CALCULATION OF EQUIVALENT DOSE RATES AROUND THE TN-MTR PACKAGING

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REVISION STATUS

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SUMMARY

The purpose of this chapter is to verify that regulatory criteria for equivalent dose rates around the TN-MTR packaging are respected for upper-bound contents of the contents to be transported:

- under routine conditions of transport
- under normal conditions of transport.
- under accident transport conditions.

The calculations were made for the different internal fittings of the packaging (RHF, MTR-68, MTR-52, MTR-52S, MTR-52SV2, MTR-44, FRM II baskets and CESOX internal fittings).

Equivalent dose rates around the TN-MTR packaging respect IAEA requirements <1> under routine, normal and accident transport conditions for all contents planned for transport, including when fuel elements are loaded in canisters.

In the case of the "beryllium elements" content, the calculations are made for an upper-bound content with ^{60}Co activity equal to 1 TBq.

In the case of the CESOX content, the calculations are made for an upper-bound content with activity equal to 5.55 PBq.

In the case of the caesium trap content, the calculations are made for an upper-bound content with ^{137}Cs activity equal to 12.5 TBq.

In the case of the gisete content, the calculations are made for an upper-bound content with ^{90}Sr activity equal to 897 TBq.

1. PURPOSE

The purpose of this chapter is to verify that regulatory criteria for equivalent dose rates around the TN-MTR packaging are respected for upper-bound contents of the contents to be transported:

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The calculations were made for the different internal fittings of the packaging (RHF, MTR-68, MTR-52, MTR-52S, MTR-52SV2, MTR-44, FRM II baskets, CESOX internal fittings, caesium trap internal fittings and gisete internal fittings).

2. CALCULATION METHODS

For RHF contents, the source calculations are made using data on elements provided by the operator and using the ORIGEN 2.1 software <2> or the BDN software <3>. Equivalent dose rates are then calculated using the MERCURE V software <4> for gamma radiation and the SN1D software <5> for neutron radiation.

For the CESOX, caesium trap and gisete contents, the source calculations are made using data provided by the operator and using the ORIGEN software described in reference <9>. Neutron and gamma equivalent dose rates are then calculated with the TRIPOLI 4.4 software in reference <10> for the CESOX and gisete contents and with the TRIPOLI 4.7 software in reference <16> for the caesium trap content.

For the irradiated UO_2 fuel element content, the source calculations are made using the APOLLO 2.5 software <12> and <13> and the DARWIN 2.2.2 form <14>. The fuel is treated like PWR 17 x 17 UO_2 fuel. Neutron and gamma equivalent dose rates are then calculated with the TRIPOLI 4.7 software in reference <16>.

For MTR plate irradiated fuel element contents (UAl_x-Al, U_3Si_2-Al, U_3O_8-Al, UMo-Al) other than RHF and the FRM II content, the source calculations are made using the CESAR 5.3 software <15>. Neutron and gamma equivalent dose rates are then calculated with the TRIPOLI 4.7 software in reference <16>.

3. RADIATION INTENSITY CRITERIA

It has to be checked that the package satisfies the IAEA regulatory requirements <1>.

- Routine transport conditions for non-exclusive use, the maximum equivalent dose rate must not exceed:
  - 2 mSv/h in contact with the package,
  - 0.1 mSv/h at 1 m from the external surface of the package,
- Routine transport conditions for exclusive use, the maximum equivalent dose rate must not exceed:

- 10 mSv/h in contact with the package,
- 2 mSv/h in contact with the external surface of the vehicle,
- 0.1 mSv/h at 2 m from vertical planes of the side walls of the vehicle.

- Normal transport conditions: no increase by more than 20% of the maximum radiation intensity in contact with the package after tests representative of NCT. This analysis is presented in Appendix 4A.1.

- Accident Transport Conditions:

  - 10 mSv/h at 1 m from the external surface of the package.

4. CALCULATION MODELS

4.1 Packaging

The calculation model of the packaging is described in detail in each Appendix.

Regardless of the transport configuration, the geometry of the TN-MTR packaging chosen for the calculation complies with the description given in Chapter 0. The resin used for neutron shielding in the calculation model is resin F. As described in Chapter 0, the neutron shielding may be composed of VYAL B resin, which has better neutron shielding properties (it contains more hydrogen atoms). Consequently, the use of the F resin in the model results in higher dose rates than would occur with the VYAL B resin, which is conservative.

Under accident transport conditions, the following assumptions are made:

- the shock absorbing cover and the resin are assumed to have disappeared (resin replaced by air),
- the effect of lead compaction during the axial drop is taken into account,
- the effect of lead crushing during the oblique drop is taken into account,

4.2 Vehicle

The TN-MTR packaging is transported in a special-purpose overpack. The external width of the overpack is equal to 2438 mm.

The external wall of the vehicle is not modelled for MTR plate irradiated fuel element contents (other than RHF and FRM II), for UO_2 contents and for beryllium elements, but the width of the TN-MTR special-purpose overpack is taken into account for the distance calculation.

For other contents (RHF, FRM II, CESOX, caesium trap and gisete), the external wall of the vehicle is conservatively considered to be the external surface of the package.

5. RADIOACTIVE CONTENTS AND CALCULATION CASES

Chapter 0A summarises all contents transported in the TN-MTR packaging. Table 4A.1 summarises upper-bound contents selected for calculations for each type of internal fitting.

5.1 RHF content

The radioactive content of the TN-MTR packaging equipped with the RHF basket is composed of 3 RHF elements, as described in Appendix 0A-1.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-1.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- measured dose rates are gamma DERs,
- DERs at the bottom of the packaging are not evaluated under routine transport conditions. The packaging is placed on its bottom.
- the maximum enrichment of ^{235}U fuel elements is [redacted]
- the burnup is 315,000 MWd/tU,
- two cooling times are studied: 300 and 600 days.

An analysis is made in Section 7 in this chapter to evaluate the impact of:

- ageing of the resin under routine transport conditions.
- allowing for the compaction of lead during axial and oblique bottom-down drops.

5.2 Contents in MTR-68, MTR-52, MTR-52S, MTR-52SV2 and MTR-44 baskets

5.2.1 Irradiated MTR plate fuel elements

The MTR-68, MTR-52, MTR-52S, MTR-52SV2 and MTR-44 baskets can transport irradiated fuel elements derived from different types of research reactors and particularly UAl_x-Al, U_ySi_z-Al, U_3O_8-Al or UMo-Al fissile core type elements, which can be grouped into 3 upper-bound contents.

The characteristics of these 3 upper-bound contents (upper-bound in terms of maximum burnup, minimum cooling time and maximum enrichment), are listed in Chapter 0A and the appendices and are summarised in Table 4A.1.

Calculations of equivalent dose rates around the TN-MTR packaging under routine transport conditions are made for these 3 upper-bound contents and for the MTR-68, MTR-52 and MTR-44 baskets, which contain 68, 52 and 44 fuel elements respectively.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-11.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- the MTR-52 basket is conservatively considered, because its DER is upper-bound for the MTR-52S and the MTR-52SV2 basket equivalent dose rates,
- the TN-MTR packaging model takes account of ageing of the resin under routine transport conditions,

- the TN-MTR packaging model takes account of compaction of the lead during an axial drop,
- DER calculations under ACT are made for the 3 upper-bound contents and only for the MTR-68 basket that has the highest DER values under routine transport conditions for all measurement points and for all distances considered.

