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TN-UO_2</td><td rowspan="1"></td><td>Name</td><td>Signature</td><td>Date</td></tr>
<tr><td>Prepared by</td><td>P. MALALEL</td><td></td><td></td></tr>
<tr><td>Checked by</td><td>N. OUKAKI</td><td></td><td></td></tr>
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POST-TEST ASSESSMENT REPORTS
P1+P2 / P11+P15

CONTENTS

REVISION SHEET

Revision	Date	MODIFICATIONS	Author / Checker
0	27/09/99	First issue of document	PML / NOU

1. SUBJECT

The purpose of this document is to present dimensional measurements of the final geometrical deformation of the qualification prototypes subjected to the regulation mechanical and thermal tests according to <1> and <2>.

These measurements were taken in two phases, corresponding to the two series of full-scale TN-UO_2 packaging prototypes (see chapter 1 of this safety file), that is:

design phase 1:

- specimen P1 (drawing <3>): sequence including the 9m free-fall drop obliquely onto a corner of the packaging lid, with maximum content weight (38 kg), in order to maximise crushing of the ends of the package.
- specimen P2 (drawing <3>): sequence including a 9 m plate drop axially onto the packaging base with maximum content weight (38 kg).

design phase 2 (final):

- specimen P11 (drawing <4>): sequence including the 9 m plate drop onto the upper corner of the packaging and the fire test, with maximum content weight (38 kg).
- specimen P15 (drawing <5>): sequence including the 9 m plate drop laterally onto the packaging centreline and the fire test, with minimum content weight (1 kg).

Photos of the specimens were taken at the various stages of the assessment, and extracts are given hereinafter. The originals are kept for examination if necessary in the "Documentation" room of the Interfaces and Tests department of the Development and Support Division.

2. GENERAL INFORMATION

2.1. Participants from the MECASTER company

M. HUBERT Technical Division

2.2. Participants from the EIFFEL company

S. SCHMITT

2.3. Participants from TRANSNUCLEAIRE

D. MENGUY DCU/SI/GE

N. OUKAKI DDS/SI

P. MALALEL DAC/GIN

3. REFERENCES

<1> Regulations for the Safe Transport of Radioactive Materials – IAEA - (1985 Edition, reviewed in 1990).

<2> Regulations for the Safe Transport of Radioactive Materials – IAEA - (1996 Edition).

<3> TRANSNUCLEAIRE Drawing TN-UO_2 ref. 10313-01 ind.C.

<4> TRANSNUCLEAIRE Drawing TN-UO2 ref. 10313-05 ind.A.

<5> TRANSNUCLEAIRE Drawing TN-UO_2 ref. 10313-05 ind.B.

4. MEASUREMENT RESULTS

4.1. Prototype P1

The assessment chronology of the various packaging components is illustrated on photographs n° 1 to 14.

The values mentioned in the following table are represented on figure 1.

MEASUREMENT (mm)	POSITION MEASURED			
	0°	90°	180° (*)	270°
D1	389	374.6		
D2	377.9	384.6		
D3	303	303.9		
e_1 (minus the plate thickness: 2*0.8)	from top to bottom: 20.5 ; 20.8 ; 21.1 ; 20.6 ; 20.3 (other measurements always higher than the minimum 18 mm)			
e_2	37.2			
f_1	no deformation			
f_2	position of cracks in the resin: 307 ; 59 ; 307			
f_3 (indenting of cup base)	14	12	13	10.7
H	812	810	758	809
h_1 (foam thickness)	104	103.6	104	103.8
h_2 (cup height)	561	560.3	562.5	561

(*): corresponds to the axis of the imprint on the lid corner.

Findings:

- the internal flask showed no cracks and no powder leaks after being turned over;
- the upper phenolic foam disk was cracked and had been forced into the top of the cup;
- slight denting of the upper part of the flask neck.

4.2. Prototype P2

The assessment chronology of the various packaging components is shown in photographs n° 15 to 25.

The values given in the following table are represented on figure 1.

MEASUREMENT (mm)	POSITION MEASURED			
	0°	90°	180°	270°
D1	396.5	402.4		
D2	395.3	401.8		
D3	304.3	305.4		
e_1 (minus plate thickness: 2*0.8)	from top to bottom: 20.3 ; 22.2 ; 21.4 ; 21.2 (other measurements always higher than the minimum 18 mm)			
e_2	from top to bottom: 37.2 ; 37 ; 37.1			
f_1	no deformation			
f_2	position of cracks in the resin: 293 ; 97 ; 286			
f_3 (indenting of cup base)	from edge to centre: 17 ; 19 ; 20			
H	708	696	708	716
h_1 (foam thickness on edge)	103.7	103.5	103.5	103.9
h_2 (cup height)	563.3	560 ;8	560.4	561.7

Findings:

- the internal flask showed no signs of cracking or powder leaks after being turned over;
- considerable denting of the upper part of the flask neck (22 mm);

- the overall crushing of the specimen (104 mm) was distributed between forcing of the cup into the lower phenolic foam disk (17 mm), flattening of the entire top of the packaging (≈ 60 mm) and folding of the base of the overpack, with forcing of the upper phenolic foam disk into the top of the cup (by 22 mm), thus pushing out the top of the flask.

4.3. Prototype P11

The various steps in the specimen assessment, performed after cooling following the thermal test, are illustrated in photographs n° 26 to 29.

The main dimensions for the criticality study (chapter 5A of this safety file) are mentioned in the following table (on the basis of the same references as in figure 1):

MEASUREMENT (mm)		POSITION MEASURED	
		0°(*)	90°
D2 (body diameter)	overpack top	383.1	374.3
	overpack middle	383.1	376.6
	overpack bottom	382.9	377.8
D3 (cup diameter)	cup top	302.5	302.8
	cup middle	302.5	303.8
	cup bottom	303	302.6
e_2 (minus thickness of overpack plate: 1 mm)	cup top	39.3	34.7
	cup middle	39.3	35.4
	cup bottom	38.9	36.6
thickness of foam **e_2** not subject to pyrolisis (orange in colour): 13 mm			

(*): corresponds to the axis of the plate imprint on the upper corner of the packaging.

Findings:

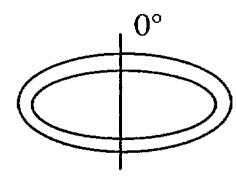
- the internal flask showed no signs of cracking or powder leak after being turned over;
- the resin cup had suffered no geometrical deformation, so we can deduce that the layer of neutron-poisoning resin contained between the stainless steel shells retained its initial dimensions (thickness varying between 18.3 and 18.6 mm depending on the prototype manufacturing file).

4.4. Prototype P15

The various steps in the specimen assessment carried out after cooling following the thermal test, are illustrated in photographs n° 30 to 33.

The essential values for the criticality study (chapter 5A of this safety file) are given in the following table (on the basis of the same references as figure 1):

MEASUREMENT (mm)		POSITION MEASURED	
		0°(*)	90°
D2 (body "diameter")	overpack top	321.7	414.5
	overpack middle	332.8	407.3
	overpack bottom	329.9	391.5
D3 (cup "diameter")	cup top	233.5	349.2
	cup middle	238.2	335.6
	cup bottom	250.9	316.7
$\mathbf{e_2}$ (minus overpack plate thickness: 1 mm)	cup top	43.1	31.7
	cup middle	46.3	34.9
	cup bottom	38.5	36.4
thickness of foam $\mathbf{e_2}$ not subject to pyrolisis (orange in colour): at least 10 mm on the flattened zone, at most 22 mm at 90°			



(*): corresponds to the axis of packaging flattening due to the falling plate.

Findings:

- the internal flask showed no signs of cracking or release of powder after being turned over;
- as the flask is captive inside the internal well, it was not possible to take dimensional measurements inside the resin cup. The visual check on the geometry of the stainless steel containment envelopes around the layer of neutron-poisoning resin indicates that it suffered no crushing such as to reduce its thickness (thickness varying between 18.3 and 18.6 mm depending on the prototype manufacturing file).

5. CONCLUSION

The dimensional measurements taken on the qualification prototypes which first of all underwent the regulation mechanical tests (specimens P1/P2/P11/P15) and thermal tests (specimens P11/P15) <1> and <2>, enable us to deduce the following main data regarding the extreme condition of the damaged package (total of all deformations):

- the thicknesses of the stainless steel envelopes and of the resin layer are maintained,
- the phenolic foam is degraded to a maximum of 27mm radially (on the basis of the minimum thickness recorded intact on P15),
- axially, the maximum effect of crushing (after the 9 m drop test with the 500 kg plate onto specimen P2), leads to the packaging height being reduced by 104 mm, spread between flattening of the entire top of the packaging (≈ 60 mm), reduction in the axial thickness of the phenolic foam shock-absorbing disks opposite the resin cup (22 mm for the upper disk and 17 mm for the lower disk) and folding of the overpack base,
- the properties of the resin and of the remaining layer of phenolic foam remain unchanged,
- the diameter of the flask can vary until it reaches the inside diameter of the packaging cavity (following thermal softening).

These data are therefore taken as conservative hypotheses for the package condition in transport accident conditions in the criticality study presented in chapter 5A of this safety file.

Furthermore, the results of the assessment on specimens P1 and P2 show that the physical condition of these specimen packages show less damage to the thermal protection of the packaging than specimens P11 and P15, which enables us to conclude that the findings on specimens P1 and P2 (which did not undergo the fire test) would not have been worse than those from specimens P11 and P15.

LIST OF FIGURES

LIST OF TEST PHOTOGRAPHS

FIGURE 0.1

OVERVIEW OF DIMENSIONAL MEASUREMENT

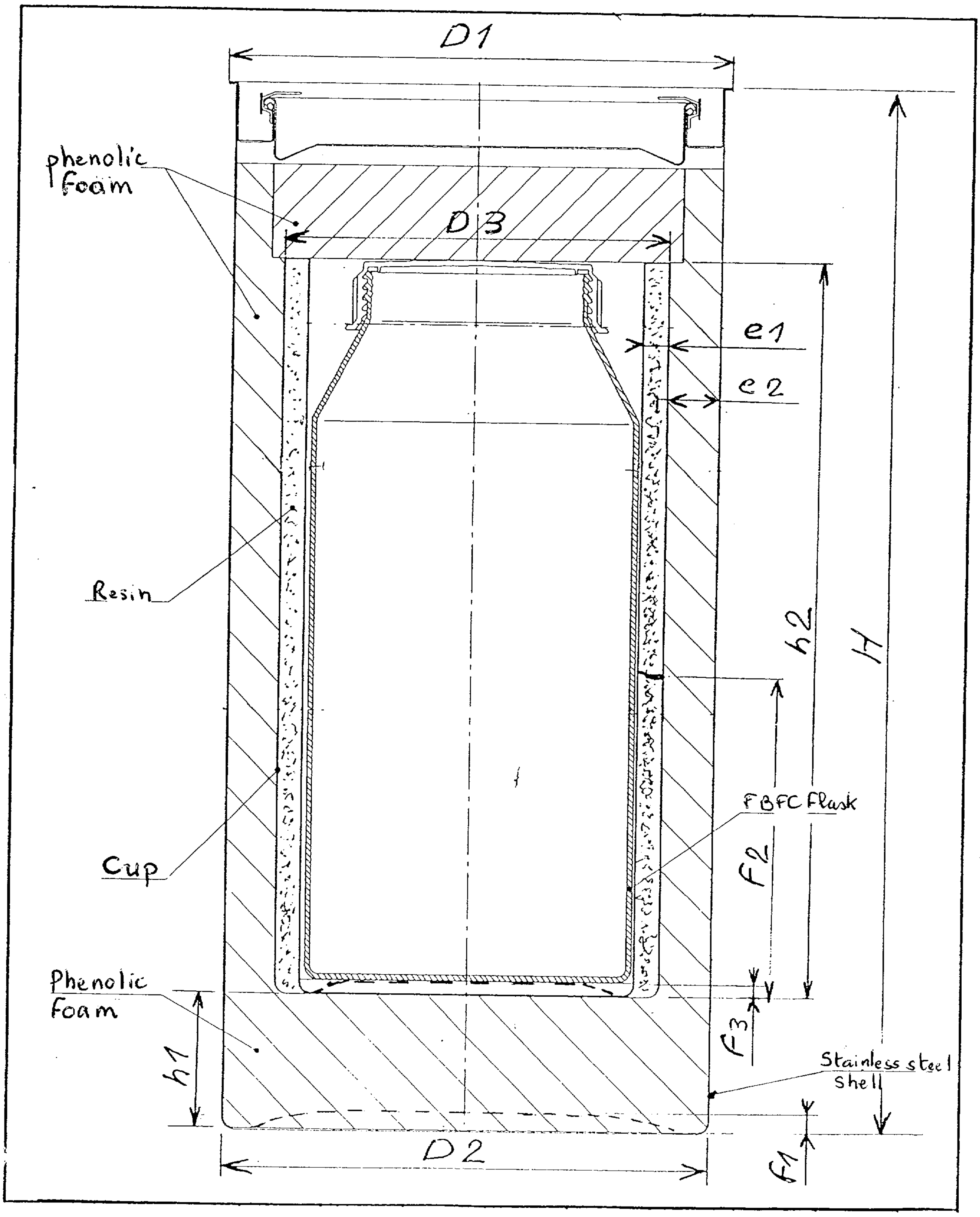


Photo n° 1 : Top view of specimen P1 before assessment

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Photo n° 2 : After removal of the lid Specimen P1

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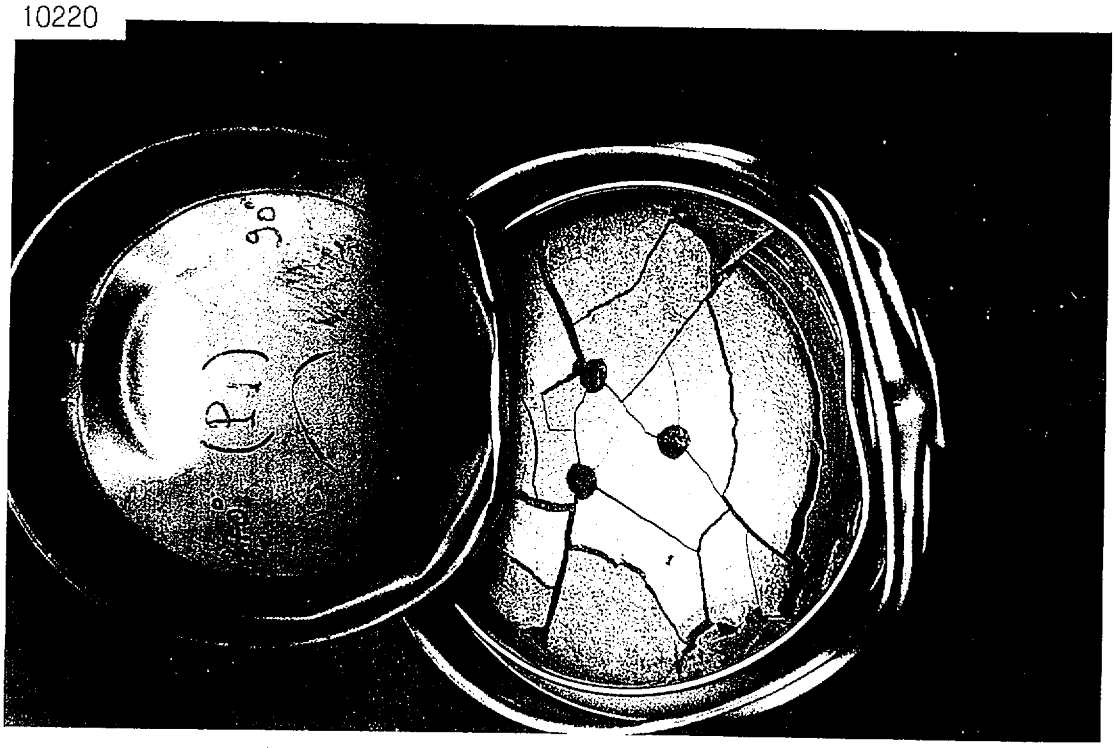

Photo n° 3 : After removal of the plug specimen P1

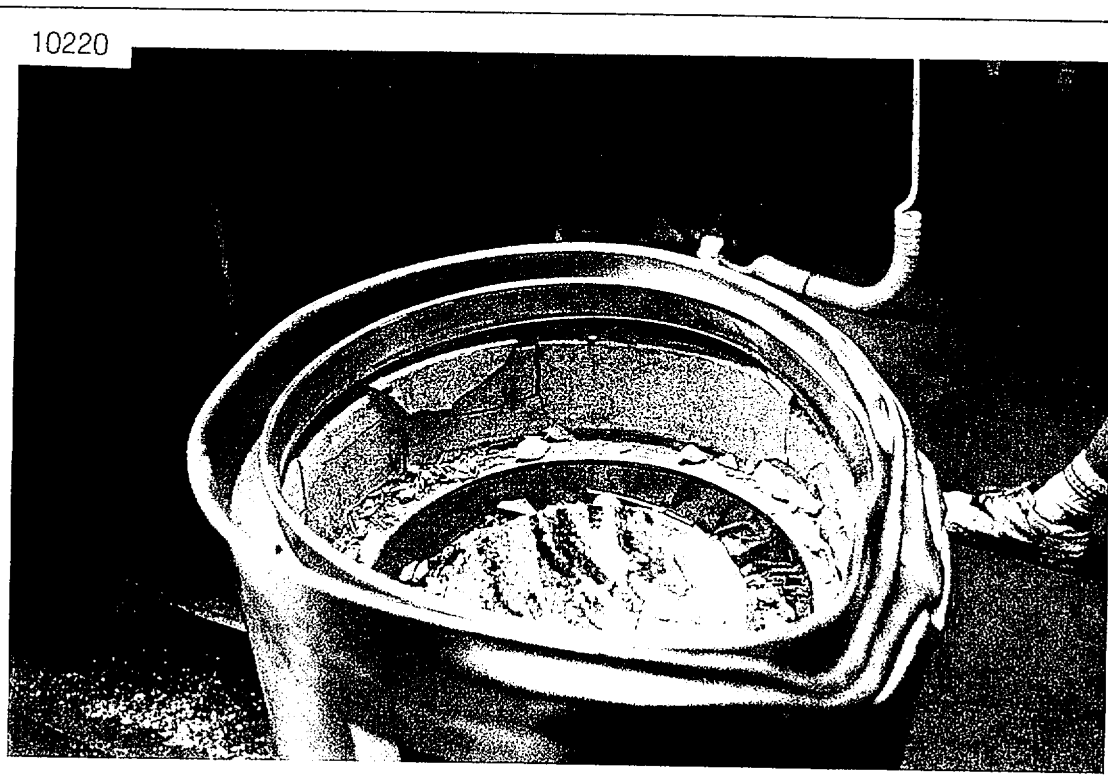

Photo n° 4 : Cutting outer shell specimen P1

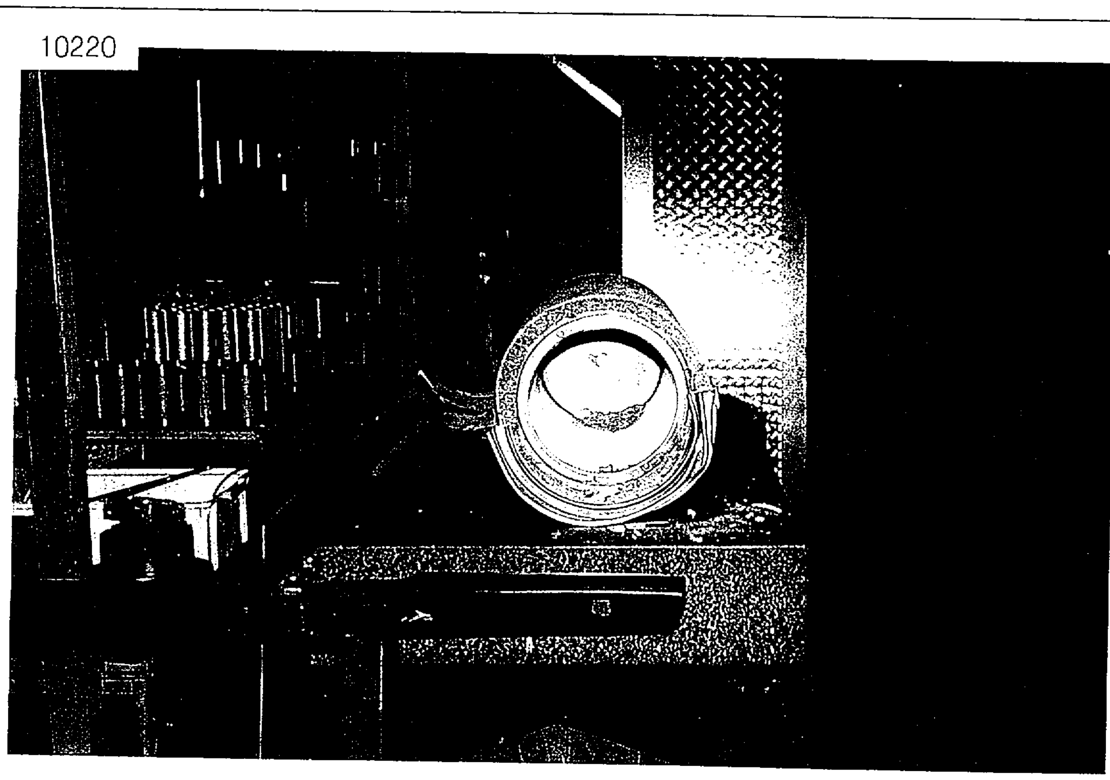

Photo n° 5 : Half outer shell view specimen P1

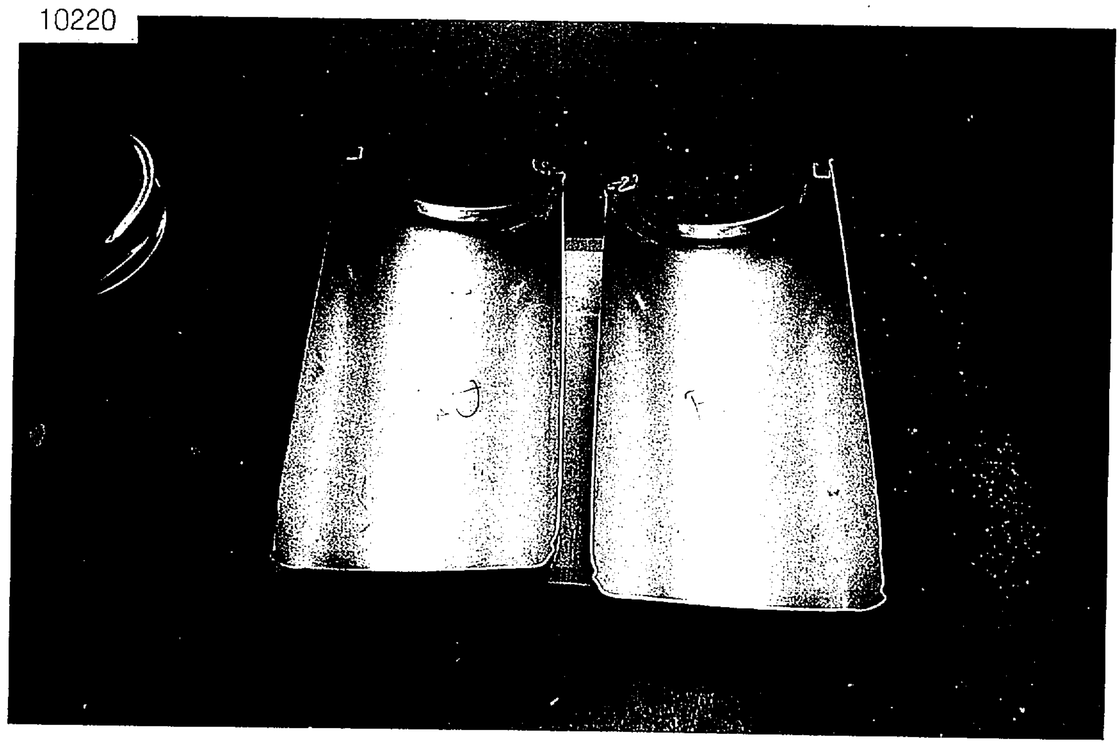

Photo n° 6 : Ditto

Photo n° 7 : Phenolic foam shell specimen P1

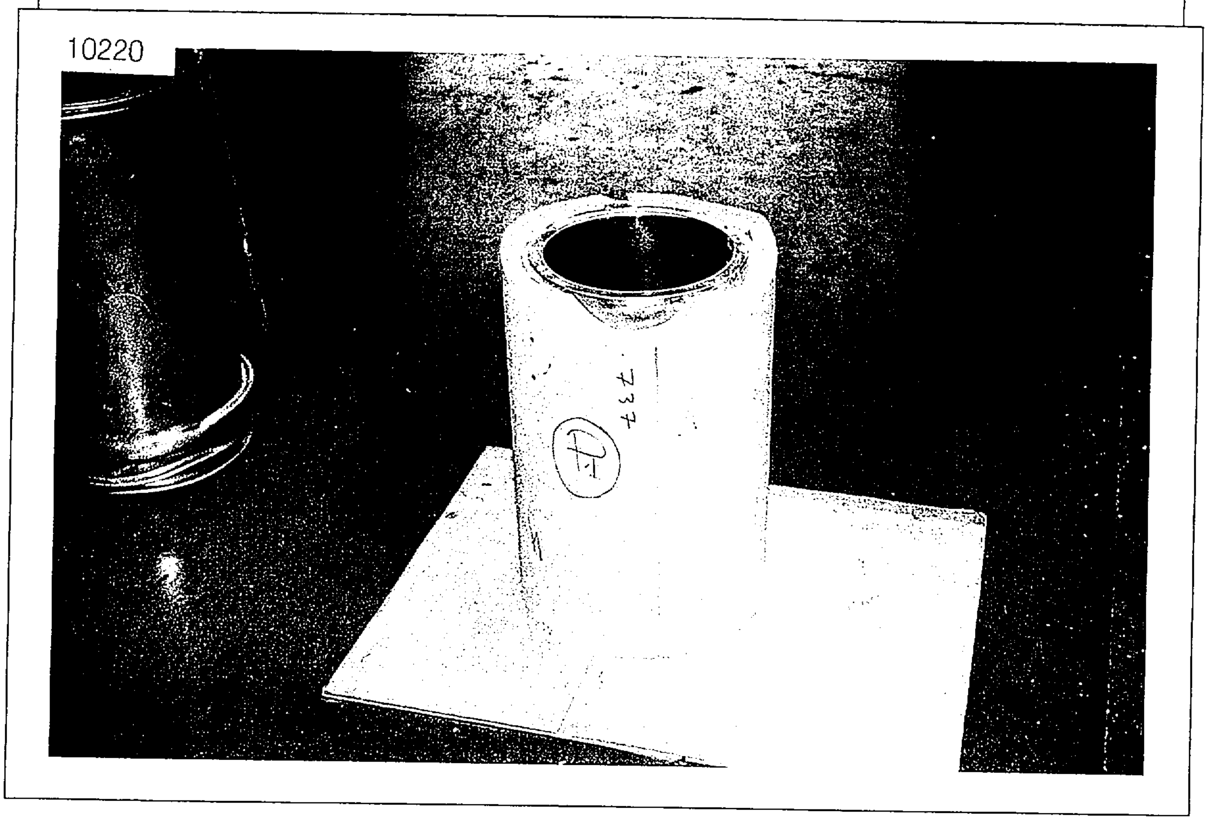

Photo n° 8 : Inferior disk phenolic foam specimen P1

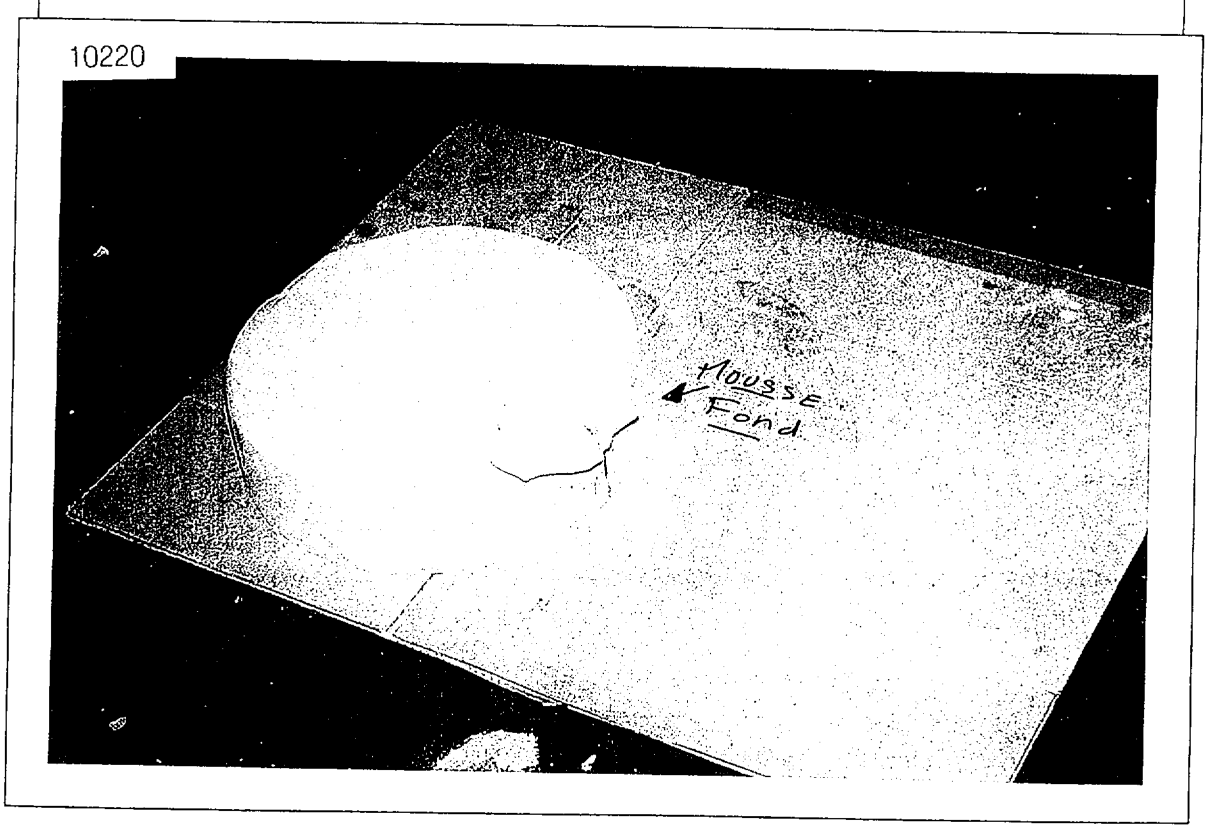

Photo n° 9 : Cup + FBFC Flask Specimen P1

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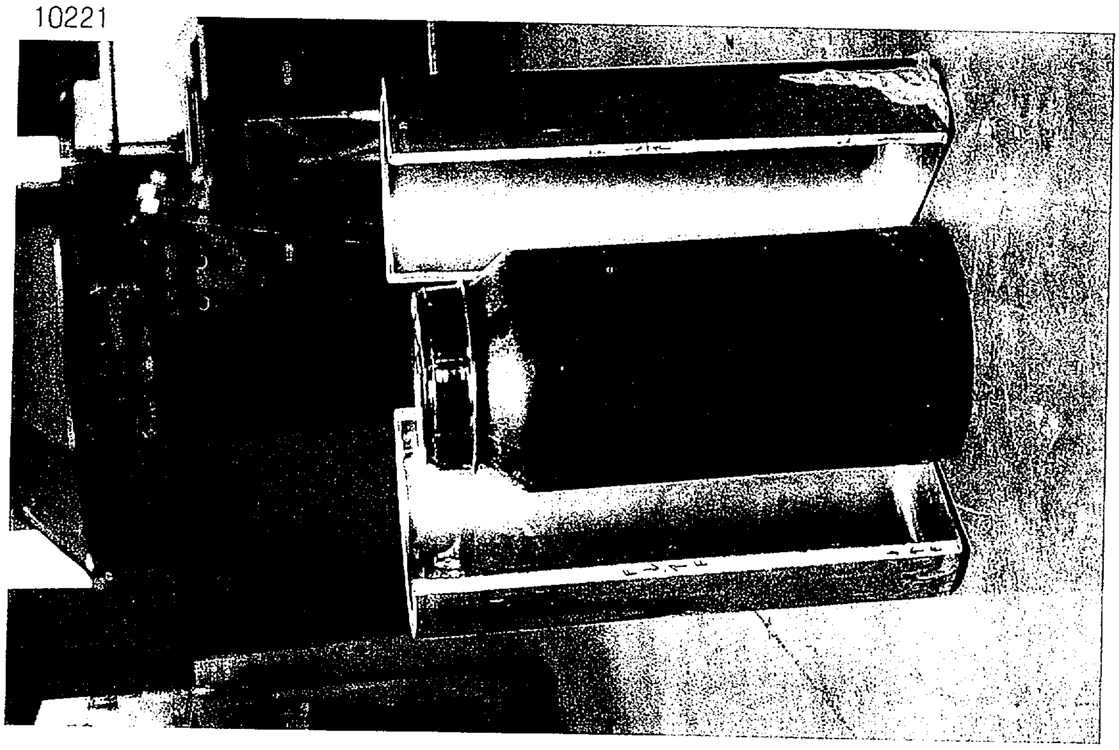

