Orano NPS SAFETY ANALYSIS REPORT FCC4 / FCC3	Unrestricted Orano CHAPTER 2.2 THERMAL ANALYSIS		
	Prepared by		
	Checked by		
Identification :	DOS-19-021165-013-NPV	Version : 1.0	Page 1 / 14

Table of contents

Status of revision

English version	French version	Date	Purpose and record of revisions	Prepared by / Checked by
Old reference : DOS-13-00081778-200				
00	00	04/2012	First issue – Revision of Appendix 13 of Safety Analysis Report TFXDC 2158 revision H and Appendix 14 of Safety Analysis Report TFXDC 2159 revision G. – Integration of explicit allowance for oxidation of the claddings by air (Appendix 2.2-2). – Integration of justification of non-allowance of oxidation of the claddings by steam. – Introduction of new thermal-mechanical calculations (Appendix 2.2-3).	
01	01	12/2015	– Addition of justifications relating to the potential presence of a maximum of 5g glycerine.	
02	02	10/2016	– Addition of the impact of pre-strain of claddings, caused by mechanical tests prior to thermal testing of their behaviour – Addition of the impact on the maximum temperature of the fuel rods of potentially continuing with the combustion of the wood in the shock absorbers on completion of the thermal test. – Update to paragraph 4: • Integration of new results for Appendix 2.2-3. – Update to Appendix 2.2-3. – Shifting of the paragraph in Chapter 2.1-13, (dealing with the thermal impact) to this chapter. • Analysis of the deviations in the representative nature of the EPR top plate with respect to the conventional top plate. • Analysis of the geometrical deviations in the EPR doors with respect to conventional doors.	
1.0	03	11/2020	– Study of the addition of a chrome thickness up to 30 µm on the cladding – Update to Appendices 2.2-2 and 2.2-3	
New reference: DOS-19-021165-013				
1.0	1.0	See first page	– Deletion of the Appendix 2.2-2 – Rework of the Appendix 2.2-1 – Update of Appendix 2.2-3 calculation results – Formal modifications	

BRAND NAMES

AFA 3G, M5, Q12, MONOBLOC, TRAPPER, AGORA, HTP, HMP and ROBUST FUELGUARD are brands or registered brands of Framatome or its subsidiaries, in the USA or in other countries.

Summary

The purpose of this Chapter is to describe the thermal analysis of the FCC3 and FCC4 package models in normal and accidental conditions of transport in accordance with the regulations (reference <1>) applicable to industrial type packages loaded with fissile materials.

This analysis includes:

- Determination of the maximum temperature reached by the package under normal conditions of transport;
- Determination of the maximum temperatures reached by the fuel rod claddings under accident conditions of transport;
- The condition of the resin after fire;
- Thermal-mechanical analysis of the creep strength of the hottest cladding tubes;
- Analysis of the impact of 5g of glycerine in the fuel assemblies on the creep behaviour of the rods;
- Analysis of the impact of pre-strain of the claddings, caused by mechanical tests prior to thermal testing of their behaviour;
- Analysis of the impact on the maximum temperature of the fuel rods of potentially continuing with the combustion of the wood in the shock absorbers on completion of the thermal test;
- Analysis of the deviations in the representative nature of the EPR top plate with respect to the conventional top plate.
- Analysis of the geometrical deviations in the EPR doors with respect to conventional doors;
- Analysis of the impact of the presence of the smooth-walled dummy or assembly model;
- Analysis of the presence of a chrome coating thickness up to 30 µm on the fuel rod claddings.

The thermal performance of the packaging was evaluated by numerical calculation and tests for the neutron-absorbing resin then the strength of the enclosure (rod claddings) was studied.

The maximum temperature reached by the FCC3 and FCC4 packages under normal conditions of transport is [redacted] °C.

The calculations carried out to determine the maximum temperatures reached by the fuel rod claddings under accidental conditions of transport showed that 3 fuel rod claddings reached temperatures over 600 °C.