This analysis remains valid when the fuel elements are loaded in cans (as described in Chapter 0A and appendices) since the additional plate thickness (steel or aluminium) due to the presence of the can acts as an additional barrier that tends to reduce equivalent dose rates around the packaging.

Section 7 in this chapter describes an analysis made to evaluate the impact of taking account of compaction of the lead in an oblique bottom-down drop.

5.2.2 *Irradiated UO_2 fuel elements in MTR-44 basket*

The MTR-44 basket can be loaded with irradiated fuel elements with UO_2 fissile core.

Calculations of equivalent dose rates around the TN-MTR packaging are made under routine transport conditions and under accident transport conditions for a content that upper-bounds the content to be transported.

Characteristics of this content are listed in Chapter 0A-5 and summarised in Table 4A.1:

- the maximum ^{235}U enrichment of fuel elements is [redacted],
- the maximum burnup is 41000 MWd/tU,
- the minimum cooling time is 10 years.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-11.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- the TN-MTR packaging model takes account of ageing of the resin under routine transport conditions,
- the TN-MTR packaging model takes account of compaction of the lead in an axial drop,

This analysis remains valid when the fuel elements are loaded in cans (as described in Chapter 0A and appendices) since the additional plate thickness (steel or aluminium) due to the presence of the can acts as an additional barrier that tends to reduce equivalent dose rates around the packaging.

Section 7 in this chapter describes an analysis made to evaluate the impact of taking account of compaction of the lead in an oblique bottom-down drop.

5.2.3 Beryllium elements in the MTR-44 basket

The MTR-44 basket can be loaded with a maximum of 44 beryllium elements. The upper-bound characteristics of this content are described in Appendix 5 to Chapter 0A.

The maximum activity of the content is 1 TBq of ^{60}Co.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-5-2.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid or its « SEC » lid
- measured dose rates are gamma DERs,
- the effect of compaction and crushing of lead in a bottom-down drop are taken into account through a reduction in the lead thickness of 130 mm around the packaging (very conservative assumption).

An analysis is made in Section 7 in this chapter to evaluate the impact of:

- ageing of the resin under routine transport conditions.

5.3 CESOX content

The CESOX content consists of a ^{144}Ce-^{144}Pr radioactive source contained in a sealed double capsule in special form itself contained in a radiological shielding composed of a tungsten alloy.

The maximum activity of the source is less than 5.55 PBq.

This content is described in Appendix 11 to Chapter 0A.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-10.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- the TN-MTR packaging model takes account of compaction of the lead during an axial drop.

An analysis is made in Section 7 in this chapter to evaluate the impact of:

- ageing of the resin under routine transport conditions.
- allowing for the compaction of lead during an oblique bottom-down drop.

5.4 FRM II content

The FRM II content is composed of an FRM II basket and 7 FRM II fuel elements as described in Appendix 12 to Chapter 0A.

Calculations of equivalent dose rates around the TN-MTR packaging are made under routine transport conditions and under accident transport conditions for a content that upper-bounds the content to be transported. The upper-bound characteristics of this content are described in Appendix 12 to Chapter 0A:

- the maximum ^{235}U enrichment of fuel elements is [redacted],
- the maximum burnup is 150,000 MWd/tU,
- the minimum cooling time is 6.5 years,

Equivalent dose rate (DER) calculations are presented in Appendix 4A-12.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- the TN-MTR packaging model takes account of ageing of the resin under routine transport conditions,
- the TN-MTR packaging model takes account of compaction of the lead during an axial drop.

Section 7 in this chapter describes an analysis made to evaluate the impact of taking account of compaction of the lead in an oblique bottom-down drop.

5.5 Caesium trap content

The content consists of a caesium trap composed of reticulated vitreous carbon containing of solidified cold sodium. This content is described in Appendix 13 to Chapter 0A.

The radioactive material in the caesium trap is principally of ^{137}Cs whose maximum activity is equal to 12.5 TBq. We find also in one more small proportion of ^{241}Am whose the maximum activity is equal to 0.3 MBq.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-13.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid
- the TN-MTR packaging model takes account of compaction of the lead during an axial drop

5.6 Gisete content

The gisete content consists of an isotopic generator, composed of a source block containing the radioactive materials and a body equipped with a closure system around this block, placed in its internal fitting. This content is described in Appendix 14 to Chapter 0A.

The radioactive material is composed of a strontium 90 titanium source (SrTiO3) with a maximum activity level equal to 897 TBq.

Equivalent dose rate (DER) calculations are presented in Appendix 4A-14.

The main assumptions are as follows:

- the packaging is equipped with its « standard » lid.
- the TN-MTR packaging model takes account of compaction of the lead during an axial drop.

An analysis is made in Section 7 in this chapter to evaluate the impact of:

- ageing of the resin under routine transport conditions.
- allowing for the compaction of lead during an oblique bottom-down drop.

6. RESULTS

6.1 RHF content

Equivalent dose rates around the TN-MTR packaging containing the RHF content are evaluated by calculation in Appendix 4A-1.

Maximum equivalent dose rates (0.62 mSv/h in contact with the package and 0.06 mSv/h at 2 metres from the package) are obtained in the uninterrupted section of the shell for routine transport conditions for a minimum cooling time of 300 days.

This package satisfies regulatory transport requirements under exclusive use.

The maximum dose rate at 1 m is 0.569 mSv/h at the lid, under accident transport conditions.

The maximum mass of uranium in a fuel element is slightly underestimated in the calculations (9.122 kg for a maximum mass of 9.360 kg). However, considering margins found on calculated equivalent dose rates, this underestimate of the uranium mass is not likely to prevent the regulatory criteria from being satisfied.

Note:

Equivalent dose rates at the bottom of the packaging have not been determined for the RHF content under routine transport conditions.

The axial contact equivalent dose rate at the bottom of the packaging has been determined in Appendix 4A-11 for irradiated plate fuel elements.

The results show that maximum axial contact equivalent dose rates are twice as high at the bottom of the packaging as at the top. The maximum axial dose rate calculated for contact at the top for the RHF content is much less than 1 mSv/h so that it is confirmed that the regulatory contact shielding criterion (2 mSv/h) is respected.

6.2 Irradiated MTR plate fuel element contents (UAl_x-Al, U_3O_8-Al, U_ySi_z-Al, UMo-Al)

Equivalent dose rates around the TN-MTR packaging loaded with the MTR-68, MTR-52, MTR-52S, MTR-52SV2 or MTR-44 basket and one of the 3 upper-bound contents defined above are evaluated by calculation in Appendix 4A-11.

Maximum equivalent dose rates (1780 mSv/h in contact with the package and 0.094 mSv/h at 2 metres from the vertical walls of the vehicle) are obtained for the MTR-68 basket at the shell under the base of the trunnion and in the uninterrupted of the shell respectively, under routine transport conditions.

