ANALYSIS OF THE BEHAVIOUR OF THE DROPPED PACKAGE MODEL BETWEEN -40°C AND THE MAXIMUM TEMPERATURE UNDER NORMAL TRANSPORT CONDITIONS

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SUMMARY

This chapter presents the study of the influence of temperature on the mechanical strength of the dropped packaging.

It is shown that the mechanical strength of the packaging under accident drop conditions is guaranteed by considering the maximum temperature reached under normal transport conditions determined in Chapter 2 and at -40°C.

For the various 9 m drop configurations under accident transport conditions, the methodology used is as follows:

- drop tests were carried out on a ½ scale model of the packaging. The drop test report is given in Chapter 1-6 and the analysis of drop tests is given in Chapter 1-7,
- <u>oblique drop</u>: refitting of the oblique top-down drop test is carried out on the ½ scale mockup. The refitted model is extrapolated to T_{NCT} and -40°C to demonstrate the resistance at temperature.
- <u>axial drop</u>: the refitted model of the oblique drop is used for an axial top-down drop configuration and is extrapolated to T_{NCT} and -40°C to demonstrate the resistance at temperature,
- <u>lateral drop</u>: refitting of the lateral drop test is carried out on the ½ scale mockup. The refitted model is extrapolated to T_{NCT} and -40°C to demonstrate the resistance at temperature.

The mechanical strength of the packaging is demonstrated for each drop configuration. The following are determined in particular:

- plastic strains in the body, the lid and its attachment screws and residual detachment of the lid so as to guarantee that the package remains leak-tight,
- The maximum accelerations applied to the packaging, to show the resistance of the internal fittings and radioactive contents in Chapter 1A.

The strength and leak-tightness of the TN-MTR packaging are guaranteed for the range of temperatures that occur under normal transport conditions.

Maximum accelerations to be considered for the mechanical design of internal fittings and fuel elements are as follows:

- for the axial drop: [redacted] in bottom-down drop and [redacted] in top-down drop,
- for the lateral drop: [redacted]

The maximum residual detachment of the lid to be used for activity release analyses under accident transport conditions is 0.042 mm.

1. PURPOSE

This chapter presents the study of the influence of temperature on the mechanical strength of the dropped packaging.

It is shown that the mechanical strength of the packaging under accident drop conditions is guaranteed by considering the maximum temperature reached under normal transport conditions determined in Chapter 2 and at -40°C.

For the various 9 m drop configurations under accident transport conditions, the methodology used is as follows:

- drop tests were carried out on a ½ scale model of the packaging. The drop test report is given in Chapter 1-6 and the analysis of drop tests is given in Chapter 1-7,
- oblique drop: refitting of the oblique top-down drop test is carried out on the ½ scale mockup. The refitted model is extrapolated to T_{NCT} and -40°C to show the resistance at temperature.
- axial drop: the refitted model of the oblique drop is used for an axial top-down drop configuration and is extrapolated to T_{NCT} and -40°C to demonstrate the resistance at temperature,
- lateral drop: a calibration of the lateral drop test carried out on the ½ scale mockup. The refitted model is extrapolated to T_{NCT} and -40°C to show the resistance at temperature.

The mechanical strength of the packaging is demonstrated for each drop configuration. The following are determined in particular:

- plastic strains in the body, the lid and its attachment screws and residual detachment of the lid so as to guarantee that the package remains leak-tight,
- The maximum accelerations applied to the packaging, to show the resistance of the internal fittings and radioactive contents in Chapter 1A.

2. TOP-DOWN OBLIQUE DROP

The worst oblique drop configuration is determined in Chapter 1-6. This is a 9 m oblique drop on the top shock absorbing cover with the centre of gravity vertically in line at the impact point corresponding to drop No. 4 in Chapter 1-6. This drop configuration maximises loads on the closing system.

2.1. Drop tests

Maximum accelerations on the full scale model at ambient temperature (≈20°C) are determined in Chapter 1-7 starting from accelerations recorded on the ½ scale mockup. The maximum acceleration is obtained on the top end and is equal to [redacted] along the horizontal axis.