The thermal-mechanical analysis carried out on these 3 fuel rods show that the risk of bursting of the Zircaloy-4 or M5 $_{\text{Framatome}}$ cladding, due to creep, can be ruled out with a minimum safety factor of 3.3.

The study carried out on the potential combustion of 5 g of glycerine contained in the FCC3 and FCC4 packagings shows that the impact upon the creep behaviour of the rods is negligible and does not affect the thermal-mechanical analyses detailed in the chapter.

The deformation of the claddings, caused by the mechanical drop tests, has no impact on their thermal-mechanical strength during the thermal fire test.

Moreover, the increased heat caused by the potential combustion of the wood in the shock-absorbers used in FCC3 and FCC4 packagings is covered by the assumptions used in the calculation of the maximum cladding temperatures, determined in Appendix 2.2-1.

Adaptation of the doors for the system holding the EPR fuel assembly grids in place, as opposed to the conventional doors used for XL, XLR and GAIA assemblies, makes no difference to the chapter’s thermal analyses.

The possible presence of the smooth-walled dummy has no impact on the chapter’s thermal analyses.

The possible presence of a chrome coating on the fuel rod claddings has no impact on the chapter's thermal analyses.

1. Purpose

The purpose of this Chapter is to describe the thermal analysis of the FCC3 and FCC4 package models in normal and accidental conditions of transport in accordance with the regulations (reference <1>) applicable to industrial type packages loaded with fissile materials.

This analysis includes:

- Determination of the maximum temperature reached by the package under normal conditions of transport;
- Determination of the maximum temperatures reached by the fuel rod claddings under accidental conditions of transport;
- The condition of the resin after fire;
- Thermal-mechanical analysis of the creep strength of the hottest cladding tubes;
- Analysis of the impact of 5g of glycerine in the fuel assemblies on the creep behaviour of the rods;
- Analysis of the impact of pre-strain of the claddings, caused by mechanical tests prior to thermal testing of their behaviour;
- Analysis of the impact on the maximum temperature of the fuel rods of potentially continuing with the combustion of the wood in the shock absorbers on completion of the thermal test;
- Analysis of the deviations in the representative nature of the EPR top plate with respect to the conventional top plate;
- Analysis of the geometrical deviations in the EPR doors with respect to conventional doors;
- Analysis of the impact of the presence of the smooth-walled dummy or assembly model;
- Analysis of the presence of a chrome coating thickness up to 30 µm on the fuel rod claddings.

The thermal performance of the packaging was evaluated by numerical calculation and tests for the neutron-absorbing resin then the strength of the enclosure (rod claddings) was studied.

2. Input data

A description of the package is given in Chapters 1.3 (contents) and 1.4 (packaging) of this Report.

The thermal characteristics of the resin are given in Appendix 2.2-4.

Confinement of the material is provided by the claddings and the only material of the packaging sensitive to high temperatures is the neutron absorbing resin.

The condition of the package after drop tests representative of accidental conditions of transport is described in Chapter 2.1.

3. Determination of maximum temperatures reached in normal conditions of transport

The maximum temperatures reached by the component parts of the package under Normal Conditions of Transport are determined by the thermal analysis in Appendix 2.2-6, assuming an ambient temperature of 38°C and a solar flux applied for 12 hours out of every 24, as per regulation <1>.

4. Determination of maximum temperatures reached by the claddings in accidental conditions of transport

4.1. Determination of maximum cladding temperatures

The maximum temperatures reached by the claddings in accidental conditions of transport are evaluated in Appendix 2.2-1 via numerical calculations.

The studies realized in appendix 2.2-1 relate the case of fuel assemblies transportations and the case of rod transportations contained into rod boxes.

On the basis of observations made following the mechanical tests (see Chapter 2.1 of this Report) the following assumptions were made in the calculations carried out:

- The outer shell was not modelled due to the fact that it perforated during the drop test onto a bar (conservative assumption);
- The frame-door clearance was assumed to be [redacted] mm at the flux entry point (top) and [redacted] mm at the flux exit point (bottom) which bounds the post-drop observations.