Photo n° 10 : Cutting view Specimen P1

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Photo n° 11 : Cutting of resin cup specimen P1

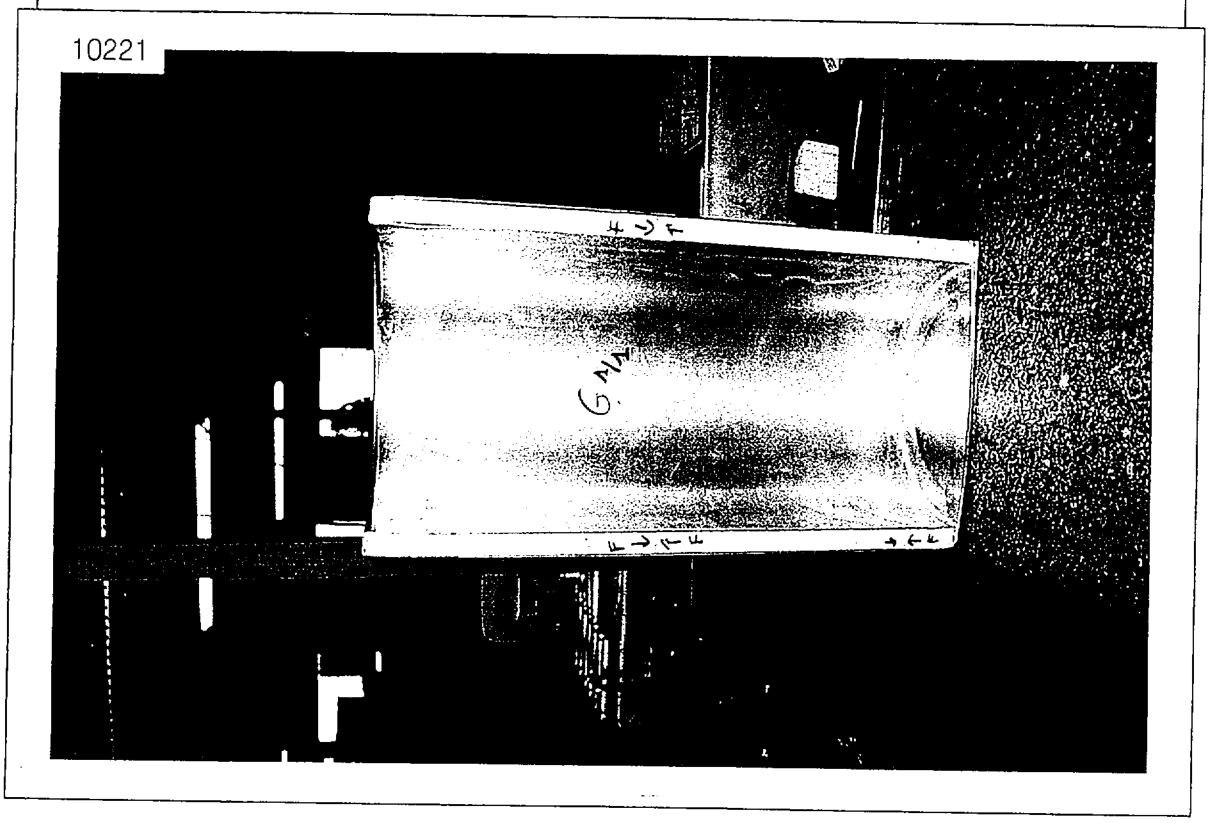

Photo n° 12 : Ditto

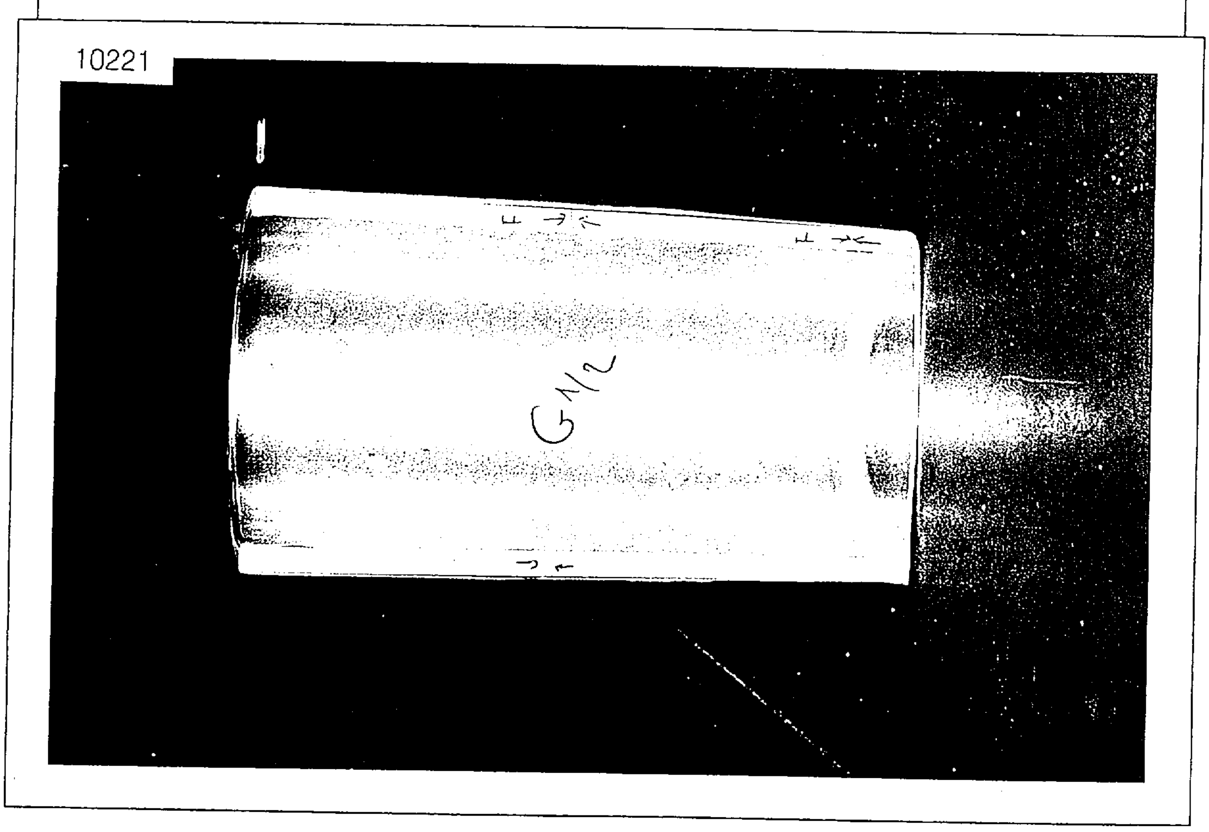

Photo n° 13 : FBFC Flask Specimen P1

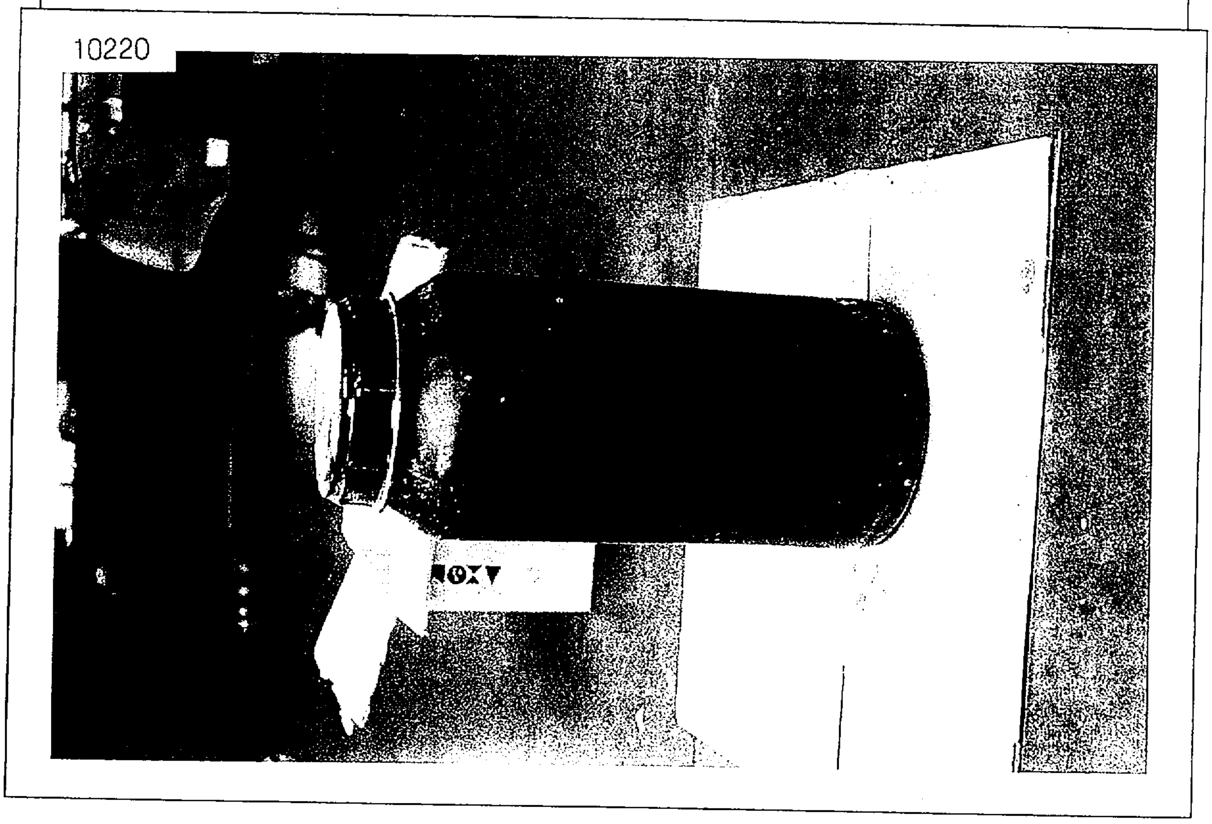

Photo n° 14 : Ditto

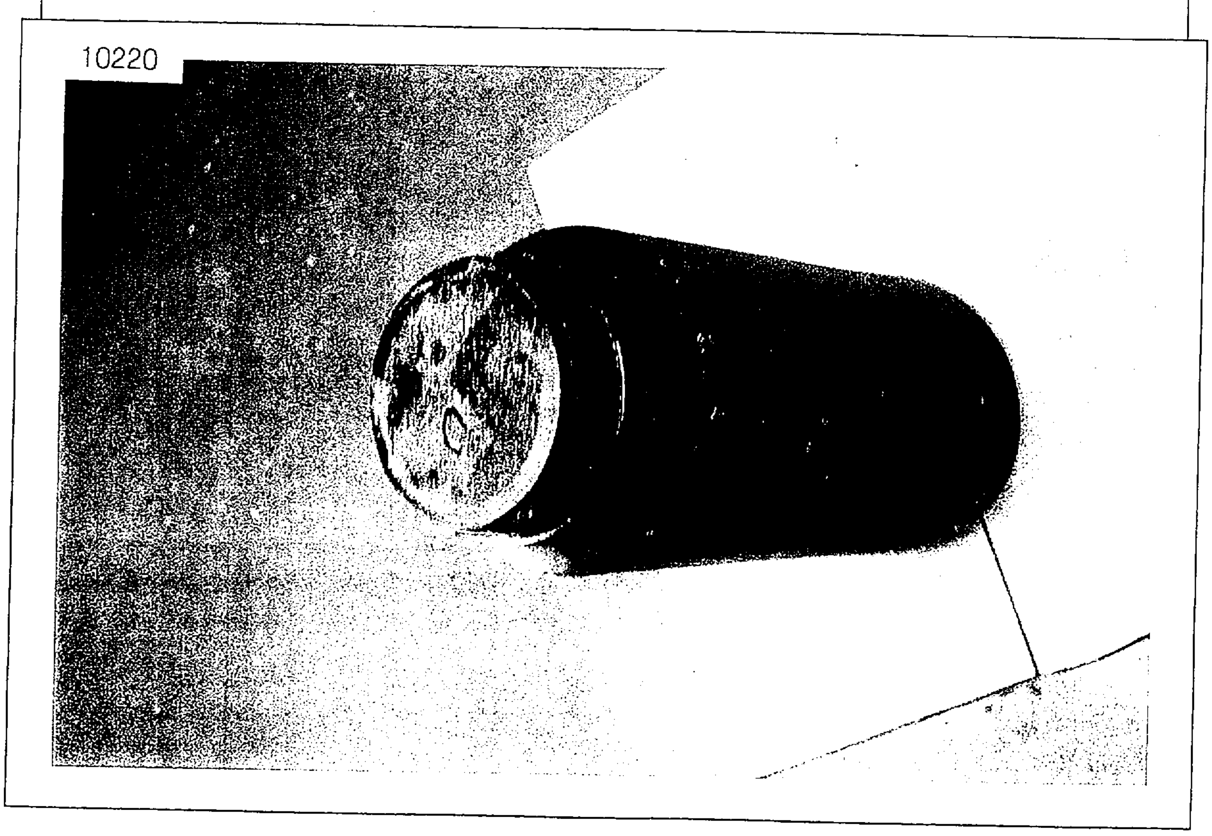

Photo n° 15 : View of specimen P2 after lid removal

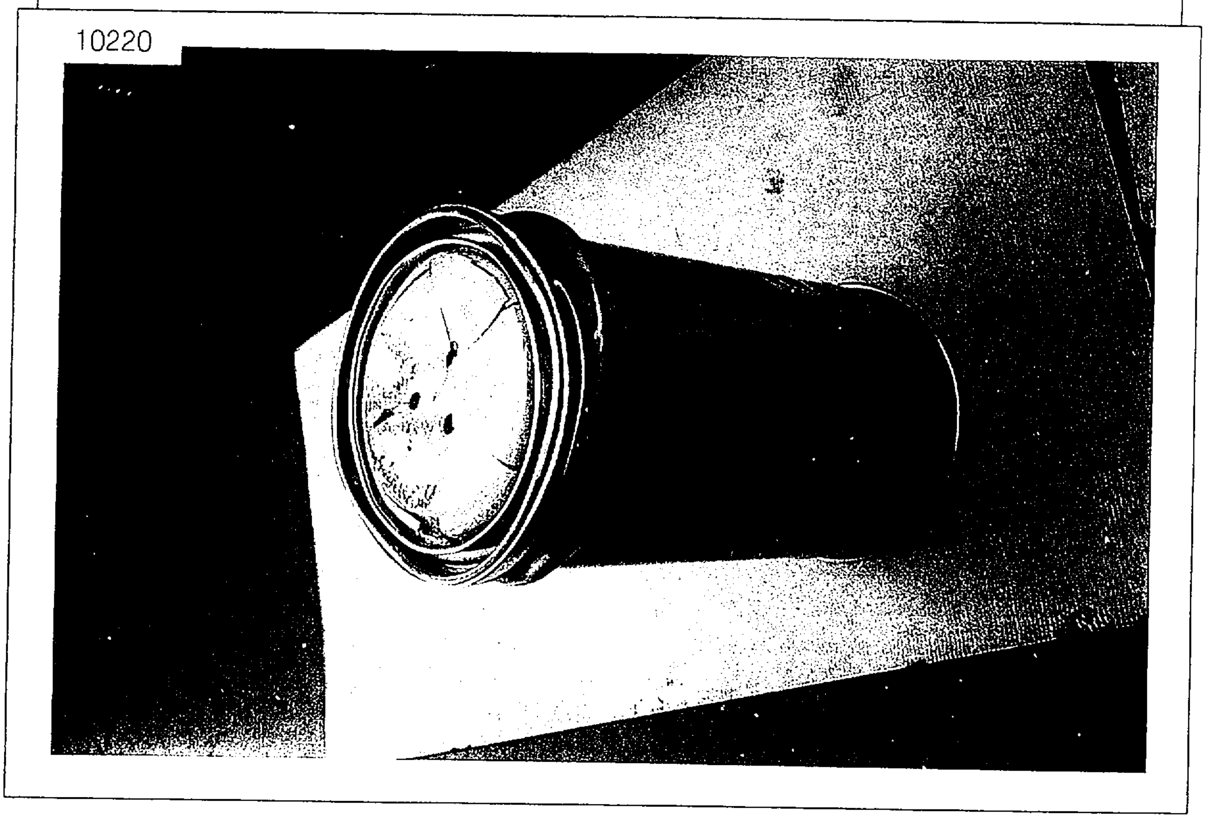

Photo n° 16 : View of specimen P2 after interior plug removal

Photo n° 17 : Preparing specimen P2 cutting

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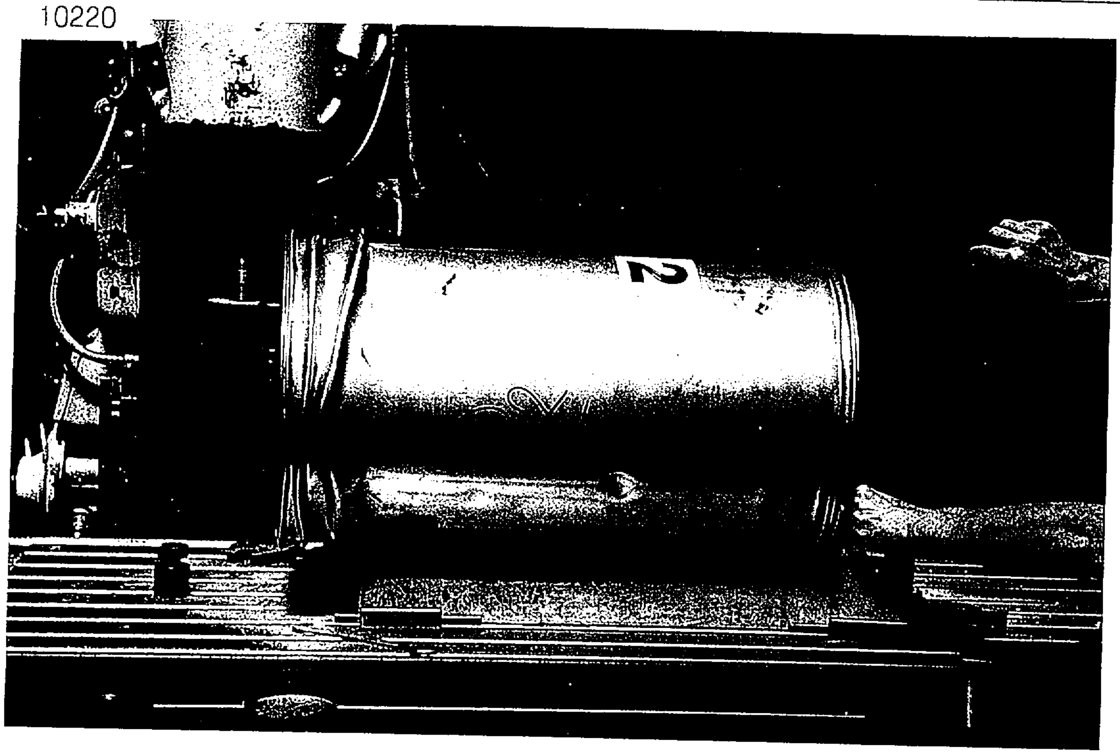

Photo n° 18 : View after outer shell cutting specimen P2

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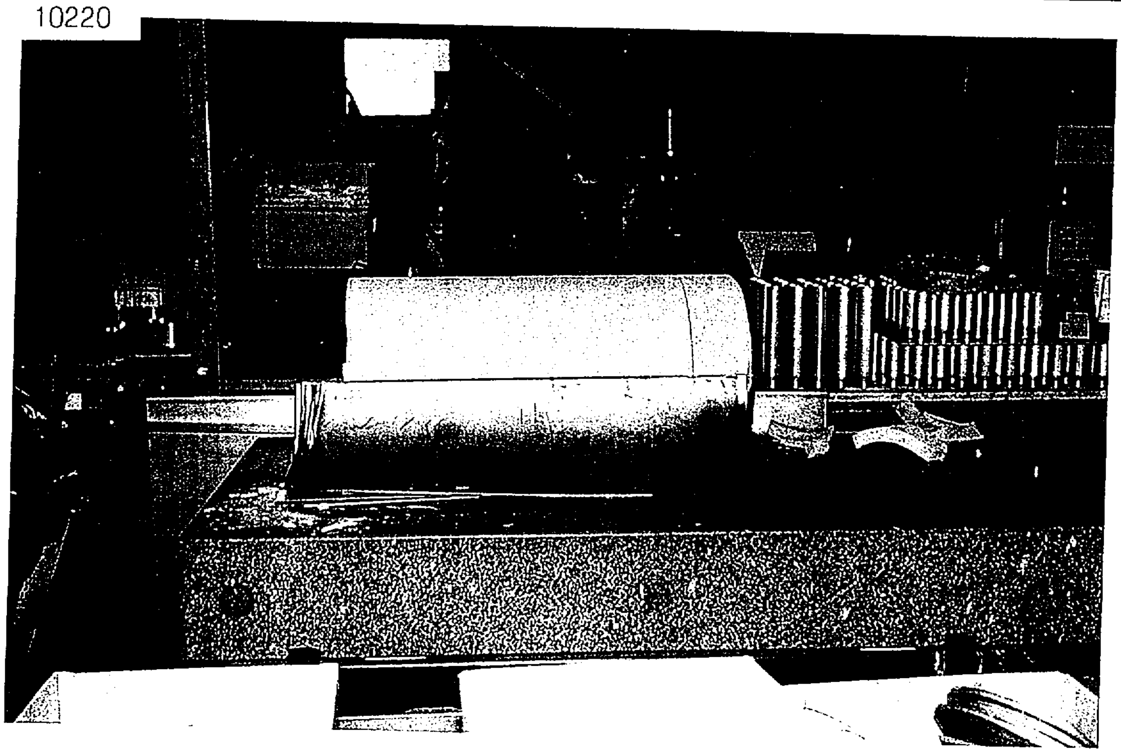

Photo n° 19 : View of half shell specimen P2

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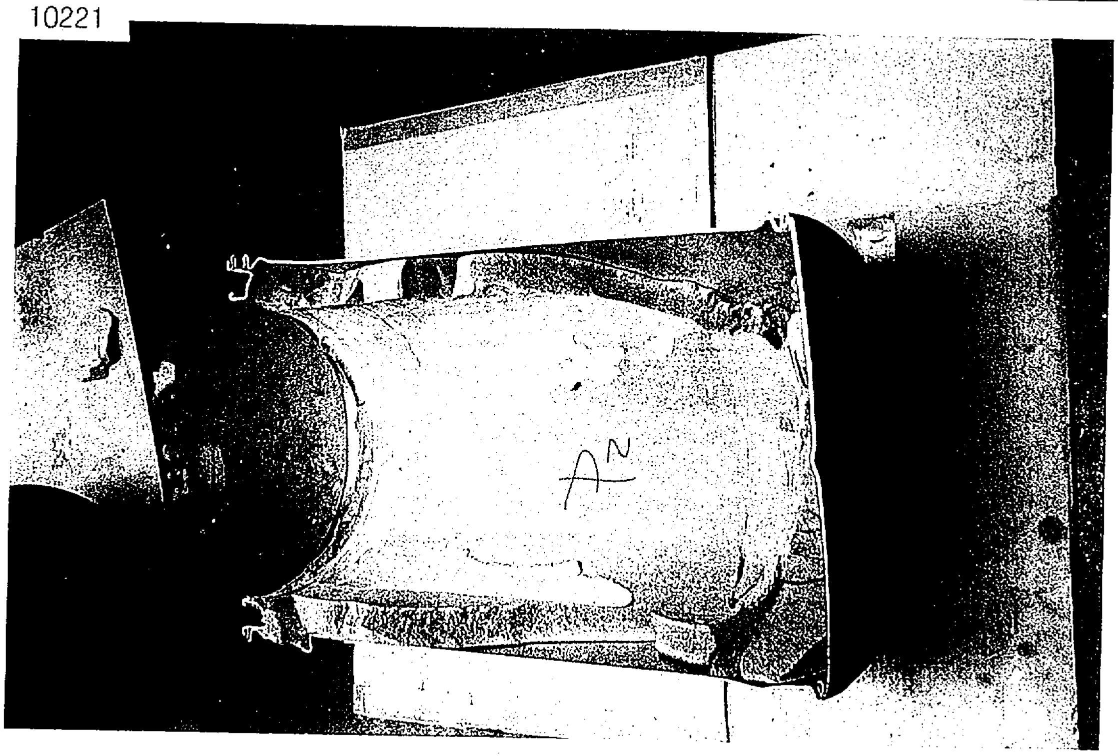

Photo n° 20 : Ditto + bottom

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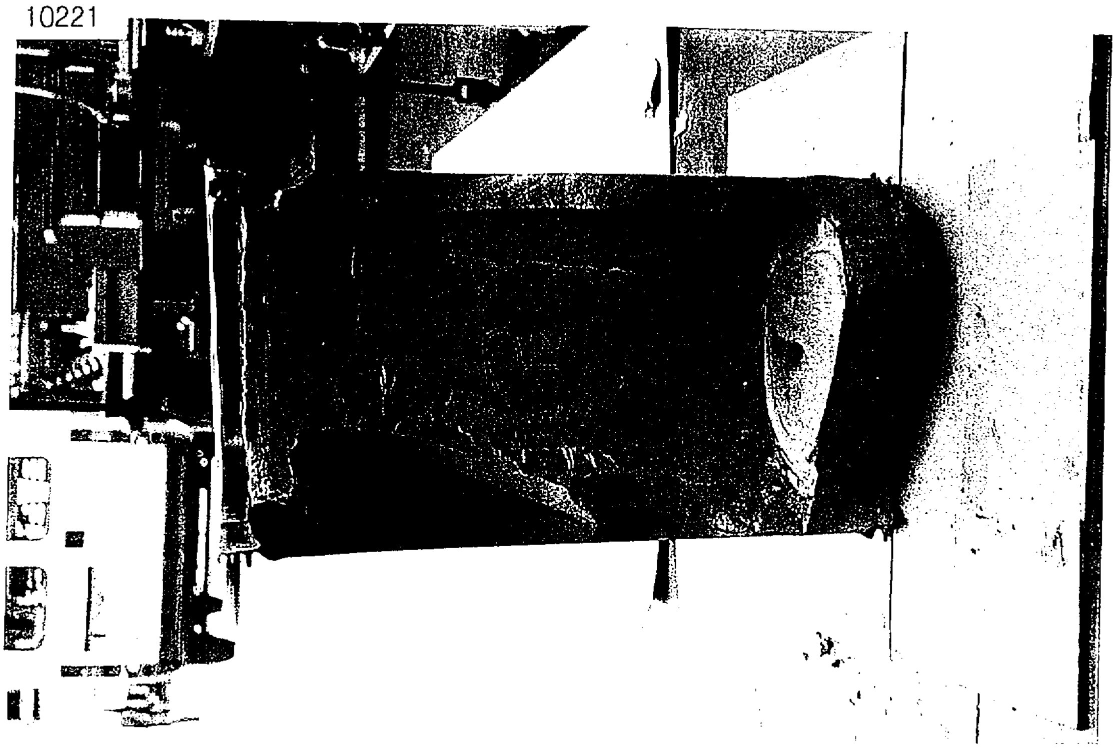

