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PACKAGING STRUCTURAL STRENGTH

CONTENTS

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ABSTRACT

This chapter presents an analysis of package conformity in routine, normal and transport accident conditions, demonstrating its mechanical compliance with the regulations applicable to type A packages (covering the requirements applicable to type IP-2) and to packages intended for the transport of fissile materials.

As regards handling and tie-down (routine transports), as the packages are small and contain a small load, they are generally transported grouped in an ISO 20 or 40 foot container.

They can be arranged in groups of 6 per 1200 x 800 pallet and are opened and closed directly on the pallet itself.

The ISO containers are loaded with complete pallets, rather than with separate packages.

No specific lifting device is therefore provided for the loaded package, although it could be handled using a standard drum gripper.

The packages are chocked inside the ISO container by vertical and longitudinal stop bars (there is no chocking across the width owing to the small residual clearance between the pallets and the container walls).

Compliance with the requirements of the tests representative of normal transport conditions is demonstrated in the report of the tests conducted on four full-scale package prototypes (appendix 1-6), which were subjected to 24 drops from 30 cm, 4 drops from 1.20 m and 4 6kg bar drop tests.

The representativeness of these prototypes, for which the "as-built" drawings are presented in appendix 1-4, is justified in the prototype descriptive note (appendix 1-5).

The water sprinkling test was not conducted, as it would have no effect on a watertight stainless steel packaging and moreover the package model criticality study takes account of the hypothesis of water penetrating inside the flask.

The stipulations for non-release of the radioactive content, and no radiation intensity increase of more than 20% over the entire outer surface of the package is thus demonstrated, given that the tests in normal conditions revealed insignificant damage to the packaging (see appendix 1-6).

The radioactive material remains contained during a drop in ambient pressure to 25 kPa as demonstrated by an analytical calculation using conventional material stress and strain formulas.

In the same way as before, compliance with the tests representative of transport accident conditions is demonstrated in the report on the tests conducted on the full-scale prototypes (appendix 1-6), which were subjected to 6 drops of 1m onto a punch bar, 1 free-fall drop of 9m and 5 drops of 9m with 500 kg plates.

The satisfactory immersion test to 15 metres of water is demonstrated by an analytical calculation using the conventional materials stress and strain formulas.

In accordance with the regulations, the package is exempted from the 0.9 m water immersion test, as the package model criticality study takes account of the hypothesis of water penetrating inside the flask.

Following the regulation tests defining the condition of the damaged package (drops and thermal test: see chapter 2), conducted in the configurations most penalising to the packaging, the physical condition of the TN-UO_2 packaging is such that it guarantees the sub-criticality of the package (isolated package and package array) in accordance with the hypotheses and conclusions of the criticality study presented in chapter 5A, and containment of the radioactive material.

1. INTRODUCTION

The purpose of this chapter is to analyse the conformity of the package in normal and transport accident conditions, demonstrating its mechanical compliance with the requirements of regulations <1> and <2> applicable to type A packages (also covering requirements applicable to type IP-2) and to packages intended for the transport of fissile materials. Its purpose is also to check the mechanical strength of the package in routine transport tie-down and handling conditions.

This analysis is chiefly based on tests representative of normal and transport accident conditions, conducted on several full-scale package prototypes.

2. BASIC DATA

The package is described in chapters 0 and 0A.

Materials:

The characteristics of the materials used for the structural elements of the packaging and primary container (flask) are specified in chapters 0 and 0A of this safety file.

The materials contributing to the structural strength of the packaging (X2 Cr Ni 18.09 stainless steel, phenolic foam, type FS 69 or BORA neutron-poisoning resin and high-density polythene) suffer no impairment of mechanical performance within a temperature range of –40°C to +70°C because:

- the X2 Cr Ni 18.09 stainless steel presents no risk of brittle fracture at - 40°C;
- phenolic foam can be used within a temperature range of – 200°C to + 120°C; moreover, a thermal test indicated no alteration to the phenolic foam after being maintained at – 40°C (no cracking): see appendix 1-2;
- the polyester-based FS 69 or BORA resin shows no deterioration at -40°C;
- the high-density polythene can be used within a temperature range of –80°C to +110°C; moreover, a test representative of the maximum deformation of the flask in transport accident conditions was conducted at –40°C with no brittle fracture (see appendix 1-3);
- the flask's EPDM seal is an elastomer whose vitreous transition temperature is lower than – 40 °C and for which the permanent steady state maximum operating temperature is higher than 70 °C.

Regulations compliance criteria:

As the criticality study performed in chapter 5A of this safety file, takes account of the hypothesis of maximum damage to the flask, with penetration of water, no leaktightness inspection criterion is set for use of this flask.

The following package acceptance criteria are therefore adopted:

- in normal transport conditions:
  - no release of radioactive and fissile content,
  - no increase of more than 20% in the radiation intensity over the entire outer surface of the package.
- in transport accident conditions:
  - no release of the radioactive and fissile content,
  - the isolated package and package array is kept sub-critical.

3. STRENGTH OF TIE-DOWN AND HANDLING DEVICES

The purpose of this paragraph is to analyse the mechanical strength of the TN-UO_2 packaging's tie-down and handling devices, when the package is placed in routine transport and handling conditions.

3.1. Mechanical strength in routine transport conditions

The packagings are transported vertically and are generally grouped on a pallet in an ISO 40-foot container, in the following configuration:

- groups of 6 packages (2x3) per 800 x 1200 mm SNCF rail type metal pallet,
- 5 pallets forming a rectangular sub-assembly of L 2400 x W 2000,
- the pallets are arranged on two levels, with the weight transportability limit being a maximum of 270 packages for maximum loading of the ISO container, or 45 pallets (see chapter 00) of packages loaded with 25 kg of UO_2 powder with an enrichment of 5%.

It should be recalled that the strength of the tie-down for the group of packages itself is not covered by the safety file.

<u>Chocking</u> (see figure 1.1):

- width-wise, there is no chocking as the residual clearance on each side of the pallets is 160 mm, for a total ISO container interior width of 2320 mm;

- vertically, installation of a stop bar on the upper face of the packages in the top-level pallets, which themselves rest on the upper faces of the packages on the bottom-level pallets;
- longitudinally, in the event of incomplete loading of the upper level (the lower level is always complete and therefore self-chocking), chocking is as follows:

  installation of two IPN stop bars across the width of the ISO container, both at the front and the rear of the container, their ends between secured to the sidewalls of the container. These bars are positioned behind the last row of packages on the upper level of pallets.

The stop bars are standard IPN 120*58 sections made of E 36-2 steel (Re = 355 MPa), modulus of inertia $\mu_x = \frac{I}{v} = 5.47 \times 10^4$ mm^4, cross-section 1420 mm^2, and mass per unit length of 11.2 kg/m.

The force, for a longitudinal acceleration of 2 g (according to <6> for road and sea, and <7> for rail), on the 2 longitudinal stop bars (20 pallets with a tare weight of 30 kg * 6 TN-UO_2 with a maximum unit weight of 83 kg, corresponding to a load of 25 kg of UO_2 powder with enrichment of 5%):

$$2F = M*\gamma = (20*(6*83+30))*2*9.81 = 207187 \text{ N}$$

The maximum bending moment for a beam secured at both ends (l = 2135 mm), with a uniformly distributed load, is given by the following:

$$M = \frac{F \times l}{12} = \frac{207187/2 \times 2135}{12} = 1.84 \times 10^7 \text{ N.mm.}$$

The maximum bending stress is: $\sigma = \dfrac{M}{\frac{I}{v}}$

thus: **σ = 337 MPa** (< Re = 355 MPa)

Check shear stresses on beam securing point:

This is equal to:

$$\tau_f = 1.5 \times \frac{F}{S} \text{ (1.5 being the form factor)}$$

thus: **54.7 MPa** ($< Re/\sqrt{3} = 205$ MPa).

The IPN 120*58 sections made of E 36 steel are therefore usable, with each one (unit length 2.335 m), having a handling weight of 26.2 kg.

The forces between these stop bars and the overpacks of the 5 TN-UO_2 packagings concerned should be taken up by semi-cylindrical cradles distributing the stresses over a compression zone compliant with the acceptable limit for phenolic foam (for the maximum crushing value of σ = 17 MPa, we obtain a minimum unit bearing surface of $1220\ mm^2 = \frac{F}{5 * \sigma}$).

Furthermore, as regards the loads due to vibrations liable to occur during routine transport, these have no effect on the TN-UO_2 packaging and its closure lid, immobilised by two anti-rotation devices (see chapter 0 of this safety file) cannot come loose.

3.2. Mechanical strength during handling

As the packages are generally grouped on a pallet both during transport and during loading/unloading handling operations (see chapter 0), the packagings are opened and closed directly on the pallet and are not handled separately.

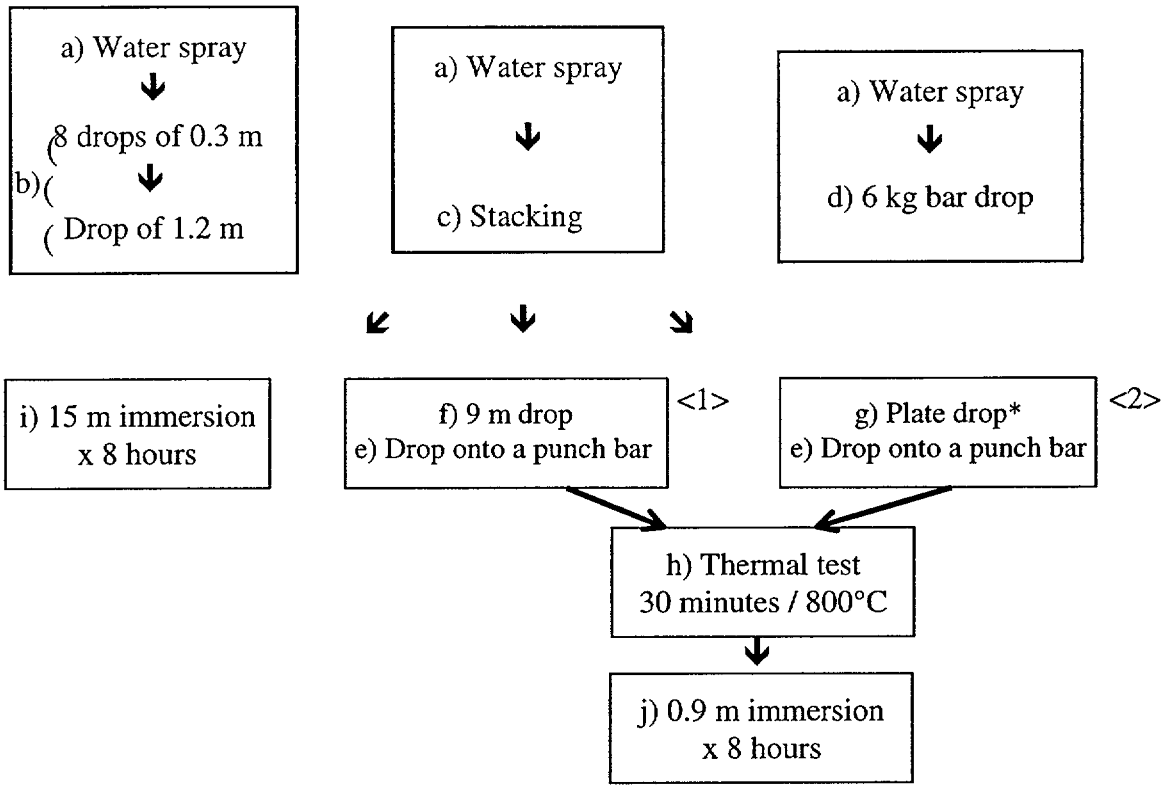
The packaging structure is not therefore subjected to loading during routine handling of the packages.

They can however be individually handled when empty, during maintenance operations, using standard drum handling accessories such as a drum gripper.

4. PACKAGE CONFORMITY WITH REGULATION REQUIREMENTS

Below we analyse the conformity of the package model comprising the TN-UO_2 packaging loaded with an FBFC type flask, with requirements <1> and <2> applicable to type A package models, type IP-2 packages and packages containing fissile materials, and which refer to the regulation tests representative of normal and transport accident conditions.

The list of tests specified according to <1> and <2> for the type A packages containing fissile materials consists of the following sequences:



*: For packages whose total weight is 500 kg or less and for which the overall density is 1000 kg/m³ or less, the special case of paragraph 682 b) of <2> stipulates performance of the mechanical accident test with a 500 kg plate being dropped onto the package, instead of the package 9m free-fall test.

After the mechanical tests, the package must undergo the regulation fire test and maintain sub-criticality of an isolated package and package in an array (case of 2x"N" damaged packages), which means that the radioactive content must be contained inside the package, the neutron-poisoning shield around the flask must not be destroyed and the separation between packages retained (geometry of the overpack around the flask).

The complete test sequence to which the package is to be subjected, must comprise a combination of tests leading to maximum overall damage to the package in the light of the criticality risk, which according to the regulations in <1> and <2> is:

- tests a) to d), which are not cumulative, followed in the most damaging order by tests e), then f) or g), then h) and completed by test j).

The other combination (tests a) to d) followed by i)) is in effect less damaging (non-leaktight packaging under 15m of water and criticality study taking account of the hypothesis of water penetrating inside the flask).

The qualification tests in normal and transport accident conditions <1> and <2> took place in two phases, on two series of full-scale prototypes of the TN-UO_2 packaging, containing a flask loaded with a maximum of 38 kg of pure powdered iron with the same apparent density as UO_2 powder (see appendix 1-5), and in accordance with the test programs defining the most penalising test configurations (see <8> and <9>).

Although the mechanical test results for the first series of prototypes (P1 to P4) demonstrated good mechanical behaviour, a failure of content containment (release of powdered iron) occurred following the thermal test, with the PEHD inner flask melting owing to a lack of packaging thermal insulation.

Changes therefore had to be made to the packaging design in order to improve the thermal protection of the flask on the second series of prototypes (P11 and P15): see appendix 1-5. These changes had no impact on the definition of the sequences leading to maximum package damage and the series of tests performed on the final design of the packaging comprised two test sequences leading to maximum package damage in terms of release of fissile material and the most penalising conditions for analysing damaged package criticality (isolated package and package array).

The overall program covering all the regulation tests <1> and <2> therefore comprised the following test sequences with distribution of the various configurations of the most penalising accident drop:

- specimen P1: sequence including the oblique 9m free-fall drop onto a corner of the packaging lid, with maximum content weight (38 kg), in order to maximise crushing of the package end zones.
- specimen P2: sequence including the 9m plate drop axially onto the packaging base, with maximum weight content (38 kg). The orientation of the specimen with it seated on its base was chosen rather than having it seated on its top, because the prior 0.30 m drop tests could have created local deformation of the upper ring, preventing this end from seating correctly. In addition, as the axial mechanical crushing effects are symmetrical, the two orientations are equivalent.
- specimen P3: sequence including the 9m plate drop laterally onto the packaging centreline, with minimum content weight (1 kg), in order to maximise package deformation and be able to observe any release of the material transported.
- specimen P4: sequence including the 9m plate drop onto the packaging upper corner, with maximum content weight (38 kg).

  final design (the sequences concerning specimens P4 and P3 were reproduced on specimens P11 and P15, are they are the ones that generated the most damage: see paragraph 4.2 and appendices 1-6 and 1-7):

- specimen P11: sequence including the 9m plate drop onto the packaging upper corner, with maximum content weight (38 kg), i.e.; identical to the sequence experienced by P4.
- specimen P15: sequence including the 9m plate drop laterally onto the packaging centreline, with minimum content weight (1 kg), i.e. identical to the sequence experienced by P3.

4.1. Tests in normal transport conditions

The four regulation tests for normal transport conditions were performed on the four prototypes.
The table of tests conducted is presented below:

TABLE 1

NORMAL TRANSPORT CONDITIONS			
TEST	**SPECIMEN**	**TEST DEFINITION**	**ORIENTATION**
<1> 623 a) <2> 723 a)	P 3	Stacking 24 h	Axial
<1> 622 b) <2> 722 c)	P 2 and P 3	8 free-fall drops of 0.30 m	Impact on each quarter of each of the 2 circular edges
	P 1 and P 4	4 free-fall drops of 0.30 m	Impact on each quarter of the base circular edge
<1> 622 a) <2> 722 a)	P 1	Free-fall drop of 1.20 m	Impact on the lid corner opposite the lid closure
	P 2	" "	Axial drop onto base
	P 3	" "	Lateral drop
	P 4	" "	Impact on the lid corner opposite the lid closure
<1> 624 <2> 724	P 1	Free-fall drop by a 6 kg bar	Bar impact on closure ring upper face
	P 2	" "	Bar impact on base centre
	P 3	" "	Bar impact on lateral centreline
	P 4	" "	Bar impact on closure ring air gap

The representativeness of these prototypes, for which the "as-built" drawing is presented in appendix 1-4, is demonstrated in the prototypes description note (appendix 1-5).
The report on these tests is presented in appendix 1-6.

4.1.1. *Water sprinkling*

The water sprinkling test does not apply, as it has no effect on a stainless steel packaging. Moreover, the package criticality model takes account of the hypothesis of water penetrating inside the flask. It was not therefore performed.

4.1.2. *Stacking*

This test was conducted with a 500 kg plate (mass of plate > 5 times the maximum mass of the package and > 13 kPa x vertical projection area of the package of overall ∅ 400 mm, i.e. 163.3 daN) placed on P3 for a 24 hour period (P3 vertical resting on its base). No deformation was observed after this test.

4.1.3. *Free-fall drops of 0.30 m and 1.20 m*

The free-fall drop tests (1.20 m preceded by 0.30 m drops) were performed with various impact configurations as described in table 1, in order to total the damage for each orientation considered with that arising from the following accident drop, in the most penalising way possible (see appendix 1-6).

After the full series of tests, we only observe minor deformation, with the closure lid remaining in place (see photographs in appendix 1-6).

4.1.4. *Penetration by the 6 kg bar*

This test was performed with various impact configurations as described in table 1, in order to test the different package zones.

After the various tests, we only observe minor deformations, with the packaging overpack and the closure lid not being damaged (see photographs in appendix 1-6).

The regulations regarding non-release of radioactive content and no more than a 20% increase in radiation intensity over the entire outer surface of the package are thus confirmed, owing to the fact that the tests in normal conditions revealed insignificant damage to the packaging (see appendix 1-6).

4.2. Tests concerning transport accident conditions

The regulation tests in transport accident conditions were performed on the first series of four prototypes (P1 to P4) and the two test sequences which revealed the most package damage were repeated on the two final design prototypes (P11 and P15).

The normal condition tests were not repeated on the second series of prototypes, as they revealed only insignificant damage to the packaging.

Below is the table of tests performed:

TABLE 2

TRANSPORT ACCIDENT CONDITIONS			
TEST	**SPECIMEN**	**TEST DEFINITION**	**ORIENTATION**
<1> 627 b) <2> 727 b)	P 1	Drop of 1 m onto a punch bar	Specimen axis angled, impact on lid closure opposite 1.20 m drop test impact
	P 2	" "	Specimen axis angled, impact in centre of base
	P 3	" "	Heavily angled specimen axis, impact on centreline
	P 4	" "	Specimen axis angled, impact on lid closure, opposite 1.20 m drop impact
<1> 627 a)	P 1	Free-fall drop from a height of 9 m	Specimen axis oblique with centre of gravity in vertical axis of impact
<2> 727 c)	P 2	Free-fall drop by a 500 kg plate from 9 m	Specimen vertical resting on top
	P 3	Free-fall drop by a 500 kg plate from 9 m	Specimen horizontal
	P 4	Free-fall drop by a 500 kg plate from 9 m	Specimen axis oblique with centre of gravity in vertical axis of impact (point of impact dito punch bar)
<1> 628 <2> 728	on P 3 + P 4	Thermal test 800 °C 30 min.	Specimen axis vertical in oven

TABLE 3

TRANSPORT ACCIDENT CONDITIONS			
TEST	**SPECIMEN**	**TEST DEFINITION**	**ORIENTATION**
<2> 727 c)	P 11	Free fall drop by a 500 kg plate from 9 m	Specimen axis oblique with centre of gravity in vertical axis of impact
	P 15		Specimen horizontal, with lid opening zone horizontal
<1> 627 b) <2> 727 b)	P 11	1 m drop onto punch bar	Specimen axis angled by about 25°, impact on lid closure
	P 15		" "
<1> 628 <2> 728	P 11 + P 15	Thermal test 800 °C 30 min.	Specimen axis vertical in oven

4.2.1. ***1 m drop onto a punch bar***

The drop onto a punch bar test was performed before the free-fall drop test in the first series of tests, in order to combine the damage with that of the following accident drop test, on the same packaging zones.