The main general assumptions used for modelling purposes are summarized below:

- 2D modelling of half of the internal equipment for reasons of symmetry, completed with a 3D modellings for the sensitivity analyses linked to the end assemblies singularities
- Fine modelling of the rods.
- Emissivity of the external surfaces of the claddings assumed to be [redacted] with a sensitivity study for an emissivity value assumed to be [redacted].
- Analysis of Zircaloy-4 and M5 $_{\text{Framatome}}$ claddings.
- Emissivity of the internal walls of the door and frame assumed to be [redacted].
- Modelling of non-degraded resin (conservative relative to modelling of air-calcined resin because intact resin has a higher conductivity).
- Analysis of 16x16, 17x17 and 18x18 arrays in the FCC4 package (14x14 and 15x15 arrays in the FCC3 package were not modelled as these are covered by the arrays studied).
- The physical properties of the materials vary with temperature, with the exception of the resin which the taken properties are these corresponding to a temperature of [redacted]°C.
- Conservatively, the container is in a horizontal position, inclined at [redacted]° angle according to the external shell revolutionnary axis.
- Initial temperature [redacted] °C.
- During the fire phase, the coefficient of absorptivity of the external walls is assumed to be 0.8 and the convective exchange coefficient is assumed to be 10 W/m²K.
- During the cooling phase, allowance for the outer shell by the addition of an equivalent thermal resistance and entering air at [redacted] °C.

Details of the first calculation cases are given in Appendix 2.2-1 and are used to confirm the modelling hypothesis solidity. The studied cases and their results are summarized below:

- Low sentivity to the meshing and to the time stepping for the twodimensional models.

- Low sentivity to the meshing and to the time stepping for the three-dimensional cases. However, the numerical parameters used are more penalyzing than for the twodimensional cases, which ensure that the results of three-dimensional cases are conservatives.
- Sensitivity to laminar or turbulent flow systems, which allows to conclude about the laminar flow choice relevance.
- Sensitivity to emissivity value of the internal side of the cavity (claddings, internal plates and guide tubes), allowing to conclude that an emissivity of [redacted] is conservative.

The FCC packagings can carry different type of assemblies. An analysis of array sensitivity shows that the 17x17 array is more penalizing concerning the rising temperature of the cladding.

From the reference case, which is the analysis of the 17x17 array, modelled in 2 dimensions, the following sensitivity studies are carried out :

- Taken into account materials properties, considering the following cases :
  - Analysis of impact of M5 $_{\text{Framatome}}$ or Zircaloy-4 cladding material.
  - Analysis of impact of claddings pre-oxydation.
  - Study of the addition of a chrome coating thickness up to 30 µm around the cladding.
- Taken into account characteristics changes of the assemblies (rod diameter and pellet diameter).
- Taken into account three-dimensional effects :
  - Assembly bottom zone.
  - Assembly top zone (considering pre-oxyded M5$_{\text{Framatome}}$ or Zircaloy-4 claddings).
- Sentivity to the assembly deformation, due to drops, considering several possible configurations :
  - Homogeneous expansion (the movement of rods is the same in all direction)
  - Heterogenous expansion (the movement varies according to the rod position)
  - Obstruction of the two gaps frame-door by rods.
  - Compacting mesured following the drop tests.

A study of transports case with non-assembled rods in rod boxes is also realised and evaluate the impact :

- Of the rod’s number
- Of the rods box modelling

The results of these investigations are presented below:

- The cladding material M5$_{\text{Framatome}}$ and Zircaloy-4 have a similar behavior.
- The changes in the assembly characteristics have little influence on the maximum temperatures reached.
- Allowance for array expansion leads to lower temperatures for the hottest claddings.