Photo n° 21 : Cutting of resin cup **P2**

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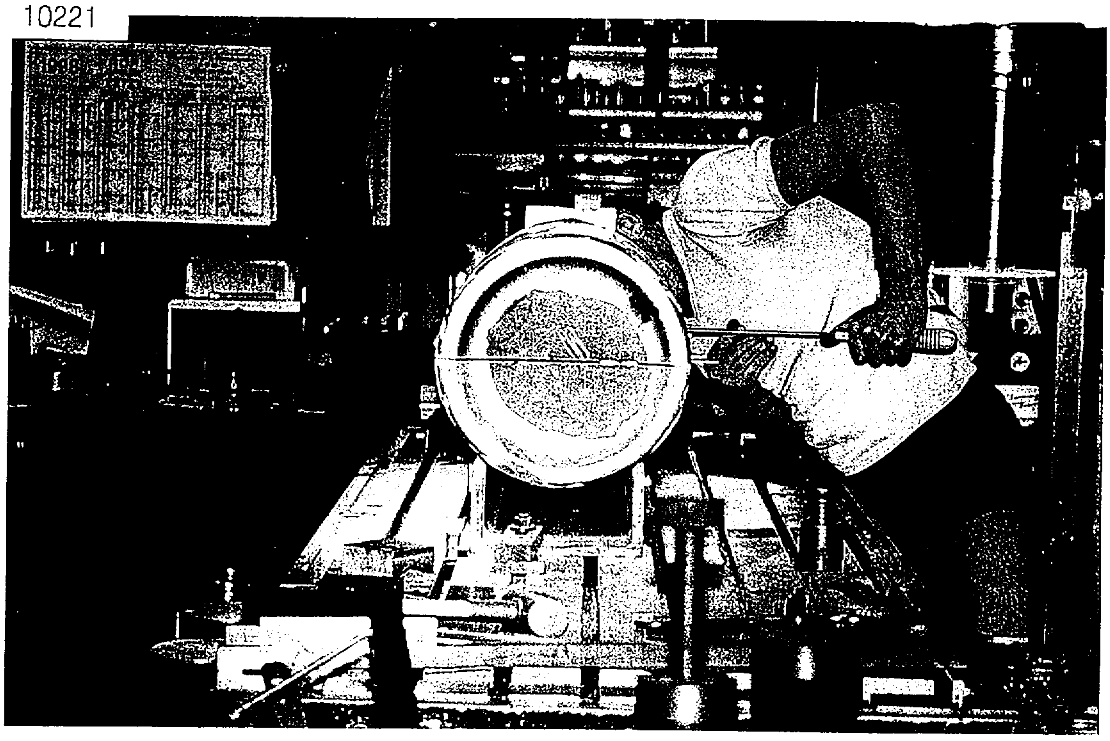

Photo n° 22 : View after cutting

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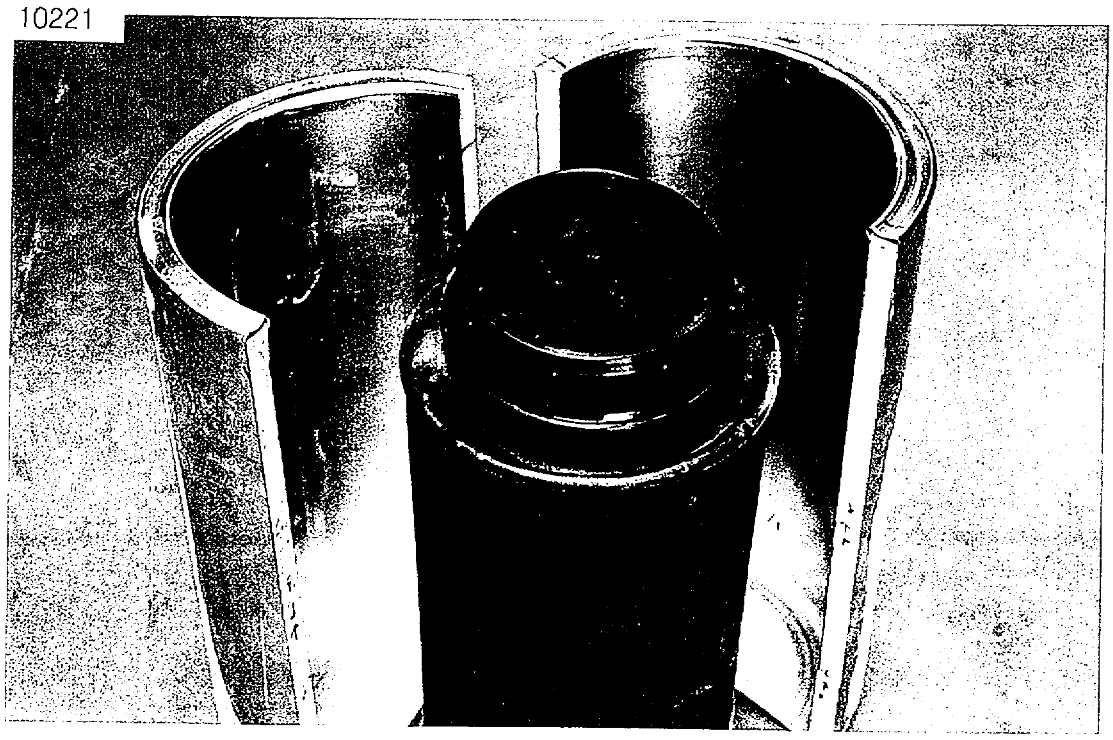

Photo n° 23 : Resin cup specimen P2

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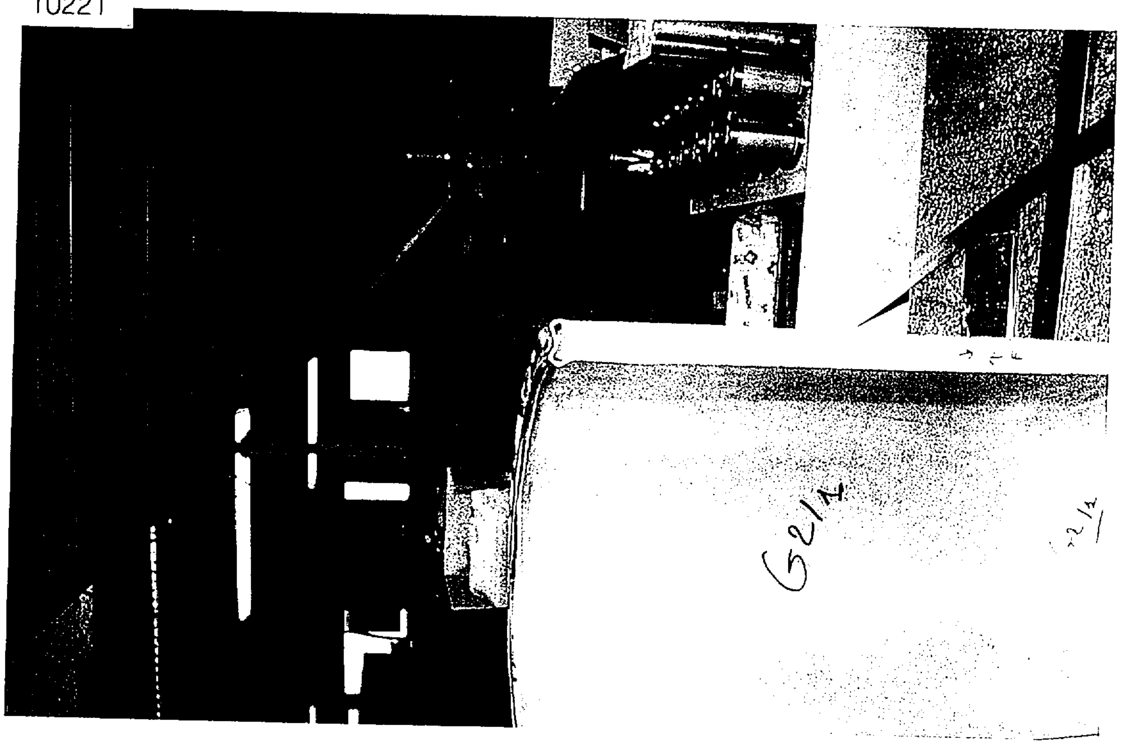

Photo n° 24 : Ditto

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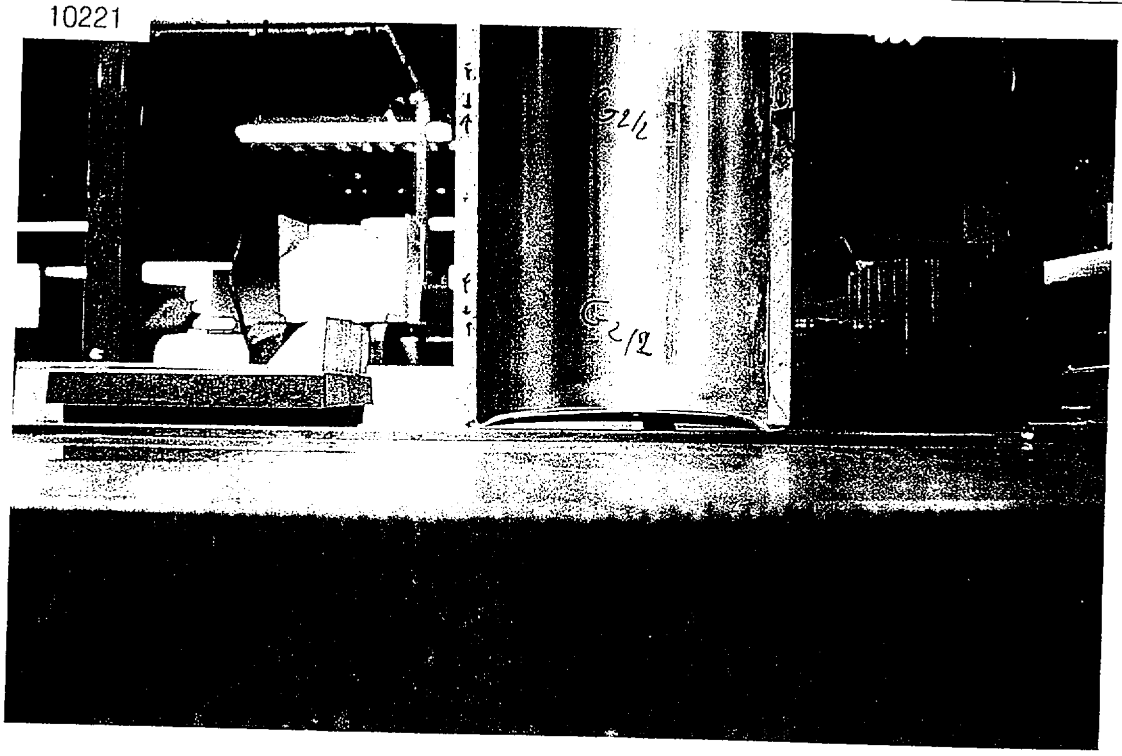


Photo n° 25 : Comparative view of FBFC Flask P1 and P2

Photo n° 26 : Detail layer of foam specimen P11

Photo n° 27 : Inner cavity of P11 after internalplug removal

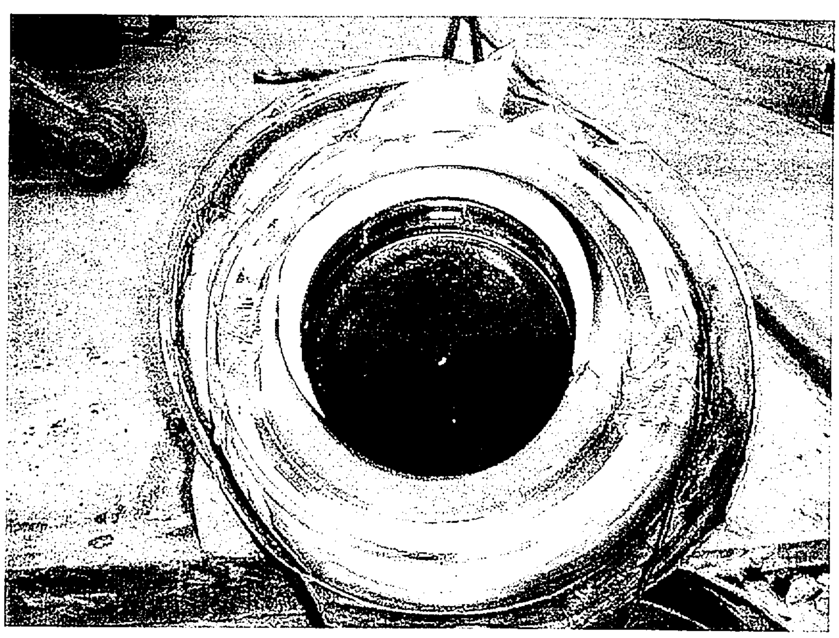


Photo n° 28 : Inner foam P11 after inner shell removal

Photo n° 29 : Inner shell specimen P11

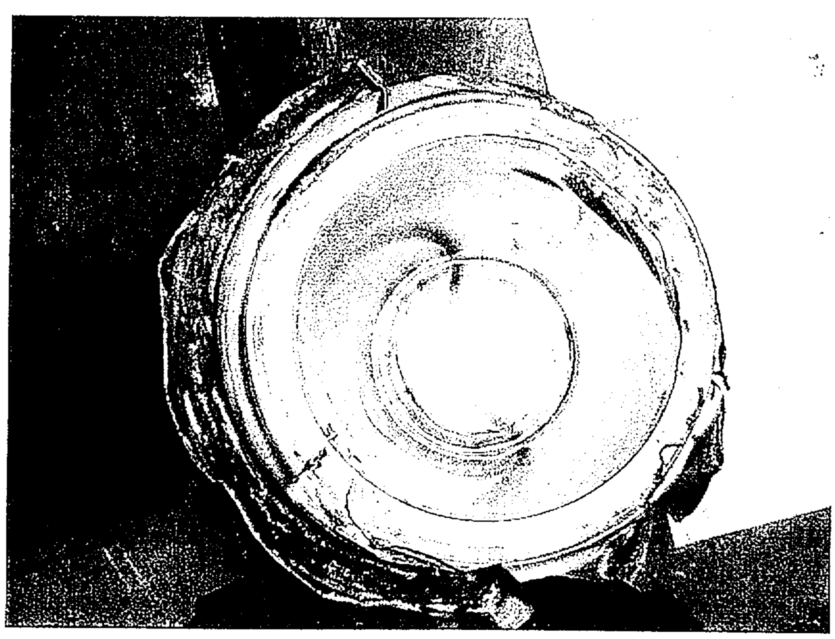


Photo n° 30 : Inner shell specimen P15 after inner plug removal

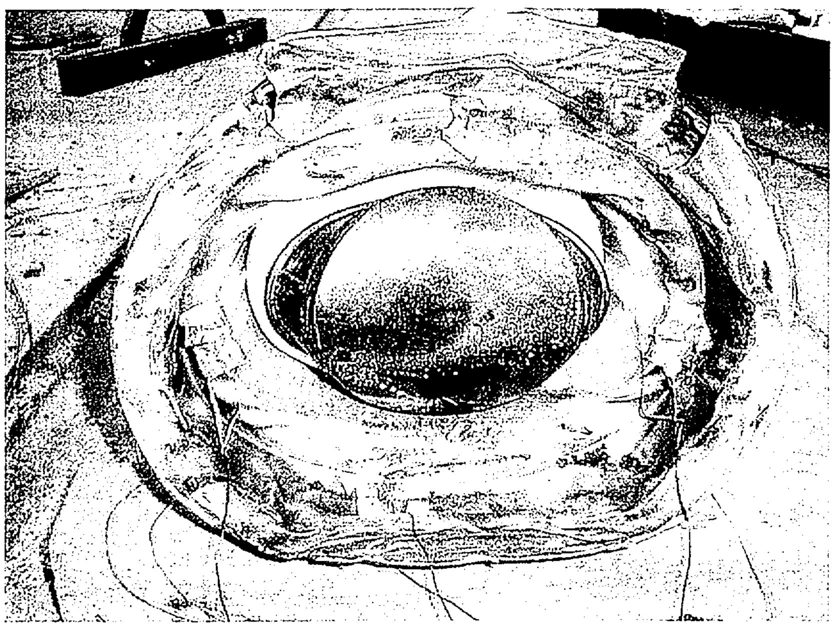
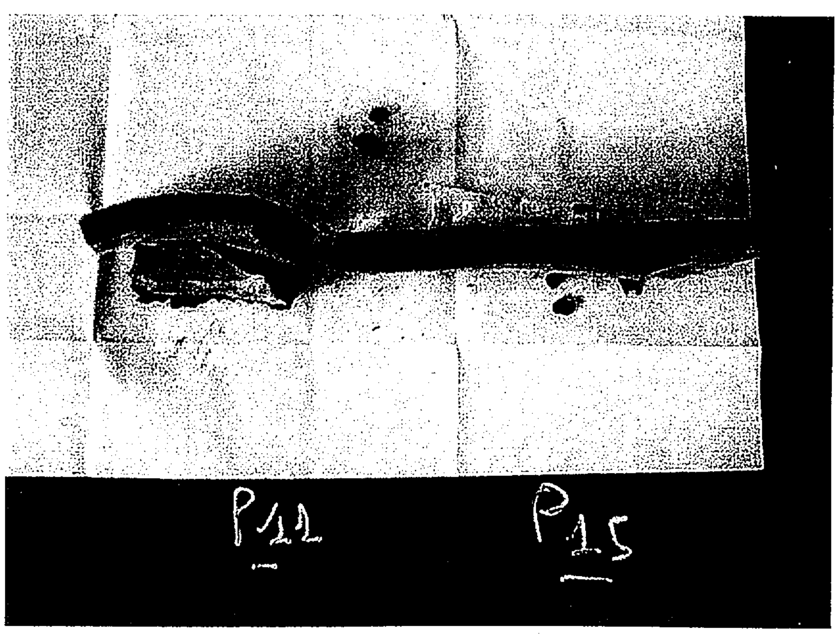


Photo n° 31 : Inner foam specimen P15 after inner shell removal

Photo n° 32 : Inner shell specimen P15

Photo n° 33 : Pieces of phenolic foam shell



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SAFETY FILE TN-UO_2		Name	Signature	Date
	Prepared by	P. MALALEL		
	Checked by	F. POTELLE		
Ref. 10313-Z-2 / Rev. 0				
Key words: Computer ref.: S:\DAC\Commun\Dossiers de Sûreté\TN-UO2\10313Z2				

THERMAL ANALYSIS IN NORMAL AND TRANSPORT ACCIDENT CONDITIONS

CONTENTS

REVISION SHEET

Revision	Date	MODIFICATIONS	Author / Checker
0	29/10/99	First issue of document	PML / FPL

ABSTRACT

This chapter presents a thermal analysis of the package in normal and transport accident conditions with regard to the regulations applicable to type A and IP-2 packages intended for transport of fissile materials.

This analysis comprises:

- a determination of the maximum temperatures reached by the package in normal transport conditions,
- justification of the package strength in transport accident conditions.

As the content gives off no heat power, it will have no effect on the temperatures of the package components, even when large numbers of them are shipped in a transport container.

The temperatures reached by each of the package components are obtained from a calculation in routine transport conditions in accordance with the regulations.

The result of the calculation in routine conditions, gives a uniform temperature distribution in the package of 50 °C.

This temperature is naturally compatible with all the packaging materials, which are therefore not degraded.

In transport accident conditions, a thermal test was conducted on two full-scale package prototypes (which first underwent the drop tests in the two most penalising configurations representative of transport accident conditions) in a high emittance oven.

In order to guarantee that the oven provides heat at least equivalent to that of a regulation hydrocarbons fire, with an average emittance of at least 0.9 and an average flame temperature of at least 800°C for at least 30 minutes, an experimental methodology (detailed in appendix 2.1) was employed:

- performance of a first calibration test on the oven control method, that is an 800°C/30 min. thermal test on a specimen identical to the packaging prototypes, with recording of the Temperature = f(time) curves of the thermocouples placed in the specimen and those measuring the environment of the outer overpack (overpack skin + environment at 100 mm).

  These measurements led to production of the Temperature/time profile to be applied to oven control (second test) in order to obtain the same heat flux as a regulation fire test on the qualification prototypes, taking account of the package temperatures in normal transport conditions, plus regulation insolation, applied before and after the test.

- performance of a second test consisting of the real thermal test in the oven, with application of the Temperature/time profile determined beforehand.

The maximum thermal evolution of the package during this test gave the following results:

- Maximum temperature of the neutron-poisoning resin = 109.3°C
- Maximum flask temperature = 99.3°C

These maximum temperatures obtained in transport accident conditions are perfectly compatible with satisfactory performance of the packaging materials.

No cracking of the primary container was observed.

The two specimens showed no release of the powder content after the test.

The layer of thermal insulation (phenolic foam) was locally degraded to a maximum thickness of 27 mm radially.

This final damage to the package was therefore taken into account in the criticality study performed in chapter 5A.

Appendices:

2-1: Thermal calculation note.

2-2: Regulation thermal test report.

1. SUBJECT

This chapter presents a thermal analysis of the package in normal and transport accident conditions with regard to the regulations <1> and <2> applicable to type A and IP-2 packages intended for transport of fissile materials.

This analysis comprises:

- a determination of the maximum temperatures reached by the package in normal transport conditions,
- justification of the package strength in transport accident conditions.

The TN-UO_2 packaging is described in chapter 0 of this safety file.

As the content gives off no heat power, it will have no effect on the temperatures of the package components, even when large numbers of them are shipped in a transport container.

2. THERMAL ANALYSIS IN NORMAL TRANSPORT CONDITIONS

The temperatures reached by each package component are the result of calculations in normal transport conditions in accordance with the IAEA regulations.

The maximum normal regulation conditions of temperature (38°C ambient temperature) and insolation are considered.

This calculation is presented in paragraph 5 of the note enclosed in appendix 2.1 of this chapter.

The calculation result in normal conditions gives a uniform temperature distribution in the package of 50 °C.

This temperature is naturally compatible with all the packaging materials, which are therefore not degraded.

3. THERMAL ANALYSIS IN TRANSPORT ACCIDENT CONDITIONS

The fire accident conditions are defined in regulations <1> and <2>.

They correspond to package exposure to a hydrocarbon and air fire with an average emittance of at least 0.9 and an average flame temperature of at least 800 °C for 30 minutes, followed by natural cooling in ambient air.

Given the small dimensions of the package, this test was performed on two full-scale prototypes (which had first undergone the drop tests in the two most penalising configurations, representative of transport accident conditions <1> and <2>), in a high emittance oven.

In order to guarantee that the oven provides heat at least equivalent to that of a regulation hydrocarbons fire, with an average emittance of at least 0.9 and an average flame temperature of at least 800°C for at least 30 minutes, the following experimental methodology (see detailed presentation in appendix 2.1) was employed:

- performance of two separate tests:
  - performance of a first calibration test on the oven control method, that is an 800°C/30 min. thermal test on a specimen identical to the packaging prototypes, with recording of the Temperature = f(time) curves of the thermocouples placed in the specimen and those measuring the environment of the outer overpack (overpack skin + environment at 100 mm).

    These measurements led to production (by adjustment of a numerical model to the package's finite elements) of the Temperature/time profile to be applied to oven control (second test) in order to obtain the same heat flux as a regulation fire test on the qualification prototypes, taking account of the package temperatures in normal transport conditions, plus regulation insolation, applied before and after the test (see appendix 2-1).

    The adjustment conditions (detailed in appendix 2-1) are summarised below:

    - adjustment of the thermal properties of the model materials in order to correlate the measurements obtained during the calibration tests with the results of the numerical calculation of radiant and convective heat exchange according to the oven temperature change law;
    - calculation of the behaviour of the package model, with its readjusted thermal properties, when a regulation radiant and convective fire is applied (steady state fire of 800°C/30 min. and average emittance 0.9), the initial temperatures of each component being assumed to be uniform and at equilibrium at the ambient temperature of 38°C, with regulation insolation being taken into account before and after the fire;
    - numerical calculation search for the new oven temperature change law to be applied (modification of the duration of the main hold time) to obtain the same package thermal response (indicating the same overall heat input).

  - a second test consisting of the real thermal test in the oven, with application of the temperature/time profile determined beforehand, that is:
    - ambient temperature rise to 800 °C in 9 min.
    - hold period: 800 °C / duration 33 min.
    - removal of specimen from oven at end of hold time, for natural cooling.

The longitudinal axis of each prototype was vertical during the thermal test, so that the maximum possible package surface was exposed to the lines of burners in the oven used.

Furthermore, directives <3> recommend that the specimen be placed on a support which disrupts the heat flux as little as possible (§ A-628.3). This led to the design of a frame supporting the specimens vertically, the structure of which ensured optimum performance of this function.

The thermal test report is given in appendix 2-2.

The main results are given below:

- Maximum temperature of neutron-poisoning resin = 109.3°C
- Maximum flask temperature = 99.3°C

These maximum temperatures obtained in transport accident conditions are perfectly compatible with satisfactory performance by the packaging materials.

- No cracking of the primary container was observed.
- The two specimens showed no signs of release of the powder content after the test.
- The layer of heat insulation (phenolic foam) was locally degraded to a maximum thickness of 27 mm radially.

This final damage to the package was taken into account in the criticality study performed in chapter 5A.

4. CONCLUSION

In normal transport conditions, the maximum temperature uniformly distributed in the package is 50 °C.

This temperature is naturally compatible with all the packaging materials, which are therefore not degraded.

The maximum temperature reached in the neutron-poisoning resin following the regulation mechanical and thermal accident tests is 109.3°C, while the maximum temperature of the flask is 99.3°C.

These maximum temperatures obtained in normal and transport accident conditions are perfectly compatible with the satisfactory performance of the packaging materials.

No release of the content was observed following the regulation mechanical and thermal accident tests.

5. REFERENCE REGULATIONS

<1> Regulations for the Safe Transport of Radioactive Materials – IAEA - (1985 Edition, reviewed in 1990).

<2> Regulations for the Safe Transport of Radioactive Materials – IAEA - (1996 Edition).

<3> IAEA N° 37 = Directives for application of the IAEA's regulations for the safe transport of radioactive materials (85 edition).

THERMAL CALCULATION NOTE

CONTENTS

ENCLOSURES:

n°1: THERMAL CALCULATION NOTE – ref. TRANSNUCLEAIRE/ 10313-B-5 rev.2

REVISION SHEET

Revision	Date	MODIFICATIONS	Author / Checker
0	29/10/99	First issue of document	PML / FPL

1. SUBJECT

This appendix presents a detailed note of the thermal calculations made to guarantee that during the oven thermal tests, the heat contributed to the specimen is at least equivalent to that of a regulation hydrocarbon fire, with an average emittance of at least 0.9 and an average flame temperature of at least 800°C for at least 30 minutes.

The numerical modelling and the thermal calibration and qualification tests were performed on full scale package model prototypes in its design variant incorporating neutron-poisoning resin with the FS 69 type composition (whose mechanical and thermal properties are slightly lower than those of the BORA type resin: see chapter 0 of this safety file), in order to penalise the damage to the specimens.

2. CONCLUSION

The results of this study show that the experimental thermal test conditions in the oven lead to heat fluxes higher than those obtained in the fire conditions specified by the IAEA regulations. Consequently, the current experimental fire test conditions on the TN-UO_2 packaging are more penalising than the fire conditions stipulated in the currently applicable IAEA regulations.

TRANSNUCLEAIRE	THERMAL CALCULATION NOTE			Page 1 of 15
TN UO2 PACKAGING		Name	Signature	Date
	Preparation	B. BOUCARD		
10313-B-5 / Rev. 2	Verification	L. CHIRON		

Mots clefs : TN UO2. IAEA fire test
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CALCULATION OF TEMPERATURE OF OVEN REPRODUCING THE HEAT FLUX FROM FIRE CONDITIONS IN IAEA REGULATIONS ON TN-UO2

CONTENTS

REVISION SHEET

Revision	Date	MODIFICATIONS	Preparation / Verification
0	21/07/98	Creation of document	L. CHIRON / F. PETIT
1	24/07/98	Modification of limit conditions. _ inclusion of normal transport conditions (insolation) for calculation of initial test conditions as per IAEA regulation. _ inclusion of a new oven temperature law in calculation simulating fire test. Modification of central package material. _ air replacing iron powder for comparison of oven test/fire test as per IAEA.	L. CHIRON / F. PETIT
2	08/01/99	Complete revision of document. Modification of limit conditions _ inclusion of a new oven temperature law for new test in an oven - inclusion of convection in new oven - replacement of F resin by resin FS69 - replacement of dry foam by wet foam with 20 per cent water	B. BOUCARD/ L. CHIRON

1. INTRODUCTION

The purpose of this study is to determine the temperature of the test oven so as to apply to a damaged TN-UO_2 package the same heat flux as that arising from fire conditions, as per the IAEA regulation <1>.

This study was carried out using the I-DEAS/TMG finite differences calculation code. The numerical model used is axisymmetrical.

The hypotheses used for modeling and recalibration are as follows:

_ the package damaged after dropping is modeled as a perfect cylinder.
_ a gap is planned between the flask and stainless steel tube, for possible recalibration (0.01 mm per default).
_ radiative and convective exchanges between the package and oven for experimental conditions.
_ the IAEA fire test imposes radiative and convective exchanges around the package.

The equivalent thermal properties (conductivity, specific heat, latent heat of vaporization and density) of the phenolic foam and FS69 resin are characterized by the calculation, in order to obtain the same experimental temperature evolutions.

From these recalibrated thermal properties, a calculation was made in accordance with the fire conditions per IAEA regulation <1>.

A comparison was made between the fire test and calculation as per the IAEA regulation. Readjustment of the maximum oven temperature will be carried out if necessary, so as to ensure test conditions at least as penalizing as those in the IAEA regulation.