Various configurations, described in table 2, were tested according to the specificity of each prototype which had first undergone the tests described in paragraph 4.1.

For the second series of tests, the drop onto a punch bar test was conducted following the free-fall drop test with the 500 kg plate, in order to accentuate the damage caused by the first test on the packaging closure zone.

These various drop onto punch bar configurations therefore cover the most severe drop cases.

The results of these tests are presented in appendix 1-6.

The packaging lid closure function was not degraded in the various drop test configurations. No puncture of the outer plate or cracking of the welds was observed.

4.2.2. *9 m free fall drop*

The 9 m package free-fall drop test was only conducted using the oblique drop onto the lid, as the other two cases (axial and lateral drops) were covered by the 9m drop test using the 500 kg plate, with the same orientations, which is a far harsher test.

This test was performed on the P1 prototype during the first series of tests and was not repeated during the second series, as the results of this test (see appendix 1-6) did not change due to any design modifications between the two series of prototypes (see appendix 1-5): in particular, stiffening of the lid closure system considerably improves the strength of the top of the packaging.

This drop led to deformation of the impacted part, although no opening of the lid nor release of the powder content was observed.

4.2.3. *9m free-fall drop test by a 500 kg plate*

The 9m drop test using a 500 kg plate was conducted in various configurations, described in tables 2 and 3, according to the specificity of each prototype and of its sequence of tests.

The sequences which indicated the most package damage during the first series of tests (drop onto corner of package P4 with oblique specimen axis and centre of gravity in the vertical axis of impact, and drop of horizontal P3 specimen flat onto target), were reproduced on two prototypes of the final design (P11 and P15).

These two drop configurations therefore cover the most severe plate drop cases.

The test results are presented in appendix 1-6.

This drop led to deformation of the impacted part, although no opening of the lid nor release of the powder content was observed.

4.2.4. *Final mechanical assessment*

The final mechanical assessment of the two specimens P11 and P15 which were subjected to the drop and puncture tests, was carried out after thermal testing in the high emittance oven simultaneously on the two specimens (see report in appendix 2-2 to this safety file).

An analysis of the regulation thermal test is given in chapter 2 of this safety file on the basis of the thermal test carried out.

This analysis shows that the maximum temperature of the neutron-poisoning resin reaches 109.3°C and that the maximum temperature reached by the flask is 99.3°C.

The layer of thermal insulation (phenolic foam) was locally degraded to a maximum thickness of 27 mm radially (see assessment report in appendix 1-7 to this safety file).

Finally, the powder was contained inside the flask: no cracking of the primary container was observed and the specimens showed no release of powder content after the test.

4.2.5. *0.9 m water immersion test*

Under the terms of the regulations, the package is exempted from this 0.9 m water immersion test, as the package model criticality study takes into account the hypothesis of water penetrating inside the flask.

4.2.6. *15 m water immersion test*

The resistance of the TN-UO_2 package to the external pressure experienced under 15 metres of water is checked, with a normal atmospheric pressure inside the cavity.

For the definition of the damaged package, this test follows the tests representative of normal transport conditions. Given their negligible consequences on the package, we will consider that the TN-UO_2 package has retained all of its initial mechanical properties.

The result of the calculations made below does not compromise the soundness of this simplifying hypothesis.

To attain maximum pressure conditions, the package is placed vertically, with the lid downmost.

We thus add the height of the package (0.8 m) to the immersion depth when calculating the pressure applied.

$$P = \rho.g.h + Patm$$

where ρ = density of water = 1000 kg/m^3
g = acceleration due to gravity = 9.81 $m.s^{-2}$
h = height of water = 15 m + height of cylinder = 15 + 0.8 = 15.8 m
Patm = maximum atmospheric pressure = 1.04 atm = 105 352 Pa

Hence P = 1000 x 9.81 x 15.8 + 105 352 = 260350 Pa

The structural zones filled respectively with phenolic foam and neutron-poisoning resin experience a pressure differential equal to the difference between the outside pressure and the pressure inside the packaging cavity, which is: ΔP = 260350 - 96000 (assuming a minimum internal atmospheric pressure) = 164350 Pa (i.e. 0.164 MPa).

These two materials have a minimum compressive stress of 17 MPa for the phenolic resin and 140 MPa for the neutron-poisoning resin (see chapter 0 of this safety file).

These packaging zones therefore suffer no damage and there is no risk of crushing of the internal well if the package is immersed to 15 metres in water.

Moreover, the upper lid made of 1.5 mm thick stainless steel will be distorted by the pressure differential and no longer be watertight, leading the packaging pressure to equalise.

Behaviour of the flask if the internal well is filled:

We will now calculate the stresses generated by the differential pressure in the shell and the base of the flask, assuming that the screw plug remains watertight.

This hypothesis is penalising, as the deformation mode of the polythene flask, when subjected to excess external pressure will lead to leaks from the seal on its large diameter neck, thereby equalising the pressure.

The high-density polythene flask can therefore be considered a hollow cylinder with a thin wall, closed at both ends.

The stress field due to external overpressure in the shell can be broken down as follows:

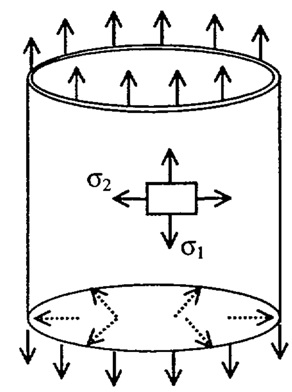
Stresses in the central part:

Tangential stress:

$$\sigma_2 = \frac{P.d}{2.e}$$ (according to formula 1c table 28 of <3>)

with: P = differential pressure applied
d = shell inside diameter = 249 mm (see chapter 0A)
e = straight shell thickness = 2.5 mm (see chapter 0A)

hence σ_2 = 8.18 MPa



Stresses due to the base effect:

As the bottom of the internal flask is flat, we consider the resulting tensile stress in the shell, due to the pressure exerted on the entire internal circular surface of the base:

$\sigma_1 = \frac{P.d}{4.e}$ (according to formula 1c table 28 of <3>)

hence $\sigma_1 = 4.09$ MPa

The maximum Von Mises stress is obtained according to the following combination of stresses:

$\sigma_{eq} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 . \sigma_2}$ (see page 233 of <4>)

i.e.: σ_{eq} = **7.1 MPa** (or a safety coefficient of more than 5 in relation to the yield strength of the material, see chapter 0A).

Stresses in the base:

The flat bottom of the flask will deform inwards, under the effect of the outside overpressure, and adopt a partly spherical form (polythene has high elongation properties: see chapter 0A).

The resulting stress in the base, due to the overpressure exerted on its entire outer surface, is given by:

$\sigma_1 = \frac{P.R_2}{2.t}$ (according to formula 3a table 28 of <3>)

i.e. for extreme hemispherical deformation:

R_2 = shell inside radius = 124.5 mm (see chapter 0)
t = straight shell thickness = 2.5 mm (see chapter 0)

i.e.: σ_1 = **4.1 MPa** (or a safety coefficient of more than 9 in relation to the yield strength of the material, see chapter 0A).

We check that the base does not shear from the shell:

the shear stresses in the base, at the base outside radius, is given (according to <1> table 24 case 10 and <5>) by the following formula:

$\tau = \frac{3}{2} \frac{\pi p a^2}{2 \pi a t}$ = **6.26 MPa** (or a safety coefficient of more than 6 in relation to the yield strength of the material, see chapter 0A).

with: p = differential pressure applied = 164350 Pa
a = outside radius of the base = 127 mm (see chapter 0A)
t = straight thickness of the base = 2.5 mm (see chapter 0A).

Stresses in the closure screw plug:

The structural part of the screw plug which will be subjected to the highest stresses at application of the external overpressure is the upper flat base.

This base has a load-bearing thickness higher than that of the bottom of the flask (3.6 mm as opposed to 2.5 mm) and an inside radius smaller than that of the flask (86 mm instead of 124.5 mm), its stress level will be lower than that of the flask, made of the same material.

There is thus no risk of failure of the flask if the package is immersed to 15 m in water.

To conclude, following the cumulative regulation tests leading to maximum overall damage to define the condition of the damaged package (drops and thermal test), conducted in the configurations most penalising to the packaging, the physical condition of the TN-UO_2 packaging is such that it guarantees the sub-criticality of the package (isolated package and array of packages) according to the hypotheses and conclusions of the criticality study presented in chapter 5A, and ensures containment of the radioactive material.

4.3. Other regulation aspects

4.3.1. *Drop in ambient pressure*

The containment envelope, consisting of the flask, retains the radioactive content even if there is a drop in ambient pressure to 25 kPa, as the analysis of its resistance to a differential pressure of 164 kPa presented in the previous paragraph demonstrates the stress level allowable in the flask walls. The bending deformation of the flask bottom and the screw plug which will be in the opposite direction to the above loading case, will in any case be physically limited, as the free height clearance between the flask and the internal cavity does not exceed 7 mm (see chapter 0).

In addition, the strength of the closure plug screw thread is guaranteed, as the level of stresses in the threads is equal to:

$$\tau = \frac{F}{S_{cisaillement}} = \frac{P \times \pi D^2 / 4}{\pi \times L/2 \times D} = \frac{P \times D}{L \times 2}$$

where: D is the pitch diameter = 176 mm (see chapter 0A)
L is the thread length = 36 mm (see chapter 0A)
P = 75 kPa

i.e.: $\tau = 0.18$ MPa

hence: $\sigma_{eq} = \sqrt{3\tau^2}$ = **0.32 MPa** (or a safety coefficient of more than 100 in relation to the yield strength of the material, see chapter 0A).

There is thus no risk of the screw plug separating in the event of a drop in ambient pressure to 25 kPa.

5. CONCLUSION

This chapter demonstrates the TN-UO_2 packaging's ability to withstand the tests representative of normal and transport accident conditions as stipulated by regulations <1> and <2>, applicable to type A packages and to packages intended for the transport of fissile materials, in particular regarding the following points:

- resistance to the regulation tests in normal transport conditions performed on full-scale specimen packages (see test report in appendix 1-6);
- resistance of the packaging to the regulation ambient pressure drop;
- resistance to the regulation tests in transport accident conditions performed on full-scale specimen packages (see test report in appendix 1-6 and thermal test report in appendix 2-2), in particular with regard to radioactive content loss and release, radiation protection and nuclear safety criteria;
- pressure resistance during the 15 m water immersion test in transport accident conditions;
- mechanical strength of the tie-down and handling devices.

Following the cumulative series of regulation tests defining the condition of the damaged package (drops and thermal test: see chapter 2), performed in the configurations most penalising for the packaging, the physical condition of the TN-UO_2 packaging is such that it guarantees the sub-criticality of the package (isolated package and package array) according to the hypotheses and conclusions of the criticality study presented in chapter 5A, and guarantees containment of the radioactive material.

The results as a whole thus lead to a favourable conclusion regarding the conformity of the TN-UO_2 packaging with the stipulations of regulations <1> and <2>, applicable to type A packages (covering the requirements for type IP-2) and to packages intended for the transport of fissile materials.

6. REFERENCES

<1> Regulations for the Safe Transport of Radioactive Materials – International Atomic Energy Agency, Vienna (1985 Edition, reviewed in 1990).

<2> Regulations for the Safe Transport of Radioactive Materials – International Atomic Energy Agency, Vienna (1996 Edition – Specifications N° ST-1).

<3> Roark's Formulas for Stress and Strain - 6th Edition.

<4> G. PISSARENKO - Aide-mémoire de résistance des matériaux - Editions MIR.

<5> GIECK, Formulaire Technique, 8ème édition.

<6> Safety Series N° 37 : Advisory Material for the IAEA Regulations for the Safe transport of Radioactive Material (1985 Edition).

<7> INSTRUCTIONS GENERALES SNCF TR2 E1 n°1, chargement des wagons sans triage à la bosse (Edition 1982).

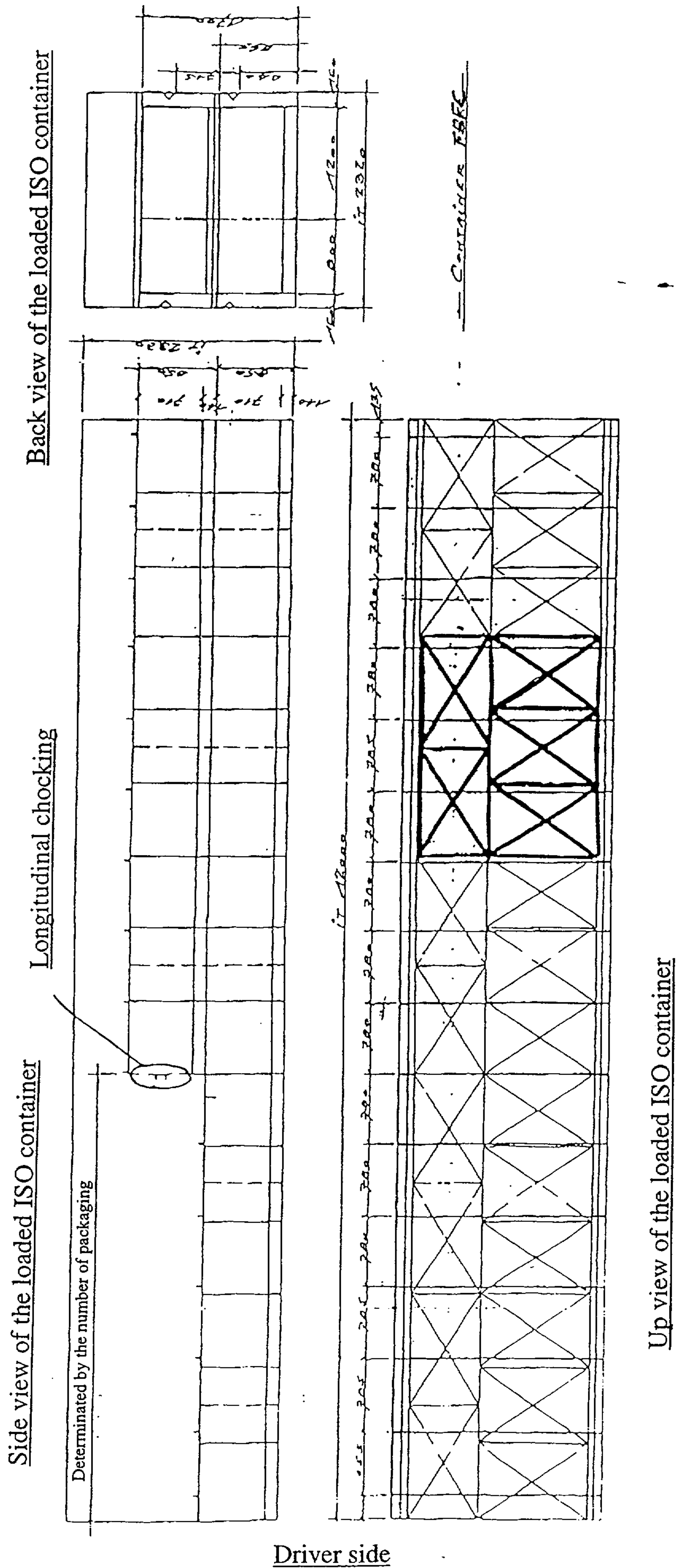
<8> IAEA qualification drop tests program ref. TRANSNUCLEAIRE 10313-P-1 rev.1 of 10/06/98.

<9> CAT / AIEA qualification drop tests program ref. TRANSNUCLEAIRE 10313-P-3 rev.1 of 18/02/99.

LIST OF FIGURES

FIGURE 1.1

DIAGRAM OF TN-UO_2 PACKAGE PALLET CHOCKING SYSTEM IN AN ISO 40' CONTAINER



PHENOLIC FOAM TEST REPORT

CONTENTS

REVISION SHEET

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

1. SUBJECT

This appendix presents the report on the various characterisation tests performed on samples of phenolic foam, the main structural material of the TN-UO_2 packaging, acting as both shock absorber and thermal insulation.

The following tests were conducted:

- climatic cycle test at – 40 °C on wet foam, in order to make sure that it does not crack;
- crushing tests on samples of phenolic foam in ambient temperature conditions, but with characterisation of the influence of its water content on its confined compression mechanical properties (humidity level varying from 40 to 53%, measured by recording the increasing weight of the samples).

  These tests were performed in one of the packaging design development phases. The level of humidity of the phenolic foam chosen for the final design was set at a maximum mass content of water of 20%, thus outside the range of the tests reported here (the qualification tests on the package model were conducted with the 20% value). These tests are of no interest in this file and are only mentioned here because they are part of the enclosed document.

These tests, performed by the Laboratoire National d'Essais, are detailed in the enclosed report.

2. CONCLUSION

A high water content in the foam (up to 53 %) does not alter its structure at low temperatures (- 40°C).

TEST REPORT

Requested by: TRANSNUCLEAIRE
9-11 rue Christophe Colomb
75008 Paris
France

Date of request: 5 October 1998 - Order N° 985

Subject: Material crushing test

Identification of samples: Four specimens of phenolic foam.

The report comprises 5 pages

1 ITEMS PROVIDED

Four specimens of phenolic foam with a diameter of 41 mm and thickness of 40 mm.

For test purposes, the test specimens were marked 1 to 4.

2 PURPOSE OF THE TEST

To study behavior of specimens to crushing after seven days of immersion in distilled water at 20 °C.

To study behavior of a specimen having undergone testing at -40 °C for one hour after total immersion in distilled water at 20 °C for seven days.

3 TEST CONDITIONS

3.1 CRUSHING TEST

After checking of geometry and density, the specimens were immersed fully in distilled water at 20 °C for seven days. After this treatment, the geometry and density of the test specimens were checked again. The specimens were subjected to the crushing test without drying.

The crushing tests were carried out with a Schenck electro-magnetic device applying the tensile force, with nominal capacity of 50 kN, Class 0.5 on the calibration 50 kN used (check carried out 2 July 1998 by an organization accredited by COFRAC).

The specimen was placed in a model with a diameter of 41.5 mm. The crushing force was transmitted by a piston with diameter of 41 mm.
For each test, the model was lubricated with silicone to reduce friction.

The tests were carried out with speed slaved to 1 mm per minute.

A force/crushing recording was made for each test.

3.2 THERMAL TEST

After checking of geometry and density and full immersion for seven days in distilled water at 20 °C, the phenolic foam specimen was placed in a thermal chamber.

Test conditions

Establishing of temperature of -40 °C at rate of 1 °C/minute.
Holding at - 40 °C for one hour.
Return to ambient temperature at rate of 1 °C/minute.
Checking of geometry and density and visual inspection.

4 RESULTS

4.1 CRUSHING TEST

The results are shown in the table below.

4.1.1 Checking of geometry and density before immersion

Specimen identification mark	Dimensions		Weight (g)	Density (g/cm3)
	Diameter (cm)	Height (cm)		
1	4.1	4.0	14.8	0.280
2	4.1	4.01	15.3	0.289
4	4.1	4.0	15.8	0.299

4.1.2. Checking of geometry and density after immersion in distilled water for seven days

Specimen identification mark	Dimensions		Weight (g)	Density (g/cm3)
	Diameter (cm)	Height (cm)		
1	4.123	4.019	25.1	0.468
2	4.130	4.031	33.2	0.615
4	4.142	4.22	32.1	0.593

4.1.3. Checking of geometry and density after crushing test

Specimen identification mark	Dimensions		Weight (g)	Density (g/cm3)
	Diameter (cm)	Height (cm)		
1	4.30	2.23	20.1	0.621
2	4.30	2.413	23.2	0.662
4	4.30	2.418	22.9	0.652

The graphs are presented in appendix to this report.

Note: After testing, the specimens were cracked, the bearing surfaces were curved and the diameters had increased and assumed a "barrel" shape.

4.2 THERMAL TEST

	Specimen identification mark	Dimensions		Weight (g)	Density (g/cm^3)
		Diameter (cm)	Height (cm)		
Before immersion	3	4.1	4.02	14.6	0.275
After immersion		4.187	4.037	33.9	0.610
After test at 40 °C		4.184	4.041	31.9	0.574

After the thermal cycle, the specimen had no cracks visible to the naked eye.