- The changes in the assembly characteristics have little influence on the maximum temperatures reached.

- Oxidation of the claddings by air has little influence on the maximum temperatures of the claddings.

- The addition of a thickness of chrome does not impact on the claddings temperatures.

- Temperatures evaluation thank to a three-dimensional model shows that the temperatures are not more penalizing on the bottom of the assembly.

- Temperatures evaluation thank to a three-dimensional model shows that the temperatures are higher, localized manner, on the top of the assembly.

- The making allowance for array expansion leads to lower temperatures for the hottest claddings.

- The making allowance of obturation of gapsframe-door provides lower temperatures on all the claddings.

- The study of the array compacting shows that, on average, the compacting provides lower temperatures on the claddings.

- The analysis of rods box transport case provide lower temperatures on the claddings.

Following these evaluations, the temperature transients of the claddings for which the maximum temperature is over 600 °C are extracted as input data for the thermal-mechanical creep strength study (see Appendix 2.2-3). Thus, the strength of the 3 hottest rods is analysed below (see § 5).

4.2. Post-fire condition of resin

The post-fire condition of the resin is described in Appendix 2.2-4. This Appendix presents an analysis of FS69 resin samples exposed to an 800 °C flame for 30 minutes.

The analyses show that a 100 % loss of hydrogen over a thickness of [redacted] mm and an average loss of 10 % of the boron, over the full thickness are bounding values for the losses observed. These values are taken into account in the criticality studies described in Chapter 2.5.

4.3. Justification of non-inclusion of oxidation of the claddings by steam

The oxidation reaction which can take place between zirconium and steam is as follows:

$Zr + 2\ H_20 \Rightarrow ZrO_2 + 2\ H_2$

According to reference <2> the enthalpy associated with this reaction is: -585 kJ/mol. This reaction is therefore exothermic. The explicit model of the oxidation reaction of zirconium by air described in Appendix 2.2-1 shows a negligible effect on the post-fire cladding temperatures reached. The aim is therefore to compare the oxidative power of the oxidation reaction of zirconium by steam with the oxidative power of the oxidation reaction of zirconium by air. Oxidative power is expressed as follows: $P_{oxydation} = \frac{\Delta H_{ZrO_2}}{M_{ZrO_2}}.\dot{m}_{ZrO_2}.S_{ZrO_2}$

In this formula the reaction enthalpy ΔH_{ZrO_2} and the surface reaction rate $\dot{m}_{ZrO_2}$ depend on the reaction. The molar mass of zirconium oxide M_{ZrO_2} and the contact surface with the hot gases S_{ZrO_2} are unchanged. According to reference <3>, the surface reaction rate is expressed as follows: $\dot{m}_{ZrO_2} = \frac{1}{2}k.t^{-1/2}$ where t is time and k is a constant, which differs depending on the reaction. Thus, to compare the oxidative powers of the 2 reactions, a direct comparison of the product $\Delta H_{ZrO_2} \times k$ is made for the different reactions. Reference document <3> gives the following expressions for the constant k:

- $k = 4{,}958 \exp(-89403/RT)$ for the oxidation reaction of Zy-4 with air,
- $k = 0{,}1303 \exp(-54250/RT)$ for the oxidation reaction of $M5_{Framatome}$ with air,
- $k = 7{,}24 \exp(-87100/RT)$ Leistikow-Schanz correlation applicable to the oxidation of zirconium alloy with steam, for temperatures ranging from 700 °C to 1600 °C.