2. MAIN STUDY PARAMETERS

The main parameters of the study are as follows:

a : Absorption capacity

C_p : Specific heat (J/kg K)

E: Insolation (W/m^2)

h : Conductive and convective exchange coefficient (W/ m^2 K)

t : time (seconds (s) or minutes (min)

L : Latent heat (J / kg)

T : Temperature (°C or K)

V : Volume (m^3)

δQ : amount of heat on an element (J)

ε : emissivity

φ : Flux density (W/m^2)

λ : Thermal conductivity (W/m K)

ρ : Density (kg/m^3)

Φ : Flux (W)

ΔT :temperature difference (°C or K)

3. CALCULATION METHOD

3.1 Geometry and materials

The model geometry, given in Figure 1, is based on Diagram 1 below. It corresponds to a package damaged after a regulation drop <1>. This damaged package used for thermal recalibration explained in § 3.4, and consisting of a prototype subjected to dropping of a 500-kg plate through 9 meters onto a corner, is shown diagramatically below:

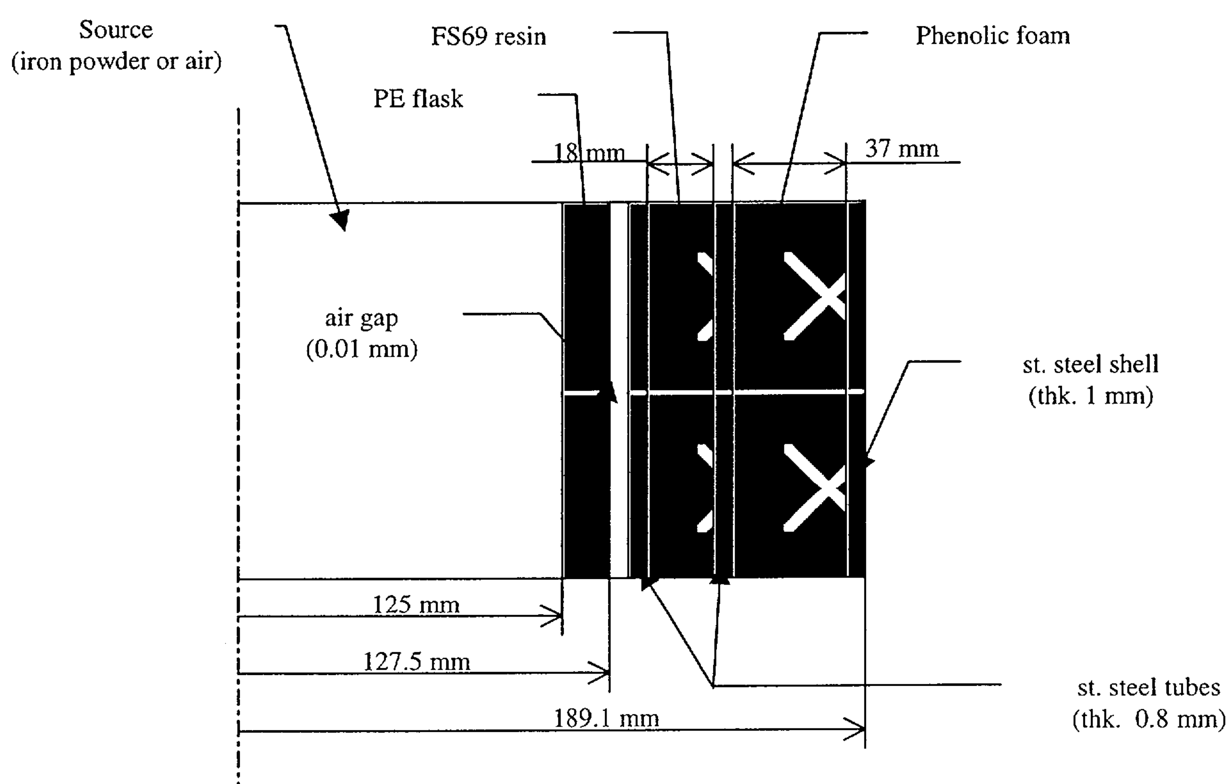


Diagram 1

The air gap between the flask and inner cavity wall is 0.01 mm (i.e. more or less nil for thermal exchanges by conduction) so as to simulate deformation of the cavity coming in contact with the flask.

The reference characteristics for the materials are shown below:

Material	**Conductivity** **λ (W/m.°K)**	**Density** **ρ (kg/m³)**	**Specific heat** **Cp (J/kg.°K)**	**Latent heat** **(J/kg)**	**Emissivity** **ε**
Stainless steel	15	7850	500	-	0.3 before fire 0.9 after fire
P 300 foam (moisture content 20%)	-	374.8 (1)	2 443 (1)	4.5×10^5 (1)	-
P 300 foam (dry)	0.042	300	2000	-	-
FS69 resin	0.7	1 690	Cp(T) (2)	-	-
HDPE flask	0.1	1400	1590	-	0.92
Iron powder	0.084	1042	260	-	-
Air (T in °C)	$0.025 + 6.86 \times 10^{-5}$ T	1	1000	-	-

(1) Calculation given in Appendix 1.
(2) Value indicated in Appendix 2.

3.2 Mesh

The meshing is of the axisymmetrical type. It consists of linear axisymmetrical elements of solid and shell types. The mesh is shown in Figures 1 and 2.

3.3 Type of calculation

The thermal calculations are performed in transient regime by finite difference method, with the TMG module interfaced with I-DEAS <2>.

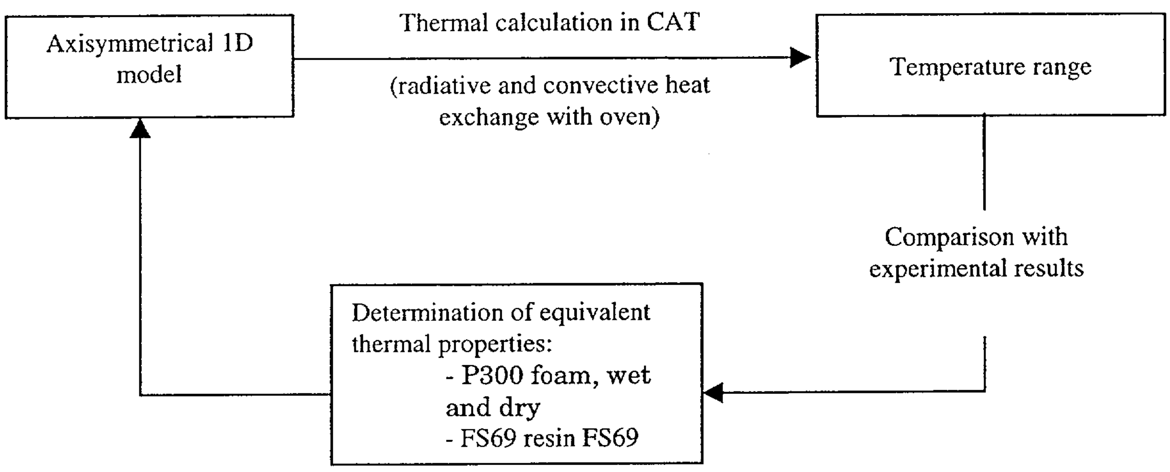
The initial temperatures are assumed uniform in the model. They issue from results of oven test. For normal IAEA fire test conditions, a permanent regime is covered prior to the transient regime, to obtain the initial model temperatures.

3.4 Approach

The calculation approach used for this study was defined in internal correspondence <4>. It is recapitulated in this chapter.

3.4.1 Recalibration of equivalent thermal properties of damaged package

The calculations involve simulating the fire conditions in an oven, and recalibrating the thermal properties of the P300 foam (before and after fire) and of the FS69 resin in such a way as to reestablish the temperatures of an oven fire test for a damaged package. The recalibration approach is outlined below.



3.4.2 Simulation of IAEA fire test with numerical model

Once the thermal properties are recalibrated, the IAEA fire test is modeled.

3.4.3 Comparison of IAEA fire test and oven test

A comparison was made of the numerical models simulating the IAEA test and oven test to verify that the oven test is more penalizing than the IAEA regulation.

4. RECALIBRATION OF THERMAL PROPERTIES

4.1 Test results (figures 4 to 8)

Eight thermocouples within the packaging and eight others around it were connected to instruments in order to indicate changes of temperature in the various materials. They are defined in the table below, with the corresponding numbers of the mesh elements. The positioning of thermocouples is shown in Diagram 2 below. Figure 2 shows the location on the mesh of the elements associated with thermocouples.

Thermocouple No.	Element No.	Position
Th 29-30	e 563	Inner surface of stainless steel shell
Th 12-11	e 258	Outer surface of stainless steel shell
Th 13-16	e 288	Middle of resin
Th 14-15	e 248	Inner stainless steel/flask interface

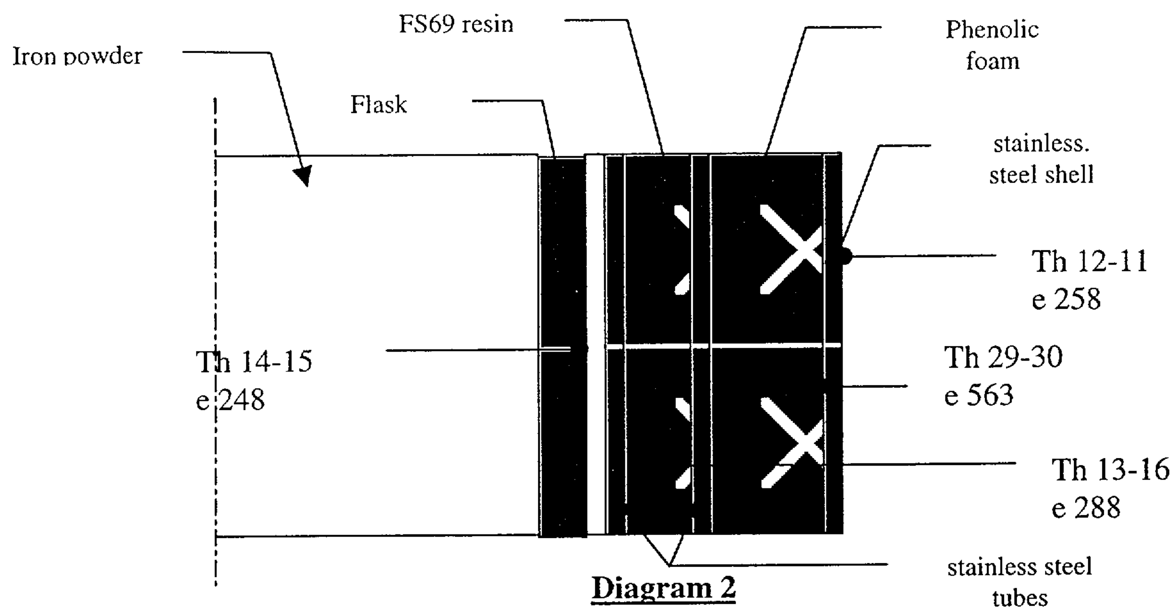


Diagram 2

The maximum temperatures from the experimental graphs (figures 5, 6, 7 and 8) are as follows:

Element No./Thermocouple No.	Tmax (°C)	t (Tmax) (s)
e 258 / Th 12-11	740	2400
e 563 / Th 29-30	710	2760
e 288 / Th 13-16	102	5400
e 248 / Th 14-15	104	4800

4.2 Model limit conditions (figure 3)

4.2.1 Initial temperatures

The initial temperatures of each component of the package are supposed uniform, i.e. at 6°C.

4.2.2 Radiative exchanges

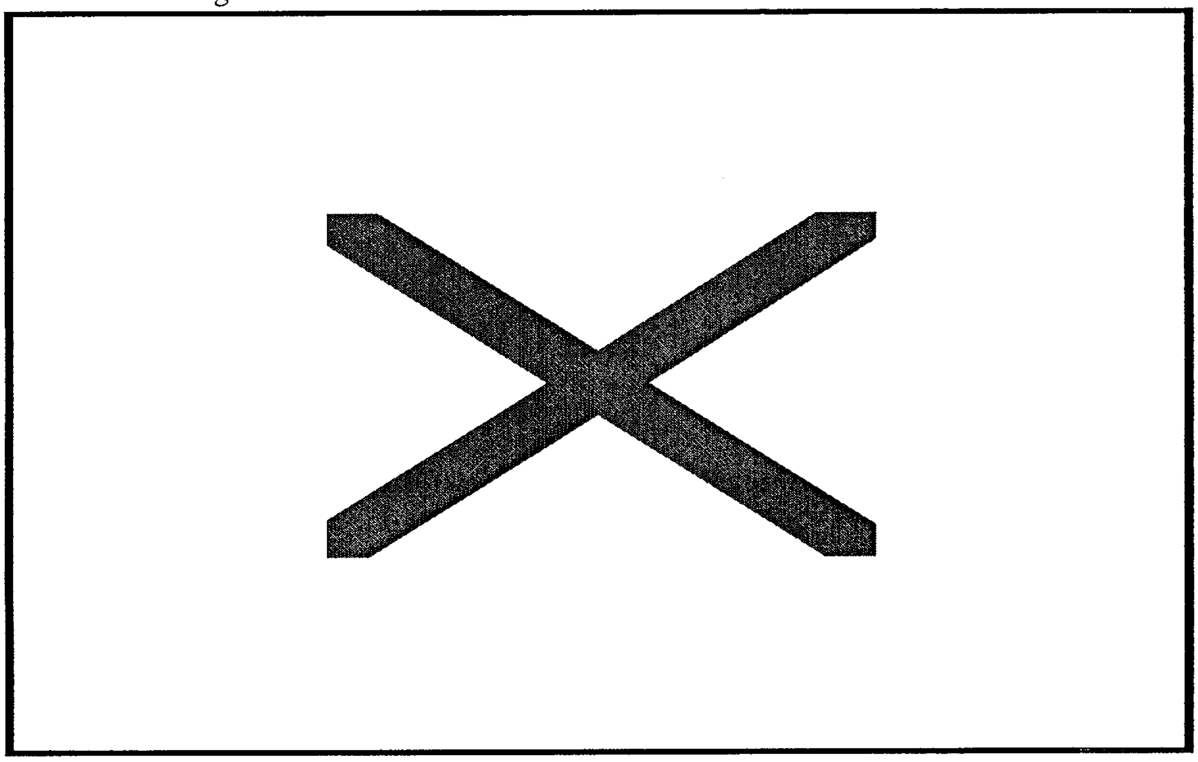
For outer radiative exchanges between the package and the oven, the emissivity of the oven is 0.9 and that of the outer surface of the shell is recalibrated to 0.4.

4.2.3 Convective exchanges

For convective exchange between the package and the oven, the exchange coefficient is 8 W/m^2K.

4.2.4 Evolution of oven temperature

The thermal behavior of the oven is modeled introducing the average temperature from the eight thermocouples around the packaging measuring the temperature inside the oven into the numerical model. This graph is shown in figure 4 and in the diagram below.



4.3 Results of recalibration

4.3.1 Equivalent recalibrated thermal properties

The table below shows the equivalent thermal properties after recalibration:

Material	**Conductivity** λ **(W/m.°K)**	**Density** ρ **(kg/m³)**	**Specific heat Cp (J/kg.°K)**	**Latent heat (J/kg)**	**Emissivity** ε
Inner stainless steel Outer stainless steel	15	7 850	500	-	0.4 0.6
P 300 foam (wet) ≤100°C	0.9 (1)	374.8	2 443	$4.5\text{x}10^5$	-
P 300 foam (dry) > 100°C	0.12 (1)	300	2 000	-	-
FS69 resin	0.7	1 690	Cp(T) (2)	-	-
HDPE flask	0.05	1 400	1 590	-	0.92
Air (T in °C)	$0.025 + 6.86\text{x}\cdot 10^{-5}\cdot T$	1	1000	-	-

(1) The program making possible to make this modification in conductivity is given in Appendix 3.
The gap between the flask and stainless steel cap remain unchanged after recalibration.

(2) See Appendix 2.

4.3.2 Comparison of temperature changes

Recalibration is made by means of comparison of temperature graphs from calculation with those from experimentation. The results are presented in the table below. Changes over time obtained with the recalibrated characteristics are presented in figures 9 and 10. It can be seen that for the recalibrated model temperature rises more slowly and with less fluctuation than for experiment. This difference arises from the fact that a 1D model was produced and that this does not take account of the thermal pathway existing between the outer surface steel and the foam-resin interface steel. In addition, the thermocouple in the foam is 80 mm from this pathway.

Location	Fire test readings		Recalibration calculation results		Difference
Average Th No. Element No.	Tmax (°C)	t (s)	Tmax (°C)	t (s)	(°C)
Th 11 – 12 e 258	740	2400	780	1980	40
Th 29 - 30 e 563	710	2760	780	1980	70
Th 13 - 16 e 288	102	5400	105	6720	3
Th 14 - 15 e 248	104	4800	104	6940	1

5. CALCULATION FOR FIRE TEST PER IAEA REGULATION

5.1 Model limit conditions (figure 3)

5.1.1 Initial temperatures

The initial temperatures for each component of the package are coming from the calculation for normal transport conditions as per the IAEA regulation. This calculation is a permanent regime for which the limit conditions are those from the transient fire calculation taken at time 0.

5.1.2 Radiative exchanges

The external radiative exchange between the package and the ambient air is taken into account, with shell emissivity of 0.3 before fire and 0.4 after fire.

5.1.3 Convective exchanges

The free convection in turbulent regime is taken into account on the outer surface of the packaging, in accordance with equation <3>:

$$h = 1.28 \times (\Delta T)^{0.33}$$ for vertical surfaces of the cylinder.

5.1.4 Insolation

The regulation level of insolation applied for 12 hours out of 24 over the entire outer cylindrical surface of the packaging is 200W/m^2 for the vertical surfaces. The density of the solar flux is applied continuously (24h/24h).
The density of the solar flux received by the outer surface is:

$$\varphi = a \times E$$

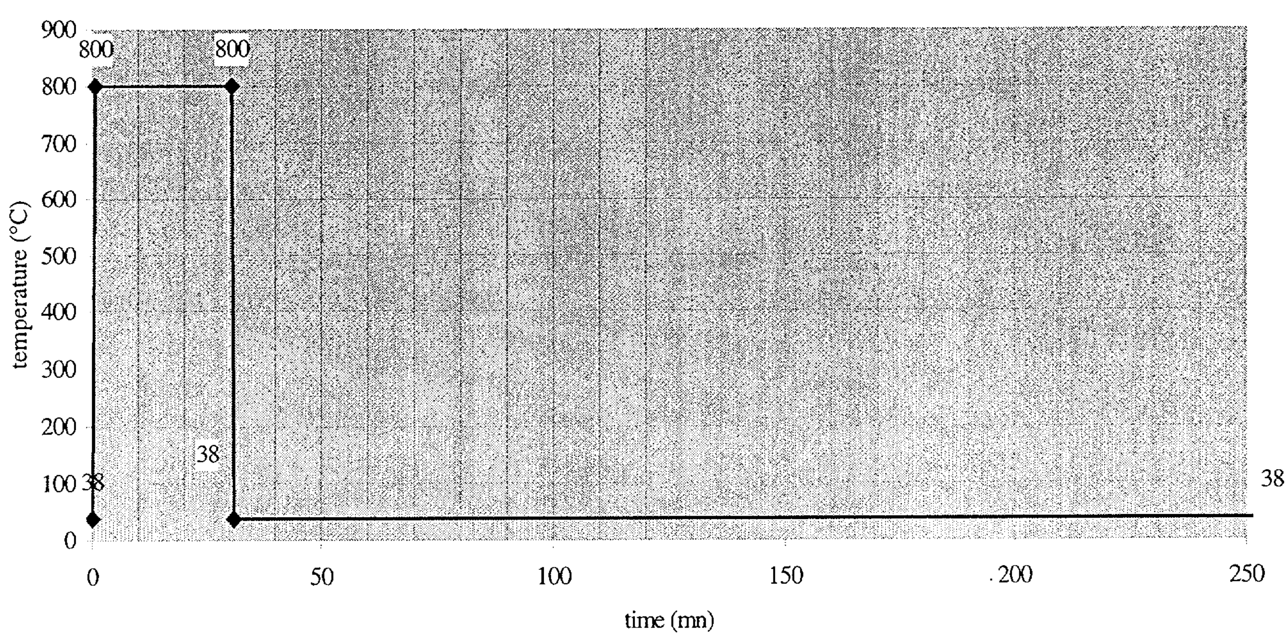
The absorption capacity of the shell alters from 0.3 before fire to 0.9 after fire. The regulation insolation therefore evolves in accordance with the following "law":

A t = 0 s	$\varphi_0 =$ 60 W/m^2
A t = 30 s	$\varphi_0 =$ 0 W/m^2
A t = 1830 s	$\varphi_0 =$ 0 W/m^2
A t = 1860 s	$\varphi_0 =$ 180 W/m^2
A t = ∞	$\varphi_0 =$ 180 W/m^2

5.1.5 Evolution of ambient temperature in fire conditions

The temperature of the ambient air evolves as per the IAEA regulation, i.e. a fire of 800 °C for 30 minutes.

<u>Fire temperature graph according to IAEA conditions</u>



5.2 Results of IAEA fire test

The evolutions of temperature of key elements over time are presented in figures 11 and 12. Positioning of the elements is shown in Figure 2. The main values are given in the comparative table shown in section 6.

6. COMPARISON OF THE FIRE TEST PER IAEA WITH AN OVEN FIRE TEST

6.1 Analysis of results

Evolution over time for the IAEA fire test is shown in figures 11 and 12.
The maximum temperatures obtained for the fire test as per the IAEA regulation are given in the left-hand part of the table below. The right-hand part gives the temperatures in the package subject to oven fire test conditions.

Location Element No.	IAEA test		Oven test		Difference (°C)
	Tmax (°C)	time (s)	Tmax (°C)	time (s)	
Outer surface of shell e 258	768	1820	780	1990	+12
Inner surface of shell e 563	768	1810	780	1990	+12
Middle of resin e 288	100	8500	105	6720	+5
St. steel tube/flask interface e 248	100	11000	104	6940	+5

The comparison of the two tests – experimental and IAEA fire test – indicates that the oven experimental conditions lead to higher temperatures than those obtained in fire conditions as per the IAEA regulation.

Comparison of graphs for the outer surface (figures 13 and 14) shows an increase in temperature of the package slower than in the IAEA regulation, i.e. a final delay of 400 s. For the oven fire test, if a time shift is introduced, it is seen that at the "plateau" representing temperature at 800°C for 1800 s, there is an extension to this of 400 s.

6.2 Amount of heat

To obtain the amounts of heat received by the model for each of the fire tests, the model elements are summed as follows:

$$\delta Q = \rho V c_p \int_{t_1}^{t_2} T dt$$

It is therefore only necessary to compare, for a single surface element, the area under the time-temperature curves obtained for each of the tests.

If a time shift is introduced, the comparison of temperature graphs (figures 13 and 14) for the two curves shows that the temperature curves for the outer surface temperature from fire test conditions are always greater than those for the IAEA regulation curve. Consequently, for the oven fire test, the package receives an amount of heat greater than that determined by the fire test as per IAEA.

7. CONCLUSION

The results of this study show that the conditions in the test oven lead to a heat flux during a period greater than those obtained in fire conditions as per the IAEA regulation.

Consequently, the present experimental conditions for the fire test on the TN-UO_2 packaging are more penalizing than the fire conditions of the current IAEA regulation in spite of the shift due to build up of temperature in the oven which is slower than in the regulation.

8. REFERENCES

<1> IAEA Safety Series No. 6 - Regulation on transport of radioactive materials - 1985 edition (amended 1990).

<2> I-DEAS finite element calculation software Master Series V4.0, developed by SDRC and associated with the thermal module analysis TMG.

<3> Heat transmission - WH Mc Adams - Chapter VII.

<4> Internal TRANSNUCLEAIRE correspondence 98-090 of 17 June 1998 ("1-D axisymmetrical thermal calculations in IAEA fire test")

<5> Archiving cartouche 3648-, file 23:

/a0313001/THERMAL			
Name	Part	FE model	Contents
Tfourhconv.arc	1D package	Feu_four2fs69	1D calculations for package in oven fire test conditions for recalibration of thermal properties.
		Feu_AIEA_CNT	1D calculation for packages in normal transport conditions
		Feu_AIEA_CAT	1D calculations for package in fire test in IAEA regulation conditions.

<6> Basics of heat transfers – J. F. Sacadura – p. 430 - Lavoisier Tec. and Doc. – 1993.

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF APPENDICES

FIGURE 1

MODEL CHARACTERISTICS

Model geometry

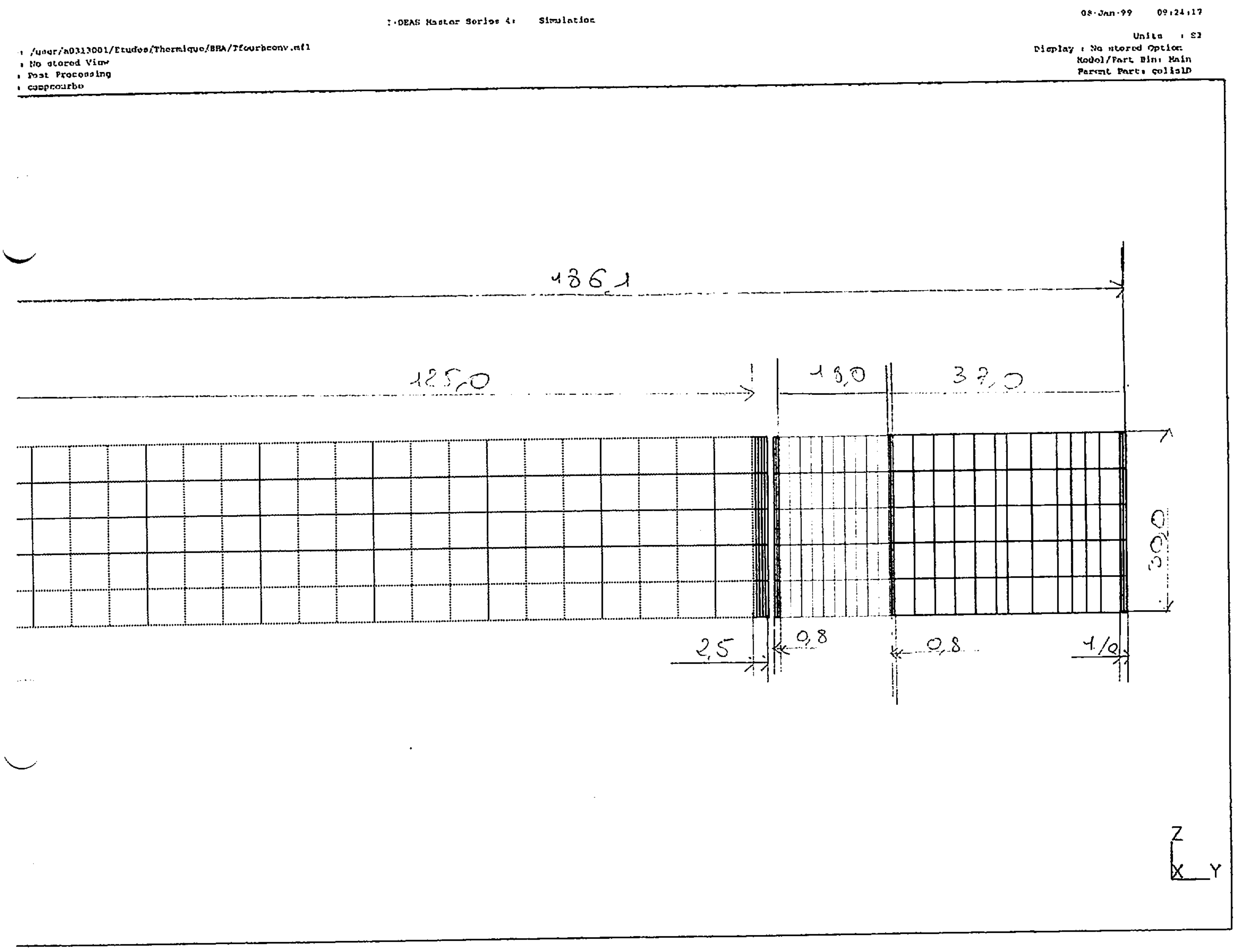


FIGURE 2

MODEL CHARACTERISTICS

Meshing of model and material

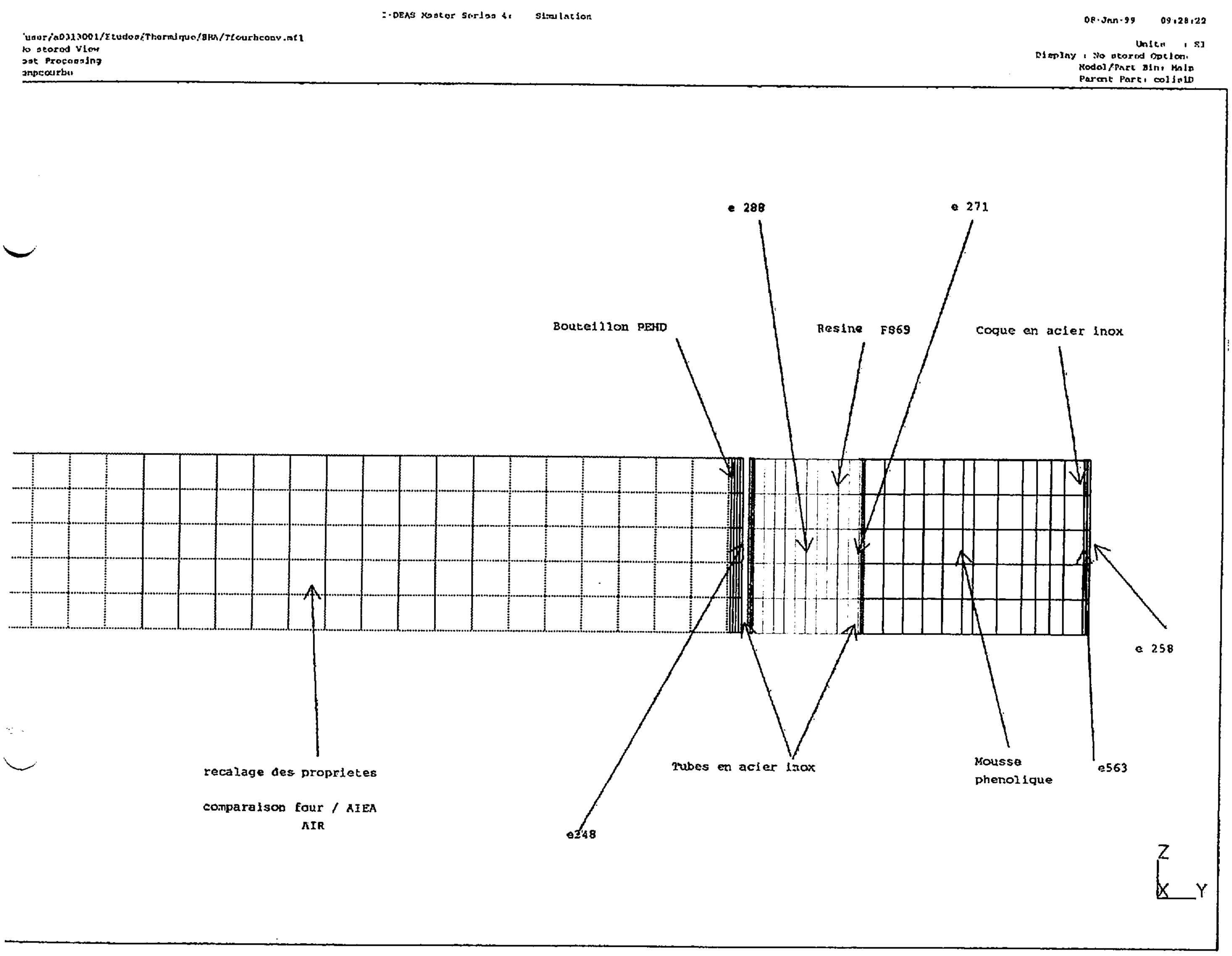


FIGURE 3

MODEL CHARACTERISTICS

Limit conditions

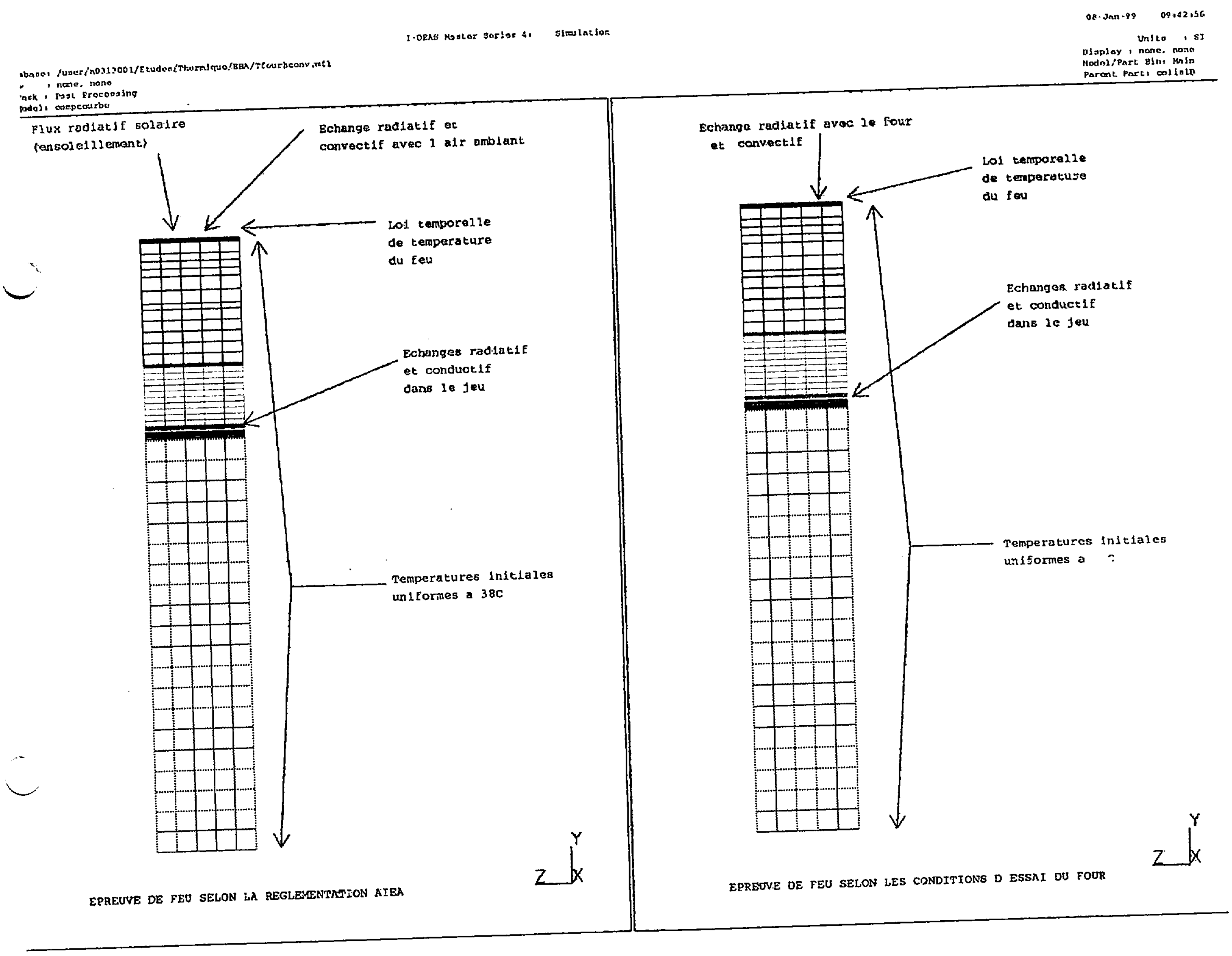


FIGURE 4

EXPERIMENTAL RESULTS

Average oven temperature

(test in order to recalibrate the thermal characteristics)

