THERMAL ANALYSIS OF INTERNAL FITTINGS OF THE TN-MTR PACKAGING

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SUMMARY

This Chapter presents thermal calculations for internal fittings for the TN-MTR packaging and checks that the temperatures reached are compatible with the characteristics of materials used for baskets and are acceptable for fuel assemblies and contents. The average gas temperature in the cavity is also calculated because it is used for the analysis of the TN-MTR packaging confinement.

Considering the results of the mechanical analysis (negligible deformations under normal and accident transport conditions), the geometry of internal fittings of the damaged packaging is identical to that described in Chapter 01 under normal and accident transport conditions.

The calculations are made by finite element computer programs and by analytical calculations.

The results are summarised in the table below:

		Maximum power of the content (inerting of the cavity assumed for the calculations)	Normal Conditions of Transport			Accident Conditions of Transport		
			T max basket	T max contents	T avg cavity gas	T max basket	T max contents	T avg cavity gas
RHF Basket		5500 W [5] (helium) or 4360 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
MTR-68 basket	General case	5500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	2856 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	BR2 S5 and S6 25 W [1]	1700 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	ANSTO 42 W [1]	2856 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
MTR-52 basket	General case (without canister or with canister 1)	5500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	2184 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	with canister 3:	4500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Broken or disassembled BR2	900 W [5] (helium)	[redacted]	[redacted] [6]	[redacted]	[redacted]	[redacted] [6]	[redacted]
MTR-52S and MTR-52SV2 baskets	General case (without canister) 42 W per compartment	2200 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	With canisters 15W per compartment [2]	780 W [5] (air)	[redacted]	[redacted]		[redacted]	[redacted]	

		Maximum power of the content (inerting of the cavity assumed for the calculations)	Normal Conditions of Transport			Accident Conditions of Transport		
			T max basket	T max contents	T avg cavity gas	T max basket	T max contents	T avg cavity gas
MTR-44 basket	General case	5500 W [5] (helium) or 3430 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	1848 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
FRM II Basket		420 W [5] (air)	[redacted]	[redacted]	[redacted] [3]	-	-	-
CESOX [4]		1,200 W [5] (air)	[redacted]	[redacted]	[redacted]	-	[redacted]	[redacted]
Caesium trap [7]		0.5 W [5'] (some gas)	[redacted]	[redacted]	[redacted]	-	-	[redacted]
Gisete [8]		160 W [5] (air)	[redacted]	-	[redacted]	-	-	[redacted]

(1) Maximum temperatures used during accident transport conditions are conservatively taken equal to maximum temperatures for the general case.

(2) Cavity gas temperatures are conservatively taken equal to maximum gas temperatures calculated for the general case with a power of 42 W per compartment.

(3) This temperature is a maximum temperature.

(4) For the CESOX content:
- The basket temperature is the temperature of the internal fittings;
- The content temperature is the temperature of the sealed double capsule;
- The cavity gas temperature is the maximum temperature of the tungsten radiation shielding.

(5) Except for the CESOX content for which the cavity must contain air, the cavity may be inerted by air, helium or any other neutral gas (nitrogen, etc.) for contents for which calculations were made with air or nitrogen inerting. The inerting gas for contents for which the calculations were made with helium inerting must be helium.

(5') For the caesium trap content, from a thermal point of view, the cavity filling gas must contain air, helium or any other neutral gas (nitrogen, etc…).

(6) The temperature of the content for the broken or disassembled BR2 content is the temperature of the BR2 canisters.

(7) These temperatures are justified in the paragraph 5.5 of this chapter.

(8) These temperatures are justified in the paragraph 5.6 of this chapter.

These temperatures are compatible with materials used for internal fittings and the different contents.

1. PURPOSE

This document presents the thermal analysis of possible contents of the TN-MTR packaging under normal and accident conditions of transport as defined by IAEA rules <1>. In particular, it presents:

- the maximum temperature reached by the basket and its content (fuel assemblies, sources);
- the average temperature of the cavity filler gas

These temperatures are used to:

- justify the mechanical strength of the baskets and fuel assemblies presented in Chapter 1A;
- Justify release assumptions given in Appendices to Chapter 3A regarding the cavity gas temperature.

This chapter includes several appendices: each appendix presents the calculation of one of the baskets that can be used in the TN-MTR packaging with its worst case radioactive content.