This package satisfies regulatory transport requirements under exclusive use.

For accident transport conditions:

– the maximum equivalent dose rate is obtained at 1 metre from the package near the top part of the shell under the trunnion and is equal to 8.517 mSv/h,
– the maximum equivalent dose rate at 1 m from the bottom of the packaging (axial at the bottom and radial near the bottom) is equal to 0.906 mSv/h.

6.3 Irradiated UO_2 fuel element contents

Equivalent dose rates around the TN-MTR packaging loaded with the MTR-44 basket and the UO_2 elements upper-bound content defined above are evaluated by calculation in Appendix 4A-11.

Maximum equivalent dose rates (0.679 mSv/h in contact with the package and 0.023 mSv/h at 2 metres from the vertical walls of the vehicle) are obtained at the bottom of the packaging and in the uninterrupted section and bottom part of the shell respectively, under routine transport conditions.

This package satisfies regulatory transport requirements under exclusive use.

For accident transport conditions

– the maximum equivalent dose rate is obtained at 1 metre from the package near the top part of the shell under the trunnion and is equal to 0.324 mSv/h,
– the maximum equivalent dose rate at 1 m from the bottom of the packaging (axial at the bottom and radial near the bottom) is equal to 0.213 mSv/h.

6.4 Beryllium element contents

Equivalent dose rates around the TN-MTR packaging loaded with the MTR-44 basket and the "beryllium elements" content are estimated from the results obtained on the ICO 4000 type irradiator (see Appendix 4A-8).

This package satisfies regulatory requirements when its characteristics comply with the characteristics presented in Chapter 0A-5.

Equivalent dose rates under routine conditions are 0.052 mSv/h in contact with the package (obtained along the centre line of packaging at the lid end) and 0.005 mSv/h at 2 m from the package (obtained along the centre line of packaging at the lid end).

This package satisfies regulatory transport requirements under exclusive use.

Under Accident Transport Conditions, maximum equivalent dose rates at 1 m from the package are 5.99 mSv/h (obtained radially from the packaging).

6.5 CESOX content

Equivalent dose rates are determined around the TN-MTR packaging loaded with the CESOX content composed of a sealed radioactive source of ^{144}Ce-^{144}Pr in special form and its radiological shielding made of tungsten alloy. The content used for the calculation upper-bounds the content to be transported.

Under routine transport conditions, the content is placed at the bottom of the packaging and is radially centred. The maximum equivalent dose rate (1.27 x 10^{-4} mSv/h in contact with the package and 3.90 x 10-^{6} mSv/h at 2 metres from the package) is obtained at the centre of the packaging. Since the equivalent dose rate in contact with the package is less than 0.1 mSv/h, the equivalent dose rate at 1 metre from the package is necessarily below this limit. Therefore this package satisfies regulatory transport requirements for transport in non-exclusive use.

Under normal transport conditions, and assuming a maximum displacement of the CESOX content in contact with the cavity wall, the maximum DER in contact with the package is less than 20% of the maximum DER recorded in contact with the package under RCT.

For accident conditions, and conservatively assuming the loss of radiological shielding of the source, the maximum equivalent dose rate (6.19 mSv/h at 1 metre from the package) occurs at the trunnions.

The thickness of the tungsten alloy radiological shielding used in the calculations in Appendix 4A-10 for routine transport conditions and normal conditions is equal to 190 mm. According to Appendix 0A-11, the minimum thickness is equal to 189 mm. This difference has no significant impact on calculated equivalent dose rates, considering the small difference in thickness (0.5%). There are also large margins on equivalent dose rate limits. Consequently, regulatory criteria under routine transport conditions and under normal conditions for transport in non-exclusive use are always respected. This difference has no impact on accident conditions because the radiation shielding is not considered, which is conservative.

6.6 FRM II contents

Equivalent dose rates around the TN-MTR packaging containing the FRM II basket and 7 FRM II fuel elements are evaluated by calculation in Appendix 4A-12.

Maximum equivalent dose rates (6.899 x 10^{-3} mSv/h in contact with the package 5.842 x 10^{-4} mSv/h at 2 metres from the package) are obtained axially at the top adjacent to the lid orifice and at the bottom of the packaging for routine transport conditions. Since the equivalent dose rate in contact with the package is less than 0.1 mSv/h, the equivalent dose rate at 1 metre from the package is necessarily below this limit. Therefore this package satisfies regulatory transport requirements for transport in non-exclusive use.

For accident transport conditions:

– the maximum equivalent dose rate (5.835 x 10^{-2} mSv/h at 1 metre from the package) is obtained near the top of the shell under the trunnion,

– the maximum equivalent dose rate at the bottom of the packaging at 1 m from the package (bottom axial and radial near the bottom) is equal to 5.100 x 10^{-3} mSv/h.

6.7 Caesium trap content

The TN-MTR packaging equipped with the caesium trap content and its internal fittings respect the criteria presented in paragraph 3 to Appendix 4A-13 in RCT, NCT and ATC:

- Under routine transport conditions, the equivalent dose rate criterion in contact is respected.

- Under normal transport conditions, the integrity of the internal fittings that hold the content in position and the limited damage to the package resulting from regulatory tests for normal transport conditions guarantee compliance with the criterion an increase in radiation intensity less than 20 %.

- Under accident transport conditions, the equivalent dose rate criterion in 1 meter from the package is respected.

Under accident transport conditions, the calculation is realised for a maximum radioactive content considered with very penalising hypotheses (total failure of packaging).

6.8 Gisete content

The TN-MTR packaging equipped with the gisete content and its internal fittings respect the criteria presented in paragraph 3 to Appendix 4A-14 in RCT, NCT and ATC:

- Under routine transport conditions, the equivalent dose rate criterion in contact is respected.

- Under normal transport conditions, the integrity of the internal fittings that hold the content in position and the limited damage to the package resulting from regulatory tests for normal transport conditions guarantee compliance with the criterion an increase in radiation intensity less than 20 %.

- Under accident transport conditions, the equivalent dose rate criterion in 1 meter from the package is respected.

7. INFLUENCE STUDIES

7.1 Study of the influence of ageing of the resin at elevated temperature on the efficiency of neutron shielding under normal transport conditions

Ageing studies of type F resin at elevated temperature (which is conservative because it has poorer radiological and ageing properties than the VYAL B type resin), based on tests, are made in the note in reference <7>.

These tests, performed on resin blocks, demonstrated that ageing occurs only on the outside face of the resin. They also conservatively characterised its radiological capabilities as a function of the outside surface of the resin block, the average temperature of this outside surface and the cross-section of the block.

The following analysis is made at the temperature of normal transport conditions for a resin aged for 50 years (which is very conservative) but for constant gamma and neutron sources starting from the transport start date and therefore not decaying with time. An equivalent lost thickness of resin can be quantified from this analysis.