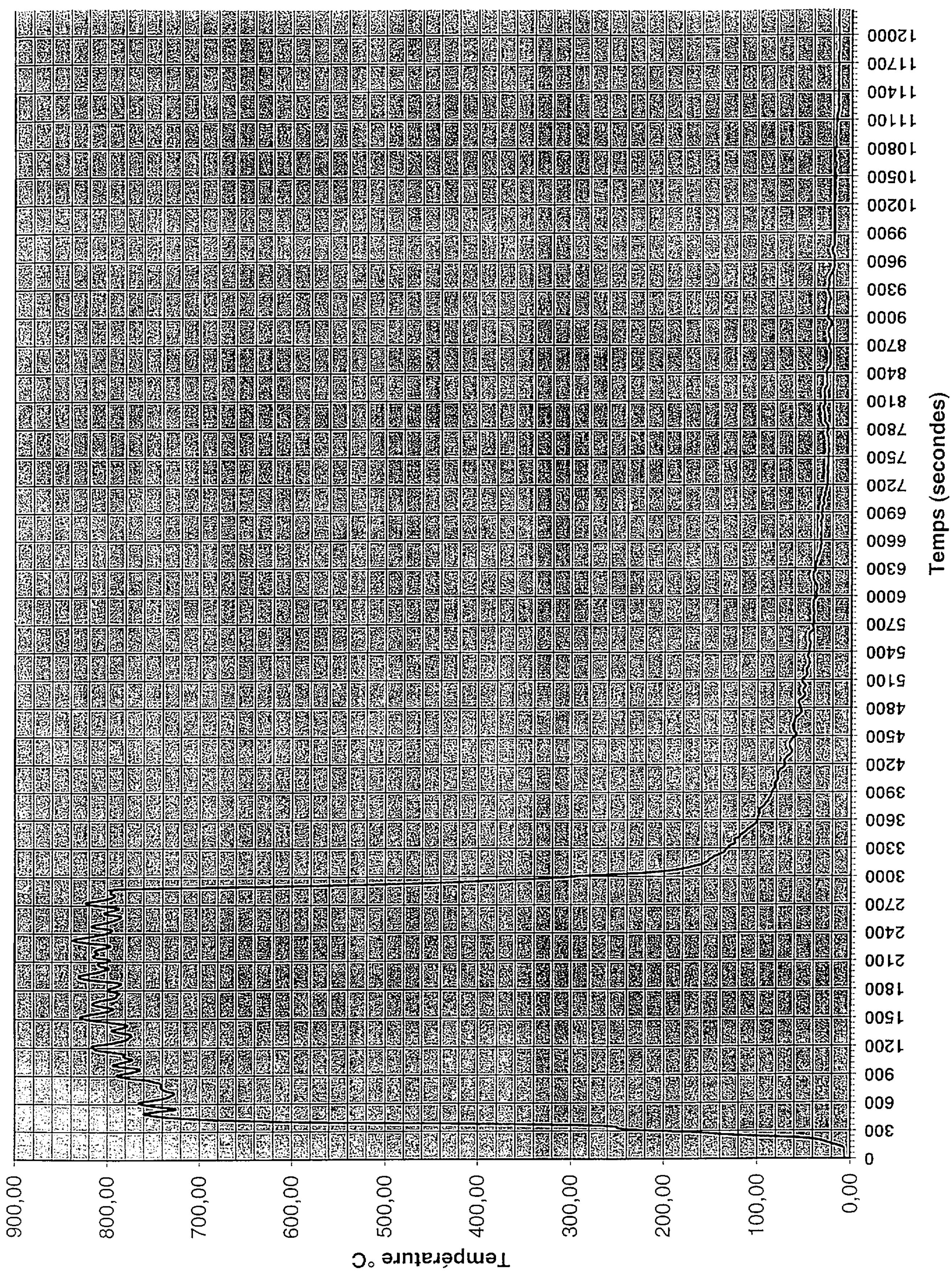


FIGURE 5

EXPERIMENTAL RESULTS

Average temperature of thermocouples Th11 and Th12 located on outer surface of stainless steel shell

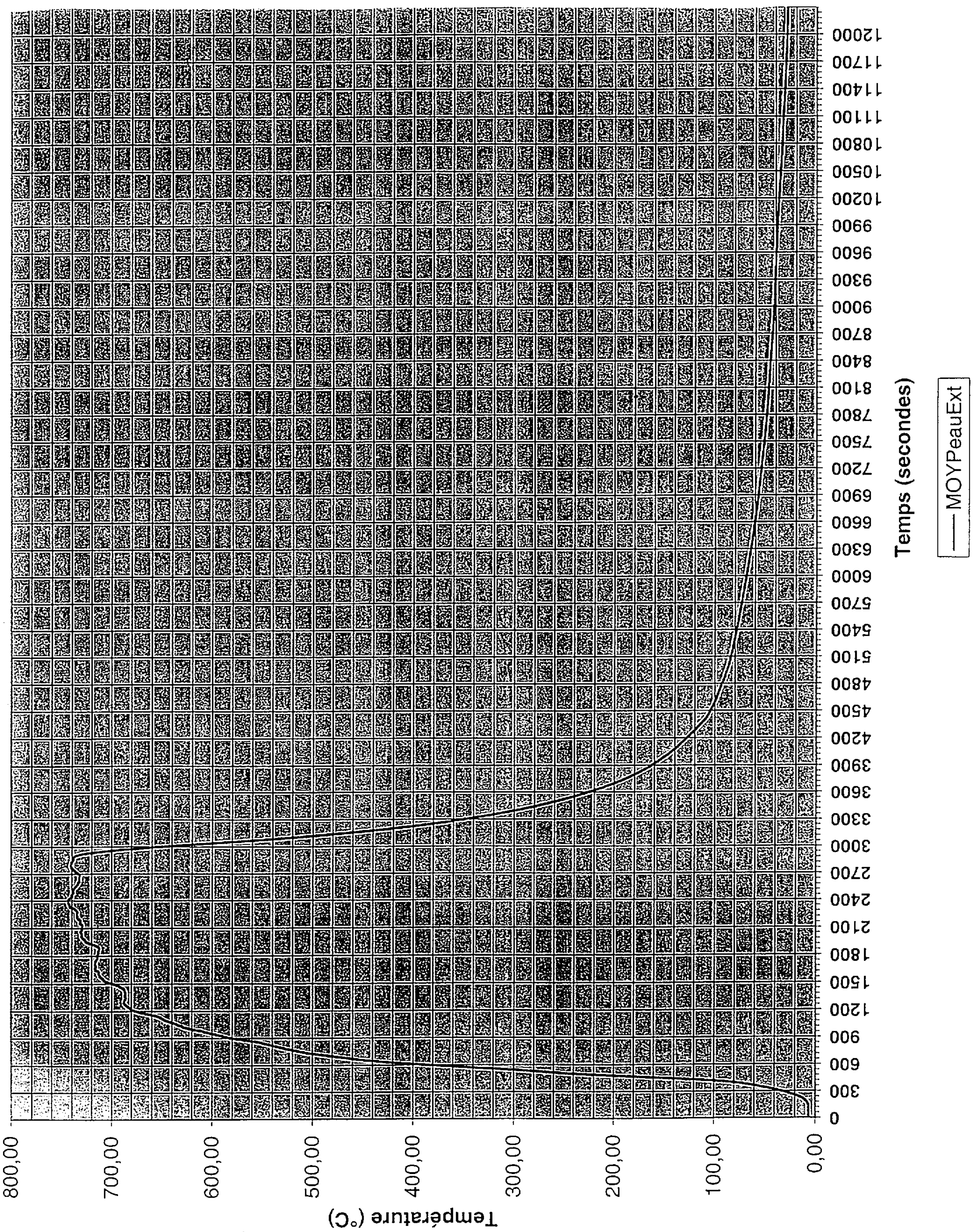


FIGURE 6

EXPERIMENTAL RESULTS

Average temperature of thermocouples Th29 and Th30 located on outer surface of stainless steel shell

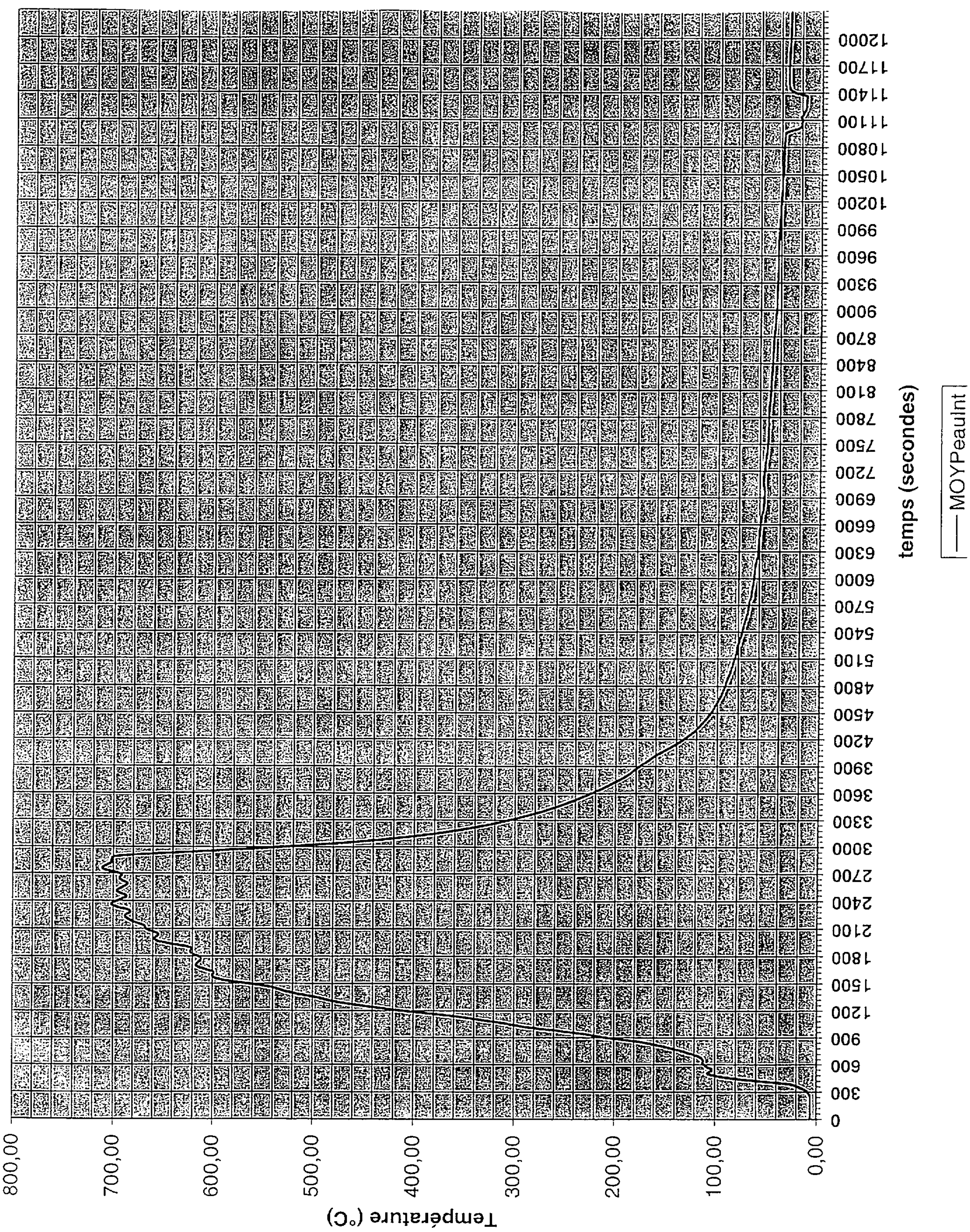


FIGURE 7

EXPERIMENTAL RESULTS

Average temperature of thermocouples Th13 and Th16 located in the middle of the resin

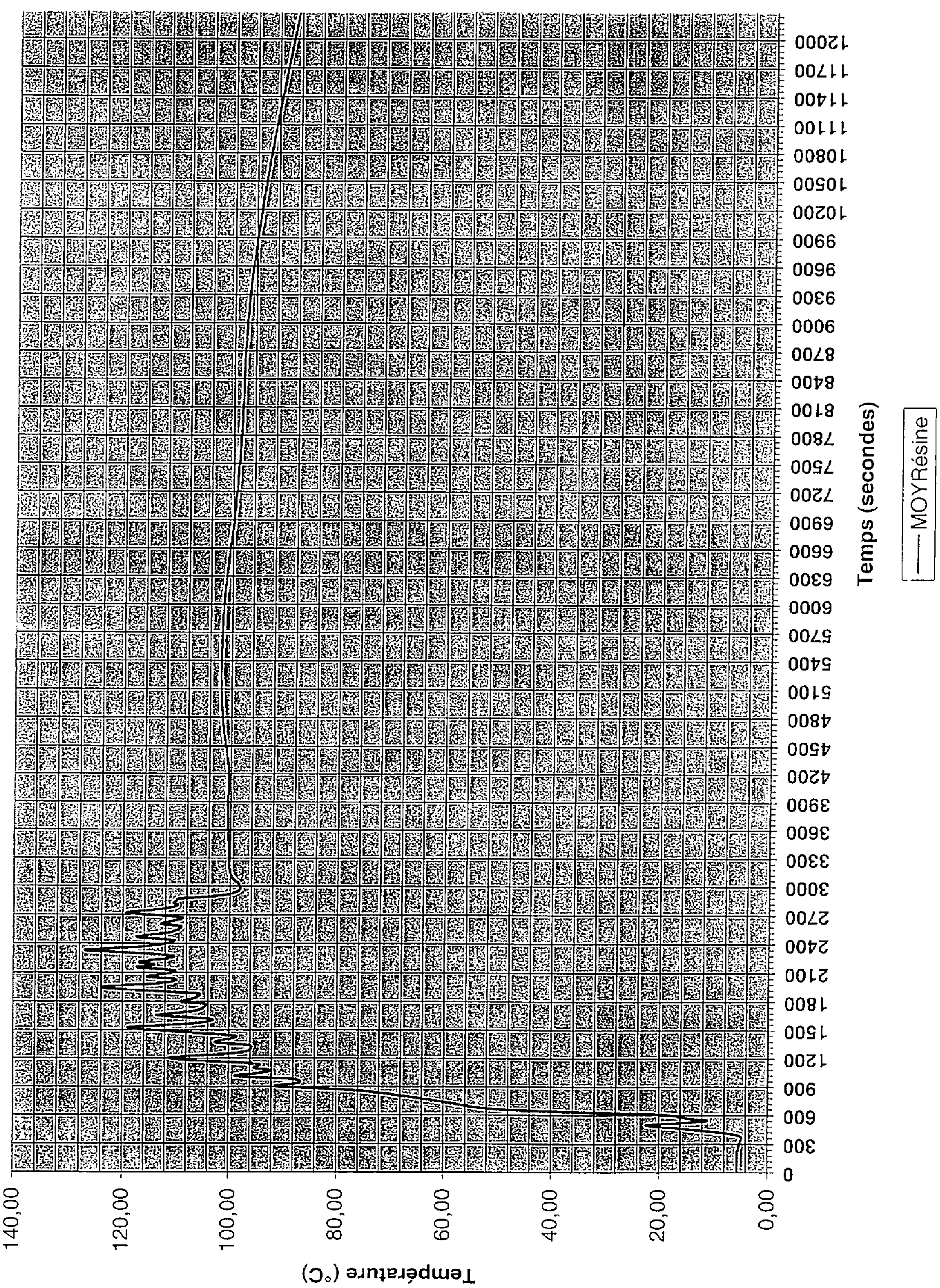


FIGURE 8

EXPERIMENTAL RESULTS

Average temperature of thermocouples Th14 and Th15 located at inner stainless steel tube/flask interface

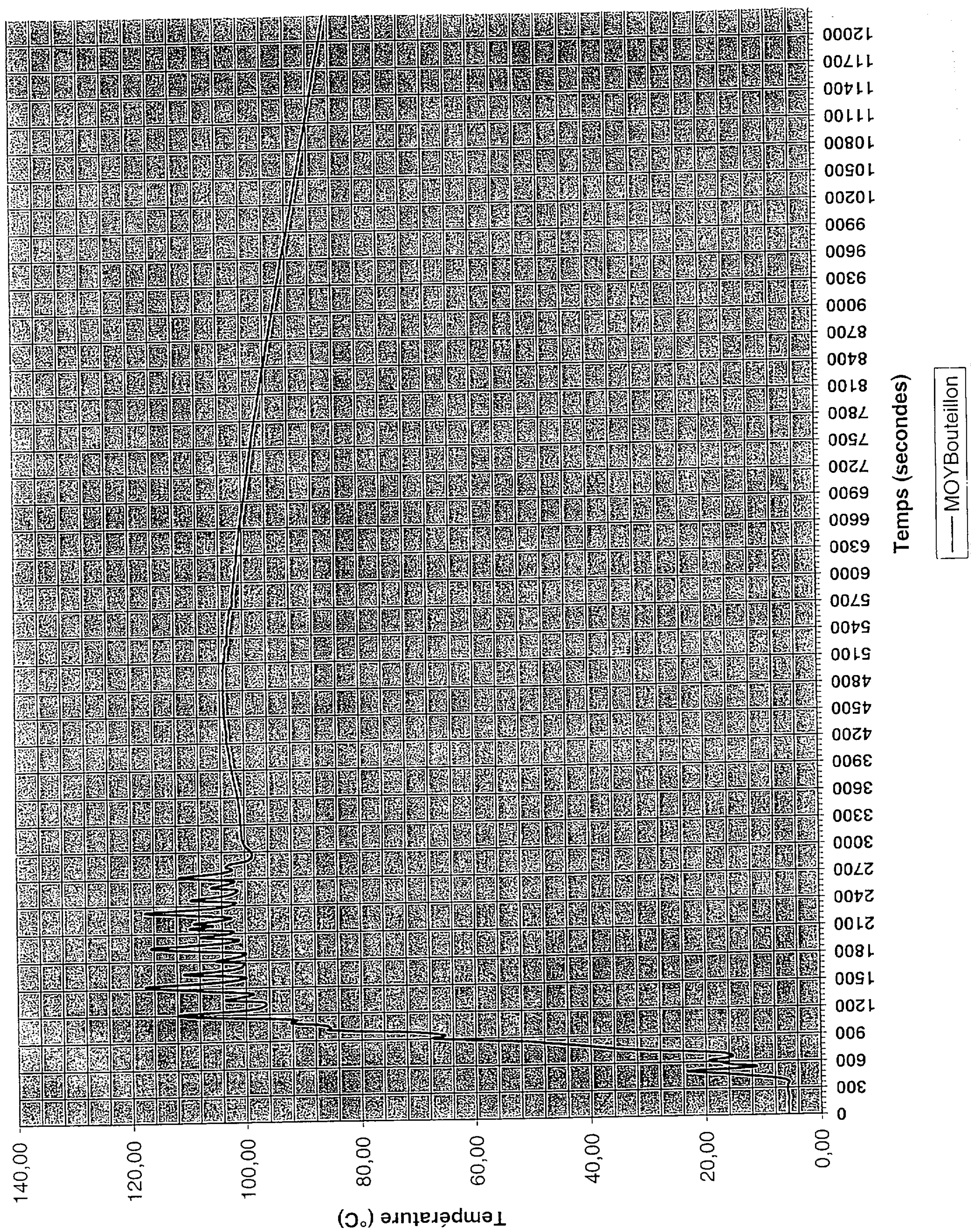
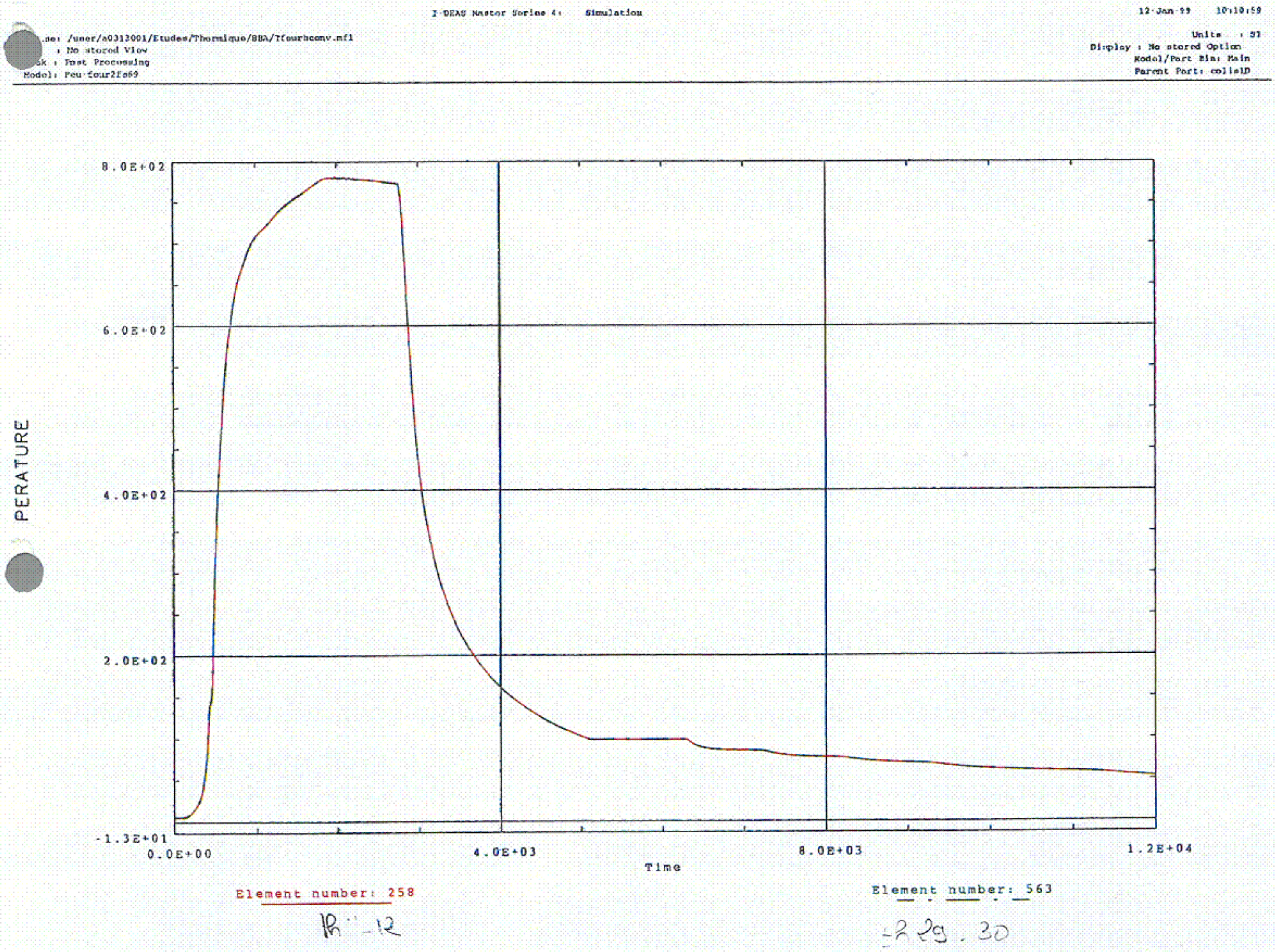


FIGURE 9

FIRE TEST AS PER OVEN TEST CONDITIONS
(IN ORDER TO RECALIBRATE THE THERMAL CHARACTERISTICS)

Evolution over time of temperature of outer surface of shell (e258) and inner surface of shell (e563)

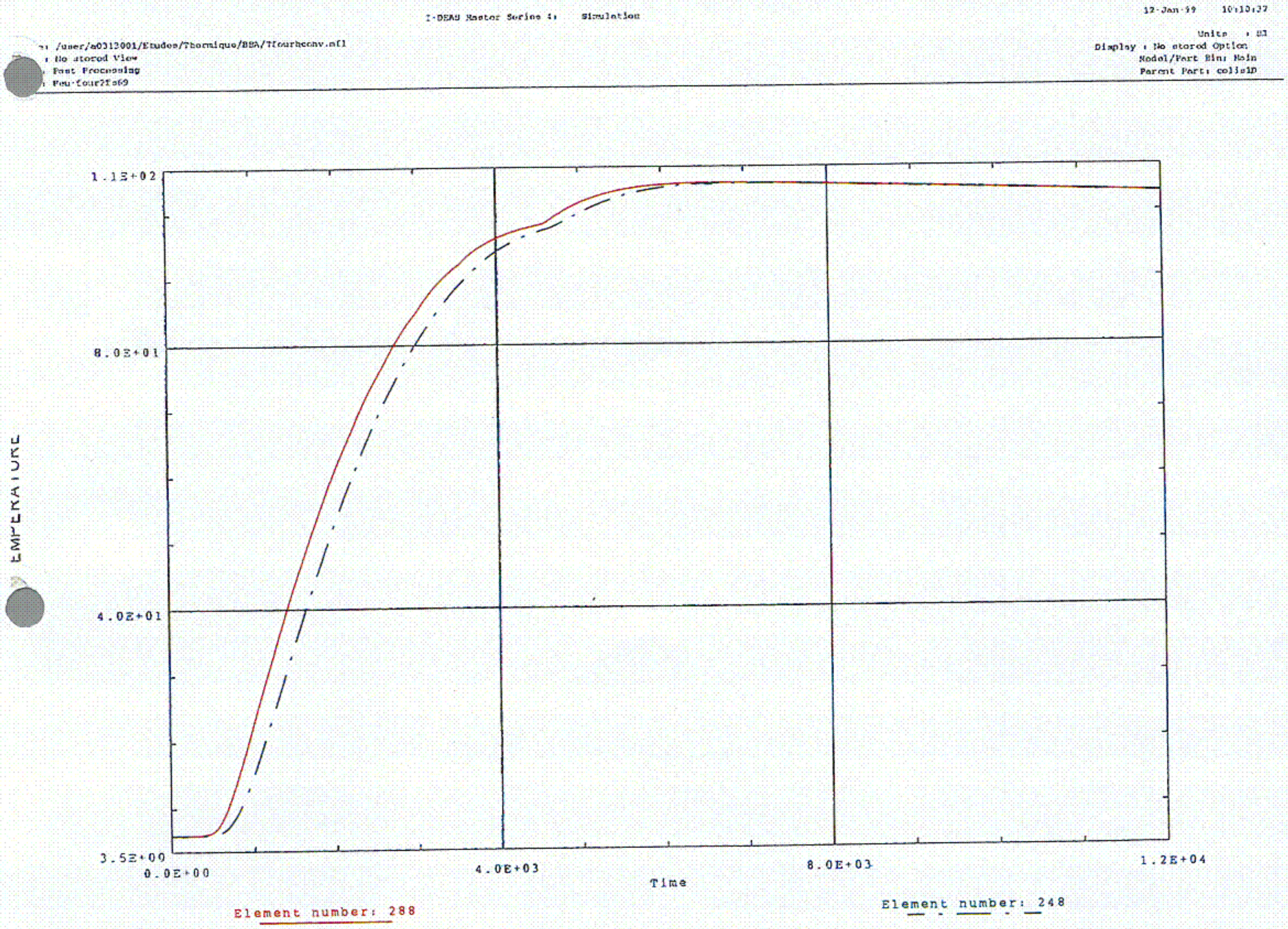


C01

FIGURE 10

FIRE TEST AS PER OVEN TEST CONDITIONS
(IN ORDER TO RECALIBRATE THE THERMAL CHARACTERISTICS)