2.2. Resistance at temperature

Numerical refitting of the 9 m oblique drop for the ½ scale mockup (drop No. 4 in Chapter 1-6) is described in Appendix 1-9-1.

The refitted numerical model is used for the packaging to study the impact of the changes in the mechanical properties of the materials at temperatures (T_{NCT} and -40°C) on the mechanical strength of the packaging (Chapter 1-9-2).

The influence of the following parameters is studied:

- package temperature (-40°C and T_{NCT}).
- the preload on the lid attachment screws (minimum and maximum preload taking account of tightening uncertainties).

The detailed results are given in Chapter 1-9-2.

The maximum acceleration reached by the package is obtained at T_{NCT} and is equal to [redacted]

The main conclusions of this study are as follows:

- overall, the wood in the shock absorbing covers does not reach the crush limit,
- the residual maximum detachment of the plug in the seal area is 0.042 mm.
- there is no plastic strain on the seal contact surface and plastic strains in the screw body are negligible, therefore the leak-tightness of the package is not affected,
- the preload in the lid screws is maintained.

Therefore the integrity of the closing system of the TN-MTR packaging is guaranteed after a 9 m oblique drop on the top shock absorbing cover representative of accident transport conditions. The packaging remains leak-tight.

2.3. Conclusions

The strength of the TN-MTR packaging under a 9 m oblique drop is demonstrated.

The maximum acceleration to be considered in an oblique drop for the design of internal fittings and fuel elements is [redacted]. However, this acceleration is not the design basis because it is bounded by accelerations obtained in an axial drop and in a 9 m lateral drop (see § 3 and 4).

The maximum residual detachment of the lid in the zone of the seals to be considered for activity release analyses under accident transport conditions is 0.042 m.

3. AXIAL DROP

3.1. Top-down axial drop

The top-down axial drop configuration is conservative considering the loads on the closing system.

3.1.1. Drop tests

The maximum acceleration on the full scale packaging at ambient temperature (≈20°C) is determined in Chapter 1-7 based on the accelerations recorded on the ½ scale mockup and is equal to [redacted]

3.1.2. Resistance at temperature

Numerical refitting of the 9 m oblique drop for the ½ scale mockup (drop No. 4 in Chapter 1-6) is described in Appendix 1-9-1.

The refitted numerical model is used for the packaging and can be used for a top-down axial drop configuration to study the impact of the changes in the mechanical properties of the materials at temperatures (T_{NCT} and -40°C) on the mechanical strength of the packaging (Chapter 1-9-3).

The influence of the following parameters is studied:

- package temperatures (-40°C and T_{NCT}).
- the preload on the lid attachment screws (minimum and maximum preload taking account of tightening uncertainties).

The detailed results are given in Chapter 1-9-3.

The maximum acceleration reached by the package is obtained at -40°C and is equal to [redacted]. This value bounds the [redacted] value obtained during drop tests.

The main conclusions of this study are as follows:

- overall, the wood in the shock absorbing covers does not reach the crush limit,
- the maximum residual detachment of the plug in the seal area is 0.025 mm.
- there is no plastic strain on the seal contact surface and plastic strains in the screw body are negligible, therefore the leak-tightness of the package is not affected,
- the preload in the lid screws is maintained.

Therefore the integrity of the closing system of the TN-MTR packaging is guaranteed after a 9 m axial drop on the top shock absorbing cover representative of accident transport conditions. The packaging remains leak-tight.

3.2. Bottom-down axial drop

The bottom-down axial drop configuration is conservative considering the loads on the content.

3.2.1. Drop tests

The maximum acceleration on the full scale packaging at ambient temperature (≈20°C) is determined in Chapter 1-7 based on accelerations recorded on the ½ scale mockup and is equal to [redacted]

3.2.2. Resistance at temperature

The maximum acceleration determined during the bottom-down axial drop of the packaging at ambient temperature (321 g according to chapter 1-7) remains unchanged at –40°C because the behaviour of steel does not change significantly between 20°C and –40°C.

At maximum temperature under normal transport conditions, the acceleration tends to drop as the mechanical properties of steel and lead become weaker. Therefore the acceleration is bounded by the acceleration obtained during the drop tests at 20°C.