The note in reference <7> shows that the ratio between hydrogen quantities in the entire resin block before and after ageing is equal to:

$$R_{H_2} = \frac{\text{quantity of hydrogen (after ageing)}}{\text{quantity of hydrogen (initial)}} = \text{[redacted]}$$

Where:

- P: perimeter of the resin block (in cm),
- S: cross-section of the resin block (in cm^2),
- X: hydrogen loss X% at the average resin temperature under transport conditions (i.e. conservatively taken at the maximum temperature of [redacted], see Chapter 2 in the safety file). For a resin aged for 50 years, we can see on figure 1 in the note in reference <7>: X = [redacted]

The perimeter of the resin block for the TN-MTR packaging is equal to:

$P = \pi \times (D_e + D_i)\, n$ where:

- D_2 is the outside diameter of the resin block, D_e = [redacted]
- D_i is the inside diameter of the resin block, D_i = [redacted]

Hence P = [redacted]

The cross-section of the resin block is equal to:

$$S = \frac{\pi \times (D_e^2 - D_i^2)}{4}$$

Hence S = [redacted]

We can then deduce R_{H_2} = [redacted]

The reduction in the initial thickness of the resin is determined from this reduction in the hydrogen content of the resin block as follows:

$$R_e = (1 - R_{H_2}) \times E$$

Where:

- R_e: the reduction in the axial or radial thickness E after the ageing phenomenon,
- E: the axial or radial thickness of the resin before the ageing phenomenon.

The resin thickness in the TN-MTR is equal to [redacted], in the radial and axial directions at the bottom end of the packaging. The reduction in the equivalent maximum thickness due to ageing of the resin at temperature is then determined:

R_e = [redacted]

Resin attenuation coefficients are equal to:

- 0.1 cm^{-1} for gamma emissions,
- 0.3 cm^{-1} for neutron emissions,

For MTR type plate fuel elements other than RHF and UO_2 fuel elements, the calculation model for the TN-MTR packaging under routine transport conditions presented in Appendices 4A-11 and 4A-12 directly takes account of a conservative reduction in the resin thickness equal to 0.5 cm. Therefore the effect of ageing of the resin is directly integrated into the results presented in sections 6.2, 6.3 and 6.6.

For other contents, the following table presents maximum equivalent dose rates under routine transport conditions calculated in Chapter 4A and appendices to the Safety file, and equivalent dose rates calculated after ageing of the resin have been taken into account:

		Contact (mSv/h)	2 m (mSv/h)
RHF content	Maximum DER under RCT before ageing (gamma contribution)	0.62	0,06
	Maximum DER under RCT with ageing	**0.65**	**0,063**
Beryllium elements	Maximum DER under RCT before ageing (gamma contribution)	$5.17.10^{-2}$	$0,45.10^{-2}$
	Maximum DER under RCT with ageing	**$5.44.10^{-2}$**	**$0,47.10^{-2}$**
CESOX content	Gamma contribution	$2.41.10^{-6}$	$4,89.10^{-8}$
	Neutron contribution	$1.24.10^{-4}$	$3,86.10^{-6}$
	Maximum DER under RCT before ageing	$1.27.10^{-4}$	$3,90.10^{-6}$
	Maximum DER under RCT with ageing	**$1.46.10^{-4}$**	**$4,54.10^{-6}$**
CESOX content Gisete	Maximum DER under RCT before ageing (Gamma contribution)	2.94×10^{-2}	3.69×10^{-4}
	Maximum DER under RCT with ageing	$\mathbf{3.09 \times 10^{-2}}$	$\mathbf{3.88 \times 10^{-4}}$
RCT criteria		**2**	**0.1**

For the caesium trap content, equivalent dose rate (DER) values are determined without considering the resin. The effect of thermal ageing of the resin has no consequence on the results obtained.

Therefore taking account of ageing of the resin at temperature causes a very slight increase in equivalent dose rates under routine conditions. Nevertheless, the equivalent dose rates obtained remain less than criteria under routine transport conditions.

Note that the neutron shielding study ignored the 25 mm thick resin of the TN-MTR packaging in the case of accident transport conditions. Consequently, ageing of the resin has no effect on the conclusions made.

7.2 Effects of lead compaction

7.2.1 Case of a bottom-down axial drop (RHF content)

The lead radiological shielding of the TN–MTR packaging can be deformed (swelling, compaction, etc.) under Accident Transport Conditions, following a 9-metre drop.

Compaction in the radial part of the lead shell was evaluated in Chapter 1-7, although it has not been observed following drop tests. The height of compaction thus calculated is 32 mm.

The effects of this compaction are taken into account in the calculations of maximum equivalent dose rates around the package model composed of the TN-MTR packaging:

- loaded with beryllium elements (see Appendix 4A-5-2),
- loaded with the CESOX content (see Appendix 4A-10),
- loaded with MTR plate fuel elements other than RHF and UO_2 elements (see Appendix 4A-11)
- loaded with the FRMII content (see Appendix 4A-12),
- loaded with the caesium trap content (see Appendix 4A-13),
- loaded with the gisete content (see Appendix 4A-14).

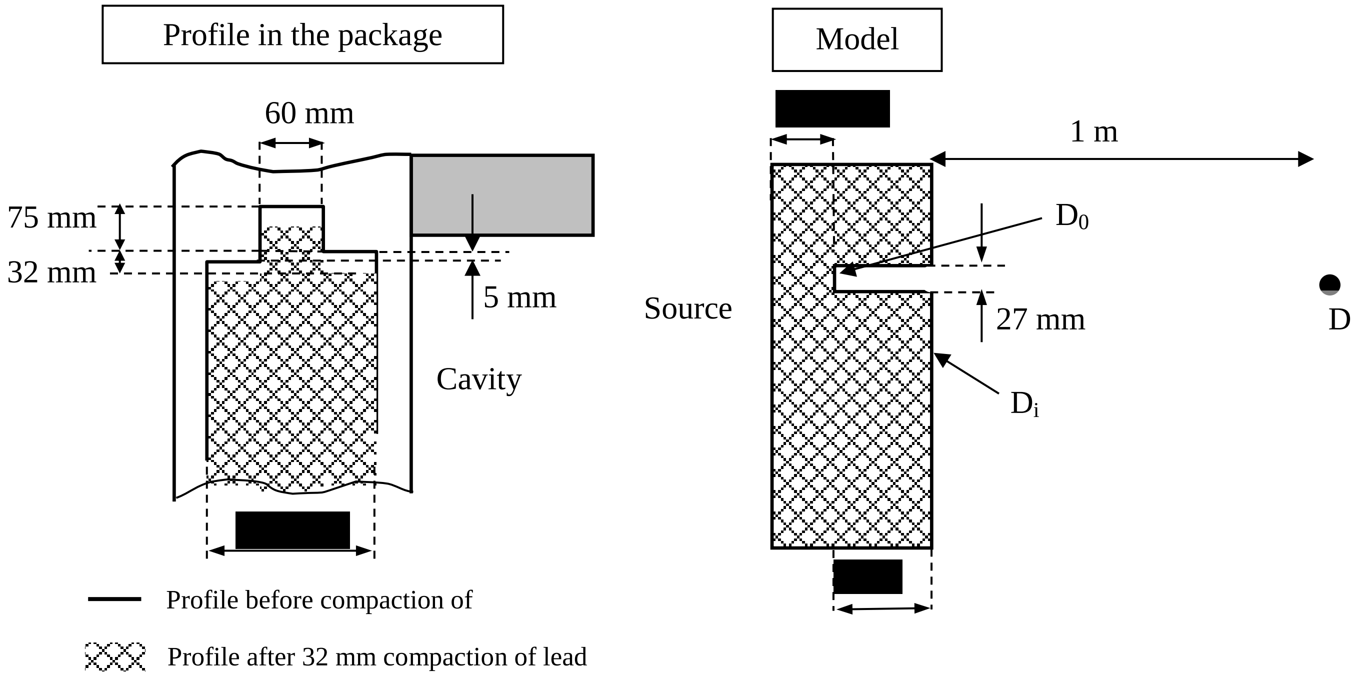
The effects of this compaction on equivalent dose rates around package models composed of the TN-MTR packaging loaded with an RHF basket and RHF fuel elements (see Appendices 4A-1) are presented below.