Evolution over time of temperature in the middle of the resin (e288),
at inner stainless steel tube/flask interface (e248)



Pn 13-16

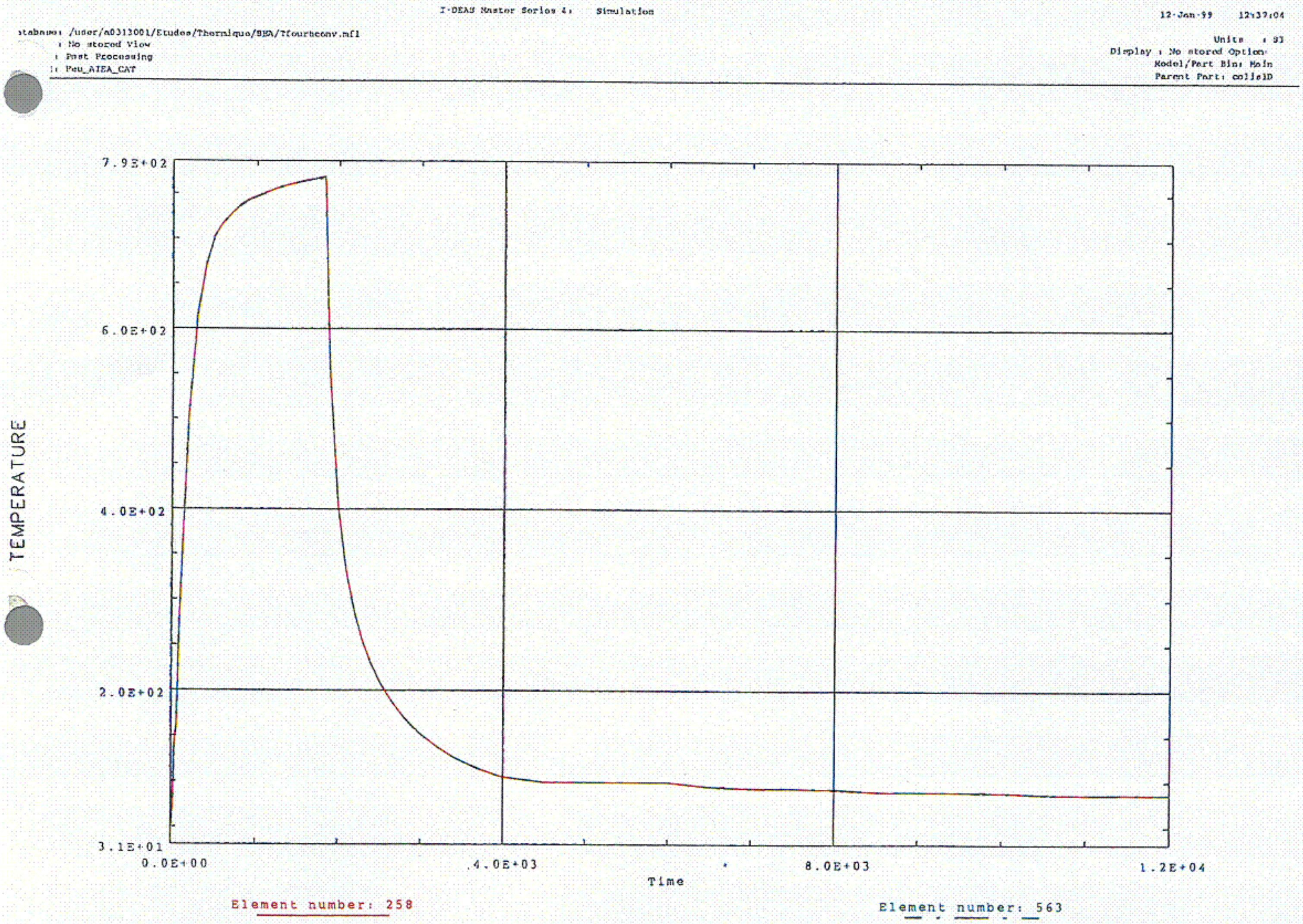
Pn 14-15

C02

FIGURE 11

FIRE TEST AS PER IAEA CONDITIONS

**Evolution over time of temperature of outer surface of shell (e258)
and inner surface of shell (e563)**



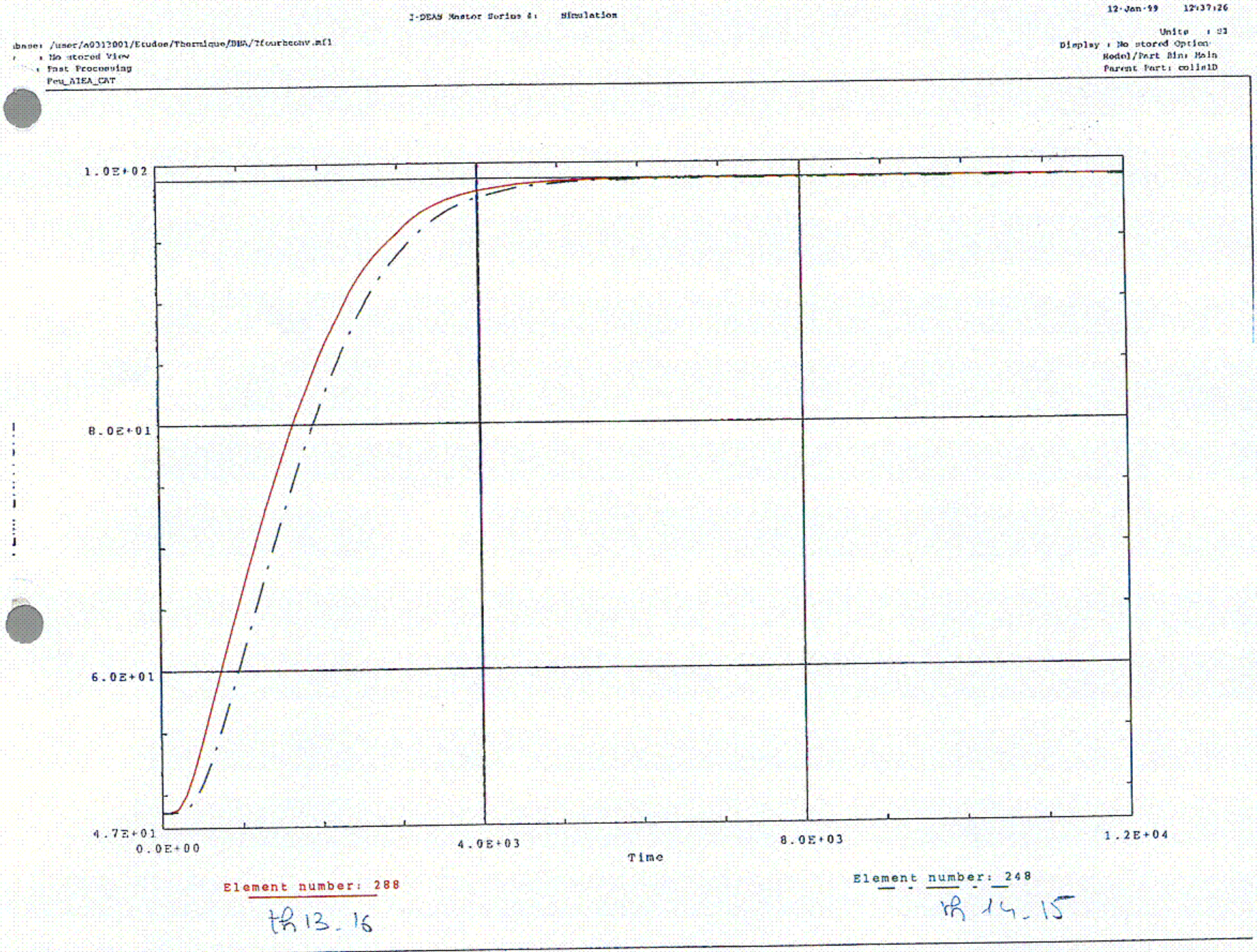
Pr. 12 Pr 29. 30

C03

FIGURE 12

FIRE TEST AS PER IAEA CONDITIONS

Evolution over time of temperature in the middle of the resin (e288), at inner stainless steel tube/flask interface (e248)

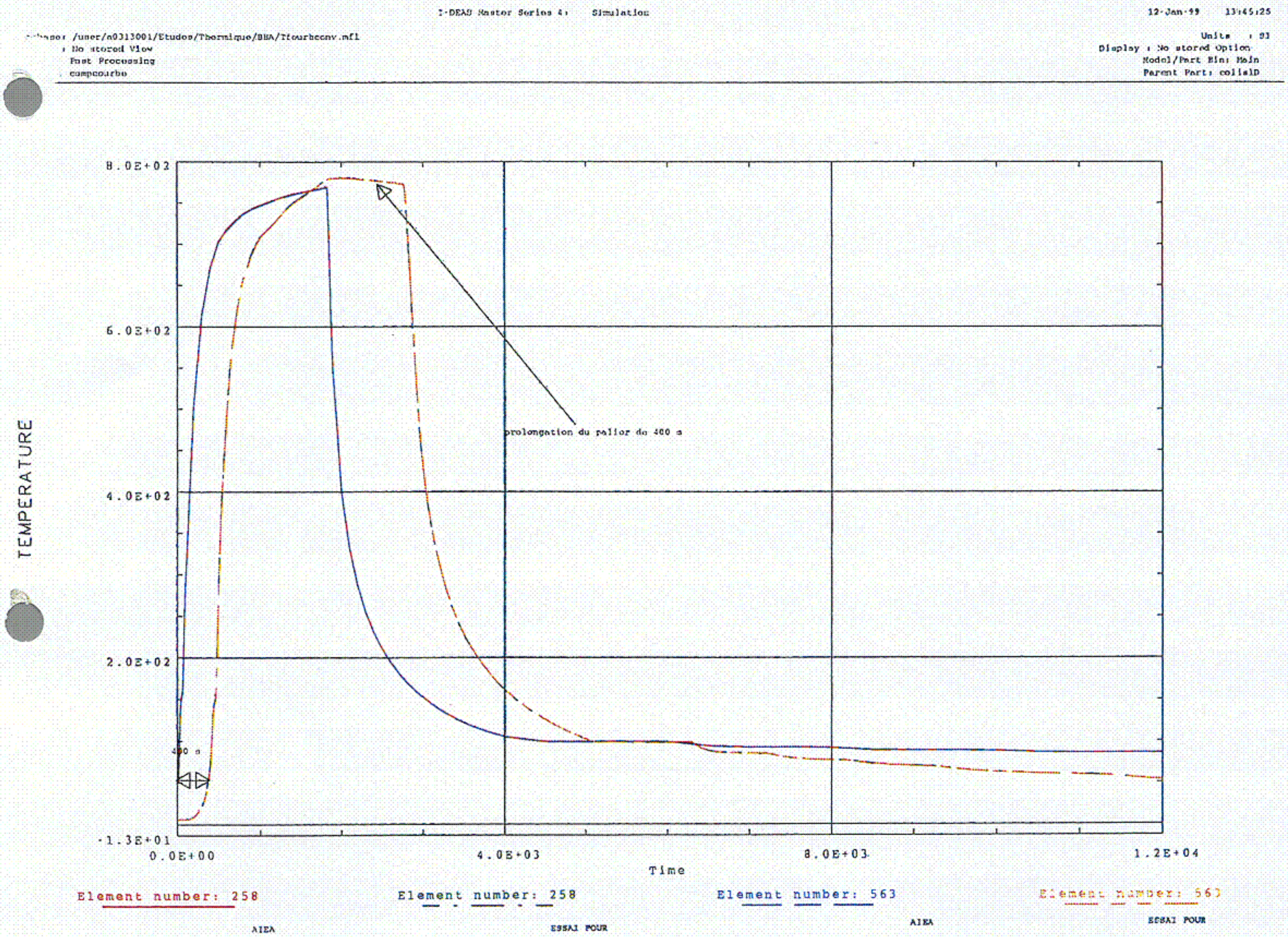


C04

FIGURE 13

COMPARISON OF OVEN TEST CONDITIONS WITH FIRE TEST

Evolution over time of temperature of outer surface of shell (e258) and at outer stainless steel tube/phenolic foam interface (e271)

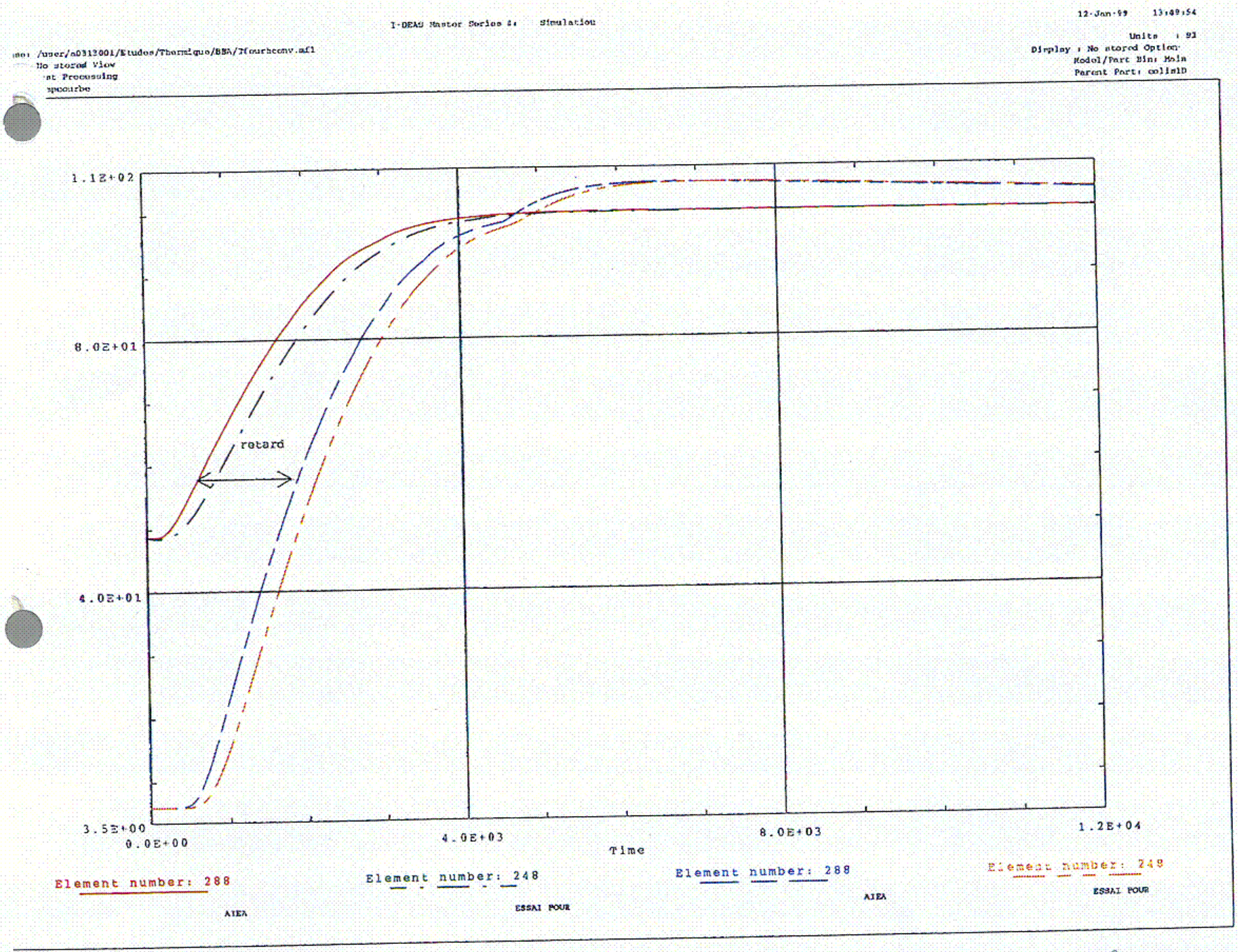


C05

FIGURE 14

COMPARISON OF OVEN TEST CONDITIONS WITH FIRE TEST

Evolution over time of temperature in middle of resin (e288) at inner stainless steel tube/flask interface (e248)



C06

APPENDIX 1 (page 1/1)

CALCULATION OF EQUIVALENT PROPERTIES OF PHENOLIC FOAM WITH 20 % WATER

Calculation of equivalent ρCp for 20 % water

The phenolic foam consists of 20% water.
I.e. $m_{water} = 0.2 \times m_t$
$m_{foam} = 0.8 \times m_t$

Calculation of density is as follows:

$$(\rho V)_{equivalent} = (\rho V)_{eau} + (\rho V)_{mousse}$$

Calculation of specific heat is as follows:

$$(\rho VC_p)_{equivalent} = (\rho VC_p)_{eau} + (\rho VC_p)_{mousse}$$

At 100°C water has the following properties <6> $Cp_{water} = 4216\ J / kg\ K$
$\rho_{water} = 960.6\ kg / m^3$

$(\rho\ V)_{water} = 0.2 \times (\rho\ V)_{total}$
$(\rho\ V)_{foam} = 0.8 \times (\rho\ V)_{total}$
$V_{total} = V_{water} + V_{foam}$

$$V_{total} = 0{,}2 \times \frac{\rho_{total}}{\rho_{eau}} V_{total} + 0{,}8 \times \frac{\rho_{total}}{\rho_{mousse}} V_{total}$$

$$\frac{1}{\rho_{total}} = \frac{0{,}2}{\rho_{eau}} + \frac{0{,}8}{\rho_{mousse}} = \frac{0{,}2}{960{,}6} + \frac{0{,}8}{300}$$

$$\rho_{total} = 374{,}84\ kg/m^3$$

and

$$C_{P\,equivalent} = 0{,}2 \times 4216 + 0{,}8 \times 2000$$

$$C_{P\,equivalent} = 2443{,}2\ kg / m^3$$

Calculation of the latent heat of vaporization:

Latent heat of water at 100 °C is $L = 539\ cal/g = 2.253 \times 10^6\ J/kg$

At 100°C, the amount of heat needed for vaporization of the water is:

$Q_{absorbed} = \rho_{water} L_{water} V_{water}$

$Q_{absorbed} / m_{total} = 0.2\ L_{water} = 0.2 \times 2.253 \times 10^6 = 4.5 \times 10^5\ J/kg$

APPENDIX 2 (page 1/1)

SPECIFIC HEAT AS A FUNCTION OF TEMPERATURE IN THE FS69 RESIN

Temperature (°C)	20	40	60	80
Specific heat (J/kg K)	1173	1229	1285	1341
Temperature (°C)	100	120	140	160
Specific heat (J/kg K)	1396.5	1452	1508	1564

APPENDIX 3 (page 1/2)

DEVELOPMENT OF A FORTRAN PROGRAM TO SIMULATE IRREVERSIBILITY OF CONDUCTIVITY OF PHENOLIC FOAM

In order to simulate vaporization of the water in the phenolic foam from 100 °C, a FORTRAN sub-routine, added to TMG, was necessary.

The algorithm is as follows:

If the temperature of the phenolic foam does not exceed 100 °C, the value of the thermal conductivity is 0.9 W/m.K and remains equal to 0.9 W/m.K.

If the temperature of the phenolic foam resin is 100°C, the value of thermal conductivity is 0.27 W/m.K and remains equal to 0.27 W/m.K during cooling.

The FORTRAN sub-routine is presented on the following page.

ANNEXE 3 (page 2/2)

```
      SUBROUTINE USER1(GG,T,C,Q,QD,R,TIME,DT,IT,
     +KODE,NOCON,MAXNO,ICONV,DTP,TF)
      DIMENSION GG(1),QD(1),T(1),C(1),Q(1),R(1),ICONV(1)
C
C Dimensionner les vecteurs si plus de conductance
C
      DIMENSION TSAVE(8000),CONDI(8000),ICONDNO(4,8000)
      DIMENSION TMOY(8000)
      LOGICAL INIT
      SAVE
      DATA KINIT/0/
C
C    KODE=1 Intervention  dans le code avant le calcul des con
C
      IF (KODE.EQ.1) THEN
C
C  Boucle d'initialisation
C
      IF (KINIT.EQ.0) THEN
      KINIT=1
C
C   Appel du groupe MOUSSE(de ses conductances,
C   des elements associes aux conductances du groupe MOUSSE,
C   et NC du nombre total de conductances.
C
      CALL TCNAME('MOUSSE','MOUSSE',ICONDNO,NC)
      DO 1 I=1,NC
C
C  initialisation du groupe TSAVE
C
      TSAVE(I)=0
C
C  initialisation des valeurs valeurs des resistances
C
      CONDI(I)=R(ICONDNO(1,I))
1     END DO
      END IF

      DO 2 I=1,NC
C
C calcul de la moyenne en temperature pour deux elements relie
C
         TMOY(I)=(T(ICONDNO(2,I))+T(ICONDNO(3,I)))*0.5
       IF ((TMOY(I).GT.100).OR.(TSAVE(I).GT.100)) THEN
C
C  modification de la valeur de la resistance
C
          R(ICONDNO(1,I))=(CONDI(I)*0.9*8.33)
           IF (TMOY(I).GT.100) THEN
C
C  sauvegarde de la temperature moyenne
C
             TSAVE(I)=TMOY(I)
           END IF
       END IF
2      END DO
       END IF
      RETURN
     END
```

THERMAL TEST REPORT

CONTENTS

REVISION SHEET

Revision	Date	MODIFICATIONS	Author / Checker
0	29/10/99	First issue of document	PML / FPL

1. SUBJECT

The subject of this document is to present the results of the thermal test in transport accident conditions, performed simultaneously on two specimens (called P11 and P15) representative of the final design of the TN-UO_2 package model and which had first undergone the regulation drop tests according to <1> and <2>.

This test was performed in accordance with the thermal test specification <3> and the general qualification test program <4>.

The dimensional measurements of final deformation of the specimens were taken after the thermal test (see <5>).

Photos were taken of the specimens at various stages in the test and extracts are given below. The originals are kept for examination if necessary in the "Documentation" room of the Interfaces and Tests department of the Development and Support Division.

2. GENERAL INFORMATION

2.1. Participants from FBFC - Romans

T. TAILLANDIER Technical Management

2.2. Participants from IPSN

F. CHALON SSTR

2.3. Participants from EIFFEL company

S. SCHMITT

M. CLERC

2.4. Participants from TRANSNUCLEAIRE

D. MENGUY	DCU/SI/GE
D. LEGRAND	DDS/SI
N. OUKAKI	DDS/SI
D. VUILLERMOZ	DDS/SI
P. MALALEL	DAC/GIN

3. REFERENCES

<1> Regulations for the Safe Transport of Radioactive Materials – IAEA – Safety Series n°6 – (1985 Edition, reviewed in 1990).

<2> Regulations for the Safe Transport of Radioactive Materials – IAEA – (1996 edition)

<3> 10313-P-01 rév.3 : Qualification thermal test.

<4> 10313-P-3 rev.1 : Drop tests program in accidental conditions of transport

<5> 10313-Z-1-7 rev.0 : Post-test assessment report P1+P2/P11+P15.

<6> Drawing TRANSNUCLEAIRE TN-UO_2 ref. 10313-05 ind.A.

<7> Drawing TRANSNUCLEAIRE TN-UO_2 ref. 10313-05 ind.B.

4. DEFINITION OF TEST SPECIMENS

The equipment tested comprised two full-scale prototypes of the TN-UO_2 packaging, each containing a flask filled with pure powdered iron with the same apparent density as UO_2 powder, and which had first undergone the regulation drop tests in accordance with <1> and <2> (see chapter 1 and appendix 1-6 of this safety file):

- specimen P11: sequence including the 9m plate drop obliquely onto the packaging upper corner, with maximum content weight (38 kg).
- specimen P15: sequence including the 9m plate drop laterally onto the packaging centreline, with minimum content weight(1 kg).

The representativeness of these prototypes, for which the production drawings are given in <6> for P11, and <7> for 15 respectively, is justified in the prototypes descriptive note (appendix 1-5 of this safety file).

5. TEST RESOURCES

The tests (oven calibration test presented in appendix 2-2-1 of this safety file, and qualification test) took place in the CFI oven on the EIFFEL Company's LAUTERBOURG site.

The test set-up in the oven and the measurement recording system (thermocouples + recorder) are described in the report appended.

6. TEST PROCEDURE

The tests were performed on 10/12/98 (calibration on prototype P10), 17/12/98 (adjustment to IAEA regulation fire conditions on prototype P9) and 09/09/99 for final qualification (prototypes P11/P15).

For information (see paragraph 4.2.4 of appendix 2-1 of this safety file), the profile determined for qualification comprises:

- rise from ambient temperature to 800 °C in 9 min.
- hold period: 800^{+30}_{-0} °C / duration 33 min.
- removal of specimen from oven at the end of the hold period.

24 calibrated thermocouples were used to monitor ambient temperature changes and the various parts of the package for the duration of the test (see locations in the report appended and on figure 1):

- 2 thermocouples inside the cavity, in contact with the flask: TC 15/16 for specimen P11 inoperative after being dropped, and TC 18/23 for specimen P15 (see curves in figure 5);
- 2 thermocouples inside the layer of neutron-poisoning resin: TC 13/14 for specimen P11, and TC 27/28 for specimen P15(see curves in figure 4);
- 1 thermocouple on the overpack outer skin: TC 32 for specimen P11, and TC 17 for specimen P15 (see curves in figure 3);
- 14 ambient thermocouples measuring the thermal environment of the packagings: TC 1/2/7/9/10/11/31 for specimen P11, and TC 3/4/5/6/8/12/29 for specimen P15 (see curves in figure 2).

Measurements and checks:

- Ambient and specimen temperature curves.
- Check on condition of lid to body join after the test.
- Check that flask is retained inside the neutron-poisoning shield.
- Check that there is no release of content.
- Dimensional measurement after opening of specimen (thickness of phenolic foam degraded, cavity geometry).

Qualification test chronology:

TIME (on clock)	OPERATION
8h00 to 11h00	Oven preheating and dummy test of door opening and hearth extraction/insertion for adjustment of the control conditions
11h45 to 12h00	Oven temperature rise to 1000°C
12:00:30	Open oven door
12:01:00	Position frame + specimens in front of oven: T0 beginning of thermal attack (radiant)
12:03:00	Place frame + specimens on hearth; electrical problem with hearth retraction motor (photos n° 5 and 6)
12:05:30	End of hearth retraction into oven
12:08:00	Close oven door (photo n° 7)
12:11:40	Beginning of 800°C hold period
12:44:40	End of 800°C hold period
12:46:00	Extract hearth from oven
12:50:00	Close oven door

The total duration of the thermal test from time T0 is thus 45 min.

The total duration of the thermal hold period at 800 $^{+30}_{-0}$ °C is 33 min., as specified.

7. RESULTS

7.1. Temperatures

The temperature curves (related to time) are shown in the enclosed figures.

The maximum thermal evolution of the package during this test gave the following results:

- Average ambient temperature during the 33 min hold period: 808.8°C.
- Maximum temperature of overpack: 734.1°C (P11) / 752.7°C (P15)
- Maximum temperature of neutron-poisoning resin: 109.3°C (P11).
- Maximum temperature of flask: 99.3°C (P15).

7.2. Assessment of specimens after testing

The various steps in dismantling the specimens after testing are illustrated on the enclosed photographs, with the physical findings being detailed in appendix 1-7 of this safety file.

Before dismantling, the temperatures of the various accessible parts of the specimens were about 45°C.

We observed:

- correct working of the fuse pellets which all had the desired effect (melted to release the steam given off by the internal materials);
- slight blackening of the outer plates of the overpack and of the upper plugs (photos n° 8, 17 and 18);
- the packaging lids were still inserted into the body and the general geometry of the specimens had not changed axially since the beginning of the mechanical tests, so we can deduce that the lid + upper plug assembly kept the flask in its initial position inside the well (see photos n° 8, 17 and 18);
- it was necessary to section the overpack below the lid in order to be able to view the cavity;
- the cellular foam seal between the lid and body was carbonised and reduced to ashes (see photos n° 19 and 20);
- the layer of phenolic foam in P11 had suffered very little thermal damage (pyrolysis: see photo n° 9) but was cracked by the crushing tests;
- flask P11 had suffered virtually no deformation and was intact (see photos n°10, 11, 13, 14 et 15); it was possible to extract it from the cavity and check that content containment was guaranteed. There was no presence of powder inside the stainless steel cavity;
- it was possible to extract the internal well completely from its phenolic foam liner and observe that the bottom of the layer of foam had suffered no thermal damage (photo n° 12);
- the internal well of P15 had suffered more deformation but as it was now captive inside the flask it was only possible to observe the upper part of the flask (screw plug + neck) which showed no signs of cracking (photos n° 18 to 20);
- we then overturned the flask + well assembly above a sheet of paper to see what was recovered: only carbonised phenolic foam debris and ashes (carbonised cellular foam seal) were collected (photo n° 25). No release of the content was observed.

8. CONCLUSION

The thermal test on the two specimens was conducted in compliance with the specifications.

The results of the test demonstrated that the packaging design guarantees good thermal protection of the primary container (polythene flask). The lid remained closed and held the flask in place inside the neutron-poisoning shield.

No cracking of the primary container was observed.

The two specimens showed no signs of powder content release after the test.

The hypotheses concerning the package condition in transport accident conditions used in the criticality study presented in chapter 5A, are therefore confirmed.