2. CALCULATION METHODS

The calculations are made by finite element computer programs with imposed boundary conditions. The following two programs are used:

- ANSYS for calculations made with MTR-68 baskets (except for the OSIRIS 42 W, BR2 and ANSTO 42W contents) and MTR-52 (except for OSIRIS 42 W and broken or disassembled BR2 contents);
- IDEAS TMG module for calculations made with RHF, MTR-44 baskets (including the OSIRIS 42 W content), MTR-52 (OSIRIS 42 W and broken or disassembled BR2 contents), MTR-68 (OSIRIS 42 W, BR2 and ANSTO 42W contents), MTR-52S, FRM-II and the CESOX content.

The results obtained can be corrected analytically as a function of the maximum thermal power defined in the appendices to Chapter 0A for each basket and as a function of the maximum cavity wall temperatures determined in Chapter 2.

The thermal analysis of the MTR-52SV2 basket is based on the thermal analysis of the MTR-52S basket because these two baskets are thermally equivalent.

3. THERMAL CRITERIA

Thermal criteria for the different contents considered are presented in the appendices.

In general, it is checked that the obtained temperatures of the contents and the internal fittings are consistent with the safety analyses in this file.

4. FINITE ELEMENT CALCULATION MODEL

4.1 Geometric model

The geometric model is specific to each basket and is presented in the corresponding appendix.

Thermal calculations for the RHF basket are made with the 3D model of the basket loaded with RHF elements. The conductivity applied to the basket is the conductivity of steel.

The MTR-68 basket (apart from the BR2, OSIRIS 42 W and ANSTO 42W contents) is represented by a two-dimensional model. This model includes a radial section of the basket and the air gap between the periphery of the basket and the packaging internal wall. The conductivity applied to the basket disk is a weighted average of the thermal conductivities of stainless steel and borated aluminium in the disks.

The MTR-52 baskets (except for OSIRIS 42 W and broken or disassembled BR2 contents), and the MTR-52S and MTR-44 baskets (except for the OSIRIS 42W content), are represented by two-dimensional models. These models include a radial section of the basket and the air gap between the periphery of the basket and the packaging internal wall. The thermal flux is transmitted only through the borated aluminium disks.

The MTR-52SV2 basket is designed for contents identical to the MTR-52S contents, particularly in terms of thermal power, and its dimensions are identical to the MTR 52S dimensions. Furthermore, the thermal properties of materials used to remove transported internal power are identical to those for the MTR-52S basket. Thus, the MTR-52SV2 basket is not modelled and the results obtained for the MTR-52S basket are applicable to the MTR-52SV2.

For the CESOX content, Appendix 2A-10 presents a 3D model of the TN-MTR packaging and the CESOX content with its internal fittings. The physical characteristics used for the calculation are also presented in this chapter.

For the BR2 S6 and S5 content, Appendix 2A-11 presents a 3D model of the packaging and the MTR-68 basket, with a 2D model of the BR2 S5 and S6 fuel elements. The physical characteristics used for the calculation are also presented in this chapter.

For the OSIRIS 42 W content, Appendix 2A-12 presents a 3D model of the packaging and the MTR-68, MTR-52 and MTR-44 baskets, with a 2D model of the OSIRIS fuel element. The physical characteristics used for the calculation are also presented in this chapter.

For the FRM-II content, Appendix 2A-13 presents a 3D model of the packaging and the FRM-II basket, with a 2D model of the FRM-II fuel element. The physical characteristics used for the calculation are also presented in this chapter.

For the ANSTO 42W content, Appendix 2A-14 presents a 3D model of the packaging and the MTR-68 basket, with a 2D model of the ANSTO fuel element. The physical characteristics used for the calculation are also presented in this chapter.

For the broken or disassembled BR2 content, Appendix 2A-15 presents a 3D model of the packaging, the MTR-52 basket and transport cases. The physical characteristics used for the calculation are also presented in this chapter.

The Caesium trap and gisete contents are not treated by numerical calculation.

4.2 Characteristics of materials

The characteristics of the materials are taken from the appendices to Chapter 0A.

5. BOUNDARY CONDITIONS AND CALCULATION METHODOLOGY

5.1 General case: RHF; MTR-68 (except for OSIRIS 42 W, BR2 and ANSTO 42 W contents); MTR-52 (except for OSIRIS 42 W and broken or disassembled BR2); MTR-52S, MTR-52SV2; MTR-44 (except tor OSIRIS 42 W contents)

Fuel elements for the RHF basket are represented in the 3D digital model. The thermal power is then applied uniformly throughout the volume in the RHF elements model.