The tests were carried out by the Laboratoire National d'Essais (LNE - national test laboratory) at Trappes (France) on 2 October 1998.

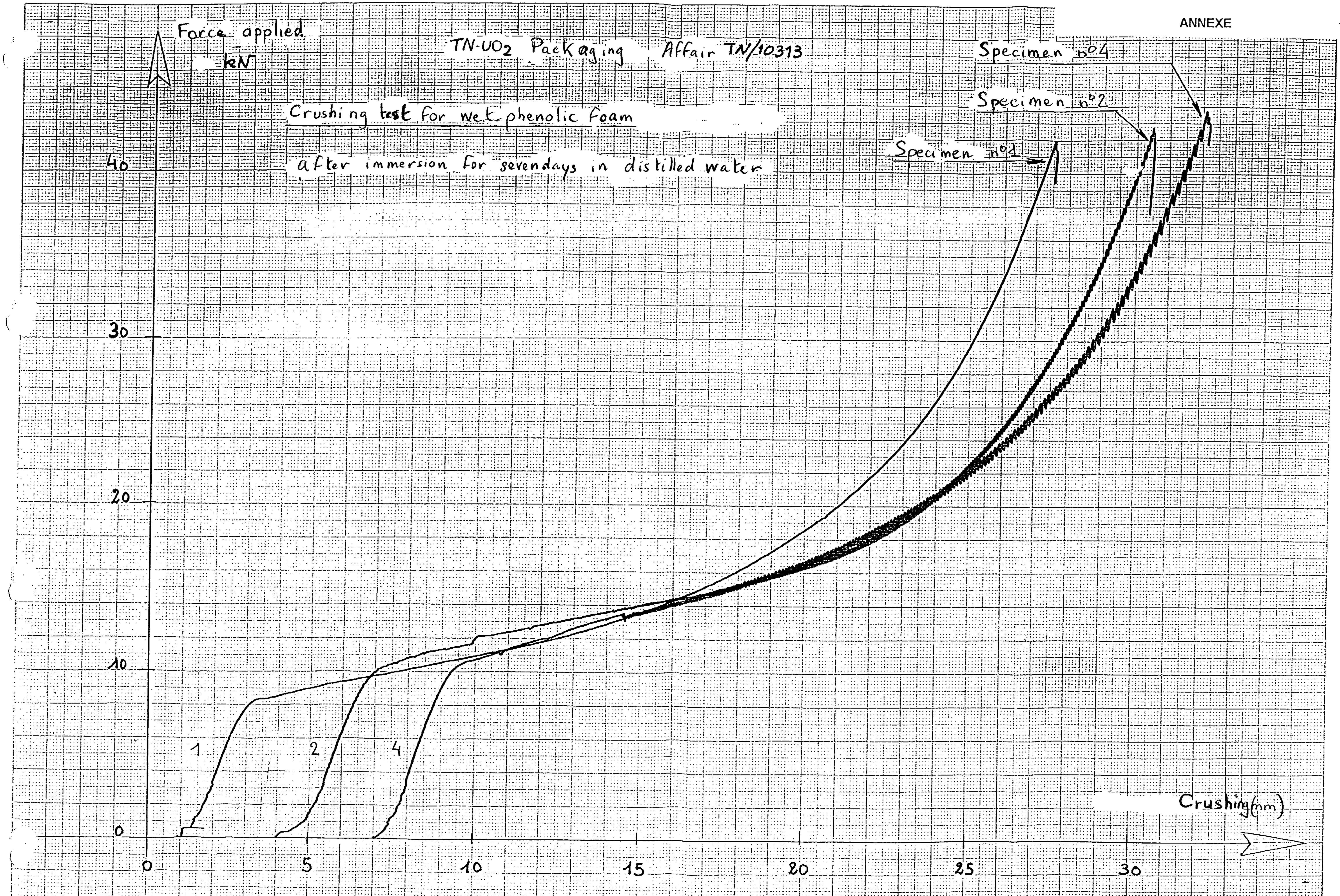
10 November 1998 (Trappes, France)

Head of Division
Equipment and Industrial Components

Test carried out by:

The results presented apply only to the test specimens, products or equipment provided to the LNE and are as they are defined in this document.

ANNEXE


Force applied
kN
TN-UO2 Packaging Affair TN/10313
Crushing test for wet phenolic foam
after immersion for sevendays in distilled water
Specimen n°4
Specimen n°2
Specimen n°1
40
30
20
10
0
1
2
4
Crushing (mm)
0
5
10
15
20
25
30

<table>
<tr><td>TRANSNUCLEAIRE</td><td colspan="3">CHAPTER 1 - APPENDIX 3</td><td>Page
1 of 3</td></tr>
<tr><td rowspan="2" colspan="2">SAFETY FILE
TN-UO_2</td><td></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 colspan="2"></td><td>Checked by</td><td>F. POTELLE</td><td></td><td></td></tr>
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Computer ref.: S:\DAC\Commun\Dossiers de Sûreté\TN-UO2\10313Z1-3</td></tr>
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MECHANICAL TEST REPORT ON FLASK AT –40°C

CONTENTS

ENCLOSURE: LNE TEST REPORT File ref. 8090655 – Document CQPE/1

REVISION SHEET

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

1. SUBJECT

This appendix presents the report on the dynamic crushing test concerning the FBFC type flask at – 40°C, simulating the maximum flask damage corresponding to the test configuration in transport accident conditions in accordance with regulations <1> and <2> which are the most penalising in terms of deformation of the TN-UO_2 packaging and its internal flask (see appendix 1-6 of this safety file).

This test, performed by the Laboratoire National d'Essais, is presented in the report enclosed.

2. CONCLUSION

The crushing test, performed in three directions (in the plane of the seal, perpendicularly and at 45°) revealed no cracking or fracture of the flask and the plug.

The shock performance of the flask is therefore not weakened at low temperatures (- 40°C).

3. REFERENCE REGULATIONS

<1>Regulations for the Safe Transport of Radioactive Materials – International Atomic Energy Agency, Vienna (1985 Edition, reviewed in 1990).

<2>Regulations for the Safe Transport of Radioactive Materials – International Atomic Energy Agency, Vienna (1996 Edition – Specifications N° ST-1).

PHENOLIC FOAM TEST REPORT

CONTENTS

REVISION SHEET

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

1. SUBJECT

This appendix presents the report on the various characterisation tests performed on samples of phenolic foam, the main structural material of the TN-UO_2 packaging, acting as both shock absorber and thermal insulation.

The following tests were conducted:

- climatic cycle test at – 40 °C on wet foam, in order to make sure that it does not crack;
- crushing tests on samples of phenolic foam in ambient temperature conditions, but with characterisation of the influence of its water content on its confined compression mechanical properties (humidity level varying from 40 to 53%, measured by recording the increasing weight of the samples).

  These tests were performed in one of the packaging design development phases. The level of humidity of the phenolic foam chosen for the final design was set at a maximum mass content of water of 20%, thus outside the range of the tests reported here (the qualification tests on the package model were conducted with the 20% value). These tests are of no interest in this file and are only mentioned here because they are part of the enclosed document.

These tests, performed by the Laboratoire National d'Essais, are detailed in the enclosed report.

2. CONCLUSION

A high water content in the foam (up to 53 %) does not alter its structure at low temperatures (- 40°C).

TEST REPORT

Requested by: TRANSNUCLEAIRE
9-11 rue Christophe Colomb
75008 Paris
France

Date of request: 9 November 1999 - Order N° 1098

Subject: Crushing test for polyethylene flasks

Identification of specimens: Three flasks marked A, B and C.
Contract N° 1303 - Year 1998 - Batch N° L01 - M40060
ATO 2002

1 ITEMS PROVIDED

The requesting party provided three high-density polyethylene flasks equipped with their caps to the Laboratory National d'Essais (LNE - national test laboratory).

These three test items have the following manufacturer's markings (moldings):

- "Affaire 10313 - year 1998
- Batch N° 01

These marks are on the base of the flasks and inner sides of the caps. The requesting party added the following information on labels:

- MTO 400 60 on all caps
- ATO 2002 on flask bodies

The flasks were marked, by us, A, B, and C.

2 PURPOSE OF TEST

To check the ability of polyethylene flasks to withstand shocks at low temperature.

3 TEST PROCEDURE

The test procedure was defined by the requesting party. It was as follows:

- Cooling of flasks to -40 +0 -2 °C (monitored with thermocouple);

- Generation of a shock: crushing of test specimen to a value of 85 mm for duration of 0.1 second (i.e. a velocity of 850 mm/s).
The shock is applied to a centerline of the flask by means of compression plate.

- The test is carried out on three flasks, on three different centerlines:

. along the molding seam
. at an angle of 45° in relation to molding seam
. perpendicular to molding seam

- A visual inspection is carried out on the flasks after the test.

4 TEST CONDITIONS

4.1 TEST EQUIPMENT

The flask was placed horizontally on a test frame base.

A hydraulic jack was fixed by its base to the upper beam of the test frame.

The hydraulic jack rod, perpendicular to the longitudinal axis of the flask, was equipped with a strain gauge and a 600 x 300 mm compression plate.

A test installation drawing is given in Appendix 1.

4.2 TEST INSTRUMENTS

The shocks were applied via an hydraulic jack with slaved movement (Schenck type PL 63 N) and the associated slaving electronics (Schenck serial 31).

The movements were measured by an induction movement sensor on the jack body.

The forces were measured with a strain gauge with a range of ± 63 kN (Schenck type PM 63 K).

Measurement of flask temperature was obtained with a K-type thermocouple connected to a BIOBLOCK CTX 1200 conditioner.

5 TESTS AND RESULTS

The tests were carried out on 3 December 1998 in our laboratory in Trappes (France),in the presence of the requesting party represented by Mr. Malalel.

5.1 ESTABLISHING TEMPERATURE OF TEST SPECIMENS

As the temperature conditioning chamber was located some distance from the test rig, the flasks were placed in cardboards filled with glass wool to slow down their heating.

A thermocouple was fixed (with adhesive tape) to each flask (on the neck close to the cap) before placing in the insulated packaging.

The three flasks were placed in the temperature conditioning chamber, set to -50 °C, for 12 hours.

The temperature was measured from removal from the conditioned chamber until generation of the shock (obtaining a temperature of -42 °C).

5.2 SHOCK TESTS

The shock tests on the three flasks were carried out as follows:

- Transfer of flasks from conditioned chamber to the benchtest;

- Positioning of flask: the compression plate is in its initial position: distance 15 mm between upper centerline of flask and the plate of compression;

- Triggering of shock pulse as soon as required temperature was reached (-42 °C). A movement of 100 mm was generated, providing crushing of the flask of 85 mm (V = 850 mm/s); reading of maximum compression force;

- Return of compression plate to initial position; removal and visual inspection of flask.

The results of the tests on the flasks are shown in the table below.

Flask mark	**Visual inspection after test shock**	**Maximum compression force/kN (for information)**
A	No cracks. The base of the flask has a central fold perpendicular to the mold seam (see Annex 2)	15.7
B	No cracks. The base of the flask has two central folds, symmetrical in relation to the horizontal center plane (mold seam plane). Less folding in the upper part close to the neck (see Appendices 3 and 4)	13.5
C	No cracks. Folding of base more or less identical to those observed for flask B. Folding close to the neck more pronounced than for flask B (see Appendices 5 and 6)	14.5

A photograph of the bases of the three flasks after testing is given in Appendix 7.

After the tests, loss of roundness of necks and caps was observed, making fitting and removal of the cap more difficult.

6 CONCLUSION

The shock tests at -40 °C carried out on the three high-density polyethylene flasks equipped with caps (Contract 10 313 - Year 1998 - Batch N° 101) showed no signs of major damage (cracks, breakage, ejection of caps, etc.).

Deformation, folding and loss of roundness were observed on the flasks, nevertheless allowing screwing and unscrewing of caps.

21 December 1998 (in Trappes, France)

Head of Division
Equipment and Industrial Components

Test Manager

The results presented apply only to the test specimens, products or equipment provided to the LNE, and as defined in this document.

