 mm steel plate between the flames and the resin, the resin is damaged through a thickness of [redacted] mm.

In terms of the TN 106 packaging, the resin is [redacted] mm deep and covered by a steel shell which in turn is [redacted] mm thick. On the basis of the fire test defined above, it is therefore a worst case scenario to consider a [redacted] mm thickness of resin to be damaged.

Thus, we can assume that the removal of [redacted] mm of resin for the sub-criticality tests on the TN 106 for a damaged packaging is a globally enveloping figure.

The impact on the temperatures of the TN 106 packaging of a loss of [redacted] mm of resin is studied in Appendix 2.2.

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10. ANALYSIS OF THE RATE OF FILLING OF THE SEAL GROOVES.

This paragraph presents the calculations for the rate of filling of the o-ring grooves used to seal the containment casing of the TN 106 at temperatures achieved during NCT & ACT.

As a conservative estimate this study was carried out at maximum power (300 W/m), that is to say, with a thermal loading leading to the highest temperatures.

10.1 Input data

O-rings

The temperatures of the seals are calculated in Appendices 2.1 & 2.2. For a worst case scenario we increase the respective temperatures to 89°C for NCT and 179°C for ACT.

The dilatation coefficient for the types of EPDM seals used (see Chapter 0) is taken from <8> for a packaging model with authorisation, a global figure of 5.15×10^{-4} K^{-1}.

The dimensions of the seals are taken to be the maximum tolerated values: these are given in Chapter 0 & summarised in Table 2.4.

Grooves

For a worst case scenario the dilatation of the groove is ignored. The parameters needed to define the trapezoidal grooves are given in Figure 2.1.

The dimensions and tolerances of the trapezoidal grooves are taken from Chapters 0 & 0.1 and presented in Table 2.4. The groove dimensions are assumed at their minimum tolerated levels.

10.2 Presentation of the calculations

The calculation for the volume of a seal in a trapezoidal groove is given in the calculation appendix at the end of this document.

10.3 Results

Table 2.5 presents the rate of filling for the o-ring seal trapezoidal grooves at high temperatures

The calculated values also show that the rate of filling of the grooves for the seals in the containment chamber remains limited under NCT & ACT (less than 108%).

11. OPERATIONAL LIFE EXPECTANCY OF THE SEALS

The aim of this paragraph is to determine the level of damage to the EPDM seals used in order to assure that the packaging remains leak tight following cumulative exposure:

- for a period of three years continuously (*) under Routine Conditions of Transport

– for a period of seven days under Accident Conditions of Transport.

(*) within the framework of the periodic maintenance carried out on the TN 106 the seals should be replaced at least every 3 years (See Chapter 7A). The scenario in question is therefore coherent with the actual utilisation of the packaging.

The service life of the seals subjected to a constant temperature is expressed in <11> & <12>:

- $L\,(\text{en heures}) = 5{,}15.10^{-32} \times \exp\left(\dfrac{317638}{R.T}\right)$ For EP8517 (French Seal)
- $L\,(\text{en heures}) = 2{,}00.10^{-12} \times \exp\left(\dfrac{137314}{R.T}\right)$ for 48DRL13 (STACEM)

Where: T is the temperature of the seal (K)

R is the perfect gas constant $R = 8.314\ J.mol^{-1} \cdot K^{-1}$

The maximum seal temperatures under NCT & ACT are, respectively, 89°C and 179°C (See Paragraphs 7.1.1 and 8.1)

The cumulative damage level is calculated as follows:

$$d = \frac{t_{CRT}}{L(T_{CRT})} + \frac{t_{CAT}}{L(T_{CAT})}$$

Where: t_{RCT} = 365 days (8760 hours)

t_{ACT} = 7 days (168 hours)

-The results are given in the following table:

	Exposure duration for seals	Damage	
		Type EP8517 (French seal)	Type 48DRL13 (STACEM)
Routine conditions of transport: 89 °C (Value taken from Chapter 2-1)	3 years	$8x10^{-11}$	$2x10^{-6}$
Accident Conditions of Transport: 179 °C (Value taken from Chapter 2-2)	7 days	0.1	0.02
Cumulative damage		0.1	0.02
Criterion		1	

The cumulative damage is therefore:

less than 0.1 < 1 - For EP8517 (French Seal)

less than 0.02 < 1 - for 48DRL13 (STACEM)

The above damage levels are extremely low. As a consequence, the resistance of the seals is guaranteed for their entire service life.