In the case of MTR-68, MTR-52 and MTR-52S baskets, the thermal power is applied to the surface in the section of the compartments in the 2D model. Fuel elements are represented by a medium for which the equivalent conductivity has been determined beforehand as a function of the temperature of the compartment walls. To achieve this, upper-bound fuel elements are included in the digital model and the temperature at the centre of the elements is calculated assuming conduction and radiation exchanges in the compartment.

For the MTR-44 basket, thermal power is applied to the wall of compartments of the 2D model in the form of a total flux.

In each digital model, a first calculation is made from an imposed cavity wall temperature and imposed total thermal power, so as to determine the maximum temperature gradient in the baskets. Conductive and radiative exchanges though the air gap separating the baskets from the cavity are included in the calculation model. The temperature gradient in each basket is then deduced for the power considered, considering that heat exchanges in the baskets only take place by conduction. The temperature at the periphery of the baskets is then calculated analytically.

The calculations for normal and accident transport conditions are made for steady state conditions using the maximum cavity temperature. According to chapter 2, the maximum temperature of the cavity is 117.3°C under normal transport conditions and 183.8°C under accident transport conditions. The following upper-bound cavity temperatures are used for a total thermal power of 5500 W so as to maximise content temperatures:

- 138°C under Normal Conditions of Transport,
- 188°C under Accident Conditions of Transport.

The maximum power is:

- 2200 W for the MTR-52S and MTR-52SV2 baskets when the load does not include any canisters and 780W for loads for which there is at least one canister,
- 4500 W for the MTR-52 basket in the case of packaging in a type 3 canister (see description in Chapter 0A-3).

Therefore the temperature of the cavity wall is corrected as a function of the allowable power under normal transport conditions and is conservatively taken to be equal to 188°C under accident transport conditions.

The maximum basket temperature is then evaluated, so that the maximum temperature of fuel elements and the temperature of gas in the cavity can thus be calculated.

5.2 CESOX

For the CESOX content, a power of 1200 W is applied inside the sealed double capsule. Maximum temperatures of the CESOX content and its internal fittings are determined by digital calculations and are presented in Chapter 2A-10 using a 3D model including the packaging and internal fittings.

5.3 OSIRIS 42 W, BR2, FRM-II and ANSTO 42 W

Basket temperatures under normal transport conditions are determined digitally in Chapters 2A-12, 2A-11, 2A-13 and 2A-14 respectively using a 3D model directly including the model of the packaging and the baskets. The temperature of the fuel element and the cavity gas temperature are determined on the 2D model using the maximum temperature of the basket compartment determined on the 3D model.

In the case of the OSIRIS 42 W content loaded in an MTR-68, MTR-52 or MTR-44 basket, a power of 42 W per element is considered, namely a total power of:

- [redacted] in the MTR-68 basket,
- in the MTR-52 basket,
- in the MTR-44 basket.

In the case of the BR2 S6 and S5 content loaded in an MTR-68 basket, a power of 25 W per element is considered, making a total power of 1700 W.

In the case of the FRM-II content, a power of 60 W per element is considered, making a total power of 420 W.

In the case of the ANSTO 42 W content loaded in an MTR-68 basket, a power of 42 W per element is considered, making a total power of [redacted].

5.4 Broken or disassembled BR2

Temperatures of canisters, cavity gases and packaging seals under normal transport conditions are determined digitally using a 3D model directly including the model of the packaging, the basket and canisters in Chapter 2A-15. A power of 25 W per canister is considered, for a total power of 900 W for 36 canisters.

Under accident transport conditions, the temperature of canisters and the temperature of the cavity gas are determined using a 2D model assuming the maximum cavity wall (shell) temperature determined in the thermal analysis of the packaging under accident transport conditions presented in Chapter 2 of this safety file, for an upper-bound content with a power of 5500 W.

5.5 Caesium trap

Under normal transport conditions, in view of negligible thermal power of this content (0.5W), the temperature of the cavity and the packaging content (internal fittings and cavity gas) is considered homogeneous and taken equal to 70°C (upper-bound temperature for a package exposed to an ambient temperature of 38°C and submitted to regulatory sunlight).