APPENDIX 1

BENCHTEST

1 Test frame

2 Electro-hydraulic jack

3 Strain gauge

4 Compression plate

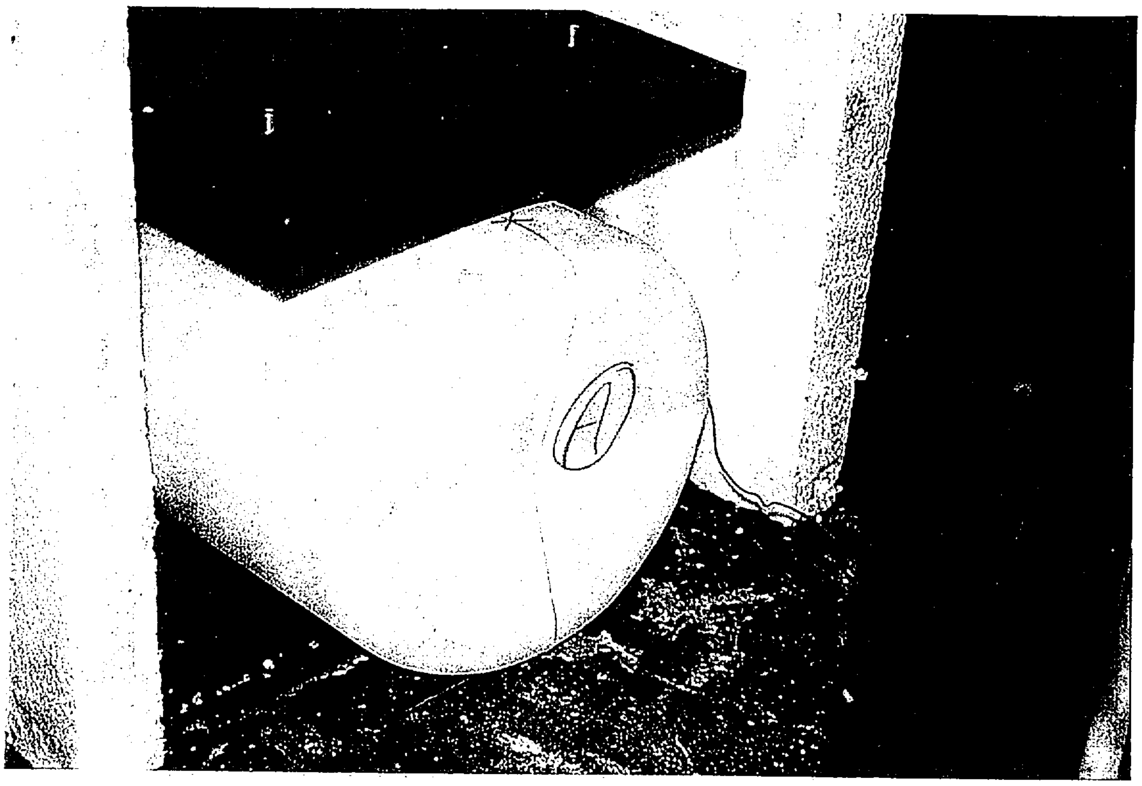
5 Flask

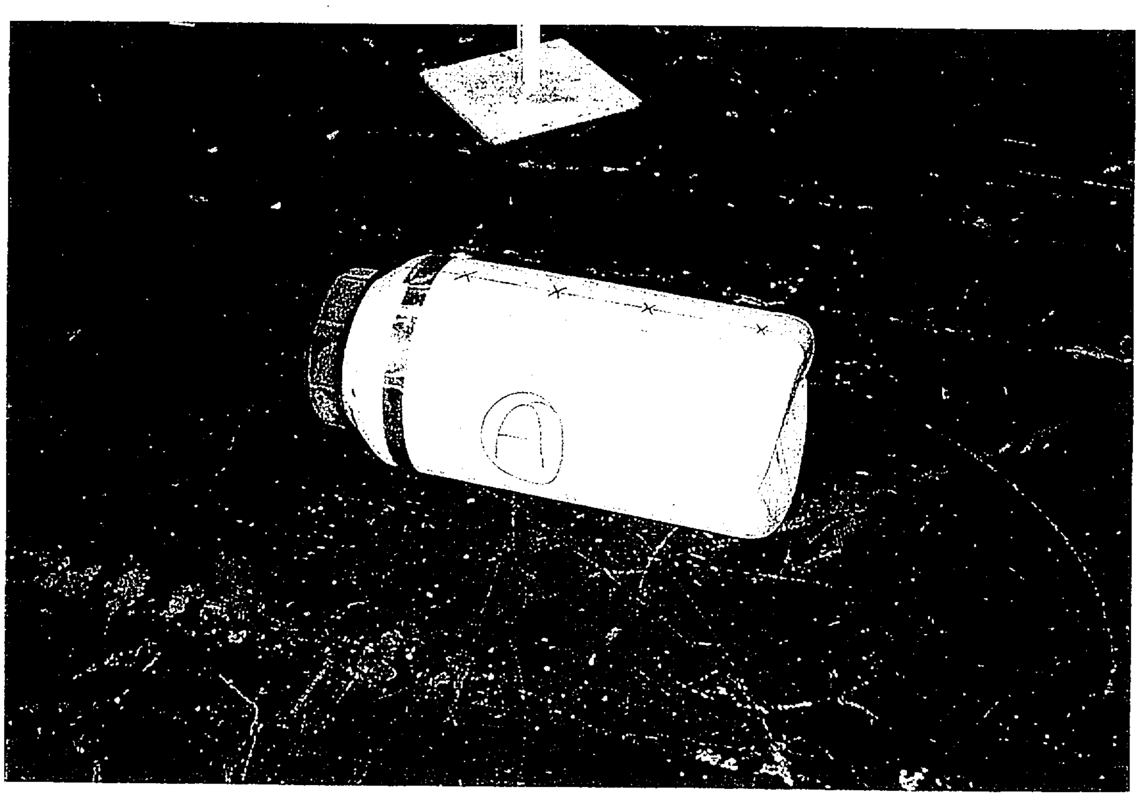
6 Initial position of the plate

7 Final position of the plate

APPENDIX 2

FLASK "A" AFTER TEST

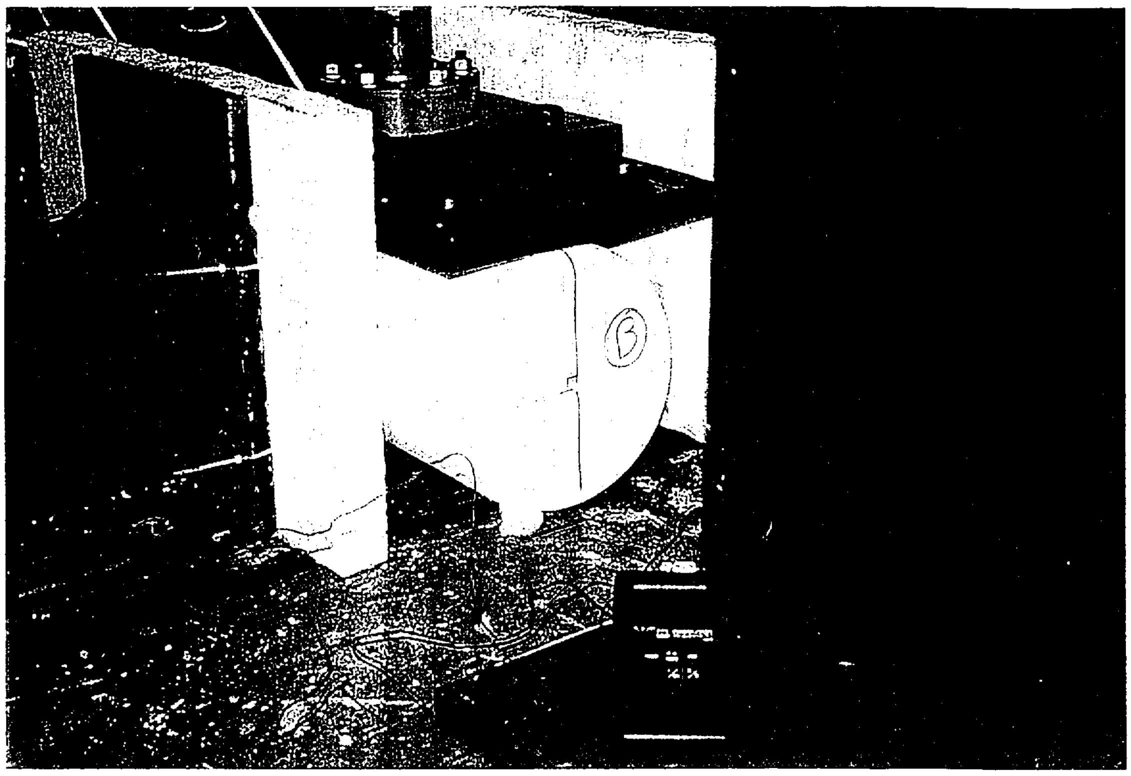




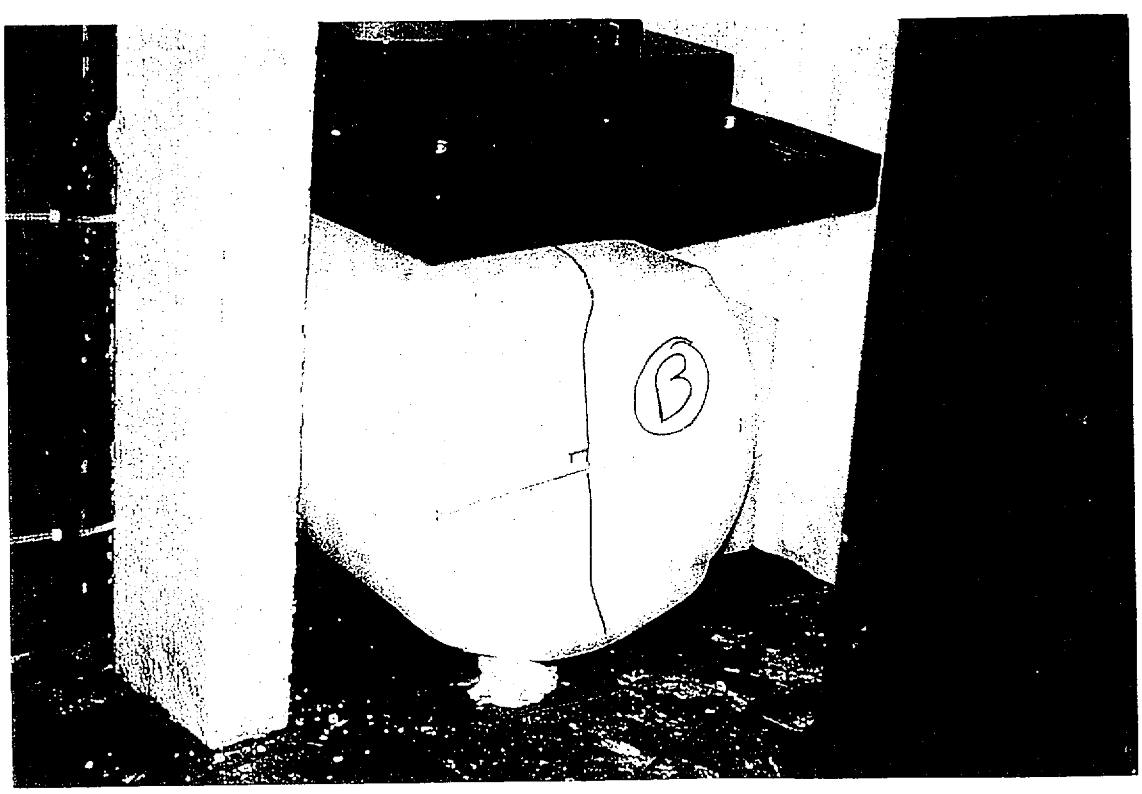
APPENDIX 3

FLASK "B"