Note that the height of the additional shielding at the top of the packaging as shown on the TN-MTR packaging design drawings is 80 mm relative to the outside level and 75 mm relative to the inside level.

The calculated compaction is less than half of this additional shielding. Therefore the lead shielding is never entirely missing (see following diagram).

The increase in dose rates at 1 m from the radial part of the package under Accident Transport Conditions can be determined as presented below.

This is done by modelling the remaining lead shielding as shown in the following diagram:



The contact dose rate (D_0) is defined by the attenuation formula defined using the maximum calculated initial dose rate (D_i) without loss of shielding in the radial part of the packaging, i.e. 0.573 mSv/h at 1 m (upper-bound value of results in Chapter 4A-1): 0.569 mSv/h at 1 m):

$D_0 = D_i \times e^{0.53\,(19-6)}$, with a lead absorption coefficient equal to 0.53 cm^{-1},

hence:

D_0 = 563 mSv/h.

Knowing this contact dose rate, the surface is considered as a source, and the dose rate at 1 m from the package is then calculated using the formula for a leak through a slit and a cosine emission source (cylindrical source) as follows:

$D = \frac{D_0 \times T}{2L}$ according to <6>.

Where:

- L: slit length (L = 1000 mm).
- T: slit width.

The slit width at ambient temperature is equal to:

T_{20} = 32 – 5 = 27 mm.

This corresponds to the shift in the level of lead between the outside level (32 mm) and the inside level of the shielding (27 mm)

This width is increased by the reduction in the properties of lead at temperature under accident transport conditions (see Chapter 1A).

The modulus of elasticity of lead A at ambient temperature is equal to 16700 MPa.

The modulus of elasticity of lead at 150°C, the temperature which upper-bounds the maximum temperature after Normal Transport Conditions ([redacted]), is equal to 15395 MPa (see Chapter 1-7)

The variation of lead properties between ambient temperature and 150°C is defined as a ratio:

$\frac{15395}{16700} = 0.922$.

Therefore the slit width under Accident Transport Conditions can be evaluated as:

$T_{150} = \frac{32}{0,922} - 5$ = 29.7 mm.

Therefore due to compaction of the lead, the maximum dose rate at 1 m becomes:

$$D_i = \frac{563 \times 29{,}7}{2000} = 8{,}4 \text{ mSv / h} .$$

This value has to be increased by the maximum initial dose rate measured in the radial part of the packaging under Accident Transport Conditions, which is less than 0.573 mSv/h (see Chapter 4A-1).

The total equivalent dose rate at 1 m from the radial part of the TN-MTR packaging under Accident Transport Conditions, allowing for the effect of compaction of lead for the RHF content, is equal to:

D_T = 8.4 + 0.573 = 8.973 mSv/h.

This value is less than the criterion in the regulations (see Section 3).

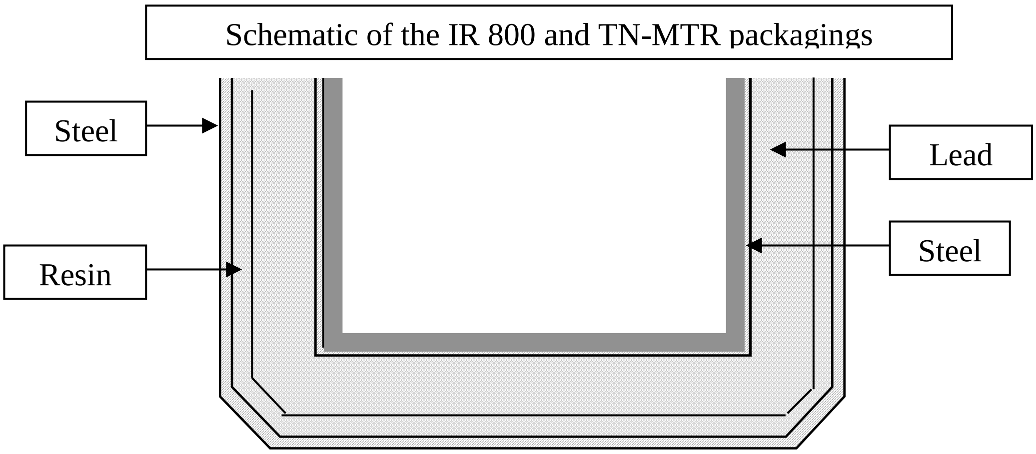
The increase in the lead temperature under Accident Transport Conditions and its compaction in the radial part of the shell do not prevent the IAEA regulatory requirements <1> for the TN-MTR packaging loaded with the RHF content from being respected.

7.2.2 Case of a bottom-down oblique drop

The analysis of the analogy between the TN-MTR packaging and the ½ scale model of the IR800 packaging is presented below.

All data related to the ½ scale mockup of the IR800 packaging are derived from the safety file in reference <8>.

The designs of the IR800 and TN-MTR packagings are identical, particularly in their lower parts. Thus, neither of the 2 packagings has a bottom shock absorbing cover, however the 2 concepts do include a recess between the bottom and the radial part.



Since the ½ scale mockup of the IR800 packaging had been subjected to a 9 m oblique drop on its recess, we will now analyse the analogy between this mockup and the TN-MTR packaging.

The dimensional and mechanical characteristics relevant for the bottom-down oblique drop are presented below:

	½ scale IR800 mockup	IR800 mockup corrected to full scale	TN-MTR Packaging
Total mass (kg)	3,154	25,232	23,400
Lead thickness (mm)	[redacted]	[redacted]	[redacted]
Resin thickness [mm]	[redacted]	[redacted]	[redacted]
Outer shell steel thickness (mm)	12	24	25
Diameter (mm)	662.5	1,325	1,480
Height (mm) on lid	1,390	2,780	1,610
Resin compression modulus (MPa)	[redacted]		[redacted]
Steel outer shell	X_2CrNi18-10 Re = 205 MPa Rm = 490 MPa		X_2CrNi19-11 Re = 200 MPa Rm = 520 MPa
Lead shell	Soft lead Density: 11.2		Soft lead Density: 11.2

Note that the mass of the IR800 mockup corrected to full scale is more than the maximum mass of the TN-MTR packaging.