Under accident transport conditions, the temperature of the cavity gas is considered conservatively equal to the temperature of the cavity gas determined for broken or disassembled BR2 content with an upper-bound power of 900W.

In view of the negligible thermal power of the content and penalising values of temperature considered, the nature of the cavity gas is without impact on the analysis.

5.6 Gisete

Due to the similarity of concept of internal fittings with the CESOX content and because the gisete content has a low maximum thermal power (160 W) and clearly smaller than CESOX content (1 200 W), the temperatures well designed for the safety of the packaging loaded with gisete content are taken at the very least equal to those considered conservatively for the CESOX content, namely:

- A maximum temperature of internal fittings taken equal to [redacted] under normal transport conditions, that is to say an upper-bound temperature from that considered for the CESOX content (87°C);
- A temperature of the cavity gas taken equal to [redacted] under normal transport conditions;
- A temperature of the cavity gas taken equal to [redacted] under accident transport conditions.

6. RESULTS

The results are presented in table 2A.1.

Temperatures reached in the different internal fittings loaded with their allowable contents are compatible with fixed limits.

7. CONCLUSION

Maximum temperatures reached by materials of baskets and other internal fittings under normal and accident transport conditions are compatible with the properties of these materials.

Maximum temperatures reached by fuel assemblies or radioactive sources are also acceptable under normal and accident transport conditions.

The average gas temperature presented in this chapter is used for the confinement analysis.

8. REFERENCES

<1> Applicable IAEA regulation: See Chapter 00

LIST OF TABLES

TABLE 2A.1

TEMPERATURES OF INTERNAL FITTINGS

		Maximum power of the content (inerting of the cavity assumed for the calculations)	Normal Conditions of Transport			Accident Conditions of Transport		
			T max basket	T max contents	T avg cavity gas	T max basket	T max contents	T avg cavity gas
RHF Basket		5500 W [5] (helium) or 4360 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
MTR-68 basket	General case	5500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	2856 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	BR2 S5 and S6 25 W [1]	1700 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	ANSTO 42 W [1]	2856 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
MTR-52 basket	General case (without canister or with canister 1)	5500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	2184 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
	with canister 3:	4500 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Broken or disassembled BR2	900 W [5] (helium)	[redacted]	[redacted] [6]	[redacted]	[redacted]	[redacted] [6]	[redacted]
MTR-52S and MTR-52SV2 baskets	General case (without canister) 42 W per compartment	2200 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	With canisters 15W per compartment [2]	780 W [5] (air)	[redacted]	[redacted]		[redacted]	[redacted]	
MTR-44 basket	General case	5500 W [5] (helium) or 3430 W [5] (air)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	OSIRIS 42 W [1]	1848 W [5] (nitrogen)	[redacted]	[redacted]	[redacted] [3]			
FRM II Basket		420 W [5] (air)	[redacted]	[redacted]	[redacted] [3]	-	-	-
CESOX [4]		1,200 W [5] (air)				-	[redacted]	[redacted]
Caesium trap [7]		0.5 W [5'] (some gas)	[redacted]	[redacted]	[redacted]	-	-	[redacted]
Gisete [8]		160 W [5] (air)	[redacted]	-	[redacted]	-	-	[redacted]

(1) Maximum temperatures used during accident transport conditions are conservatively taken equal to maximum temperatures for the general case.
(2) Cavity gas temperatures are conservatively taken equal to maximum gas temperatures calculated for the general case with a power of 42 W per compartment.
(3) This temperature is a maximum temperature.
(4) For the CESOX content:
- The basket temperature is the temperature of the internal fittings;
- The content temperature is the temperature of the sealed double capsule;

- The cavity gas temperature is the maximum temperature of the tungsten radiation shielding.

(5) Except for the CESOX content for which the cavity must contain air, the cavity may be inerted by air, helium or any other neutral gas (nitrogen, etc.) for contents for which calculations were made with air or nitrogen inerting. The inerting gas for contents for which the calculations were made with helium inerting must be helium.

(5') For the caesium trap content, from a thermal point of view, the cavity filling gas must contain air, helium or any other neutral gas (nitrogen, etc…).

(6) The temperature of the content for the broken or disassembled BR2 content is the temperature of the BR2 canisters.

(7) These temperatures are justified in the paragraph 5.5 of this chapter.

(8) These temperatures are justified in the paragraph 5.6 of this chapter.