LIST OF FIGURES

LIST OF TEST PHOTOGRAPHS

Photo	Index	Title	Nbr of pages
1 2	A A	Photo n° 1: Position of specimens P11 + P15 on test frame ditto	1
3 4	A A	Positioning of assembly in front of oven door Raising of assembly in front of oven door	1
5 6	A A	Extraction of oven hearth after pre-heating Placing specimens on hearth in oven	1
7 8	A A	Closure of oven door Opening of specimen P11	1
9 10	A A	Detailed view of foam layer, specimen P11 View of cavity, specimen P11 after extracting upper plug	1
11 12	A A	View of cavity, specimen P11 after extracting upper plug Interior view of foam, specimen P11 after extracting internal well	1
13 14	A A	View of flask, specimen P11 ditto	1
15 16	A A	View of flask, specimen P11 Interior view of well, specimen P11	1
17 18	A A	Opening of specimen P15 ditto after extracting upper plug	1
19 20	A A	View of cavity, specimen P15 after extracting upper plug ditto	1
21 22	A A	Interior view of foam, specimen P15 after extracting internal well View of internal well extracted from specimen P15	1
23 24	A A	Portions of layer of phenolic foam shell ditto	1
25	A	Debris collected after turning over flask + well P15	1
		TOTAL	13

FIGURE 1

POSITION OF PACKAGING INTERNAL THERMOCOUPLES

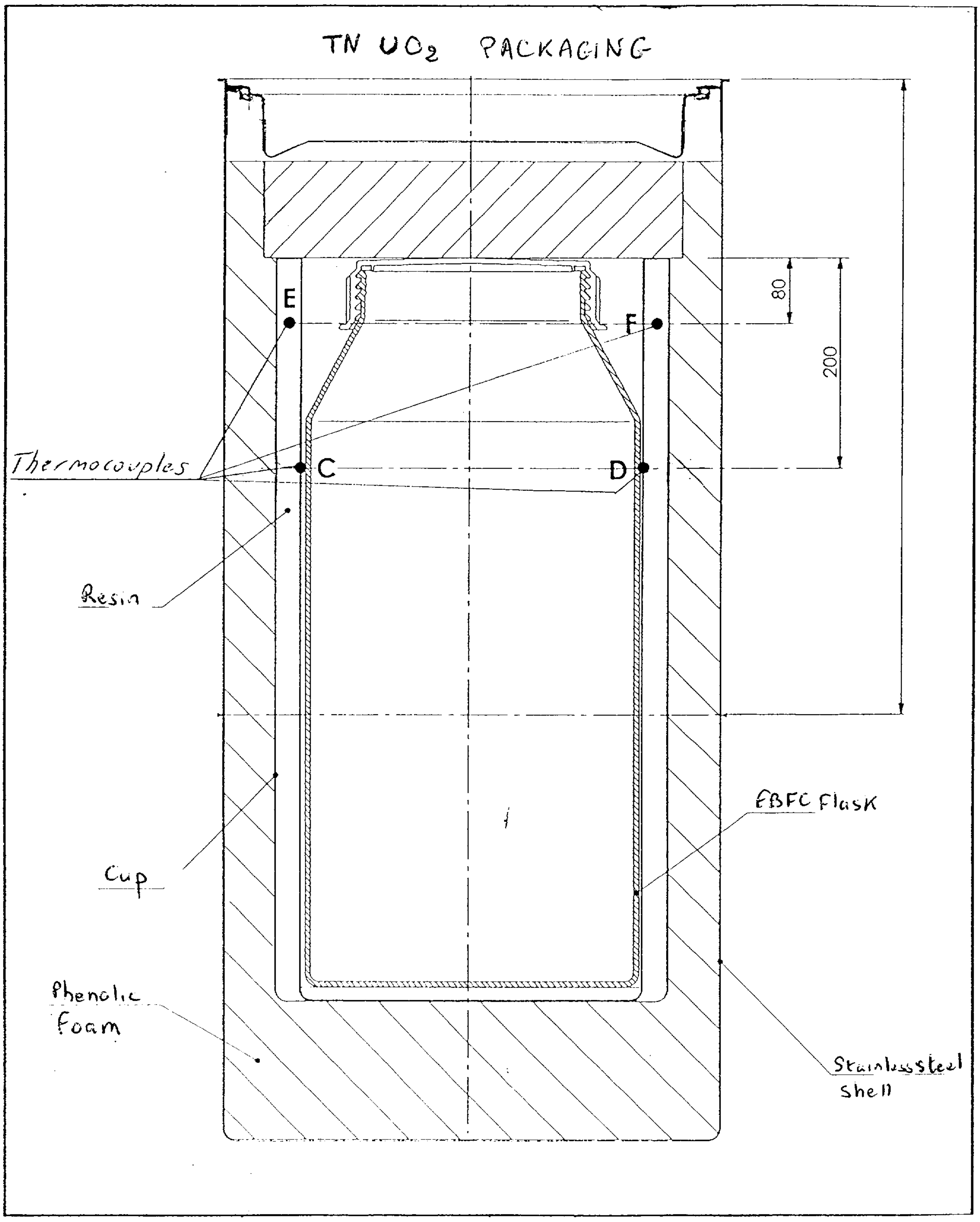
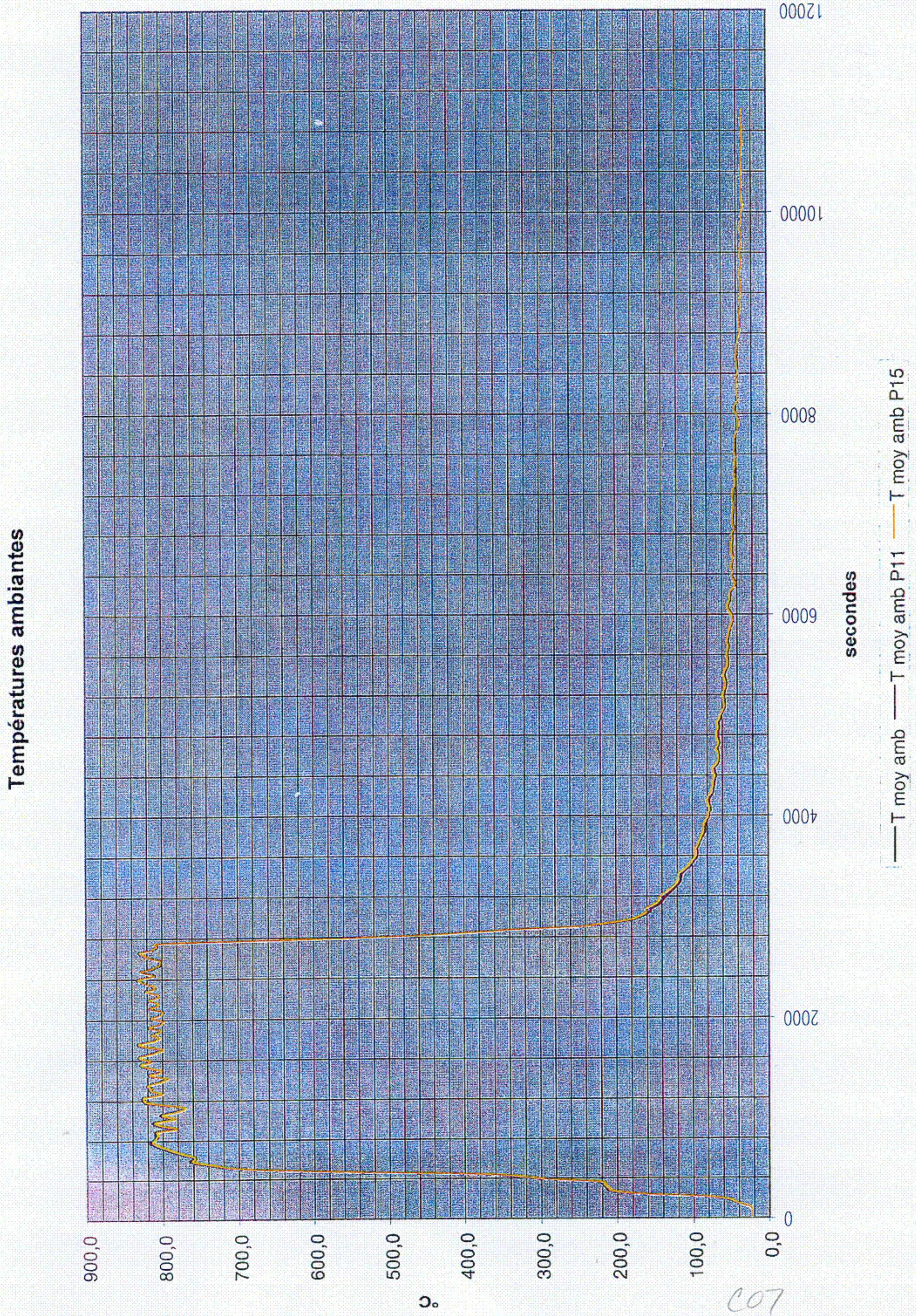


FIGURE 2


Températures ambiantes
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300,0
200,0
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6000
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10000
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secondes
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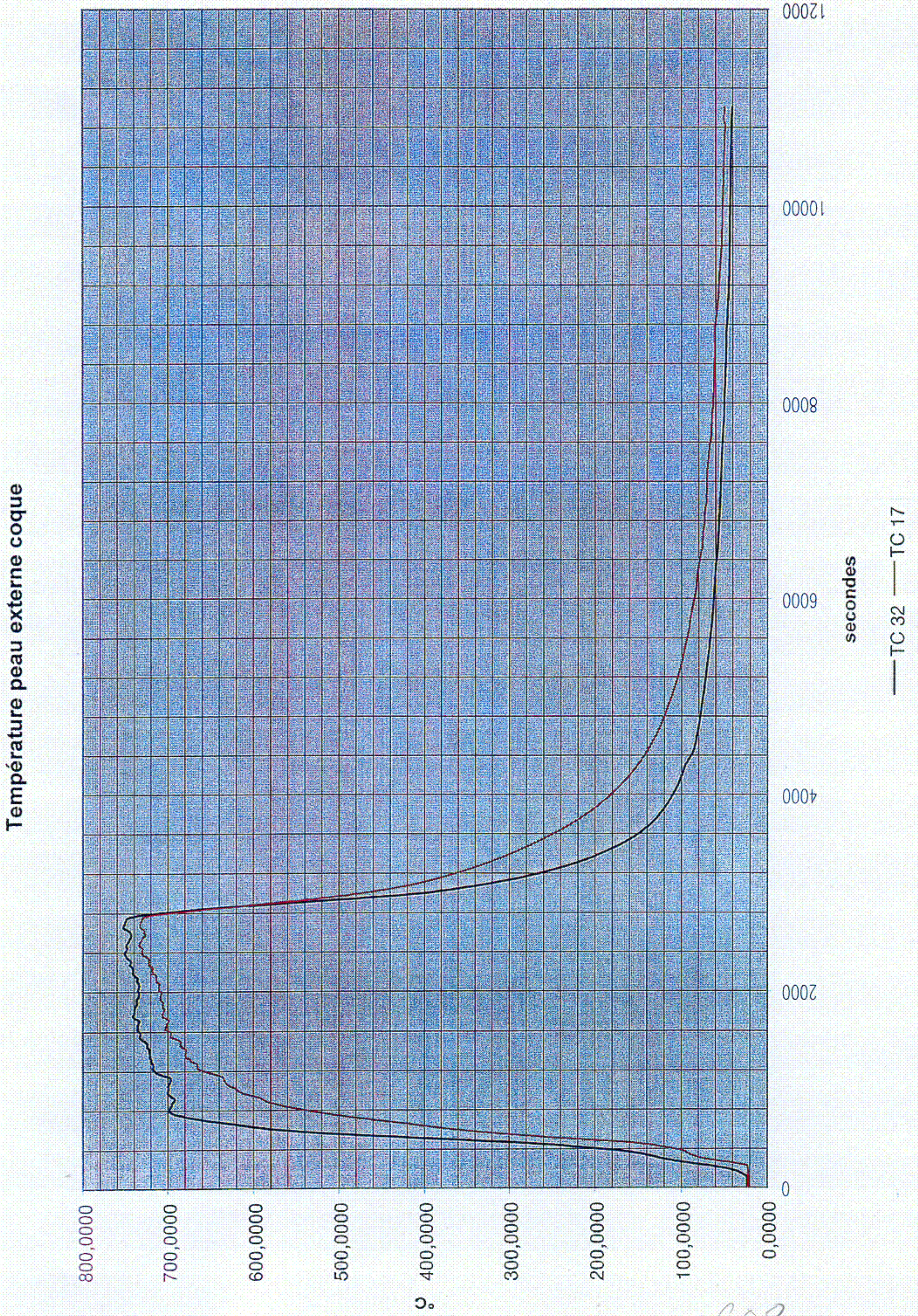
T moy amb P11
T moy amb P15

C07

FIGURE 3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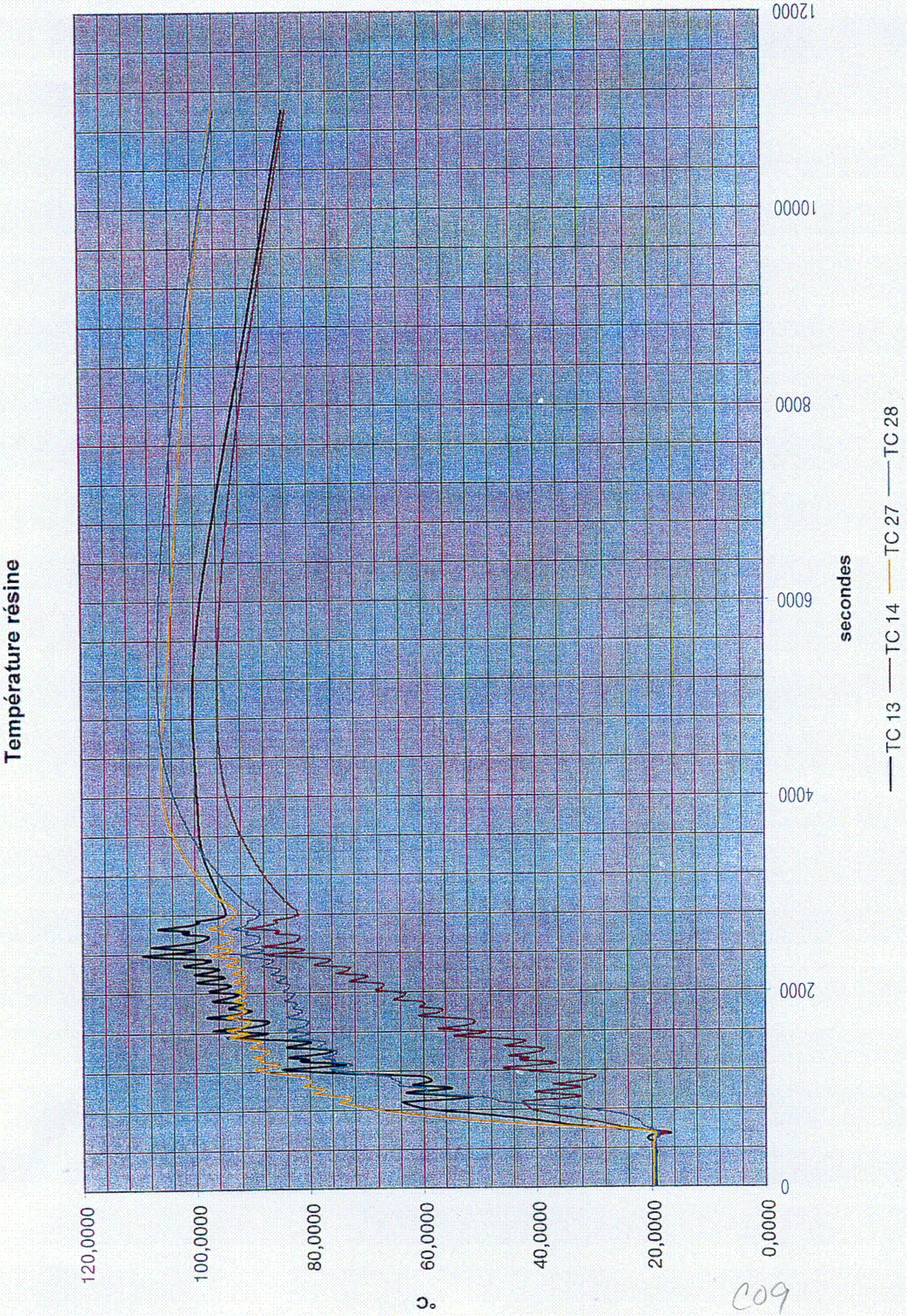
TC 32
TC 17

C08

FIGURE 4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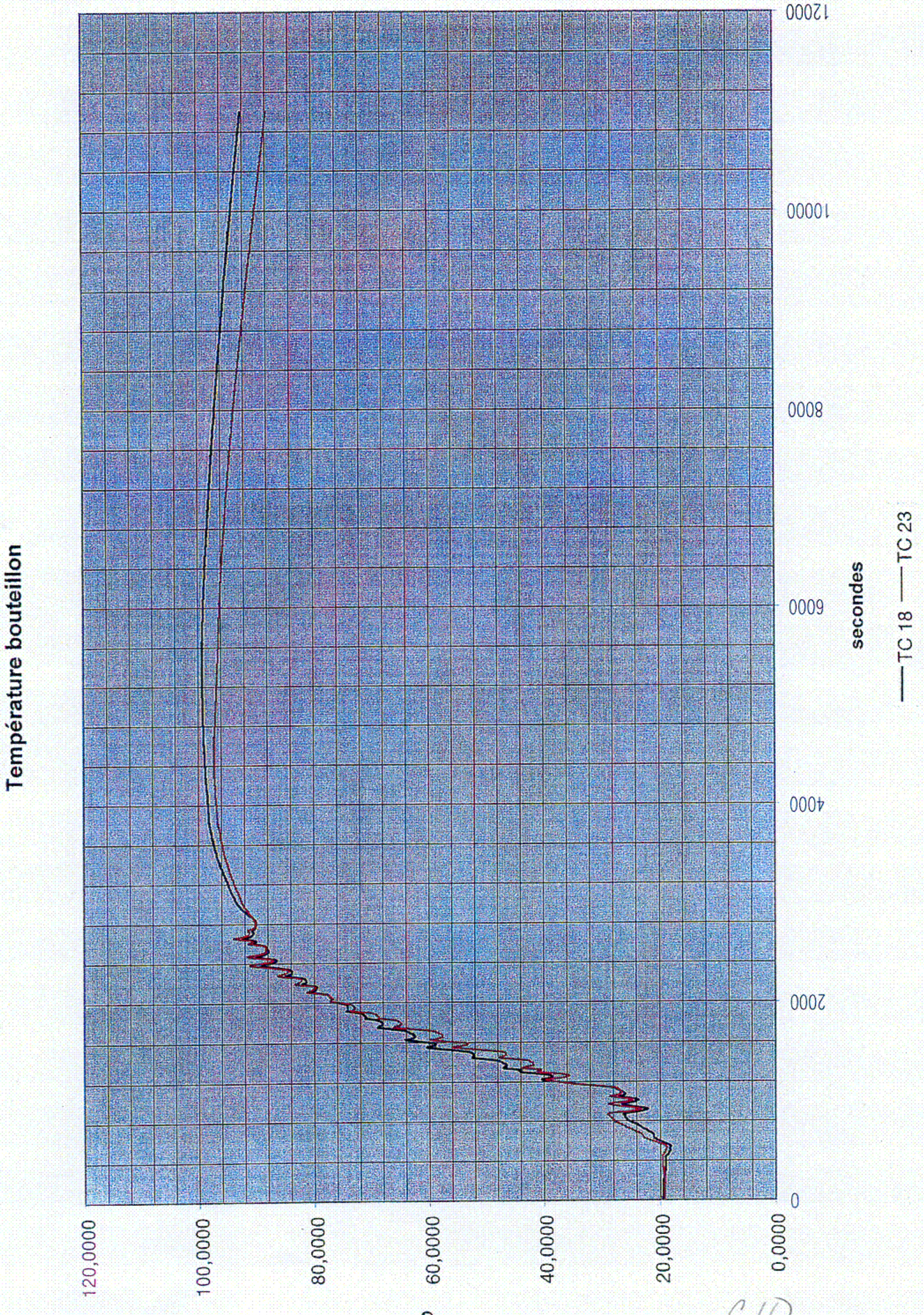
TC 13
TC 14
TC 27
TC 28