Furthermore, outer shell steel thicknesses are almost identical. The resin thickness for the mockup of the IR800 corrected to full scale is more than it is for the TN-MTR, but since the resin does not act as a shock absorber during the drop due to its very high compression modulus (for all types of resin), this difference in thickness has no influence on the analysis of the analogy between the IR800 mockup and the TN-MTR.

Furthermore, the lead thickness is more for the TN-MTR packaging than for the full scale mockup of the IR800 packaging but this has no influence on the mechanical strength of the lead during a drop.

Finally, the material properties of the ½ scale mockup of the IR800 and of the TN-MTR packaging have the same order of magnitude.

All the above facts demonstrate that the nature of the ½ scale mockup of the IR800 packaging makes it at least equivalent to the TN-MTR packaging in terms of safety and mechanical strength for the 9 m bottom-down oblique drop (allowing for the scale factor).

Geometric readings taken from the safety file in reference <8> during the 9 m bottom-down oblique drop of the ½ scale mockup of the IR800 packaging give a maximum lead compressed thickness equal to 20.4 mm, equivalent to a compressed thickness equal to 40.8 mm after correction to full scale.

The maximum dose rate under accident transport conditions at the bottom of the packaging is recorded for the MTR type elements in Appendix 4A-11 and is equal to 0.906 mSv/h (see Section 6), regardless of the content considered.

For a compressed lead thickness equal to 40.8 mm, the equivalent dose rate D at 1 m under accident transport conditions can be evaluated as follows:

$$D = D_0 \times e^{-\mu \cdot (-4{,}08)}$$

Where

- μ = 0.53 cm^{-1}, the attenuation coefficient of lead,
- D_0 = 0.906 mSv/h,

Hence:

$$D = 0{,}906 \times e^{-0{,}53(-4{,}08)}$$

$$D = 7{,}87 \text{ mSv/h}$$

The equivalent dose rate at 1 m under accident transport conditions in the case of a 9 m bottom-down oblique drop of the TN-MTR packaging is equal to 7.87 mSv/h, which is less than the regulatory equivalent dose rate criterion to be respected for accident transport conditions, that is equal to 10 mSv/h.

8. CONCLUSION

For contents that upper-bound contents to be transported defined in Chapter 01 and the appendix, the equivalent dose rates around the TN-MTR packaging respect IAEA requirements <1> under routine and accident transport conditions for all contents planned for transport, including when fuel elements are loaded in cans.

Appendix 4A.1 to this Chapter justifies that the criterion stating that the DER should not increase by more than 20% under Normal Transport Condition is respected.

Depending on the transported radioactive content and its real characteristics, it may be necessary to make the transport under exclusive use (see table 4A.2).

9. REFERENCES

<1> Applicable IAEA regulations: see chapter 00

<2> Origen 22.1 - OAK RIDGE NATIONAL LABORATORY RSIC Computer Code Collection - Isotope Generation and Depletion Code Matrix Exponential Method

<3> SPR Nuclear Data Bank / Grenoble Version 1.1 Sept. 86

<4> « Mercure V » User's Manual. DMT report 94/458 SERMA/LEPP/94/1670. Mercure 5.2, a 3D Monte-Carlo program to integrate punctual nuclei of attenuation in straight line C. DUPONT CEA/DRN/DMT/SERMA

<5> SN1D analysis Code, User's Manual CEA/DRN 93/438 SERMA/LEPP/93-1532

<6> Reactor Shielding Design Manual - T. Rockwell III

<7> Technical note NTC-06-00039590 « Influence of ageing of F resin on equivalent dose rates of package models in the TN 24 family »

<8> Safety file for the IR 800 packaging « 160 EMBAL PFM NOT 06000114 »

<9> ORIGEN-ARP: Automatic rapid processing for spent fuel depletion, decay, and source term analysis. ORNL/TM-2005/39, Version 6, Vol. I, Sect. D1

<10> TRIPOLI-4 Version 4: User's manual - report CEA-R-6170

<11> Deleted

<12> APOLLO2: Reference Manual for Version 2.5 - DMT Report SSERMA/LENR/RT/99-2718/A June 2000,

<13> APOLLO2: Complement to the reference Manual for Version 2.5 - DM2S Report SERMA/LENR/RT/02-3072/A 2002,

<14> User's Guide for the DARWIN/PEPIN2 V2.2 software DM2S Report SERMA/LLPR/RT/07-4168/A

<15> Technical note « Performing RTR calculations for TNI (Packaging approval) using CESAR 5.3 » produced by AREVA NC La Hague – NTD 2014-51686 version 1.0 (SPE-14-00108791-002-00)

<16> TRIPOLI-4 version 7 User's guide. DM2S Report SERMA/LENR/RT/10/-4941/A

<17> TN international note: « Mechanical strength of the TN-MTR packaging in 0.3 m oblique drop at temperature ». Ref.: NTC-10-00026056

LIST OF TABLES

LIST OF APPENDICES

TABLE 4A.1 (1/2)
SUMMARY TABLE OF ELEMENT UPPER-BOUND PROPERTIES USED FOR THE CALCULATIONS

The following table contains upper-bound properties of elements used in equivalent dose rate calculations. Calculations were not made for all transported elements; they were made only for worst case elements so as to cover all envisaged load cases. Only elements for which calculations were made are listed below.

Basket	Content	Number of elements in the packaging	^{235}U enrichment	Total mass of U per element	Cooling time	Burnup (MWd/tU)
RHF	**RHF**	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
MTR-68	Content 1 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Content 2 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]
	Content 3 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]
MTR-52, MTR-52S, MTR-52SV2	Content 1 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Content 2 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]
	Content 3 (UAl_x-Al, U_ySi_z - Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]

TABLE 4A.1 (2/2)
SUMMARY TABLE OF ELEMENT UPPER-BOUND PROPERTIES USED FOR THE CALCULATIONS

Basket	Content	Number of elements in the packaging	^{235}U enrichment	Total mass of U per element	Cooling time	Burnup (MWd/tU)
MTR-44	Content 1 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Content 2 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]
	Content 3 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		[redacted]	[redacted]	[redacted]	[redacted]
	Content 4 (UO_2)		[redacted]	[redacted]	[redacted]	[redacted]
	Beryllium	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
FRMII	FRM-II	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
CESOX content with a ^{144}Ce-^{144}Pr radioactive source, sealed in special form		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Caesium trap content composed of solidified sodium trapping radioactive isotopes, principally the ^{137}Cs and ^{241}Am		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Gisete content composed of a strontium 90 titanium source ($SrTiO_3$)		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE 4A.2 (1/2)
SUMMARY RESULTS TABLE UNDER ROUTINE TRANSPORT CONDITIONS