Therefore the maximum acceleration to be considered for a bottom-down drop is [redacted] for the design of the internal fittings and the content.

3.3. Conclusions

The strength of the TN-MTR packaging under a 9 m axial drop is demonstrated.

The maximum acceleration to be considered in an axial drop for the design of internal fittings and fuel elements is [redacted]. This acceleration obtained during a bottom-down drop bounds the maximum acceleration experienced in a top-down drop equal to [redacted]

The maximum 0.025 mm residual detachment of the lid in the seals area is bounded by the residual detachment obtained in an oblique drop (0.042 mm – see §2).

4. LATERAL DROP

The lateral drop configuration that leads to the maximum acceleration during the drop tests is drop No. 3 in Chapter 1-6, i.e. the 9 m lateral drop along the axis of the trunnions with the packaging axis inclined by 4.9° on the bottom side of the packaging.

4.1. Drop tests

The maximum accelerations on the full scale packaging at ambient temperature (≈20°C) are determined in Chapter 1-7 on the basis of the accelerations recorded on the ½ scale mockup and are equal to.

- Top: [redacted]
- Bottom: [redacted]

4.2. Resistance at temperature

Numerical refitting of this 9 m lateral drop for the ½ scale mockup (drop No. 3 in Chapter 1-6) is described in Appendix 1-9-4.

The refitted numerical model is used for the packaging to study the impact of the changes in the mechanical properties of the materials at temperatures (T_{NCT} and -40°C) on the mechanical strength of the packaging (Chapter 1-9-5).

The detailed results are given in Chapter 1-9-5.

The maximum acceleration reached by the package is obtained at -40°C and is equal to [redacted]. This value is lower than the value obtained during the drop tests on the mockup at 20°C (corrected by the scale factor) The maximum acceleration occurs during the second impact at the bottom end. This zone is not very sensitive to variations in mechanical properties with the temperature (steel and lead). Therefore, the package acceleration to be used for the design of the internal fittings will conservatively be assumed to be the acceleration determined in Chapter 1-7 ([redacted]) which bounds this acceleration.

The main conclusions of this study are as follows:

- the trunnion does not touch the ground after the drop,
- overall, the wood does not reach its crush limit except for a few elements that are compressed locally, particularly at the ring,
- the closing system remains intact: there is no yielding in the body of the lid screws. Similarly, there is no residual detachment of the seal groove,
- the preload in the lid screws is maintained.

Therefore the integrity of the closing system of the TN-MTR packaging is guaranteed after a 9 m lateral drop representative of accident transport conditions. The packaging remains leak-tight.

4.3. Conclusions

The strength of the TN-MTR packaging under a 9 m lateral drop is demonstrated.

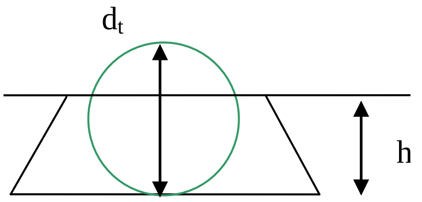
The maximum acceleration to be used in the lateral drop for the design of internal fittings and fuel elements is [redacted]

5. COMPRESSION RATE FOR LID SEALS

The minimum compression rate for lid seals allowing for the effect of a temperature of -40°C, residual detachment and geometrical tolerances is determined below.

The analysis is made for a temperature of -40°C that is compatible with the working temperature range of EPDM seals.

The compression rate is determined as follows:



Compression rate = $1 - (h + u)/d_t$

The diameter of the O-ring seal at -40°C is equal to:

$$d(t_{-40°C}) = d.(1+\alpha_{lin}.\Delta T)$$

Where:

- d: O-ring diameter at 20°C,
- h: depth of the seal groove at 20°C,
- u: maximum lid residual detachment
- α_{lin}: coefficient of linear expansion of the seal =171.6 x 10^{-6} /K,
- ΔT: temperature difference between -40°C and 20°C = - 60°C.