The enthalpy of oxidation of zirconium by air is given in Appendix 2.2-1 and has the value 1100 kJ/mol. The calculation of the product $\Delta H_{ZrO_2} \times k$ is given in the following table, taking into account a conservative temperature of 800 °C (1073 K):

	ΔH_{ZrO_2} (kJ/mol)	k (kg.m^{-2}s$^{-1/2}$)	$\Delta H_{ZrO_2} \times k$
Oxidation of Zy-4 by air	-1100	2.2×10^{-4}	-0.24
Oxidation of $M5_{Framatome}$ by air	-1100	3×10^{-4}	-0.33
Oxidation of a zirconium alloy by steam	-585	4.2×10^{-4}	-0.24

The results show that the oxidative power contributed by the oxidation reaction of zirconium by steam is comparable to that contributed by the oxidation reaction of zirconium by air. As determined in the previous section, making explicit allowance in the numerical calculations for oxidation of the cladding by air has little influence on maximum cladding temperatures and it is therefore justified not to take into account oxidation of the claddings by steam in the calculation of maximum cladding temperatures reached in accidental conditions of fire.

4.4. Analysis of the impact of cladding deformation resulting from the mechanical drop tests on their thermal-mechanical behaviour during the fire test

Appendix 2.2-1 gives the three most conservative temperature transients for the zirconium alloy claddings during the regulatory fire test. These temperature transients can be simplified in the following manner:

Cladding 1: T > [redacted]°C for [redacted] minutes, T > [redacted]°C for [redacted] minutes, T > [redacted]°C for [redacted] minutes, with a maximum temperature of [redacted]°C.

Cladding 2: T > [redacted]°C for [redacted] minutes, T > [redacted]°C for [redacted] minutes, with a maximum temperature of [redacted]°C.

Cladding 3: T > [redacted]°C for [redacted] minutes, T > [redacted]°C for [redacted] minutes and a maximum temperature of [redacted]°C.

These cladding types may, before the fire test, be locally distorted and strain-hardened when the assembly is dropped onto the bar.

When these deformed claddings are subjected to the aforementioned temperature and timing conditions, one can expect a relaxation of the mechanical stresses created by the drop test, within these claddings.

Tensile tests carried out at ambient temperatures, on strain- hardened claddings versus annealing time, at temperatures representative of the fire test ([redacted]°C, [redacted]°C & [redacted]°C) have been carried out, and an analysis of the data produced during these tests show that the strain-hardened zirconium alloy claddings are fully re-crystallised and that the internal stresses have been fully relaxed:

- at [redacted]°C - after [redacted] minutes held at this temperature,
- at [redacted]°C and [redacted]°C - after the first minutes of annealing.

We can therefore deduce that the temperature conditions and the duration of the fire test will lead to a complete relaxation of the stresses caused by the local deformations created prior to the test. Thus, the thermal-mechanical strength of these claddings is not brought into question by the deformations caused by the regulatory drop tests.

4.5. Analysis of the impact of the maximum temperature of the fuel rods, in the case of the potential continuation of combustion of the wood in the shock absorbers on completion of the thermal test

Any continuation of the combustion of the covers in FCC3 and FCC4 packagings, after the fire test, would have no impact on the results of the thermal study. In fact, the maximum temperature of the rods is determined on the basis of the circulation of hot air around the internal fittings of the FCC3 and FCC4 packagings. These maximum temperatures are determined conservatively, ignoring the shells and covers, in order to take into account perforation of the shell during the drop test onto a bar. Therefore there is no need to consider the additional heat created by the combustion of these covers.

In addition, in the event the drop test onto a bar impacts on one of the two covers, and perforates it, the additional heat created by the combustion of the wood within this cover would below, given the volume of wood and the distance between the cover and the internal fittings (greater than [redacted] mm). In addition, the flows of air around the internal fittings would be lower than those used by the Safety Analysis Report, due to the absence of the shell.

Thus, the increased heat caused by the potential combustion of the wood in the shock-absorbers used in FCC3 and FCC4 packagings is covered by the assumptions used in the calculation of the maximum cladding temperatures, determined in Appendix 2.2-1.

5. Thermal-mechanical analysis of creep strength

Appendix 2.2-3 analyses the thermal-mechanical behaviour of a fuel rod in the conditions defined in Appendix 2.2-1 in order to rule out any risk of bursting of the claddings by creep.