C09

FIGURE 5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TC 18
TC 23

C10

Photo n° 1 : Layout of specimens P11 + P15 on test jig

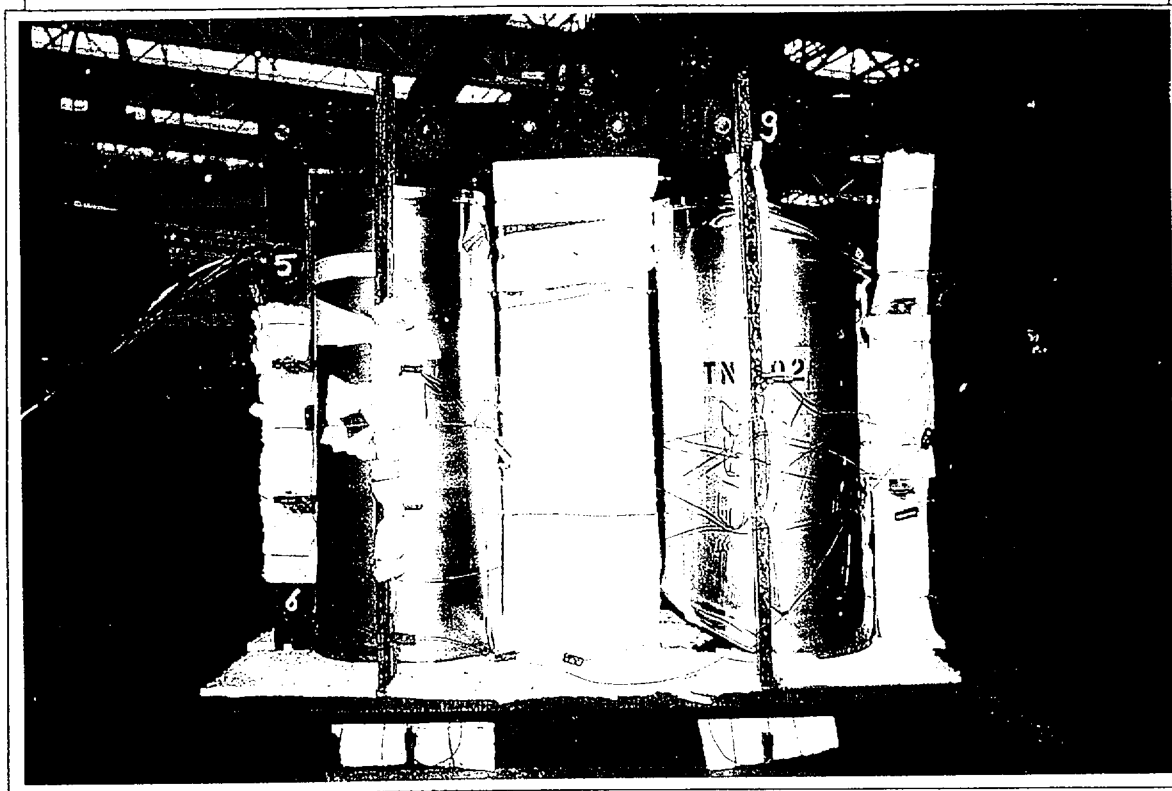

Photo n° 2 : Ditto

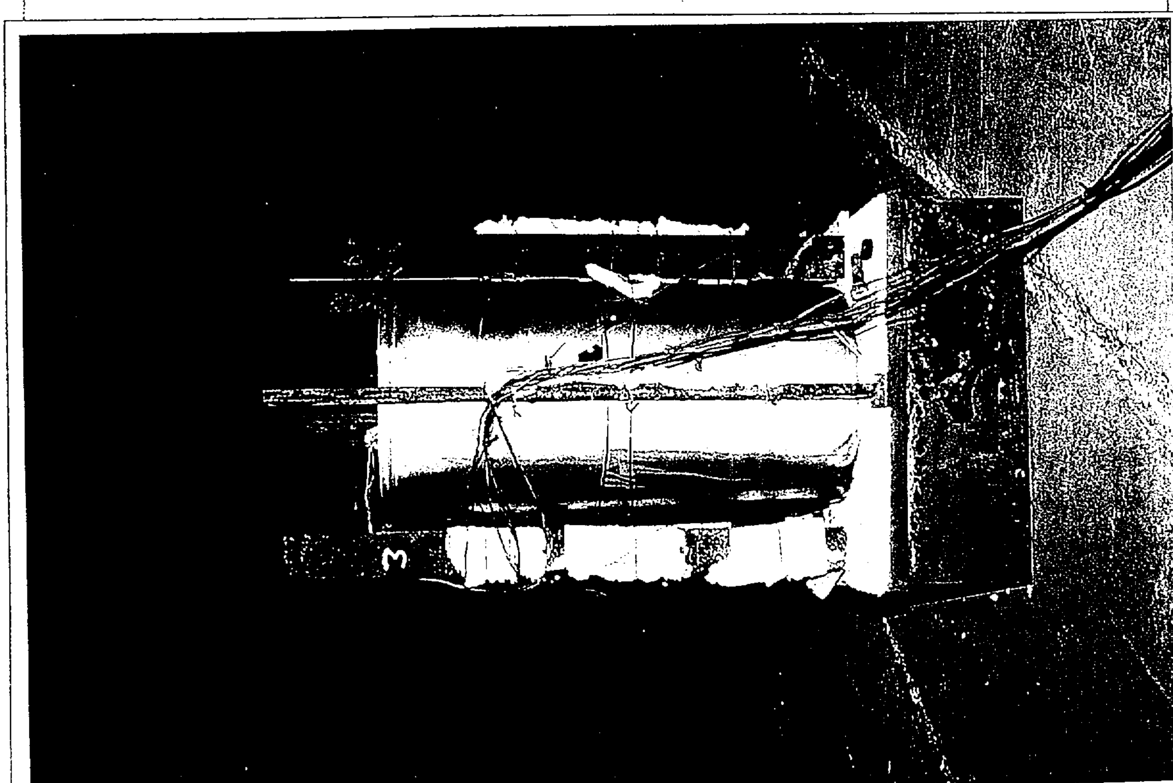

Photo n° 3 : Specimens in front of the oven door

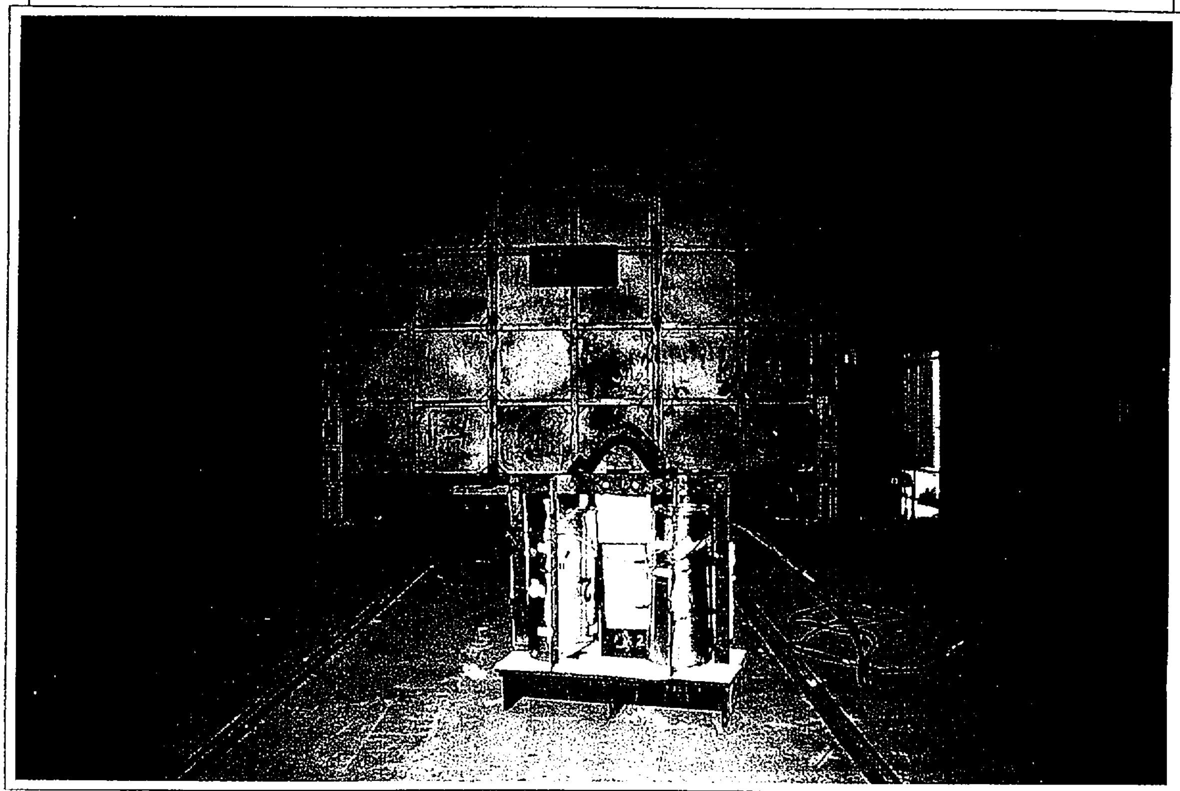

Photo n° 4 : Handling of the jig in front of the oven door

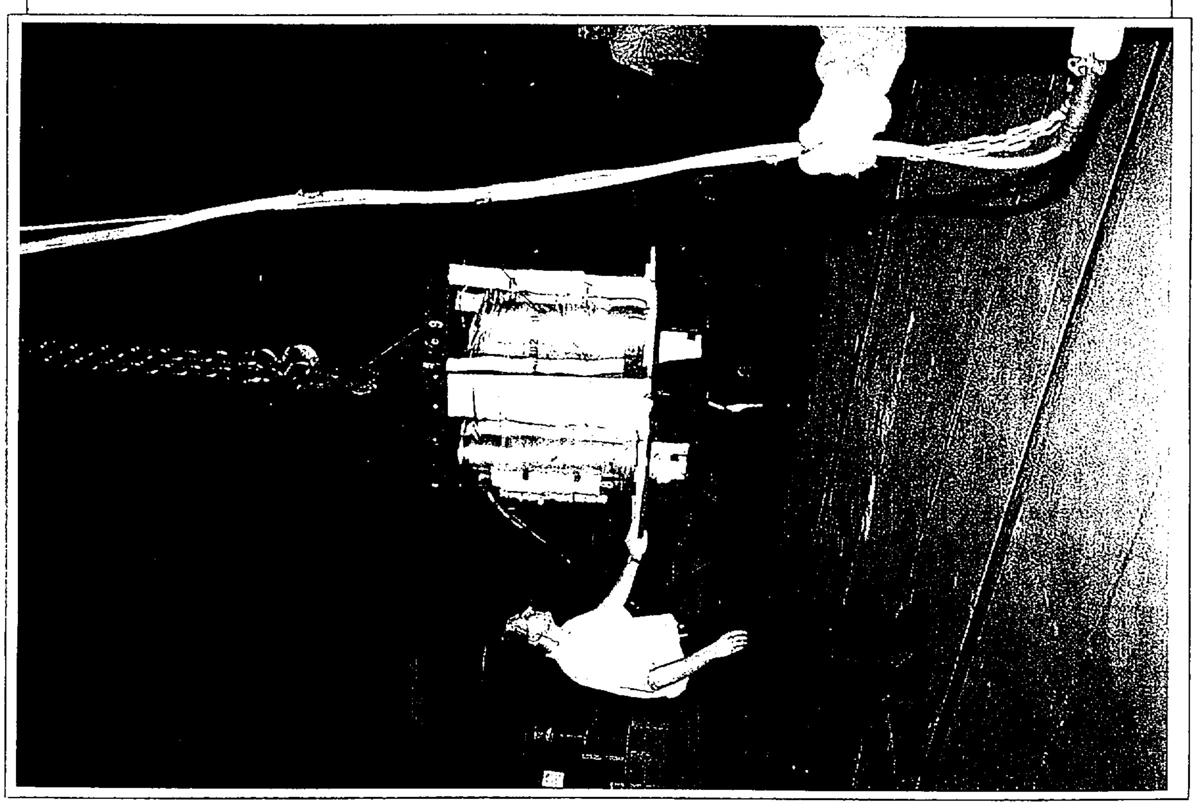

Photo n° 5 : Exit of the oven floor after preheating

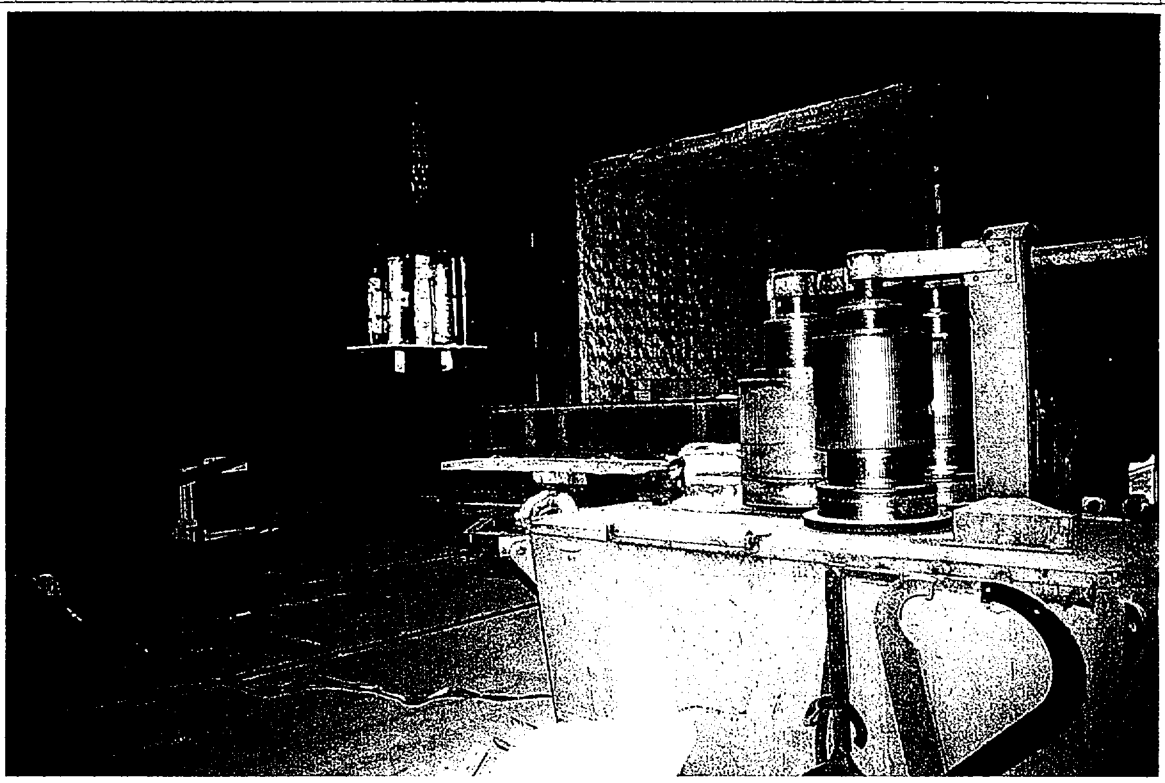

Photo n° 6 : Specimens on the oven floor

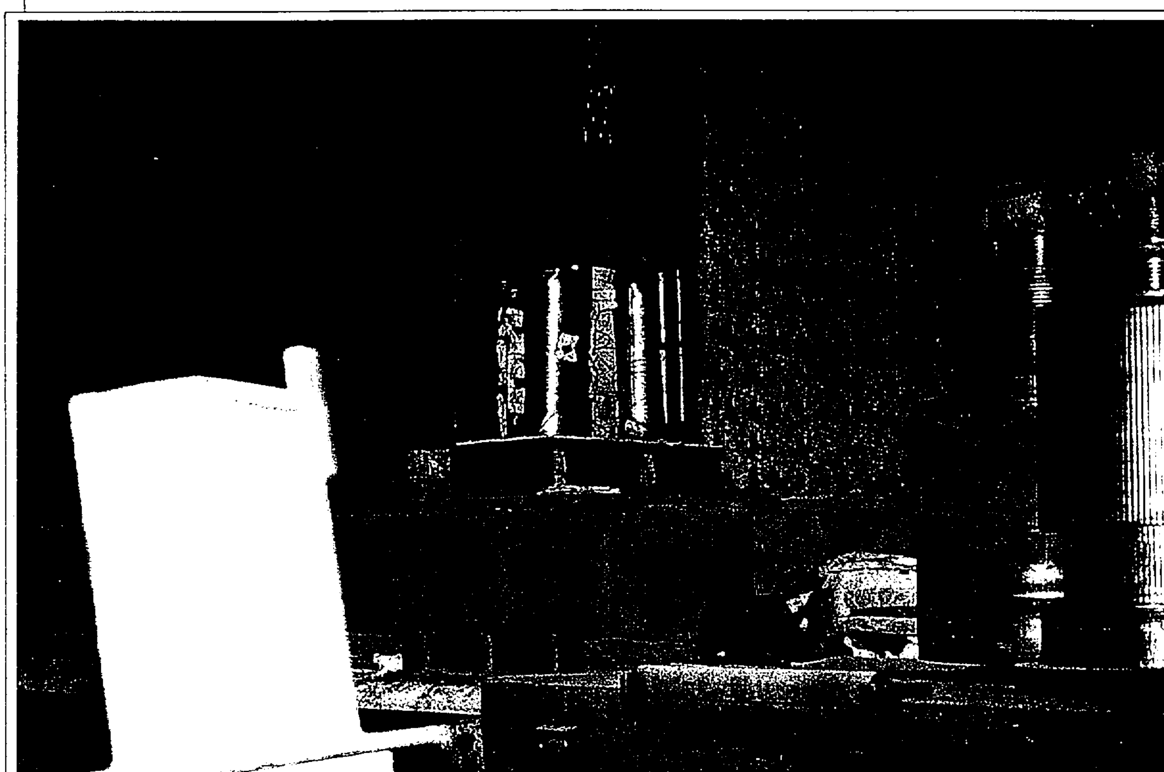

Photo n° 7 : Closing of the oven door

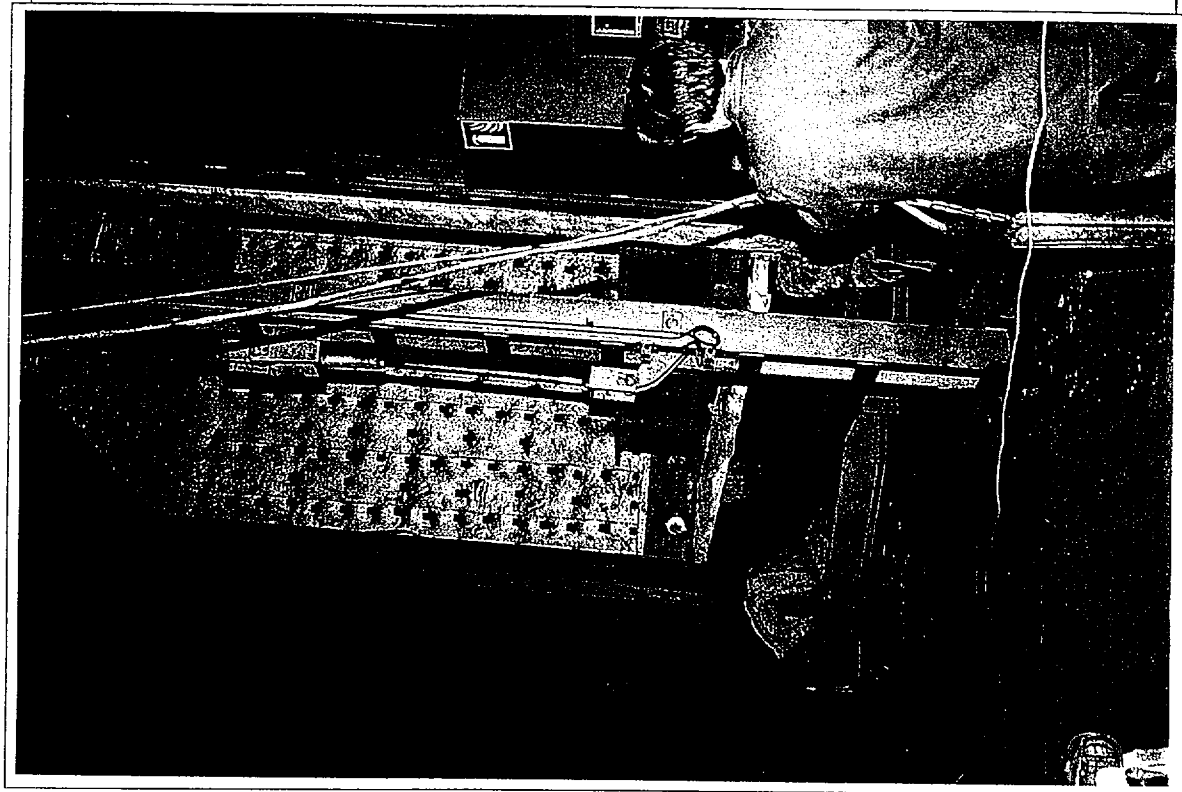

Photo n° 8 : Opening of specimen P11

Photo n° 9 : Detail of the foam **spécimen P11**

Photo n° 10 : Internal shell of specimen P11

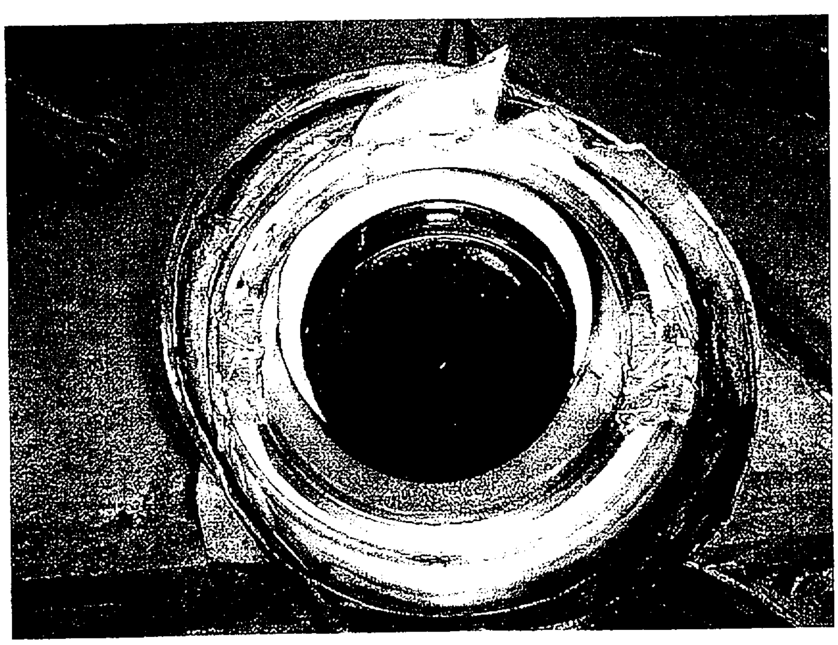

Photo n° 11 : Ditto

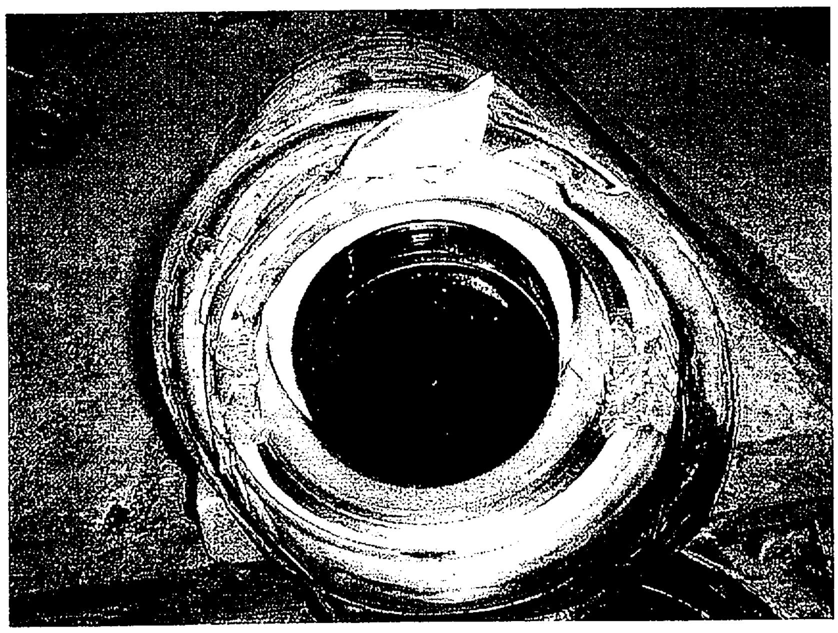

Photo n° 12 : Foam of specimen P11 after innershell removal

Photo n° 13 : FBFC Flask specimen P11

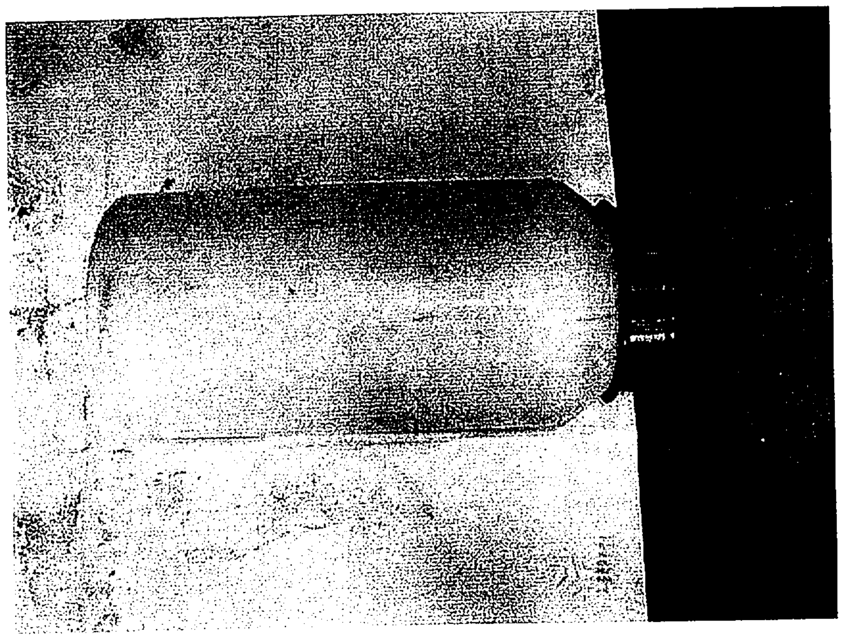

Photo n° 14 : Ditto

Photo n° 15 : FBFC Flask specimen P11

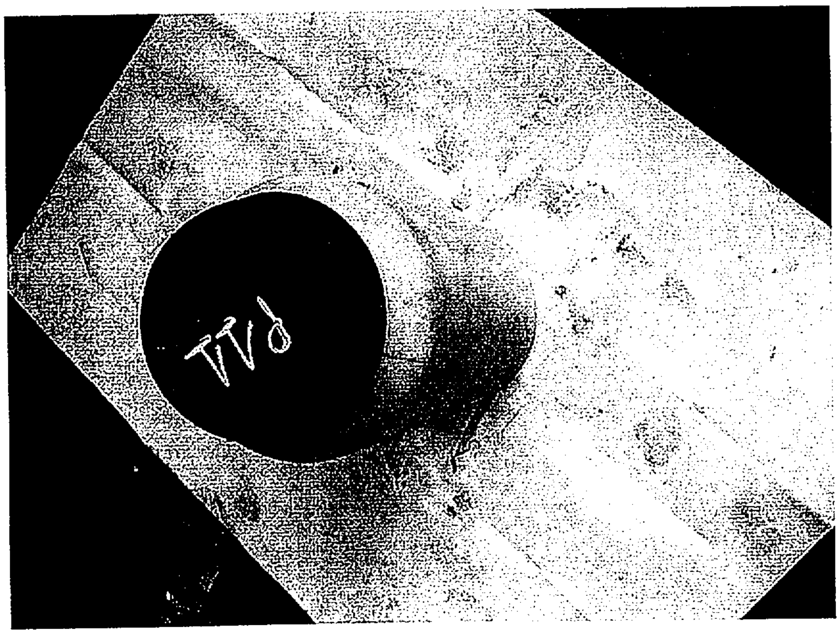

Photo n° 16 : Inner shell specimen P11

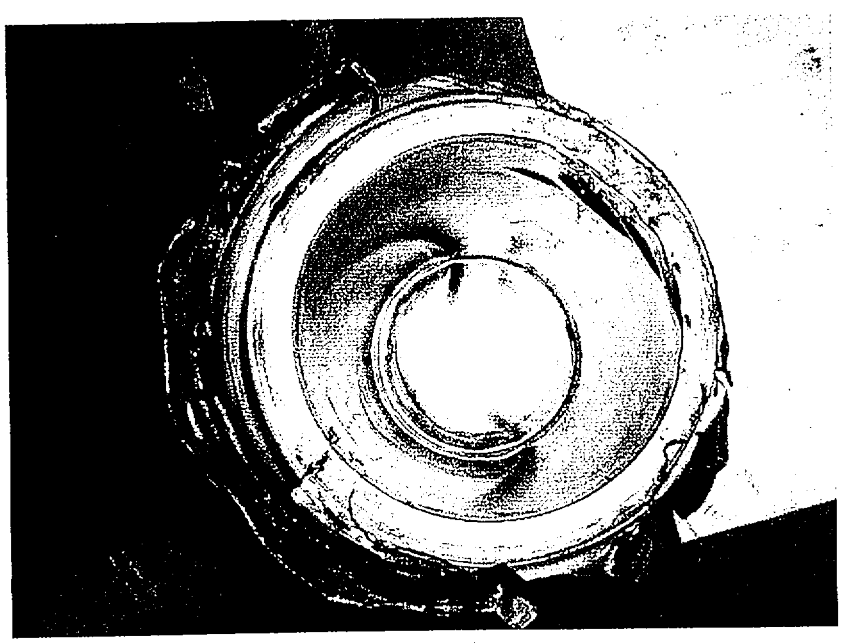

Photo n° 17 : Opening of Specimen P15

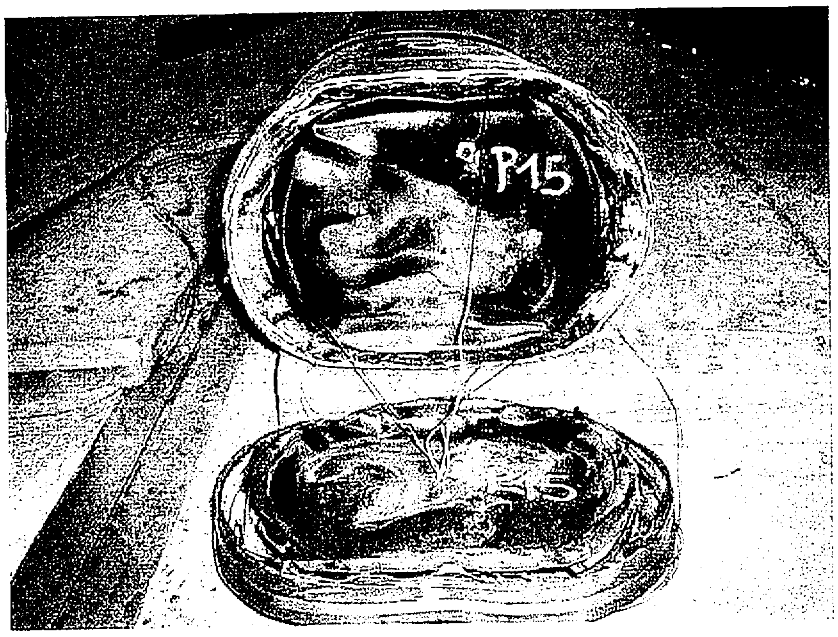

Photo n° 18 : Ditto after plug removal

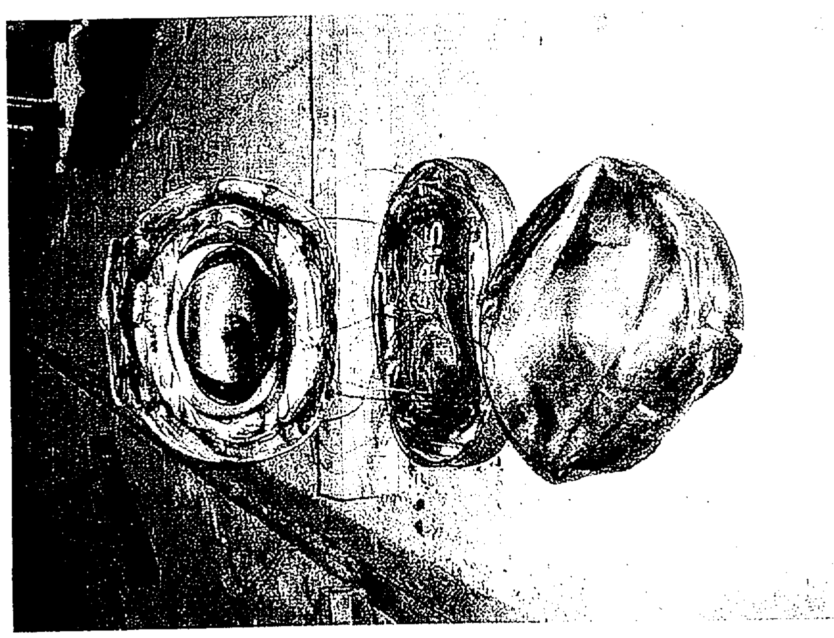

Photo n° 19 : Inner shell of specimen P15

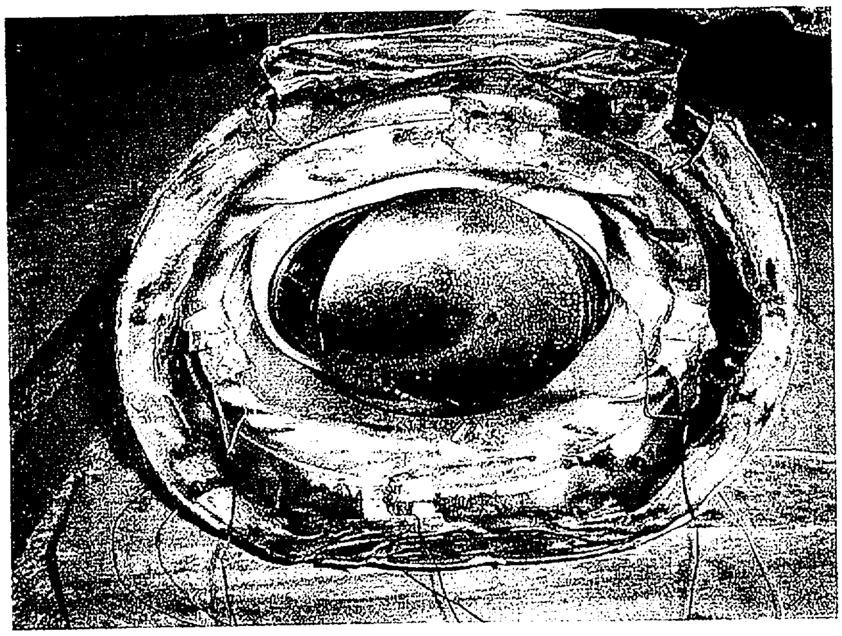

Photo n° 20 : Ditto

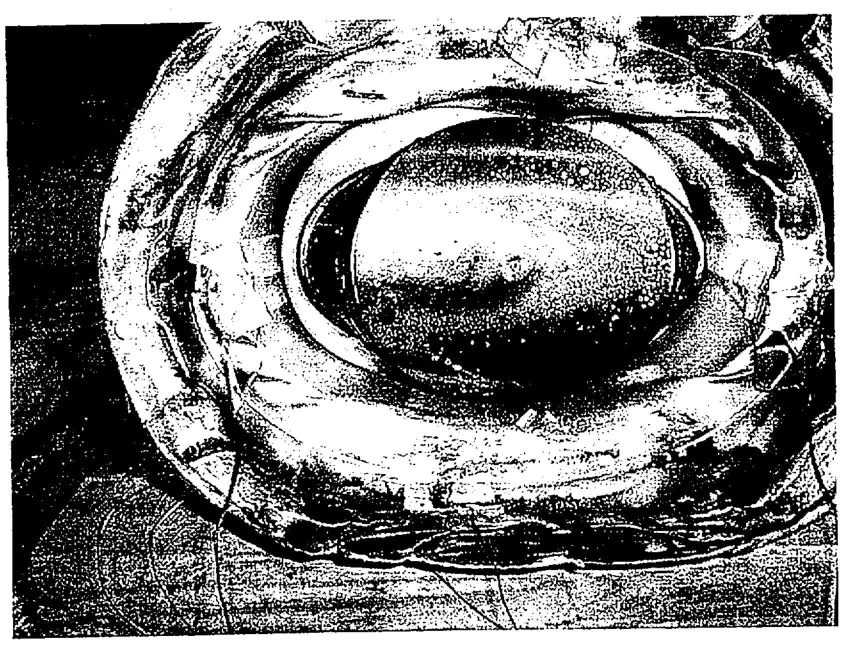

Photo n° 21 : Foam after inner shell removal Specimen P15

Photo n° 22 : Inner shell specimen P15

Photo n° 23 : Pieces of phenolic foam

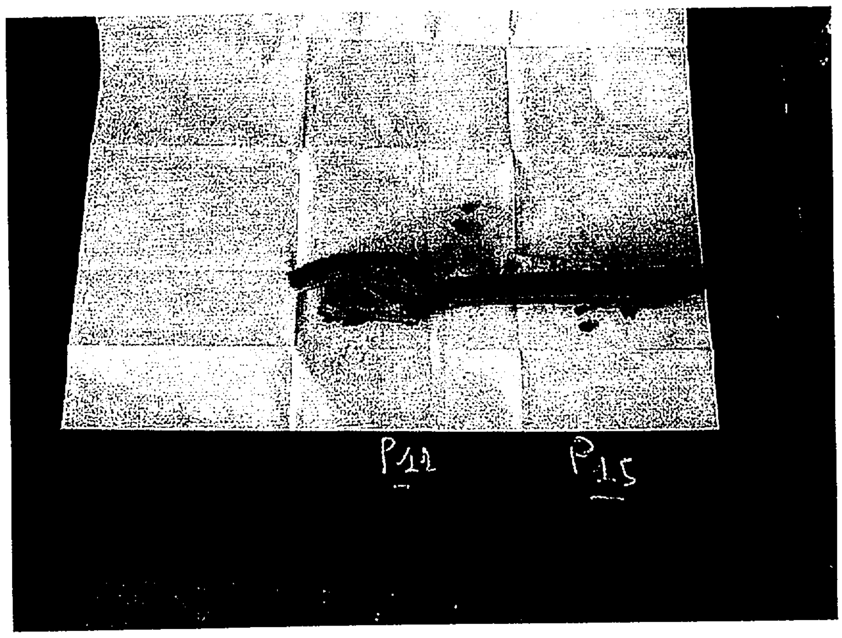

Photo n° 24 : Ditto

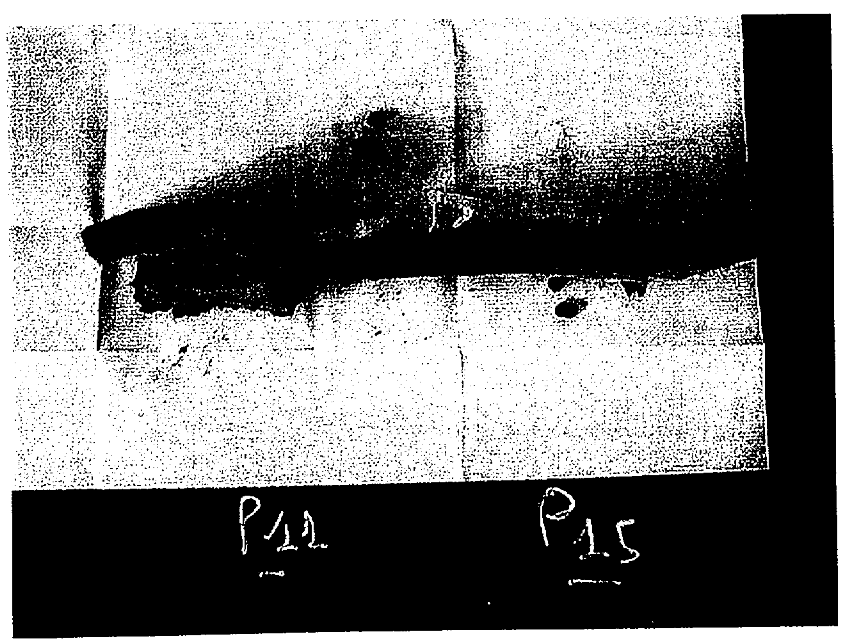

Photo n° 25 : Fragments obtained after returning flask + inner shell Specimen P15