Basket	Content	Number of elements in the packaging	Maximum equivalent dose rate (mSv/h)			Observations
			in contact with the package	at 1 m from the package	at 2 m from the package or the vehicle	
RHF	**RHF**	[redacted]	0.65	-	0.063	Transport under exclusive use
MTR-68	Content 1 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)	[redacted]	1.639	-	0.094[1]	Transport under exclusive use
	Content 2 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		1.780	-	0.094[1]	
	Content 3 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		0.455	-	0.022[1]	
MTR-52, MTR-52S, MTR-52SV2	Content 1 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)	[redacted]	1.193	-	0.065[1]	Transport under exclusive use
	Content 2 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		0.953	-	0.063[1]	
	Content 3 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		0.221	-	0.013[1]	

[1] DER values given are values for measurements at 2 metres from the vertical surfaces of the vehicle

TABLE 4A.2 (2/2)
SUMMARY RESULTS TABLE UNDER ROUTINE TRANSPORT CONDITIONS

Basket	Content	Number of elements in the packaging	Maximum equivalent dose rate (mSv/h)			Observations
			in contact with the package	At 1 m	at 2 m from the package or the vehicle	
MTR-44	Contents 1 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)	[redacted]	1.342	-	0,045[1]	Transport under exclusive use
	Content 2 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		1.391	-	0,035[1]	
	Content 3 (UAl_x-Al, U_ySi_z -Al, U_3O_8-Al, UMo-Al)		0.263	-	0,008[1]	
	Content 4 (UO_2)		0.679	-	0,023[1]	
	Beryllium	[redacted]	0.0544	-	$0{,}47.10^{-2}$ [1]	
FRMII	FRM-II	[redacted]	$6.9.10^{-3}$	$\leq 6.9.10^{-3}$	$5{,}842.10^{-4}$	-
CESOX content with a ^{144}Ce-^{144}Pr radioactive source, sealed in special form		[redacted]	$1.46.10^{-4}$	$\leq 1.46.10^{-4}$	$4.54.10^{-6}$	-
Caesium trap content composed of solidified sodium trapping radioactive isotopes, principally the ^{137}Cs and ^{241}Am		[redacted]	≤ 2	-	$\leq 2.54.10^{-2}$	-
Gisete content composed of a strontium 90 titanium source ($SrTiO_3$)		[redacted]	$3.09.10^{-2}$	-	$3.88.10^{-4}$	-

(1) DER values given are values for measurements at 2 metres from the vertical surfaces of the vehicle

ANNEXE 4A.1 (1/4)
JUSTIFICATION THAT THE MAXIMUM RADIATION INTENSITY IS NOT INCREASED BY MORE THAN 20% UNDER NORMAL TRANSPORT CONDITIONS

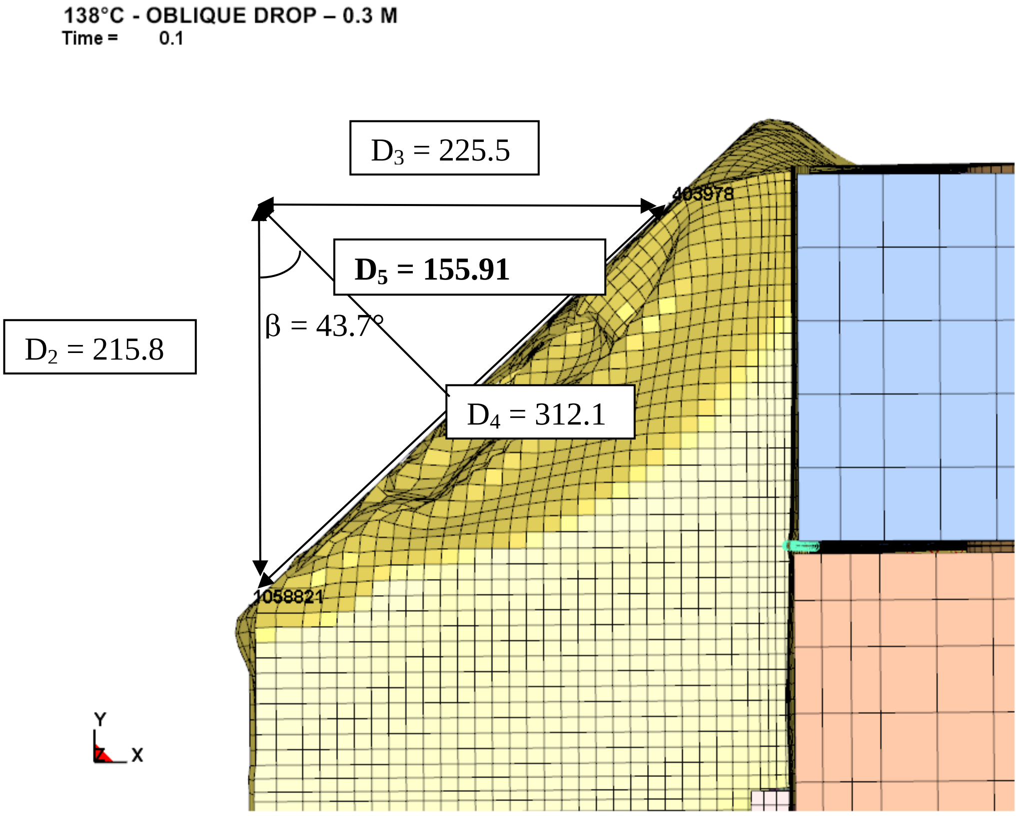
Case of an oblique drop on the shock absorbing cover

The maximum increase in the equivalent dose rate after a 0.3 m oblique drop on the top shock absorbing cover representative of normal transport conditions is evaluated, to justify that the maximum radiation intensity in contact with the package under normal transport conditions is not more than 20% higher than it is under routine transport conditions.

Crushing of the top shock absorbing cover for the 0.3 m oblique drop on the shock absorbing cover at a temperature that upper-bounds normal transport conditions (138°C), is calculated using a digital model presented in technical note <17>.