Before test

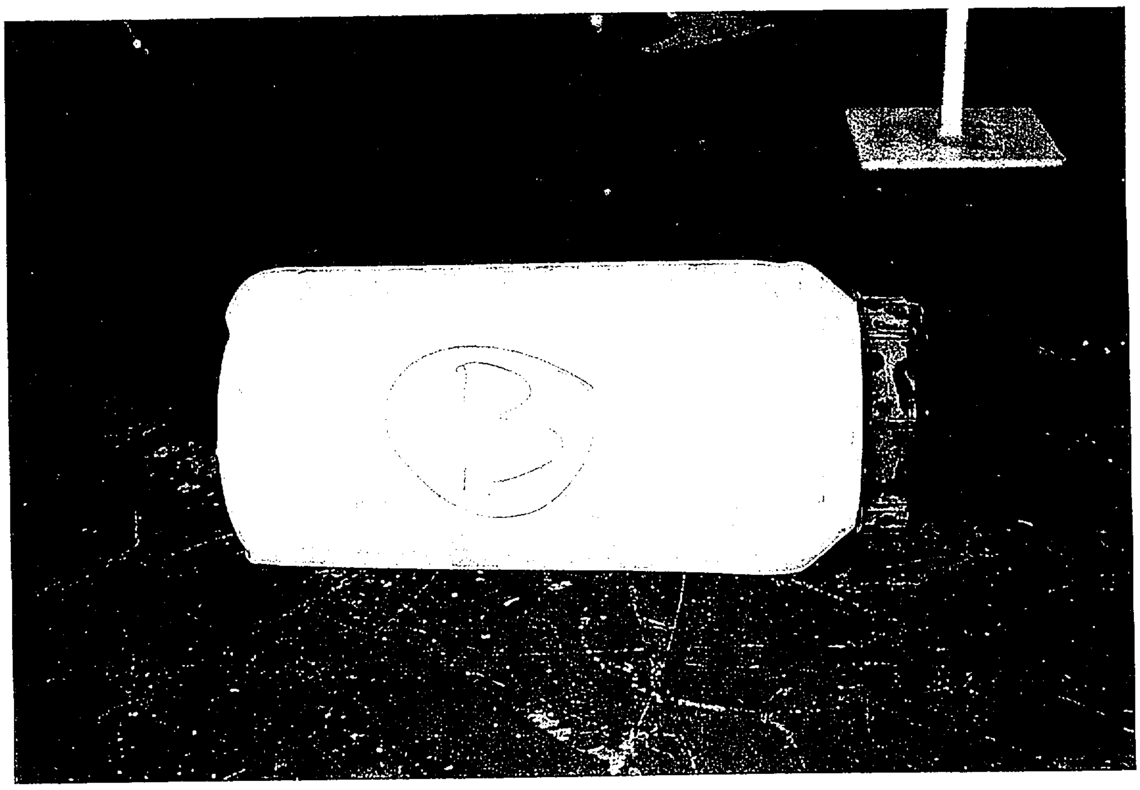


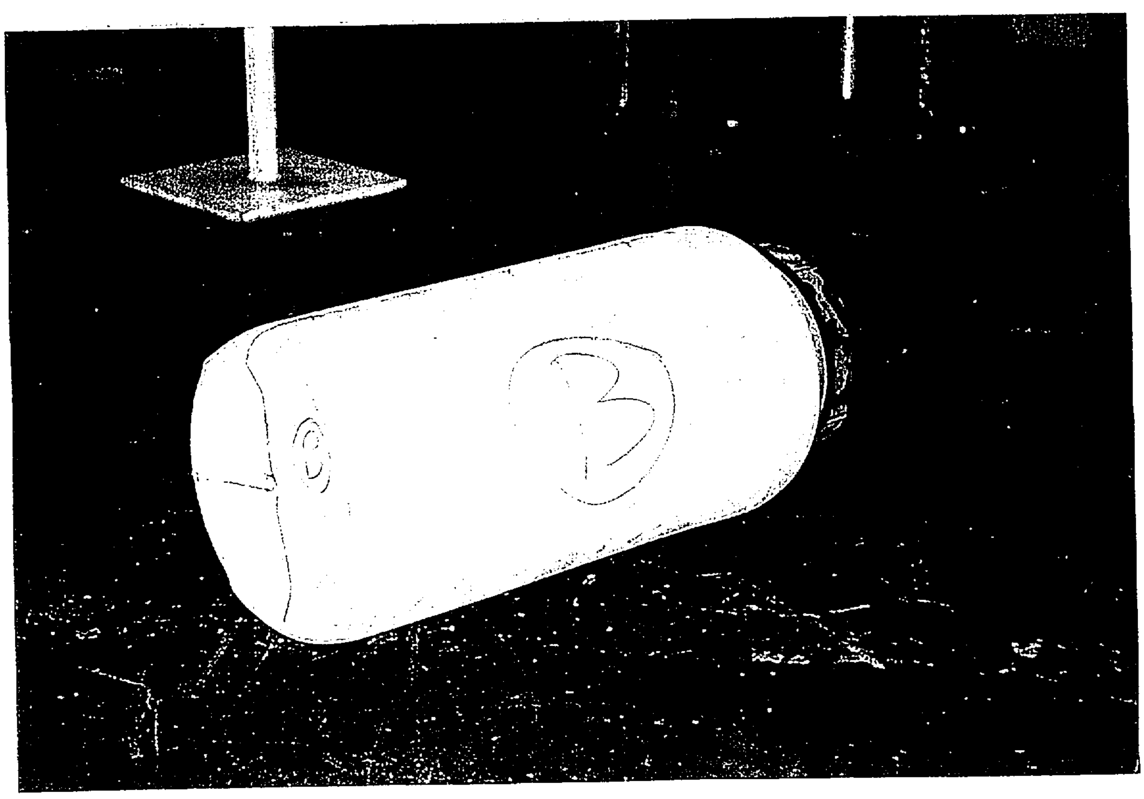
After test



APPENDIX 4

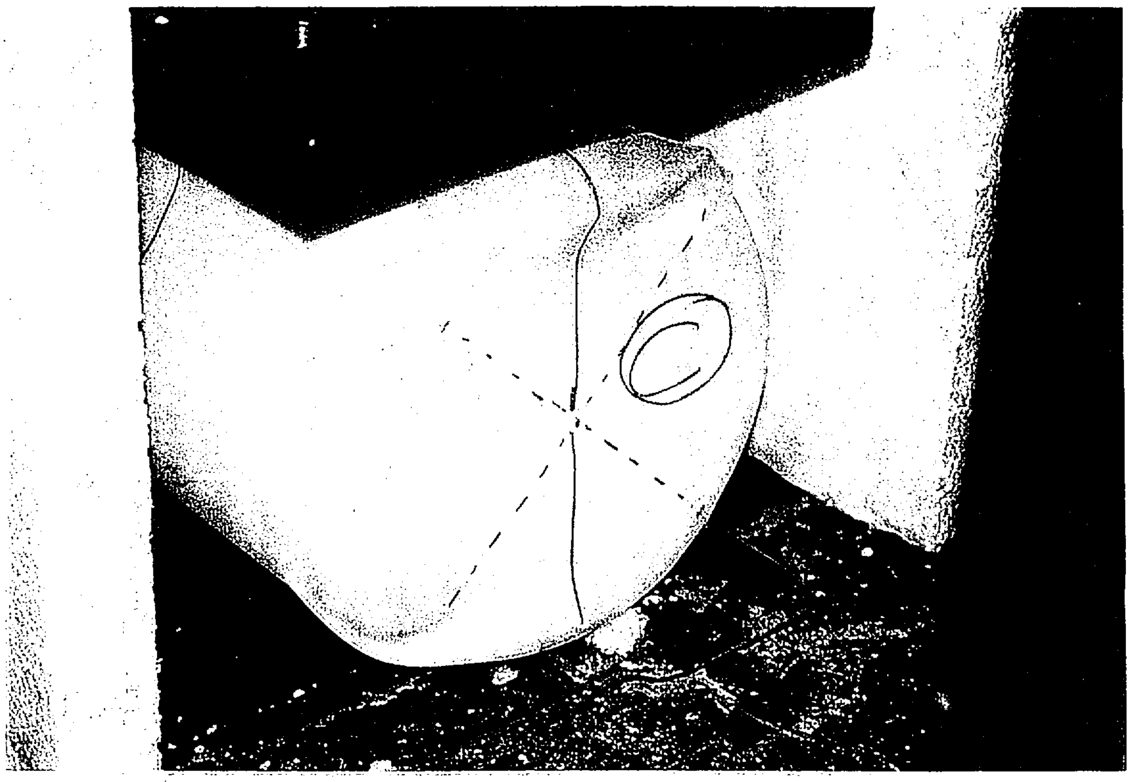
FLASK "B" AFTER TEST

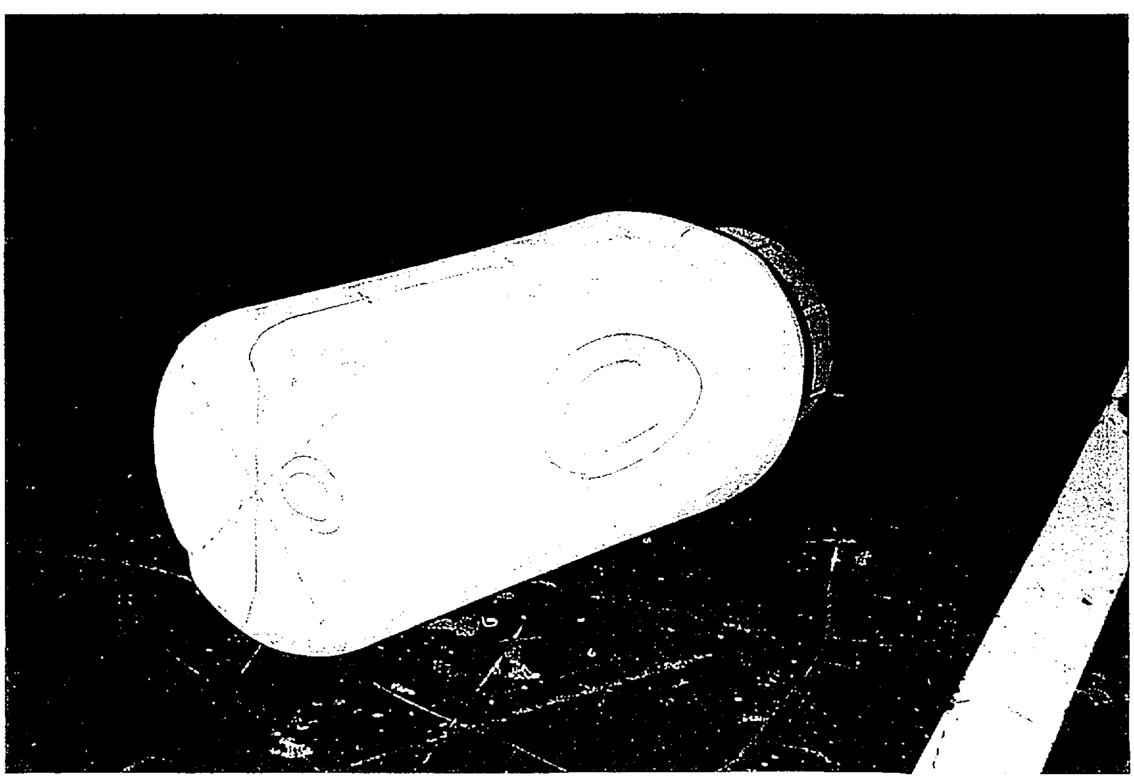




APPENDIX 5

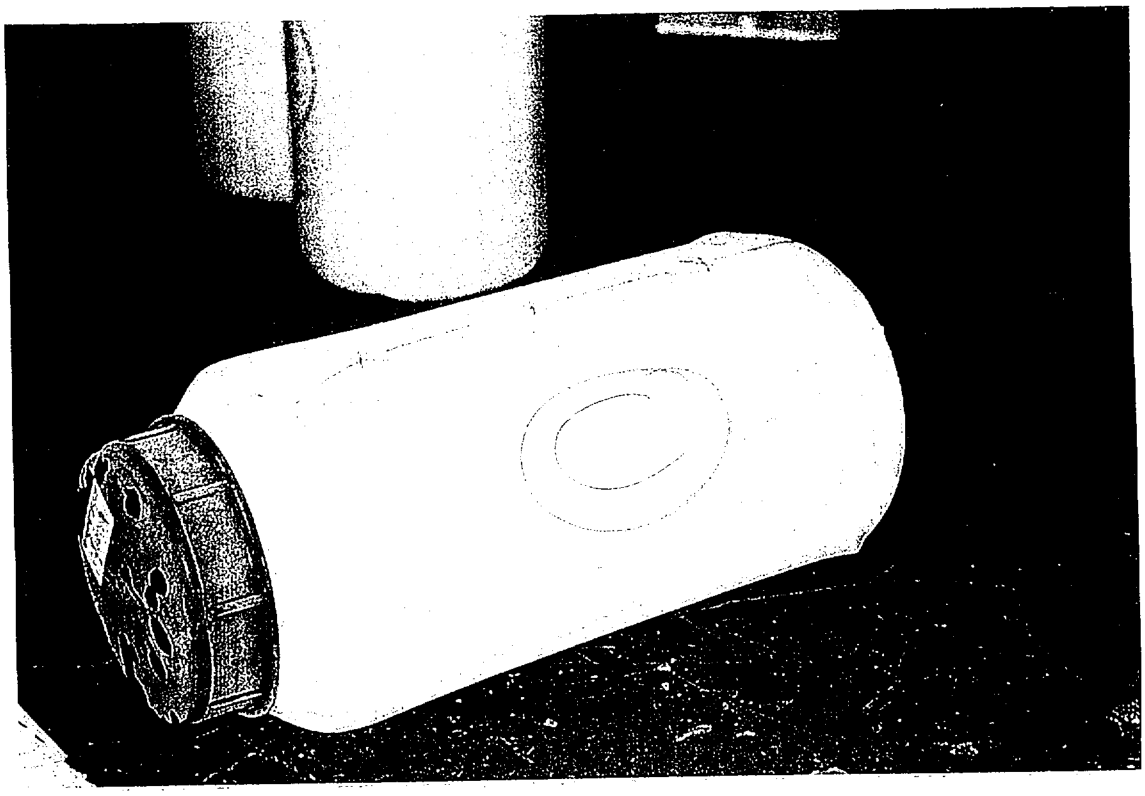
FLASK "C" AFTER TEST

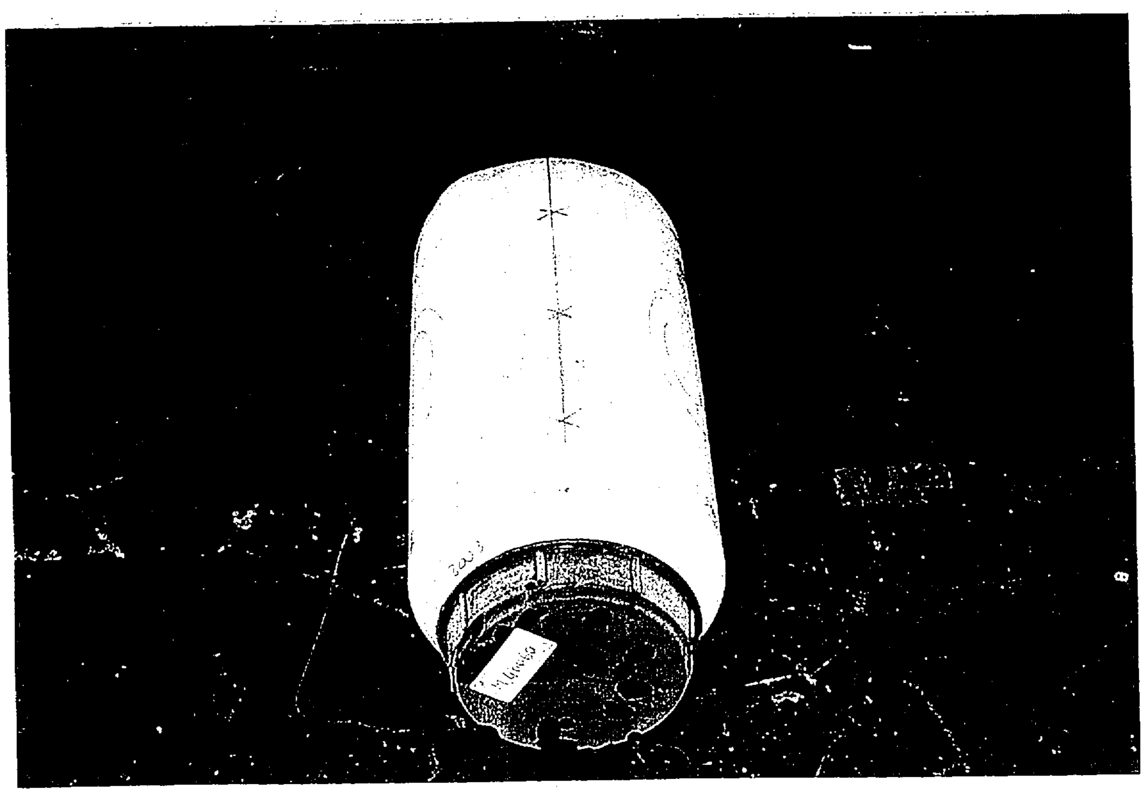




APPENDIX 6

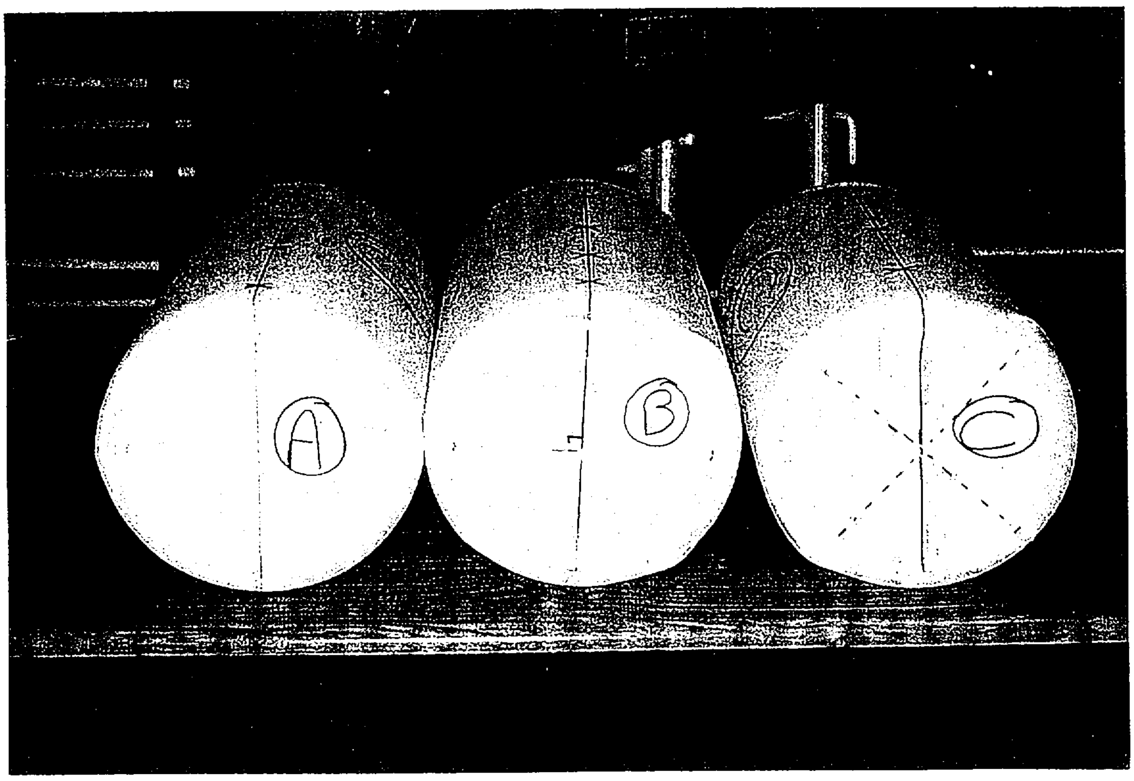
FLASK "C" AFTER TEST





APPENDIX 7

BASES OF THE THREE FLASKS AFTER TEST



"AS-BUILT" DRAWINGS OF QUALIFICATION PROTOTYPES WHICH WERE SUBJECTED TO THE DROP TESTS AND THE THERMAL TEST

REFERENCE	INDEX	TITLE
10313-01	C	TN-UO2 DESIGN DRAWING (Prototypes P1 to P4)
10313-02	A	TN-UO2 PACKAGING DETAIL OF FOAM BLOCKS (Prototypes P1 to P4)
10313-03	A	TN-UO2 PACKAGING DETAIL OF V-SEGMENT HOOP (Prototypes P1 to P4)
10313-05	A	TN-UO2 PACKAGING– Prototype P11 GENERAL DRAWING
10313-05	B	TN-UO2 PACKAGING – Prototype P15 GENERAL DRAWING

DIFFERENCES BETWEEN PROTOTYPES AND PACKAGE

CONTENTS

REVISION SHEET

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

1. SUBJECT

The purpose of this appendix is to give a precise description of all the differences between the various prototypes subjected to mechanical and thermal testing and the TN-UO_2 package model as defined in chapters 0 and 0A of this safety file.

2. DIFFERENCES BETWEEN THE PROTOTYPES AND THE PACKAGE MODEL

The TN-UO_2 package model consists of a protective overpack with plug and closure lid, containing a flask for containment of the radioactive material to be transported.

The packaging, comprising the overpack and the FBFC type flask, is described in chapter 0 of this safety file and a drawing of it is given in appendix 0-1.

The specimens tested comprised two series of full-scale prototypes of the TN-UO_2 packaging, containing a cylindrical flask loaded with a maximum of 38 kg of pure powdered iron of the same apparent density as the UO_2 powder (about 1.7).

The qualification tests in normal and transport accident conditions <1> and <2> took place in two phases:

- 1st series of tests performed on four prototypes (called P1, P2, P3, P4: drawing in appendix 1-4), comprising in sequence all the tests in normal and transport accident conditions according to various damage configurations (see appendix 1-6 of this safety file).

  Although the mechanical test results demonstrated good performance by the prototypes, a failure in the content containment (release of powdered iron) appeared following the thermal test, owing to melting of the PEHD inner flask as a result of insufficient thermal insulation of the packaging.

  Changes were therefore made to the packaging design in order to improve the thermal protection of the flask.

- 2nd series of tests performed on two prototypes (called P11 and P15: drawing in appendix 1-4), comprising a sequence of tests in transport accident conditions reproducing the two sequences which revealed the most damage to the package during the first series.

  The tests in normal conditions were not repeated, as they revealed insignificant damage to the packaging (see appendix 1-6), and moreover, the packaging closure system had been strengthened.

The last two qualification prototypes (P11 and P15), from the pre-production packaging run, are perfectly representative of the final design of the packaging model, with the exception of elements which do not compromise package safety (hole for the dia. 8 instrumentation wires made in the centre of the lid, ID plate, upper cleanness shroud, ref. 22 on the design drawing in appendix 0-1).

The differences between the first series of prototypes (P1 to P4) and the final design are as follows:

- in the final design, choice of a grade of high-density polythene (material making up the flask and the plug) with better temperature resistance, better rupture elongation, and better tensile strength;

  This modification in no way changes the behaviour of the packaging structure with regard to the various tests already performed on the first series of prototypes (P1 to P4).

- in the final design, containment of the upper part of the phenolic foam shell by a thin plate of stainless steel designed to retard pyrolysis of the foam;

  this modification has no negative impact with regard to the tests on the first series of prototypes (P1 to P4); it increases the protection of the layer of foam and makes internal decontamination of the packaging easier.

- in the final design, strengthening of the mechanical and thermal performance of the upper plug:

  - insertion of a perforated aluminium alloy disk, designed to limit crushing of the top of the packaging during the test in which a 500 kg plate is dropped onto the horizontally positioned package;
  - replacement of part of the phenolic foam insulation by a layer of plaster, to improve the thermal performance of the plug;
  - overall encapsulation of the plug by a thin sheet of stainless steel designed to retard pyrolysis of the upper foam disk; this plate contains four fuse pellets to allow release of steam produced during the thermal test, without pressurising the plug;

    a thin sheet (0.8 mm) with high elongation was chosen for the plug containment, to avoid disrupting the ability of the phenolic foam to absorb shocks and deform.

  These improvements to the upper plug design in no way degrade the performance of the packaging structure with regard to the different tests already performed on the first series of prototypes (P1 to P4).

- humidification with a mass content of water of 20%, of the phenolic foam elements, for improved fire resistance, without altering the shock absorbing mechanical properties (see appendix 1-2) ;

  this modification does not impair the performance of the packaging structure with regard to the various tests already performed on the first series of prototypes (P1 to P4), and improves the thermal insulation of the foam layer.

In the same way as for the plug, fuse pellets were added to the outer plate of the phenolic foam layer envelope, to allow free release of steam produced by the foam during the thermal test.

- replacement of the lid closure hoop by a bayonet clamping and locking system integral with the lid. This concept was developed to limit any gaps around the lid as a result of deformation caused by the various accident drop tests.

  This modification does not impair the performance of the packaging structure with regard to the various tests already performed on the first series of prototypes (P1 to P4).

All these modifications implemented in the design of the second series of prototypes and in the final design, do not therefore alter the behaviour of the package in the various tests already performed in the first phase and not repeated in the second phase.

The last two qualification prototypes (P11 and P15), were in particular manufactured using FS 69 type resin for the neutron-poisoning shield. This resin offers poorer mechanical strength than the BORA type resin (see chapter 0 of this safety file), which is penalising for packaging performance in shock conditions.

3. 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).

TRANSNUCLEAIRE	CHAPTER 1 - APPENDIX 6			Page 1 of 3
		Name	Signature	Date
SAFETY FILE TN-UO_2	Prepared by	P. MALALEL		
	Checked by	F. POTELLE		
Ref. 10313-Z-1-6 / Rev. 0				
Key words: Computer ref.: S:\Dac\Commun\Dossiers de Sûreté\TN-UO2\USA\10313Z1-6.doc				

DROP TEST REPORTS

CONTENTS

REVISION SHEET

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

1. SUBJECT

This appendix presents the reports on the various mechanical qualification tests in normal and transport accident conditions <1> and <2>, performed on the two series of full-scale prototypes of the TN-UO_2 packaging.

The report appended in enclosure n°1 presents the results of the first series of tests performed on four prototypes (called P1, P2, P3, P4), comprising a sequence of all the tests in transport accident conditions in the various damage configurations.

The report appended in enclosure n°2 presents all the results of the tests in normal and transport accident conditions, in the various damage configurations, performed on the four prototypes P1, P2, P3, and P4.

The report appended in enclosure n°3 presents the results of the second series of tests performed on two prototypes (called P11 and P15), comprising a sequence of tests in transport accident conditions reproducing the two sequences which showed the most package damage during the first series of tests.

2. 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).

CONFIDENTIAL

AQUITAINE SCIENTIFIC AND TECHNICAL TEST CENTER

TEST REPORT

TRANSNUCLEAIRE CONTRACT

PACKAGING TN-UO2

QUALIFICATION TEST

A. BOURDETTE

Number of pages:

CONFIDENTIAL

CONTENTS

I - INTRODUCTION

These tests, performed on behalf of TRANSNUCLEAIRE, come within the framework of the qualification of the TN-UO_2 packaging (for Type A package and package for fissile materials).

II - REFERENCE DOCUMENTS

- GENERAL DOCUMENT

1/- IAEA Safety Standards - N° 6 - 1985 Edition (revised in 1990)

- SPECIFIC DOCUMENTS

2/- TRANSNUCLAIRE Procedure 10313-P-1-Issue 1 of 10 June 1998
Packaging TN-UO2 - Qualification Test Program

3/- TRANSNUCLEAIRE Design Drawing "TN-UO2", Ref. 10313 01 ind. C02 ind. A/ - 03 ind. A

4/- Test Order CESTA/DEV/SDET/GACC CI99 of 25 June 1998.

III - DEFINITION OF TEST SPECIMENS

The tests applied to four specimen packages representative of the package model comprising a TN-UO2 packaging and flask with a maximum load of 38 kg of UO_2 powder or pellets.

- Full-scale prototype of TN-UO2 packaging as defined in ref. 3.

- Flask with maximum load of 38 kg of pure iron filings, of same bulk density as UO_2 powder (~ 1.7).

The design of this packaging is presented in Figure 1.

Main characteristics of the packaging

- Inner and outer skin in stainless steel
- Outer diameter 380 mm
- Overall height: 800 mm
- Maximum total weight of packaging + flask contents: 83 kg

IV - TEST DEFINITION

The tests performed by the CESTA are the regulation tests for qualification for abnormal transport conditions, with the exception of the fire test, i.e.:

- free drop test
- plate free-drop test
- punch test

Previously, the specimens were subjected, on another site, to regulation qualification tests for normal transport conditions.

IV-1 - TEST PROGRAM

The tests to be carried out on four specimens, in chronological order, were as follows:

SPECIMEN TEST	P1 Contents 38 kg	P2 Contents 38 kg	P3 Contents 1 kg	P4 Contents 38 kg
Punch	X	X	X	X
Plate drop test		X	X	X
Free drop	X			

IV-2 - TEST SPECIFICATIONS

The test specifications are identical to those defined in reference documents 2 and 4.

They are stipulated at the moment of testing by TRANSNUCLEAIRE, taking account of the directives from the IPSN (French Nuclear Safety authority) present during testing.

IV-2-1 - PUNCH TEST

- **Operating mode**

As per IAEA Standard N° 6, chapter IV, paragraph 627, step b).

- **Severity**

Free drop from 1 meter onto standard punch, diameter 150 mm.

- **Drop configurations**

- Specimen P1:

- Impact on lid side
- Specimen center line at slant, center of gravity vertical to point of impact (inclination 20° in relation to vertical)
- Point of impact on closing ring

- Specimen P2

- Impact base side
- Specimen center line inclined 20° to vertical
- Impact point on diameter, at 75 mm from lower generating line

- Specimen P3

- Impact on generating line
- Specimen center line inclined at 30° to horizontal, lid downwards
- Center of gravity vertical to point of impact
- Point of impact at 275 mm from end, lid side

- Specimen P4

- Ditto specimen P1

- On request from IPSN, the impact point on the ring closure was brought closer to the ring itself.

NOTE: These three drop configurations are represented in Figures 2 to 4.

IV-2-2 - FREE DROP TEST

- **Operating mode**

As per IAEA Standard N° 6, chapter VI, paragraph 627, step a).

- **Severity**

9m vertical drop through onto unyielding, flat, horizontal target.

- **Drop configurations**

- Specimen P1 only:

- Impact on lid side
- Specimen center line at slant, center of gravity vertical to point of impact (inclination of 26.5°/vertical)
- Point of impact at 180° from ring closure

This test configuration is described in Figure 5.

IV-2-3 - PLATE DROP TEST

- **Operating mode**

As per IAEA Standard N° 6, chapter VI, paragraph 627, step c)

- **Severity**

Vertical drop of a 500-kg weight (solid mild steel plate, 1m x 1m, horizontal), from a height of 9 meters, onto specimen placed on unyielding target.

- **Impact configurations** (see figure 6)

- Specimen P2:

- Specimen vertical, resting on lid
- Impact on base, plate center line coincident with specimen center line

- Specimen P3:

- Horizontal specimen
- Impact on generating line damaged by previous punch test

- Specimen P4:

- Specimen at slant, resting on base, with center of gravity vertical to point of impact
- Impact on ring closure, area damaged by previous punch test

IV-3 - CHECKING ON SPECIMENS

- AFTER EACH TEST (without opening)

- Visual check of outside of specimen
- Check of closing device (no unscrewing)
- Checking of appearance of welds
- Checking that contents are not dispersed (iron powder)

- AFTER ALL TESTS (Expert examination)

- Measurement of deformation of specimen and final geometry of neutron-absorbing shield.

All checks carried out by TRANSNUCLEAIRE personnel.

V - DEFINITION OF TEST MEANS USED

V-1 - DROP INSTALLATION

- TEE/CESTA 10 T test drop gantry
- Target consisting of 300-tonne concrete reaction block, covered with 25m x 1.5m steel plate with thickness of 100 mm

V-2 - SPECIFIC FIXTURES

- Punch test

- Punch with height of 400 mm, provided by CESTA/DEV/SDET/GACC (E24 steel punch).

- Punch fixed to steel plate, itself welded to steel target described above.

- Plate drop test

- 500-kg plate supplied by TRANSNUCLEAIRE (actual weight 501 kg).

- Specimen resting on steel target, wedged (specimens P3 and P4) with polystyrene blocks (see Figure 6).

V-3 - MEANS FOR HANDLING AND DROP RELEASE

- Handling of specimen with sling provided by TRANSNUCLEAIRE.

- Handling of 500-kg plate using 4-strand sling.

- Release of specimen or plate using suitable C.M.U. pyrotechnic shackle.

VI - TEST PROCEDURES

VI-1 - PUNCH TESTS

- Setting of inclination of specimen (handling and hoisting to punch height).

- Setting of punch under the specimen, and positioning vertical to point of impact.

- Safetying of load (resting on bridge).

- Fixing of punch on target.

- Hoisting of specimen to drop height: 1 meter.

- Checking of test parameters

- Inclination: set using inclinometer
- Drop height: set with template

VI-2 - 9-M DROP HEIGHT

- Setting of specimen inclination before hoisting to drop height.

- Hoisting of specimen to 9-m drop height.

- Checking of test parameters

- Inclination: set using inclinometer
- 9-m long plumb line attached at low point of specimen

VI-3 - 500-kg PLATE DROP TESTS

- Positioning and setting of specimen on target (plumb line at winch hook).

- Slinging and hoisting of plate.

- Checking of horizontal positioning of plate.

- Hoisting of plate to drop height: 9 meters.

VII - OBSERVATIONS

VII-1 - PHOTOGRAPHS

- Specimens in test configuration
- Specimens after each test

VII-2 - VIDEO

- Recording of impacts
- Reporting

VII-3 - HIGH-SPEED FILM

- Observation of impacts with 16-mm camera running at 1000 fps.

VIII - CARRYING OUT OF TESTS

These tests were carried out at TEE/CESTA on 29 and 30 June 1998.

They were carried out in the presence of M. Leroy, from the IPSN (French Nuclear Safety authority).

They were carried out as per the test program and specifications defined in paragraph IV.

IX - PRESENTATION OF RESULTS PROVIDED

These results consist, essentially, for each test, of:

- the description of the general reaction of the packaging, resulting from analysis of the high-speed film and video observations illustrated by screen grabs;

- the summary description of the condition of the packaging after the test, based on photographs;

- screen grabs and photographs relating to the eight tests performed are given in the corresponding eight appendices.

X-7 - <u>SPECIMEN P4 - PUNCH TEST</u>
(LID SIDE IMPACT, ON RING CLOSURE)

- Impact occurred in specified conditions (inclination 20°).
- Reaction of packaging to the impact is fully similar as that observed during the same test on specimen P1.
- The fact that the punch impact was closer to the ring meant that the packaging became more upright during the ring closure deformation and lid base crushing phases.

X-8 - <u>SPECIMEN P4 - PLATE DROP TEST</u>
(LID SIDE IMPACT, ON RING CLOSURE)

- When impact occurred, the plate had an inclination of around 4° to horizontal, essentially a transverse orientation in relation to the packaging.
- The packaging crushing phase (crushing of circular edges on impact side and ground side), during which inclination of the packaging remained more or less unchanged, had a duration of # 12 ms.
- After this, the packaging tipped over its base and escaped from the plate, of which the residual speed was around 4 to 5 m/s (for a theoretical impact speed of 13.28 m/s).
- The plate impacted the packaging again, base side, after this had fallen onto the target.

XI- SUMMARY DESCRIPTION OF CONDITION OF PACKAGING

- <u>SPECIMEN P1</u> - (LID SIDE IMPACTS)

- **<u>Punch test</u>** (see photographs in Appendix 1)

The ring closure acted as a spring; the actual ring was only slightly deformed.

The detailed results of inspection of the condition of the packaging after testing and final expert examination will form the subject of a report from TRANSNUCLEAIRE, responsible for carrying out the inspections.

X - GENERAL REACTION OF PACKAGING

X-1 - SPECIMEN P1 - PUNCH TEST (IMPACT ON LID SIDE, ON RING CLOSURE)

- Impact took place in specified conditions:

- inclination of the packaging: 20 ° (± 0.5°);
- point of impact away from the ring closure.

- On impact, the ring closure was bent and moved back in relation to the punch onto which the base of the lid falls. The duration of this impact phase was around 25 ms.
- After this impact phase, the packaging rebounded.
- As soon as impact on the ring closure occurred, the packaging began to come upright; this continued during the rebound phase.
- The packaging fell onto the punch at the moment t = 250 ms

- its vertical inclination was between 16° and 17°;
- the point of impact was in the central part of the lid.

- After this second impact the packaging pivoted and fell onto the target.