12. CONCLUSION

The thermal behaviour of the TN 106 packaging transporting:

- A loading with a linear power of 300 W/m (maximum power),
- localised loading of 100 W (any position),
- a load of linear power of 70 W/m in the cavity (reduced power),

is acceptable under normal and accidental transport conditions.

In particular, it has been demonstrated that:

- the temperature reached by the seals is acceptable and the confinement of the radioactive material is retained after a fire test,
- the temperature of the lead is below its melt temperature, therefore protection against radiation is retained,
- the temperature on the surface of the packaging, excluding exposure to sunlight, is always below 85°C.

It is also demonstrated that the rate of filling the grooves for the seals in the containment chamber remains limited under NCT & ACT (less than 108%).

13. REFERENCES

<1> Finite element calculation software: NX I-DEAS 5M3 TMG 5.0.974 developed by Siemens PLM software

<2> Deleted

<3> Test Report No. L200 445 dated 25th May 2000

<4, 5, 6> Deleted

<7> Applicable IAEA regulations: See Chapter 00

<8> Mail – ASN – Ref. ASN DGSNR/SD1/D533/2005 dated 21st July 2005

<9> Note – COGEMA LOGISTICS – ref. DT 03-R-1 Rev. 0 : Thermal test report on shock absorbing cover model

<10> Mail – COGEMA LOGISTICS – Ref. S/05-086 dated 18th Nov. 2005

<11> Mail – ASN – Ref. ASN/DIT/0061/2009 dated 28th Jan. 2009

<12> Mail – TN International – Ref. CEX-09-00136347-079 dated 28th July 2009

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TABLE 2.1

ACCEPTANCE CRITERIA

Elements	Normal Conditions of transport	Accident Conditions of transport
Outer shell	85[1]	-
Resin	[redacted]	-
Lead	[redacted]	327
Seals	220	220

(1) Packaging out of the sun and uncased

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

TABLE 2.2

NORMAL CONDITIONS OF TRANSPORT
PRINCIPAL RESULTS

Maximum power (300 W/m)

300 W/m	T_{max} (°C)	Criteria (°C)
Packaging		
Lead	[redacted]	327
Resin	[redacted]	150
External surface of the packaging	79.7	85(1)
Inner shell	91.9	-
Seal		
Revolving plug	84.1	220
Front lid	83.7	
Back lid	88.4	
Orifice A	83.8	
Orifice B	88.1	
Front closure plate	84.0	

(1) Packaging not exposed to direct sunlight

Power 100 W (regardless of position)

100 W	T_{max} (°C)	Criteria (°C)
Packaging		
Lead	[redacted]	327
Resin	[redacted]	150
External surface of the packaging	73.1	85(1)
inner shell	81.8	-
Seal		
Revolving plug	76.6	220
Front lid	76.5	
Back lid	80.9	
Orifice A	76.6	
Orifice B	80.1	
Front closure plate	76.8	

Reduced power (70 W/m)

70 W/m	T_{max} (°C)	Criteria (°C)
External surface of the packaging	69	85(1)
inner shell	72	-
Seals	72	220

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TABLE 2.3

ACCIDENT CONDITIONS OF TRANSPORT (FIRE)
PRINCIPAL RESULTS

Maximum power (300 W/m)

300 W/m	T_{max} (°C)	Criteria (°C)
Packaging		
Lead	[redacted]	327
inner shell	152.8	-
Seal		
Revolving plug	179.0 (1)	220
Front lid	115.9	
Back cover	118.8	
Orifice A	116.1	
Orifice B	162.0 (2)	
Front closure plate	116.5	

(1) Including puncturing of the cover around the revolving plug closure plate
(2) Including puncturing of the cover around the orifice B closure plate

Power 100 W (regardless of position)

100 W	T_{max} (°C)	Criteria (°C)
Packaging		
Lead	[redacted]	327
inner shell	143.8	-
Seal		
Revolving plug	128.1	220
Front lid	109.7	
Back lid	112.5	
Orifice A	109.9	
Orifice B	111.6	
Front closure plate	110.3	

Reduced power (70 W/m)

70 W/m	T_{max} (°C)	Criteria (°C)
inner shell	133	-
Seals	133	220

Shaded Areas are Proprietary Information Withheld Pursuant to 10 CFR 2.390

TABLE 2.4

DIMENSIONS OF SEAL GROOVES IN CONTAINMENT CASING FOR TN 106 PACKAGING

Proprietary information withheld pursuant to 10 CFR 2.390