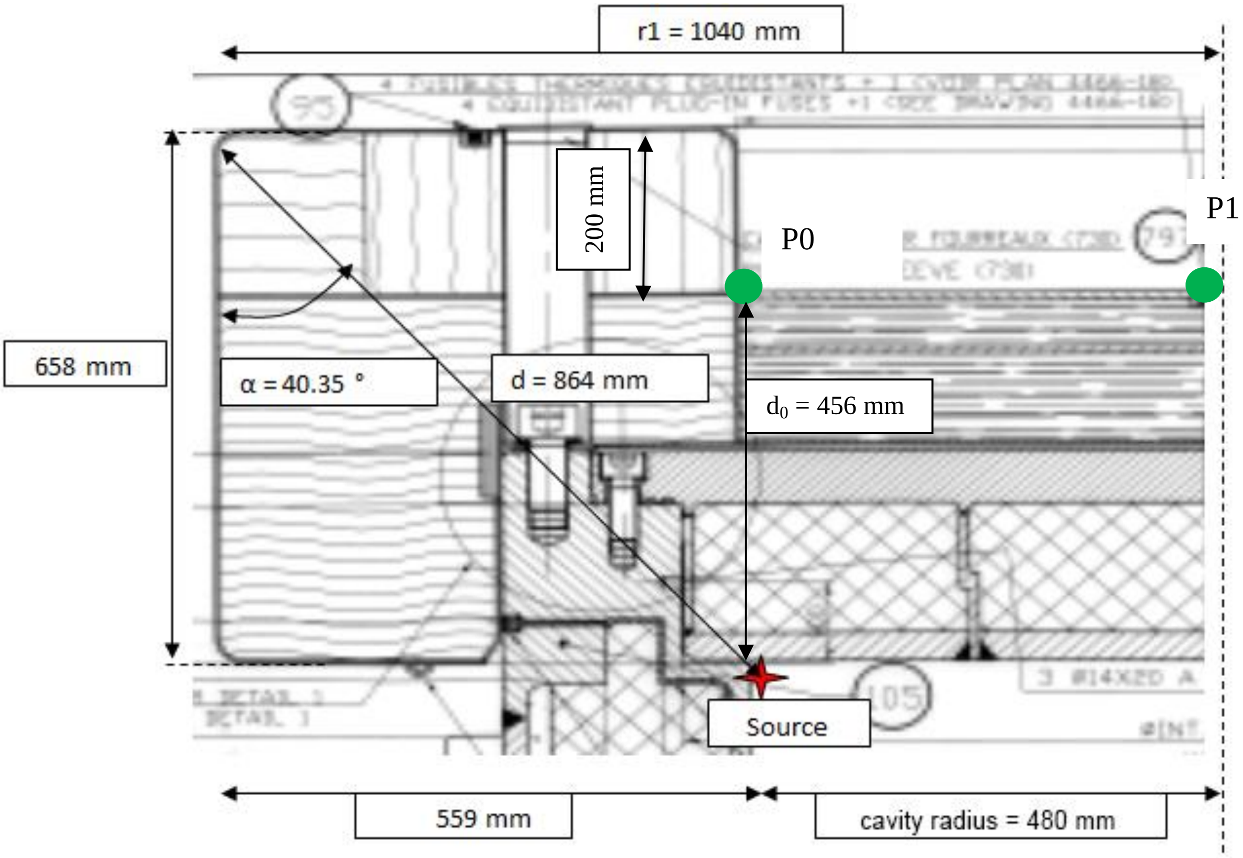
The deformation after a 0.3 m drop is D_5 = 155.91 mm.

The deformation profile of the shock absorbing cover is:



APPENDIX 4A.1 (2/4)

The dose rate closest to the corner of the shock absorbing cover for each content (presented in Appendices 4A-1 to 4A-12) is the dose rate at point P_0 or P_1. The distance between these points on the corner of the shock absorbing cover is more than 200 mm of balsa.



A radially offset pointwise source installed in contact with the lid is considered.

Before the shock absorbing cover is crushed, the minimum distance between the corner of the shock absorbing cover and the source is equal to the distance d = 864 mm.

After the shock absorbing cover has been crushed, the distance d is reduced by a distance d_e equal to:

$$d' = d - d_e = d - \frac{D_5}{\cos(\beta - \alpha)} = 707.8$$

Since the distance d' remains greater than the distance d_0, after the NCT drop, equivalent dose rates at the shock absorbing cover remain less than the DER values calculated under routine transport conditions at point P_0 or P_1.

Therefore the maximum radiation intensity in contact with the package under normal transport conditions is not more than 20% higher than it is under routine transport conditions. The regulatory criterion for normal transport conditions is respected:

APPENDIX 4A.1 (3/4)

Case of an axial drop on the shock absorbing cover

The maximum increase in the equivalent dose rate after a 0.3 m axial drop on the top shock absorbing cover representative of normal transport conditions is evaluated, to justify that the maximum radiation intensity in contact with the package under normal transport conditions is not more than 20% higher than it is under routine transport conditions.

Maximum crushing of the TN-MTR packaging shock absorbing cover for a 9 m axial drop at the maximum temperature of normal transport conditions is evaluated in Appendix 1-9-3.

The corresponding impact energy is equal to:

$E_a = M_a \times g \times ha = 23400 \times 9.81 \times 9.25 = 2\ 123\ 375$ J

Maximum crushing at the upper ring of the shock absorbing cover is 118.2 mm, the equivalent crush stress in the shock absorbing cover is equal to:

$$\sigma = \frac{E}{u_1 \times S}$$

where:

$$S = S_{balsa//} + S_{balsa\perp} = \left[\frac{\pi}{4}\left(1{,}76^2 - 0{,}99^2\right) + \frac{\pi}{4}\left(2{,}07^2 - 1{,}76^2\right)\right] = 2{,}60\ m^2$$

$$u_1 = 118{,}2\ mm$$

We have:

$$\sigma = \frac{2123375}{118{,}2 \times 10^{-3} \times 2{,}60} = 6{,}9\ MPa$$

This equivalent compression stress is unchanged for a 0.3 m drop.

We can thus determine crushing u_2 of the packaging top shock absorbing cover for a 0.3 m drop, based on the same reasoning as above. This gives us:

$$u_2 = \frac{E}{\sigma \times S}$$

Where: $E = m \times g \times h = 23400 \times 9{,}81 \times 0{,}3 = 68866$ J

$$\sigma = 6{,}9\ MPa$$

$$S = 2{,}60\ m^2$$

We have:

u_2 = 3.8 mm along the drop axis

APPENDIX 4A.1 (4/4)

Assuming that the source is located at the centre of the cavity close to the packaging lid, we will determine the $\frac{d^2}{(d-u)^2}$ ratio, using:

d: the distance between the first point of impact on the shock absorbing cover and the source

d = 658 mm and u = 3.8 mm,

Thus d – u = 654.2 mm and $\frac{d^2}{(d-u)^2} = 1.012$.

Therefore the increase in the dose rate after a 0.3 m axial drop on the top shock absorbing cover representative of normal transport conditions is not more than 1.2%.

Therefore the maximum radiation intensity in contact with the package under normal transport conditions is not more than 20% higher than it is under routine transport conditions. The regulatory criterion for normal transport conditions is respected.

APPENDIX 4A.2

CALCULATION OF THE REDUCED DENSITY OF THE LID STAINLESS STEEL

The calculation of the reduced density of the stainless steel plugs of the lid is shown below:

$$
\begin{aligned}
V_{air} &= 11^2 \times \frac{\pi}{4} \times \left[39{,}5 + 90 + 142 - 39{,}5 + \frac{11}{2} \right] \\
&+ \frac{\pi}{4} \times \left[40^2 \times 49 + 24^2 \times (89 - 49) \right] \\
&+ \frac{\pi}{4} \times \left[98^2 - 94^2 \right] \times 148 \\
&+ \frac{\pi}{4} \times \left[94^2 - 90^2 \right] \times 74 = 2.343x10^2 \; cm^3
\end{aligned}
$$

$$V_{total} = \pi \times \frac{98^2}{4} \times 260 = 1.961x10^3 \; cm^3$$

$$D_{reduceddensity} = \frac{V_{steel}}{V_{total}} \times 7.85 = \frac{V_{total} - V_{air}}{V_{total}} \times 7.85 = 6.91$$