The following table gives lid seal compression rate, taking into account the gap after the drop:

	Nominal case	Case with tolerances	Case with tolerances and at -40°C	Case with tolerances at -40°C, and after drop
Seal diameter d (mm)	7.80	7.65	7.57	7.57
Groove depth h (mm)	5.5	5.55	5.55	5.55
Detachment of the lid u (mm)	-	-	-	0.042
Compression ratio	29.5	27.5	26.7	26.1

(%)				

The minimum compression rate is therefore 26.1%.

The tests described in the mail reference <1> show that seals remain leak-tight for compression rates of up to [redacted]

Consequently, the leak-tightness of seals in the TN-MTR packaging for which the minimum compression rate is 26.1% after the drop is guaranteed.

6. FORCES IN THE ORIFICE PLUG SCREWS

Chapter 1-5 demonstrates that there is no guarantee that the preload on orifice plug screws is representative. It is subsequently checked that the preload applied to orifice plug attachment screws is nevertheless sufficient to resist drop forces representative of accident transport conditions.

6.1. AXIAL DROP

The minimum preload on plug screws must be higher than the sum of the forces applied to the plugs in the case of a drop and the forces applied by the seals and by the maximum internal pressure on the plugs.

$$F_{\text{mini nécessary}} = F_{\text{seal}} + F_{\text{pressure}} + F_{\text{drop}}$$

Where:

- $F_{\text{min necessary}}$: the minimum preload to be applied by the screws
- $F_{\text{pressure:}}$ the force applied by the maximum internal pressure on the plug = 1 kN (see Chapter 1-10)
- F_{seal} the force applied by the internal and external seals on the plug = 3 kN (see Chapter 1-10)
- F_{drop} the force applied to the plug in a drop = $\dfrac{m \times \gamma}{n}$
- m: the mass of the plug: 7 kg
- γ: the maximum acceleration in the case of a drop taken to be equal to [redacted]
- n = number of plug attachment screws

Thus in axial drop, $F_{\text{min necessary}}$ = 9.5 kN.

This force is less than the minimum preload of plug screws (24 kN) defined in Chapter 1-10. Therefore there is no risk of the plugs detaching in the case of an axial drop.

6.2. Oblique drop

In the case of an oblique drop on the top shock absorbing cover, the plug screws are loaded by the force due to the rotation moment of the plug relative to the point of contact during the drop.

The torque relative to tipping is equal to:

$$C_o = m \times \gamma \times R \times \cos\theta = 391 \text{ N.m}$$

Where:

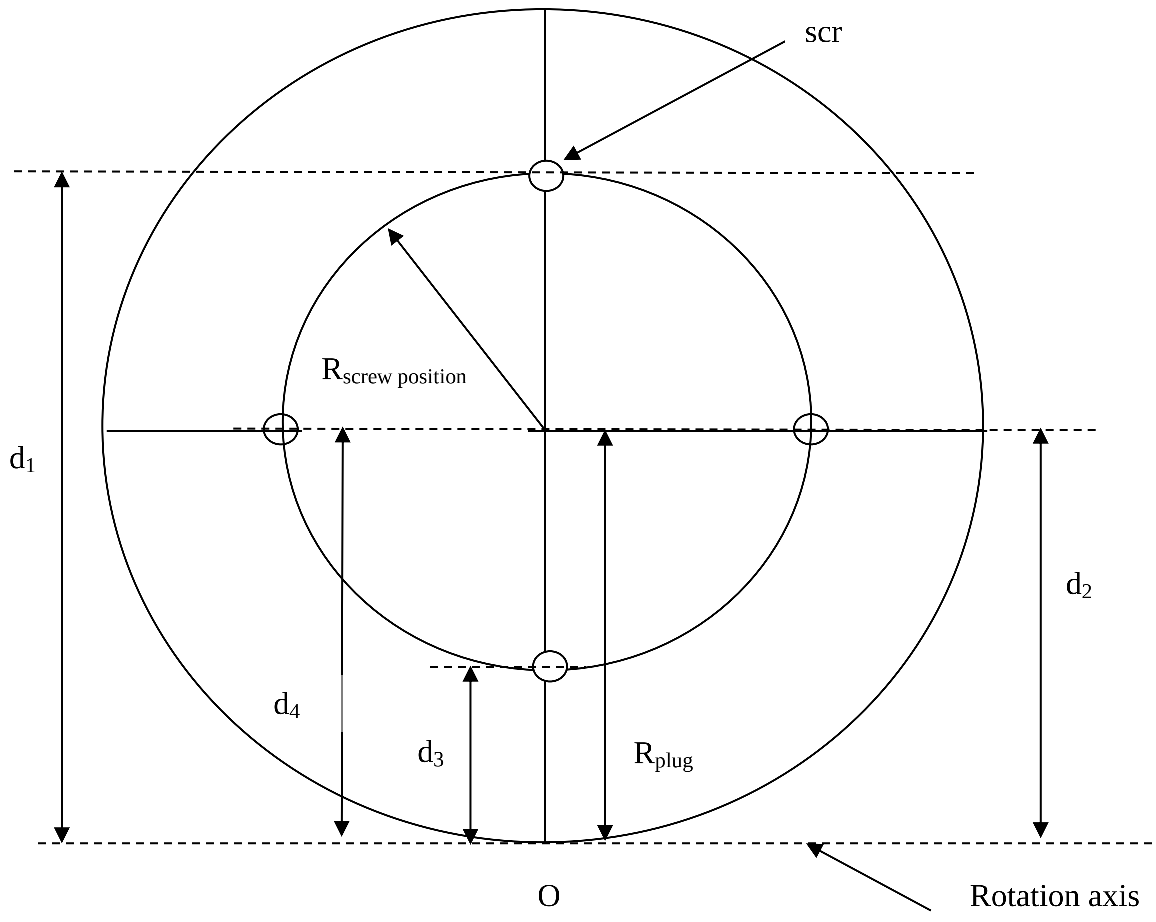
- m is the mass of the plug, m = 7 kg
- R is the radius of the plug, $R = 89{,}75\ \text{mm}$
- θ is the drop angle, θ = 47° (see chapter 1-9-2)
- γ is the maximum acceleration in the case of a drop on the corner of the shock absorbing cover, γ = [redacted] (see section 2.3)

This torque is distributed as a tension force F_i on each screw:

$$C_o = \sum_{i=1}^{4} F_i \times d_i$$

where

- d_i is the distance from screw No. i to point O, as shown on the figure below.



The tension force depends on the leverage:

$$\frac{F_i}{d_i} = k$$

Where:

- k is a constant, $k = \frac{F_1}{d_1}$

We can then write:

$$C_o = \frac{F_1}{d_1} \times \sum_{i=1}^{4} d_i^2 \;\text{ or }\; F_1 = \frac{C_o \times d_1}{\sum_{i=1}^{4} d_i^2}$$

Where:

- $d_1 = R_{plug} + R_{screw\ position} = 89.75 + 75 = 164.75$ mm
- $d_2 = d_1 = 89.75$ mm
- $d_3 = R_{plug} + R_{screw\ position} = 89.75 - 75 = 14.75$ mm
- $d_4 = d_1 = 89.75$ mm

The minimum force applied to orifice plug screws in the case of an oblique drop is equal to:

$F_{min\ necessary} = F_1 = 1.5$ kN.

This force is less than the minimum preload of plug screws equal to 24 kN defined in Chapter 1-10. Therefore there is no risk of the plugs detaching in the case of an oblique top-down drop.

6.3. Conclusion

The torque equal to 40 N.m ± 10% required in Chapter 0 for orifice plug screws is sufficient to guarantee that the plugs do not detach in the case of drops representative of accident transport conditions. There will be no risk of lack of leak-tightness.

7. CONCLUSION

The strength and leak-tightness of the TN-MTR packaging are guaranteed for the range of temperatures that occur under normal transport conditions.

Maximum accelerations to be considered for the mechanical design of internal fittings and fuel elements are as follows:

- for the axial drop: [redacted] in bottom-down drop and [redacted] in top-down drop,
- for the lateral drop: [redacted]

The maximum residual detachment of the lid to be used for activity release analyses is 0.042 mm.

8. REFERENCES

<1> TN International Note NTC-08-00112066-000 Rev. 1, "Note de synthèse des tests d’étanchéité sur joints toriques élastomères à différents taux de compression" (Summary of leak tightness tests on elastomer O-rings at different compression rates). "