X-2 - SPECIMEN P1 - 9-METER FREE DROP TEST (IMPACT ON LID SIDE, AT 180° FROM THE RING CLOSURE)

- During fall, the inclination of the packaging changed. At impact, it was 32° (± 0.5°), for an initial setting of 26.5°.
- The phase of crushing of the circular impact edge had a duration of around 25 ms. During this time, the inclination of the packaging went from 32 to 49°.

On the base of the lid, the punch caused a crescent shaped dent with a chord of 120 mm and bend of 55 mm, with a maximum depth of 24 mm.

- **9-m free drop test** (see Appendix 2)

The circular edge was crushed on both sides of the point of impact, over a sector of around 90°.

Wrinkling of the packaging side wall had a tendency to consolidate closure.

- SPECIMEN P2 (BASE SIDE IMPACTS)

- **Punch test** (see Appendix 3)

The damage, on the base of the packaging, was limited to a crescent shaped dent with a depth of 15 mm.

- **Plate drop test** (see Appendix 4)

The side wall was wrinkled, on both base (impact side) and lid side (ground side).

Total residual crushing was around 100 mm.

On the lid side, resting on the ground, collapse of the central part was observed (or lid base), under the effect of the thrust of the packaging contents. The closing system was more or less intact.

- SPECIMEN P3 (IMPACTS ON GENERATING LINE)

- **Punch test** (see Appendix 5)

The punch caused a crescent shaped dent with a depth of around 15 mm, at the impact generating line.

- **Plate drop test** (see Appendix 6)

- Lid side

The packaging was severely crushed, but the lid and closing ring remained in place.

It had a more or less square cross section:

- height: 230 mm (residual crushing of 150 mm)
- width: 465 mm

Phenolic foam, shredded, belonging to the upper cap of the packaging, was ejected via the sealing surface.

- Base side

- Vertical diameter: 310 mm (crushing of 70 mm)
- Horizontal diameter: 395 mm

- SPECIMEN P4 (IMPACTS ON LID SIDE)

- **Punch test** (see Appendix 7)

Results comparable with those of test performed on specimen P1, the ring closure being more deformed.

- **Plate drop test** (see Appendix 8)

The circular edges on the impact side (lid) and ground bearing side (base) had a flattened area due to crushing, with wrinkling of the packaging wall.

Crushing heights, along the impact center line, are respectively around 125 and 100 mm.

- Beyond the area of impact, rebound from the target occurred and the packaging continued its rotation in the vertical plane of its fall until it impacted the target on its base side:

  - its inclination to horizontal was around 25°;
  - the impact occurred at t = 105 ms

- After this second impact the packaging continued its rotation until impact occurred on the generating line on the opposite side.

X-3 - <u>SPECIMEN P2 - PUNCH TEST</u>
(IMPACT ON BASE SIDE)

- Impact occurred in specified conditions (inclination of 20°).

- Base crushing phase had a duration of around 10 ms.

- As soon as impact occurred, the packaging began to come upright and this continued during the rebound phase.

- The packaging fell onto the punch at the moment t = 260 ms

  - its inclination to vertical was 4°;
  - the point of impact was on the side opposite that of the initial impact.

- After this second impact, the packaging pivoted on the punch and fell onto the target.

X-4 - <u>SPECIMEN P2 - PLATE DROP TEST</u>
(FLAT IMPACT, BASE SIDE)

- On impact, the plate had an inclination of around 4.5° in relation to the horizontal plane.

- The packaging crushing phase had a duration of 18 ms. The total crushing under impact (base + lid side) was estimated at 115 mm.
  At the end of crushing, the inclination of the plate was 2.5°.

- After this crushing phase, the plate rebounded (Vr # 2.8 ms), as did the packaging (Vr # 0.9 ms), which also slid on the target.

- The plate fell back, at a slant, onto the edge of the packaging.

X-5 - SPECIMEN P3 - PUNCH TEST
(IMPACT ON GENERATING LINE)

- Impact occurred in specified conditions with packaging inclination of 30.5° (± 0.5°).

- The impact phase, which resulted in the formation of a localized dent and deformation along the entire generating line, had a duration of # 7 ms.

- As soon as rebound began, the packaging began to describe a rotation tending to lie it down.

- The packaging fell back onto the punch at the moment t # 260 ms:

- the impact occurred on the same generating line, at 90 mm from the end on base side;
- the inclination of the packaging in relation to horizontal was 5°, with the base downwards (opposite way round to first impact).

X-6 - SPECIMEN P3 - PLATE DROP TEST
(FLAT IMPACT ON GENERATING LINE)

- Plate impact was almost flat.

- The duration of the packaging crushing phase was # 22 ms.

- Crushing was far more severe on the lid side, where it reached a maximum value estimated at 160 mm (observation side).

- After this crushing, relaxation of deformation of the packaging was observed, followed by rebound of the plate and of the packaging itself. The rebound speeds were estimated at 2.3 m/s for the plate and 1.4 m/s for the packaging.

- The plate fell back onto the packaging, base side.

XI- SUMMARY DESCRIPTION OF CONDITION OF PACKAGING

XII - COMMENTS

Enclosed documents : 6 Figures
8 Appendices

XII - COMMENT

The tests on the various packagings were performed, overall, in relation to specifications.

Globally, and with the reservation of the results of internal expert examination, the behavior of the packaging can be considered to be satisfactory, in that its integrity, in all cases, was retained (no dispersion of contents).

FIGURES

FIGURE 1

TN-UO_2 PACKAGING DESIGN DRAWING

Cap fixed by locking ring (1)

Phenolic foam shock (2)

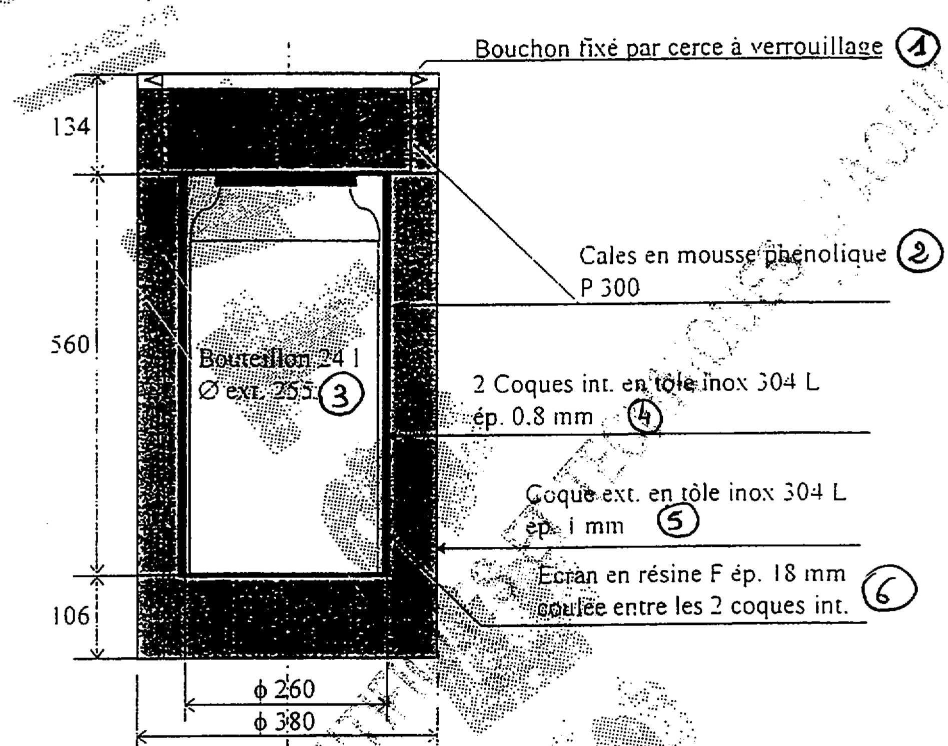
24-l flask (3)

Outer dia. 255 (3)

2 inner shells in stainless steel 304 L, thickness 0.8 mm (4)

Outer shell in stainless steel 304 L, thickness 1 mm (5)

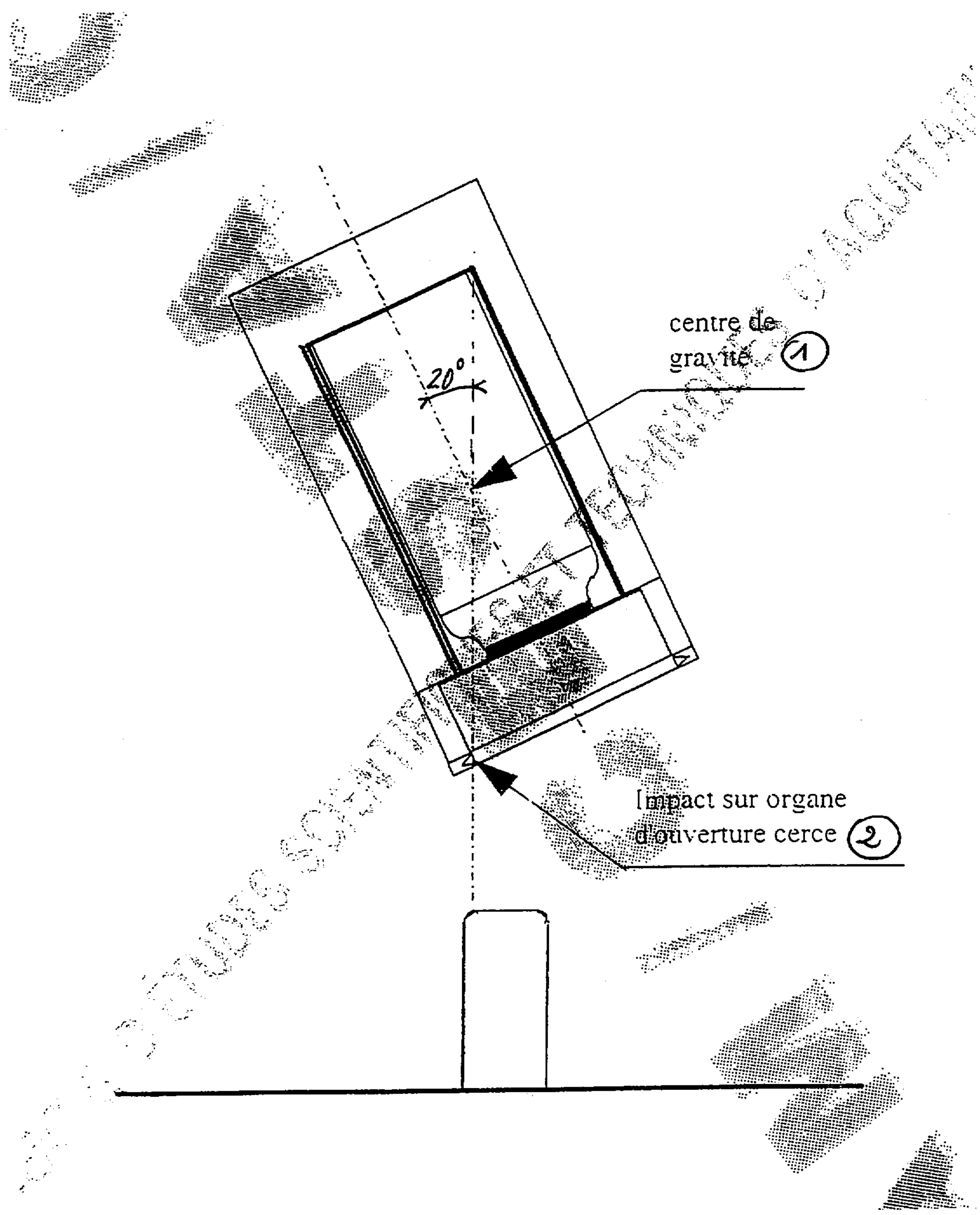
F resin shield, thickness 18 mm, poured between the two inner shells (6)



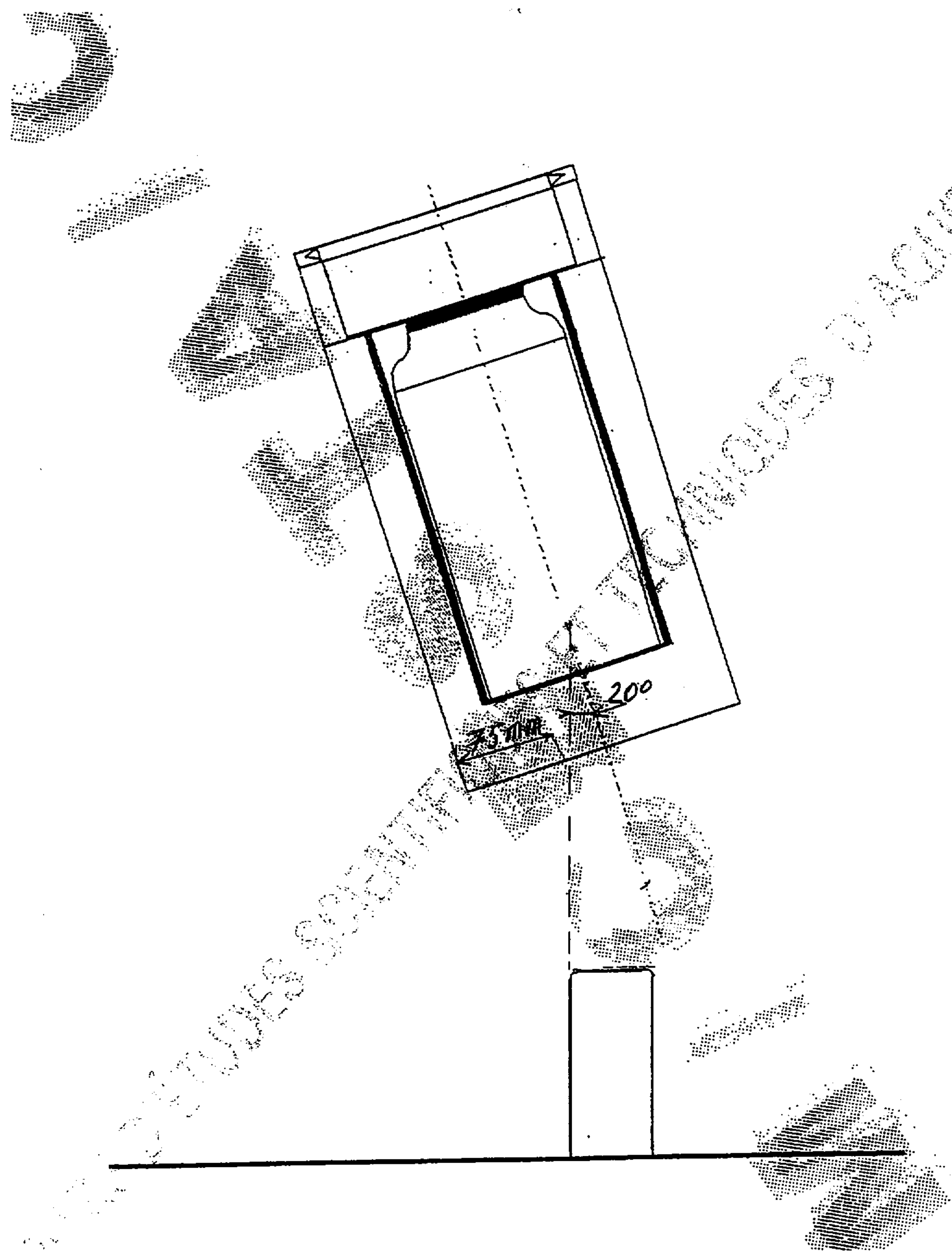
STRESS OF THE PACKAGING DURING DROPPING OF LID ONTO PUNCH

Center of gravity ①

Impact on ring opening device ②

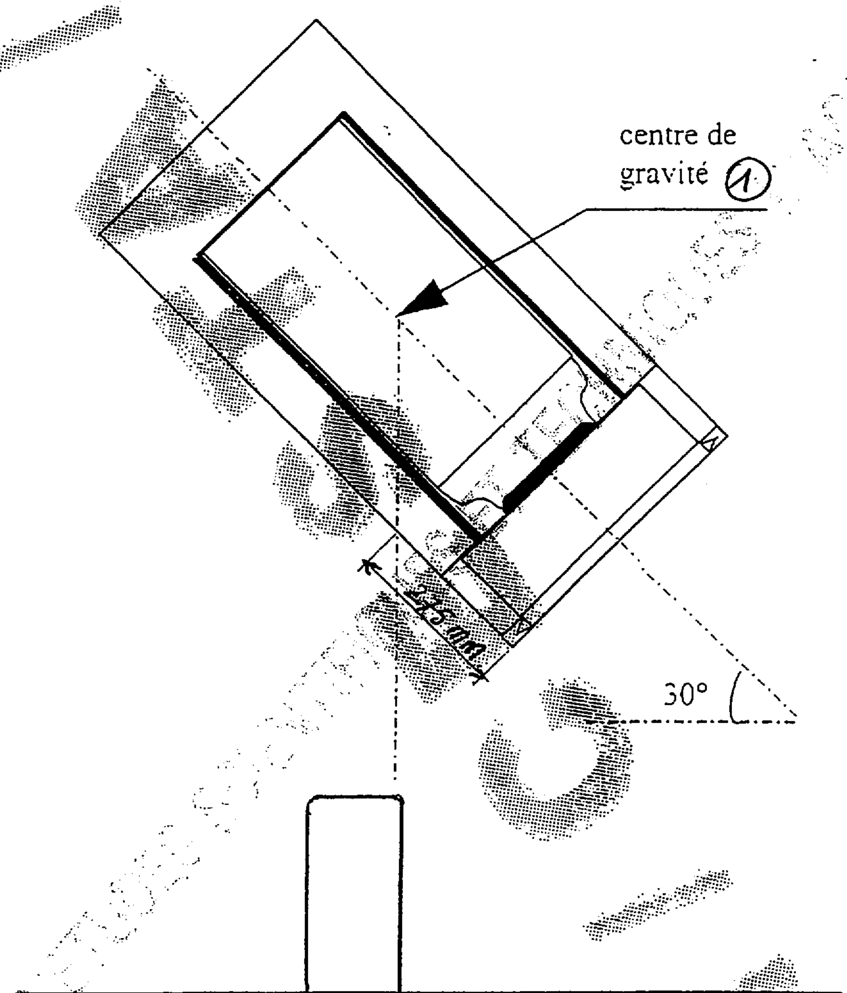


STRESS OF THE PACKAGING DURING DROPPING OF BASE ONTO PUNCH



STRESS OF THE PACKAGING DURING LATERAL DROP ONTO PUNCH

Center of gravity (1)