The analysis is made in the hottest zone of the rods for the cladding materials Zy-4 and $M5_{Framatome}$.

The creep laws and instability criterion used in this Appendix are derived from the creep tests carried out on sections of $M5_{Framatome}$ and Zy-4 alloy cladding.

At each time step the circumferential stress is recalculated and compared to the instability criterion. It is also verified that the maximum circumferential strain remains acceptable.

The minimum ratios (calculated circumferential stress/instability stress) are given below for the 3 hottest claddings:

<u>Cladding material $M5_{Framatome}$</u>:

- Cladding 1: 4.2,
- Cladding 2: 4.5,
- Cladding 3: 4.5

<u>Cladding material Zy-4 :</u>

- Cladding 1: 3.3,
- Cladding 2: 3.4,
- Cladding 3: 3.4

Thus the risk of bursting of the claddings by creep is ruled out with a minimum safety factor of 4.2 for the $M5_{Framatome}$ cladding and 3.3 for the Zy-4 cladding.

6. Analysis of the impact of glycerine

Appendix 2.2-5 analyses, for FCC3 and FCC4 package models, the impact of the presence of 5g of glycerine in the fuel assemblies upon the studies covering the creep behaviour of the rods under regulatory fire conditions. It is proven that the heating of the claddings generates no significant distortions which might modify the thermal-mechanical behaviour of the rods during the fire test.

All the thermal and creep analyses, under regulatory fire conditions, in this report are conservatively carried out using the PWR 17x17 assembly, which covers all other types of fuel assembly, that is PWR 14x14 and PWR 15x15 assemblies. Therefore, the conclusions of this analysis on the impact of glycerine on PWR 17x17 fuel assemblies are also applicable to the other types of assembly.

Glycerine is a hydrogen-containing material, with an auto-ignition temperature less than the maximum temperature reached by the rods under the regulatory fire test conditions.
The evaluation of the temperatures of the claddings in the presence of 5g of glycerine is based upon two types of scenario:

- Either, using analytic calculations following the layered combustion of glycerine during the regulatory fire test for ACT;
- Or, by numerical calculations, based upon the results of flame tests.

It has been shown that these scenarios have no impact on the resistance of fuel rod cladding to the phenomenon of creep.

This analysis is based upon the results of the creep studies, carried out in Appendix 2.2-1, which were carried out in the absence of glycerine.

7. Analysis of the deviations in the representative nature of the EPR top plate with respect to the conventional top plate

Chapter 1.4 details the securing of FCC3 and FCC4 assemblies, notably in terms of their top plate. In order to be able to transport the assembly with its RCCA, a protrusion from the top plate is required to house and clamp its hub. Taking into account the materials used in the top plate (stainless steel and bronze), as well as this protrusion, their mechanical strength has been shown, in Paragraph 3.5 - Chapter 2.1-13, to be maintained after the drops during ACT. Thus, the thermal inertia of the top plate remains unchanged.

Moreover, given the absence of tearing on the protrusion, no opening providing an entry point for hot gases into the cavity can appear. Thus, the top plate does not cause any additional thermal impact on the behaviour of the internal equipment during fire test relative to the thermal analysis of the package given in this chapter and detailed in Appendices 2.2-1 and 2.2-3 to 2.2-5.

The axial securing system for the assemblies, using their lower nozzle, is detailed in Paragraph 2.3, Chapter 1.4. The following drawing illustrates this system.

Proprietary drawing

In accidental conditions of transport, the M8 screw in the claw system restraining the bottom nozzle of the assembly is sized so as to fail. Indeed, the free part of the M8 clamping screw is the most fragile part as it is therefore the element which will be subjected to all of the tensile stresses due to the drops and which presents the smallest tensile stress area. It will be the first to fail following the drops.