STRESS OF THE PACKAGING DURING SLANTED DROP

Area of opening of ring diametrically opposite to point of impact

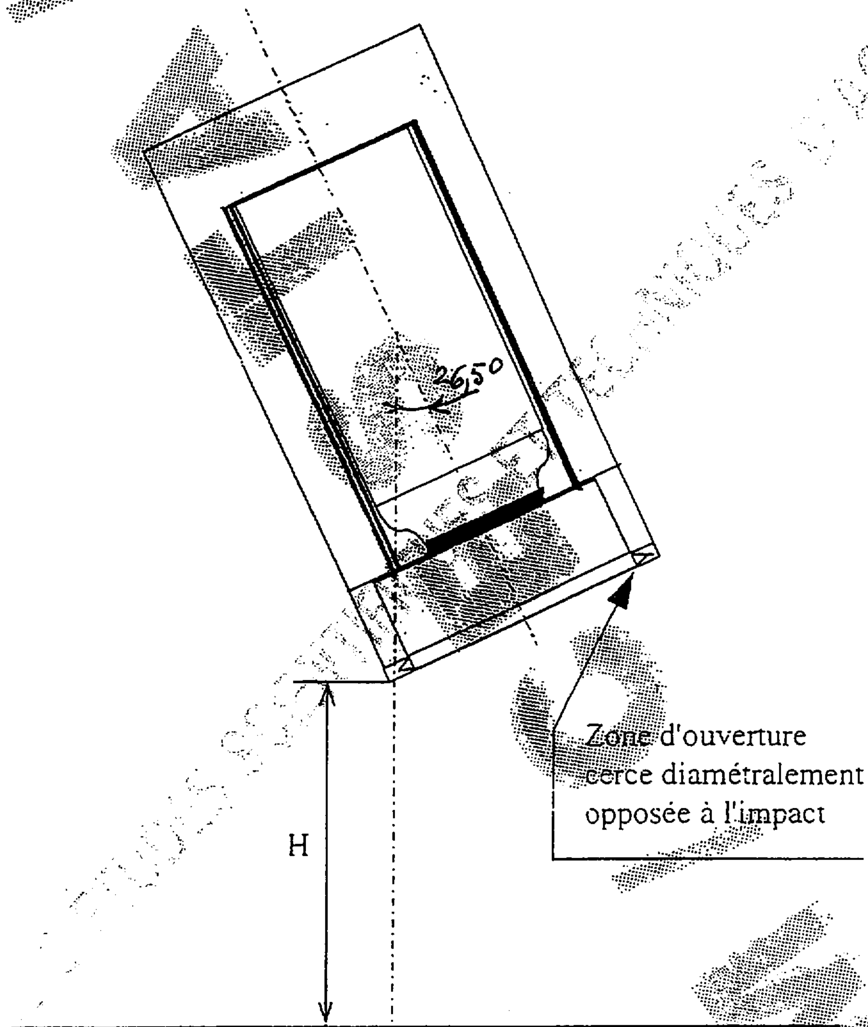
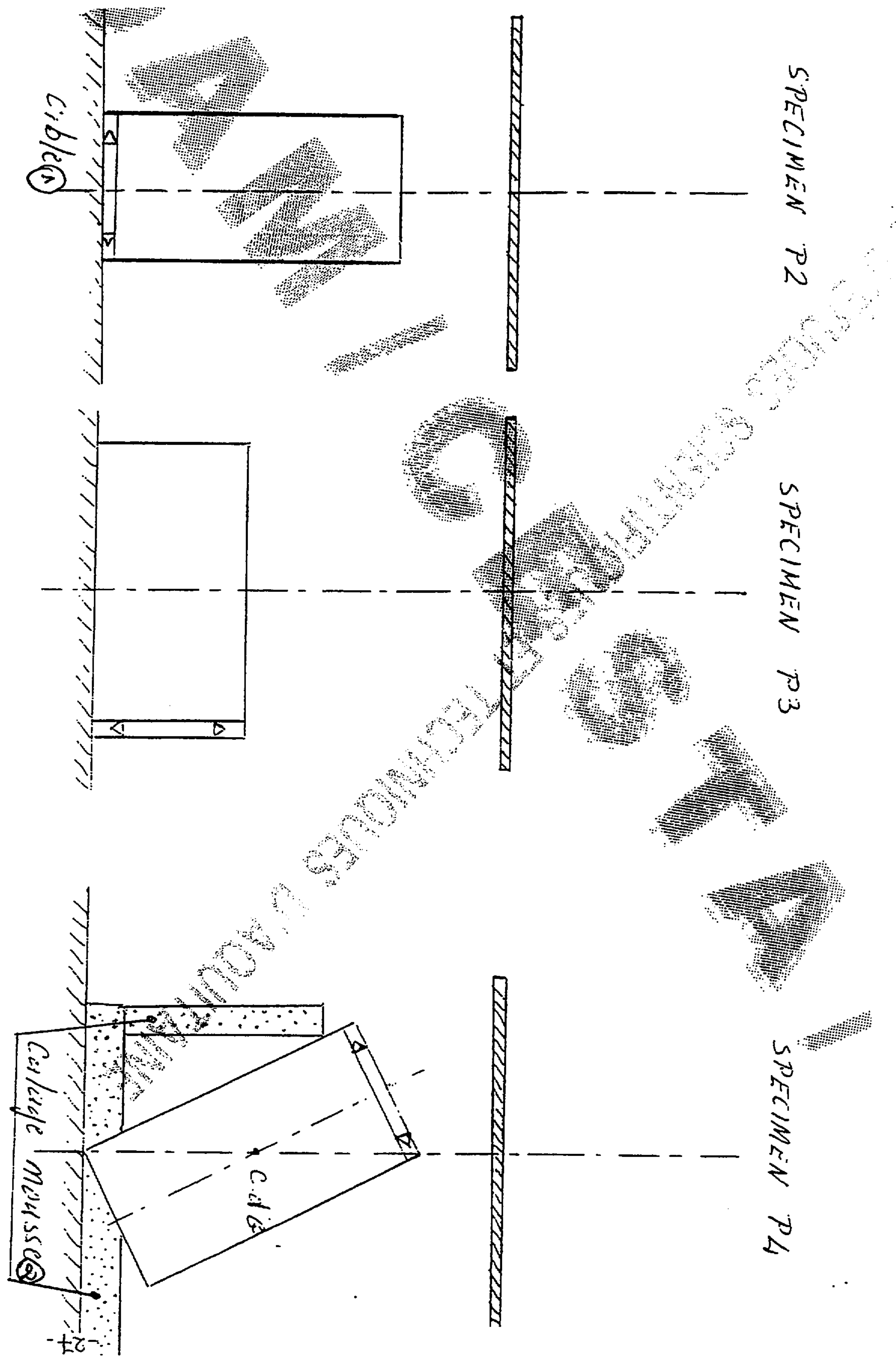


FIGURE 6

PLATE DROP TEST

CdG = Center of gravity

Target (1) Foam wedging (2)



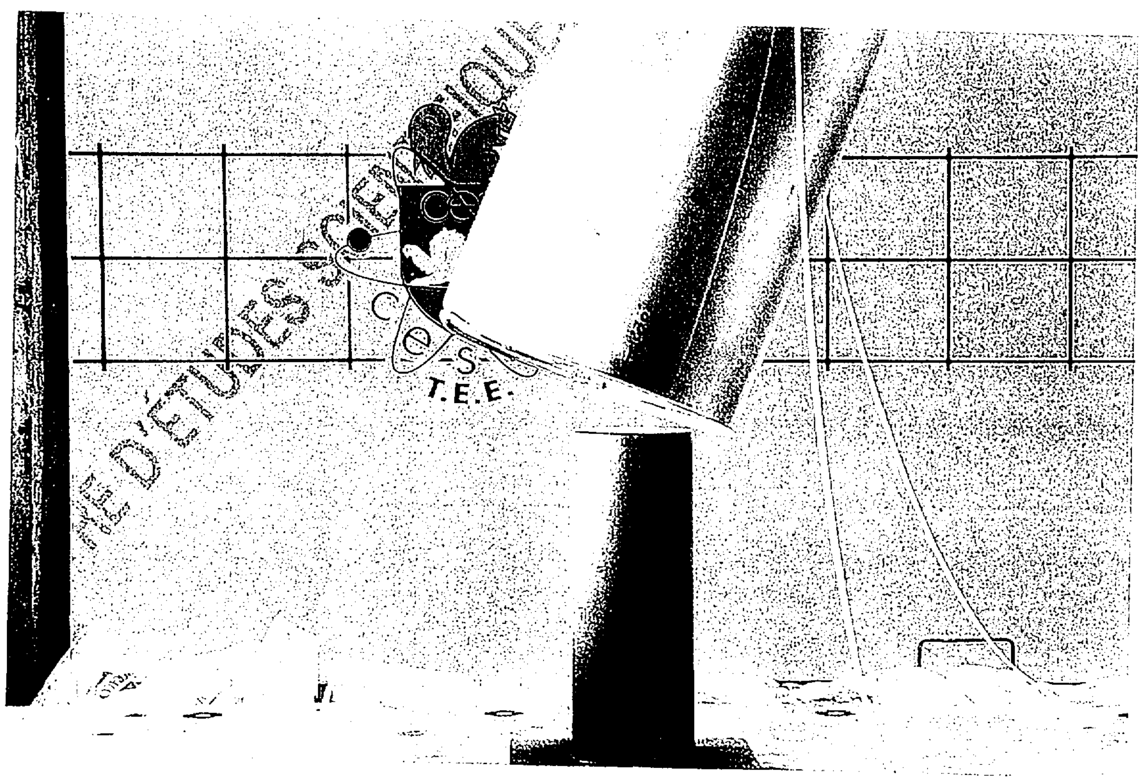
PHOTOGRAPH FILE

APPENDIX 1

SPECIMEN P1

PUNCH TEST

CONFIDENTIEL INDUSTRIEL



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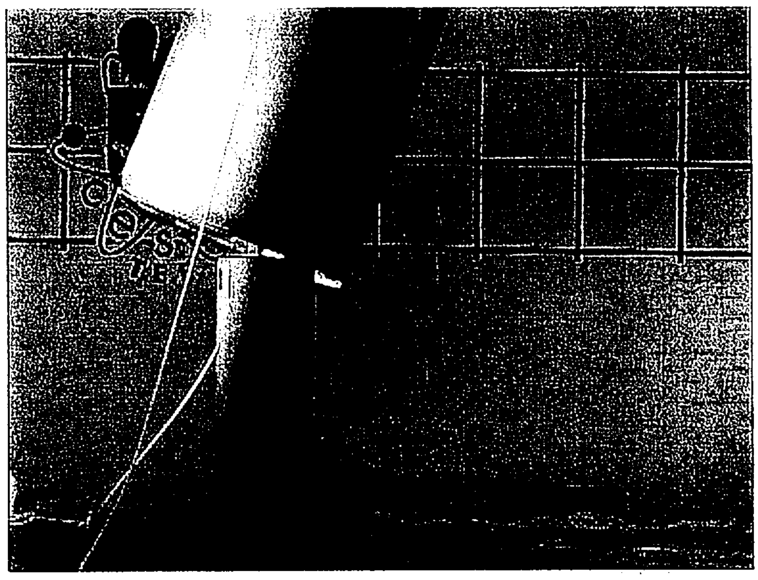

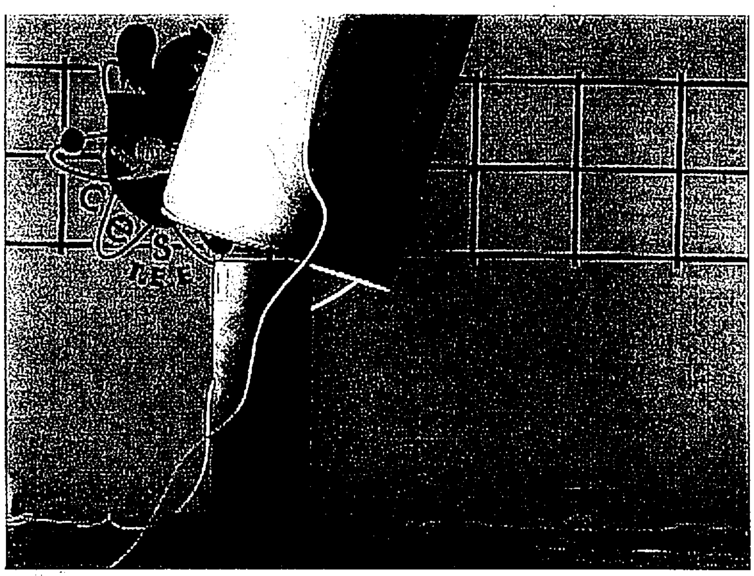

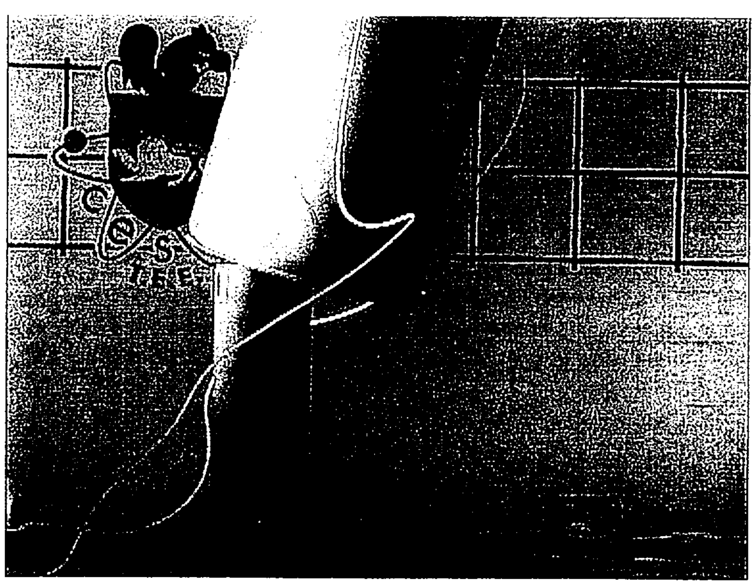

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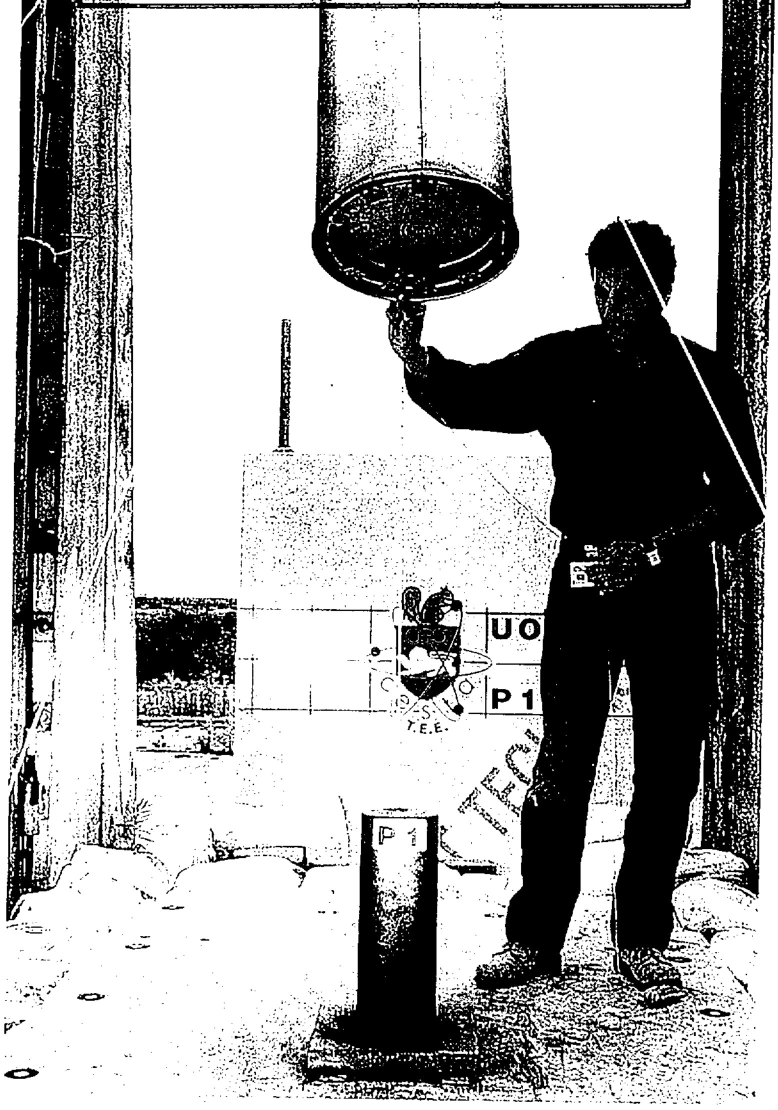
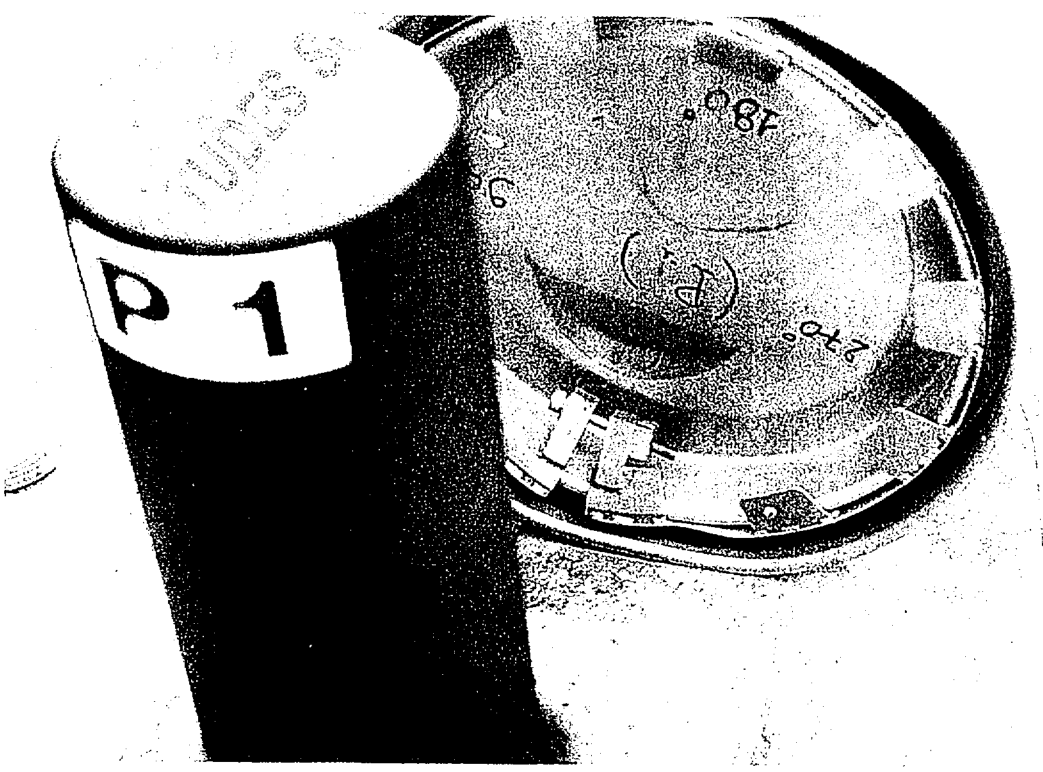
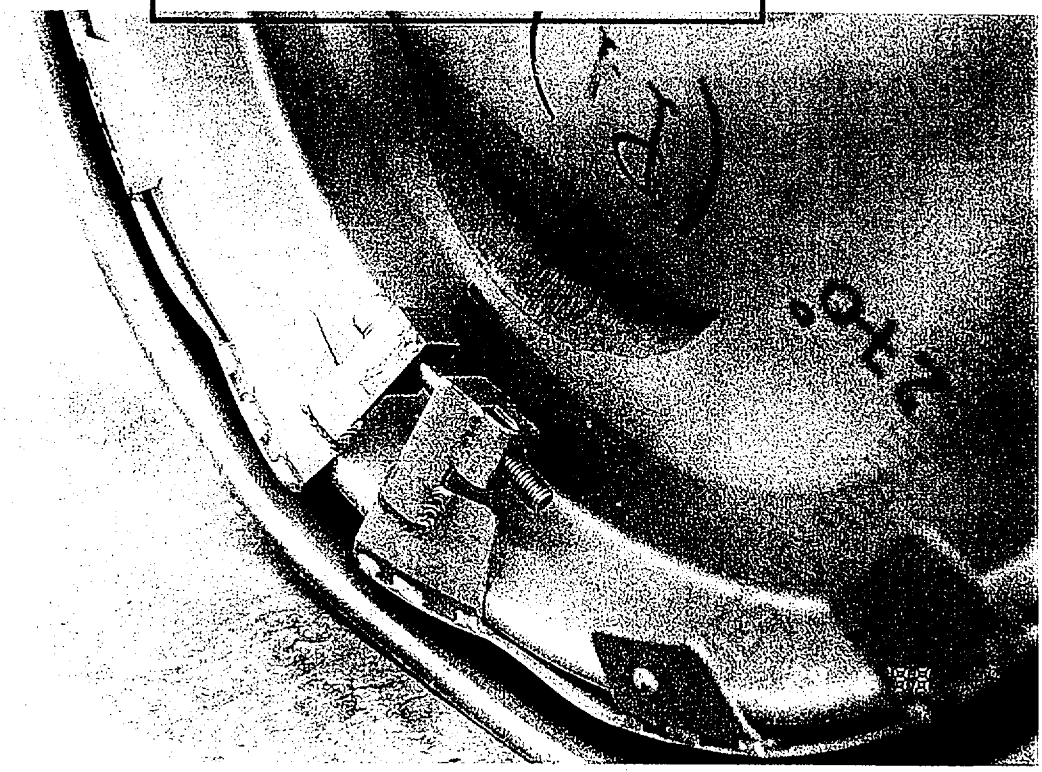
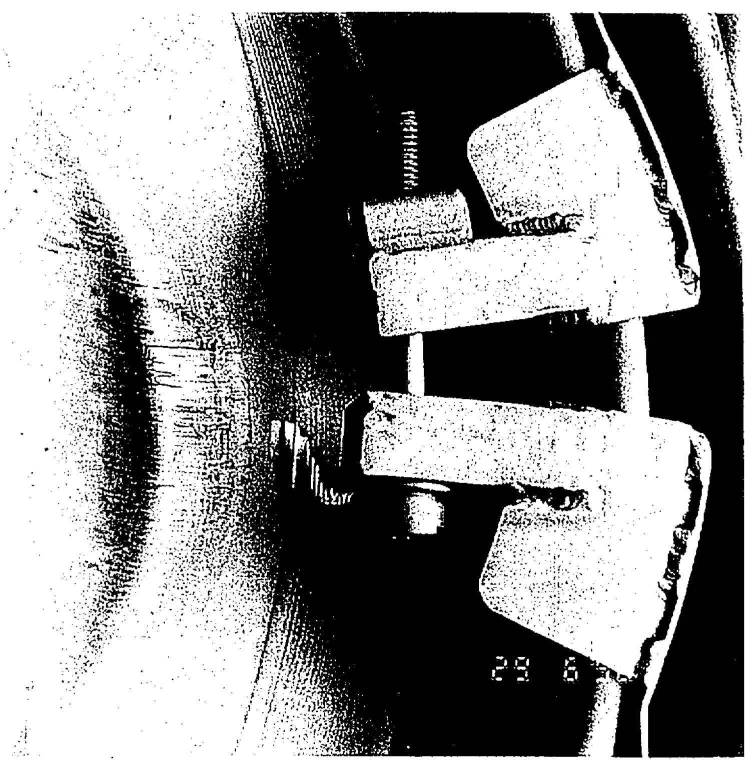