Thus, the slide will not be damaged after the failure of the screw and will continue to perform its function of closing off the oblong hole in the top plate irrespective of its position. The presence of the assembly bottom nozzle restraint system does not modify the leakage paths relative to the hot gas circulation paths in the cavity in accident conditions of fire, and the assembly restraint system via the bottom nozzle therefore has no impact on the thermal analysis of the package.

8. Analysis of the geometrical deviations in the EPR doors with respect to conventional doors

As described in Paragraph 2.3.5.4 of Chapter 1.4, EPR fuel assembly grids are not positioned at the same elevations as the grids of XL/GAIA type assemblies or those of XLR type assemblies. Special doors (229 K 0670 in Appendix 1.4-1 of the FCC4 report) replace the conventional doors (229 K 0497 in Appendix 1.4-1 of the FCC4 report). The adaptation of the doors for the restraint system of the EPR fuel assembly grids has no impact on the thermal justification of the doors because the dimensions of the shoulders are negligible in relation to the ribs and the increase of the stamped parts represents only a 30% increase in their surface area.

9. Analysis of the impact of the presence of the smooth-walled dummy

The material used in the smooth-walled dummy (stainless steel) and its dimensions have no impact on the maximum temperature reached during the regulatory fire test by the claddings of the EPR fuel assembly located within the second cavity of the FCC4 packaging (moreover, the thermal model of the fire test in Appendix 2.2-1 only models a single cavity).

10. Conclusion

The maximum temperature reached by the FCC3 and FCC4 packaged under normal conditions of transport was [redacted]°C.

The calculations carried out to determine the maximum temperatures reached by the fuel rod claddings under accidental conditions of transport showed that 3 fuel rod claddings reached temperatures over 600 °C.

The thermal-mechanical analysis carried out on these 3 fuel rods show that the risk of bursting of the Zircaloy-4 and $M5_{Framatome}$ cladding, due to creep, can be ruled out with a minimum safety factor of 3.3. There is therefore no dispersal of material on completion of the test representative of accidental conditions of transport.

The deformation of the claddings, caused by the mechanical drop tests, has no impact on their thermal-mechanical strength during the thermal fire test.

The increased heat caused by the potential combustion of the wood in the shock-absorbers used in FCC3 and FCC4 packagings is covered by the assumptions used in the calculation of the maximum cladding temperatures, determined in Appendix 2.2-1.

The study carried out on the potential combustion of 5 g of glycerine contained in the FCC3 and FCC4 packages shows that the impact upon the creep behaviour of the rods is negligible and does not affect the thermal-mechanical analyses detailed in the chapter.

The adaptation of the doors for the system holding the EPR fuel assembly grids in place, as opposed to the conventional doors used for XL/GAIA and XLR assemblies, makes no difference to the chapter's thermal analyses.

The possible presence of the smooth-walled dummy has no impact on the chapter's thermal analyses.

11. References

<1> Regulations for the Safe Transport of Radioactive Materials - at the revision indicated in Chapter 1.2.

<2> <2>High Temperature Materials (HiTemp 2011) Conference organised by Netzsch, Boston, MA, USA, (20-22 Sept. 2011)

<3> Zircaloy-4 and M5® high temperature oxidation and nitriding in air, Duriez, C. and Dupont, T. and Schmet, B. and Enoch, F., Journal of Nuclear Materials, 2008

List of Appendices

Appendix	Title	Number of pages
2.2-1	Framatome document - D02-ARV-01-167-814 Revision A "Justification by CFD simulation of the thermal resistant of FCC package during fire test"	2 + 115
2.2-2	Deletion of the Appendix	-
2.2-3	Framatome document - "Fuel rod behaviour during IAEA thermal test in container "	37
2.2-4	TRANSNUCLEAIRE report 10373-B-1 - Rev. 3 "Summary note on the characterisation of FS 69 resin"	2 + 10
2.2-5	AREVA TN document - “Analysis of the impact of glycerine on the thermal safety analyses”	21
2.2-6	AREVA TN document – “ FCC package thermal behaviour in normal condition of transport”	12
TOTAL		**199**