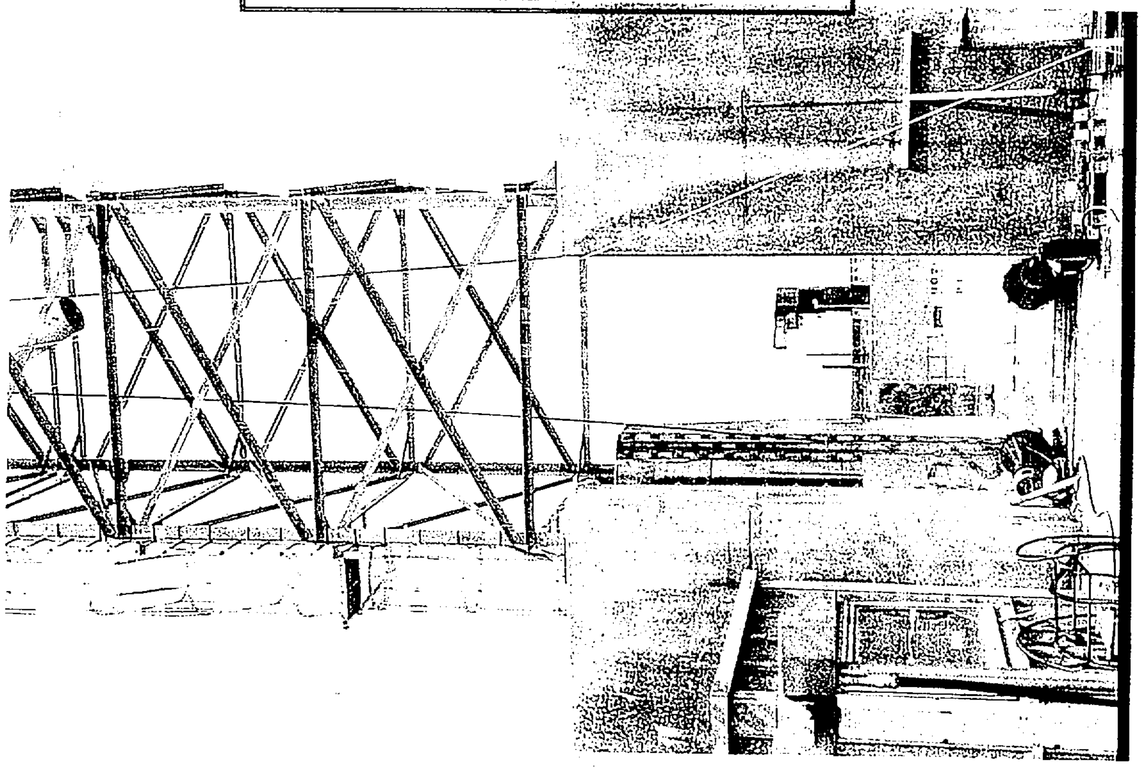
1-4

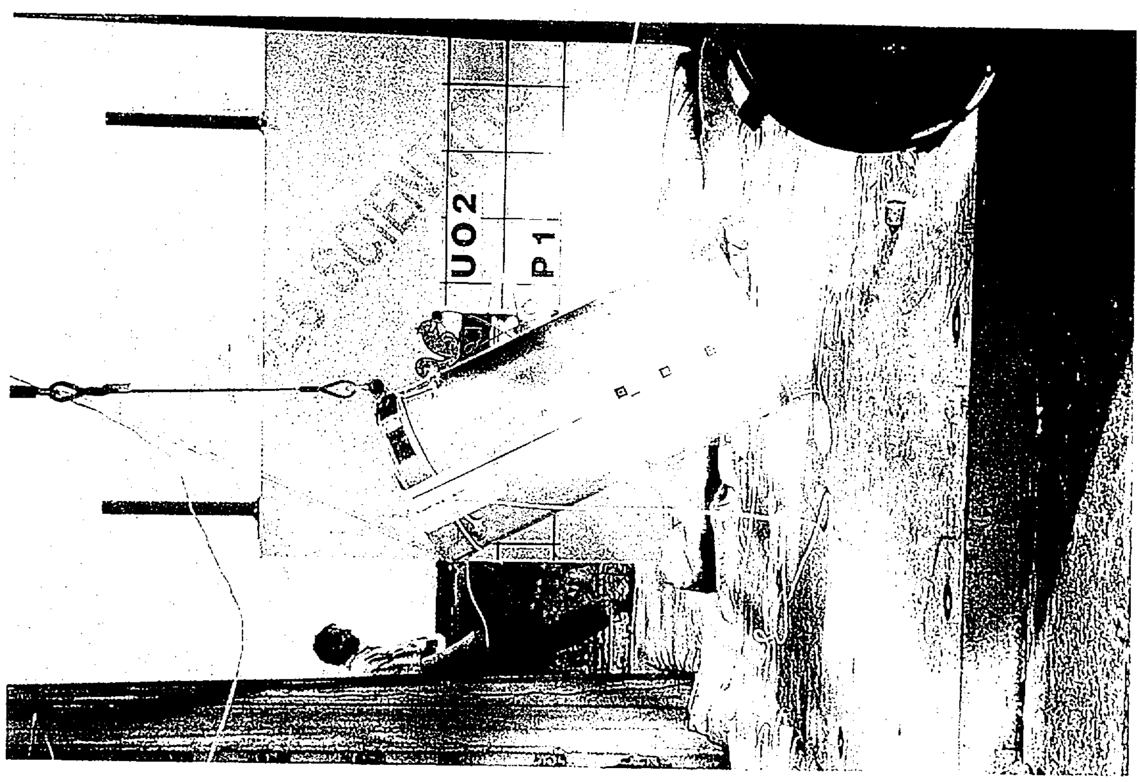
APPENDIX 2

SPECIMEN P1

9-METER DROP TEST

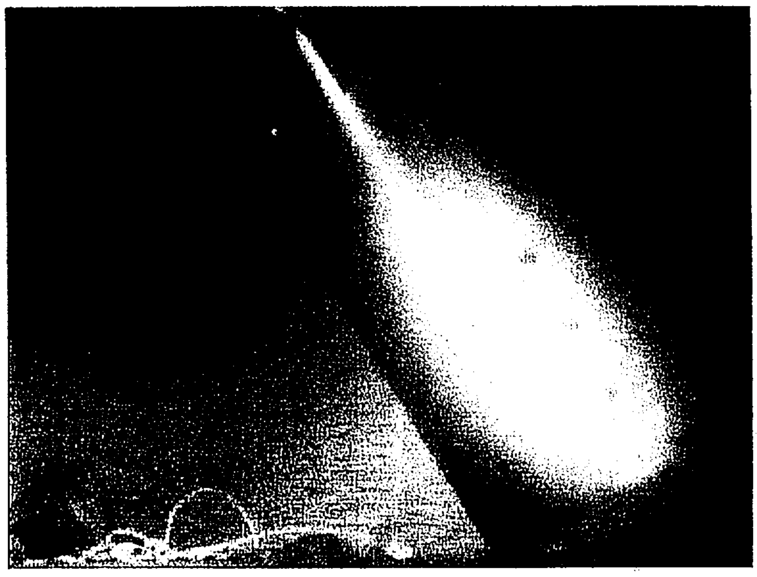
CONFIDENTIEL INDUSTRIEL

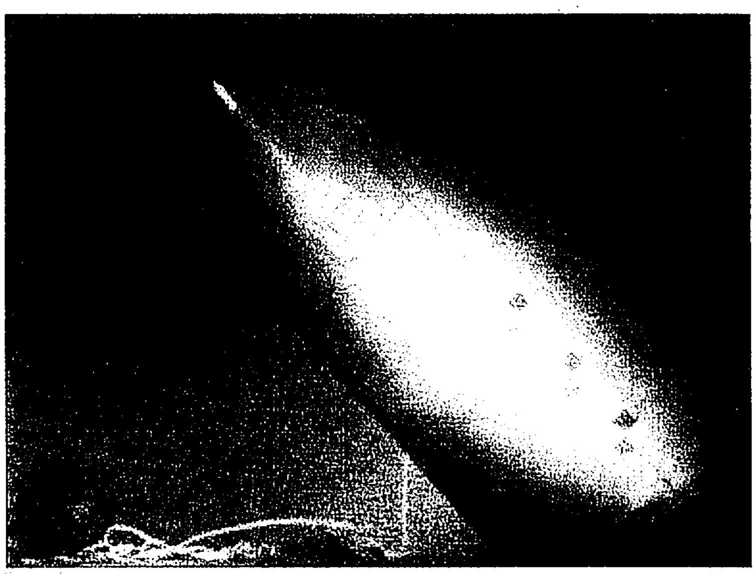




2-1

CONFIDENTIEL INDUSTRIEL





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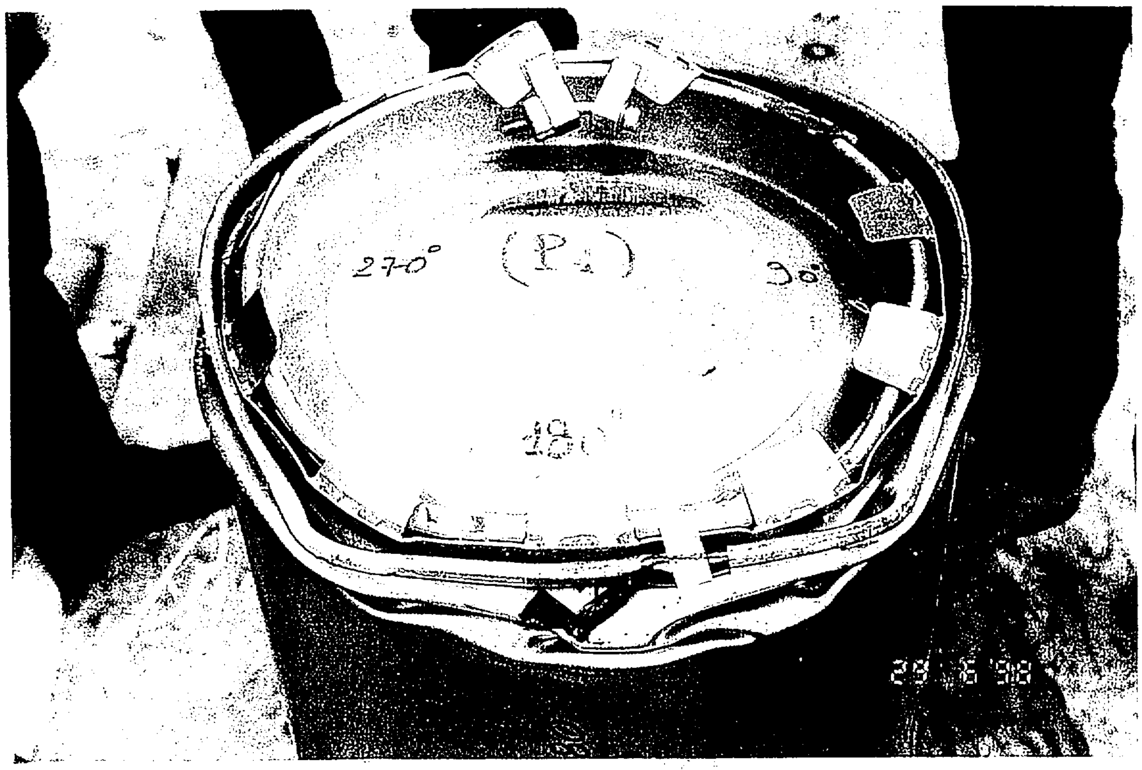
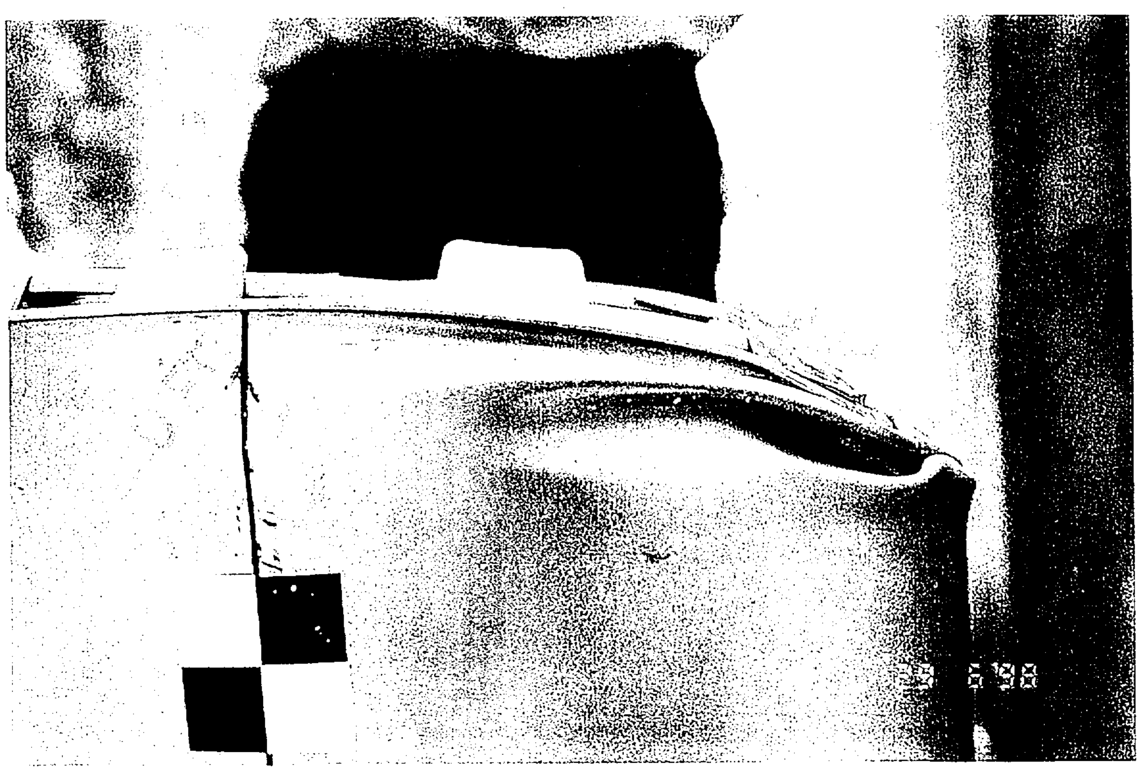




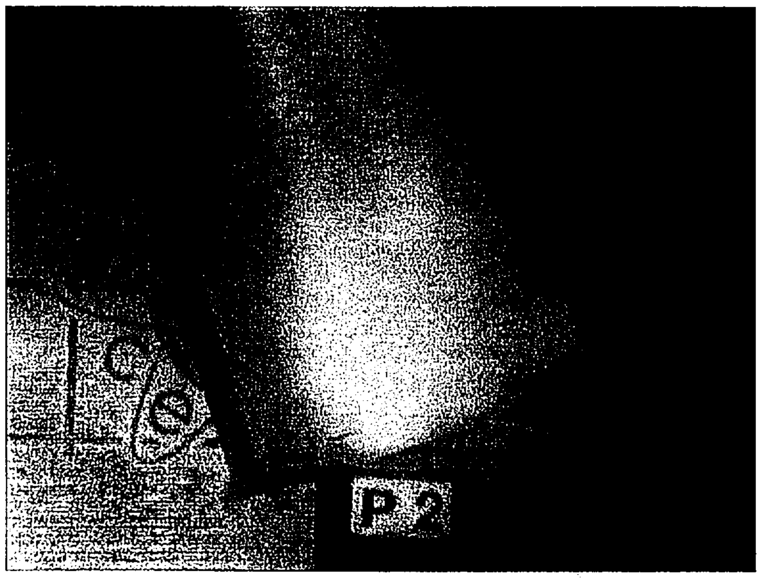
2-3

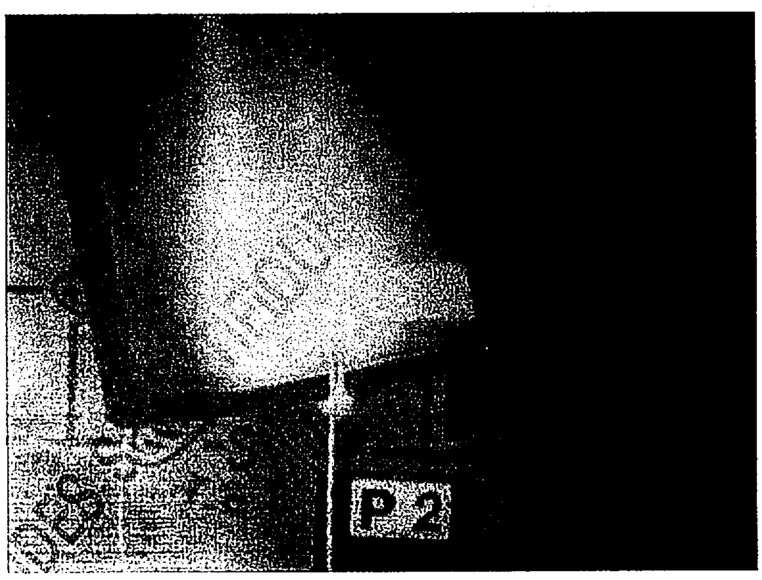
APPENDIX 3

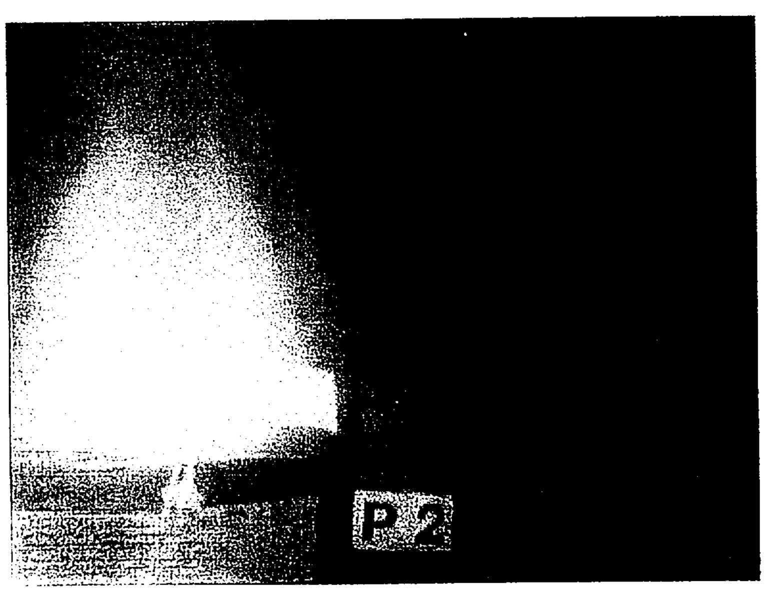
SPECIMEN P2

PUNCH TEST

CONFIDENTIEL INDUSTRIEL







3-

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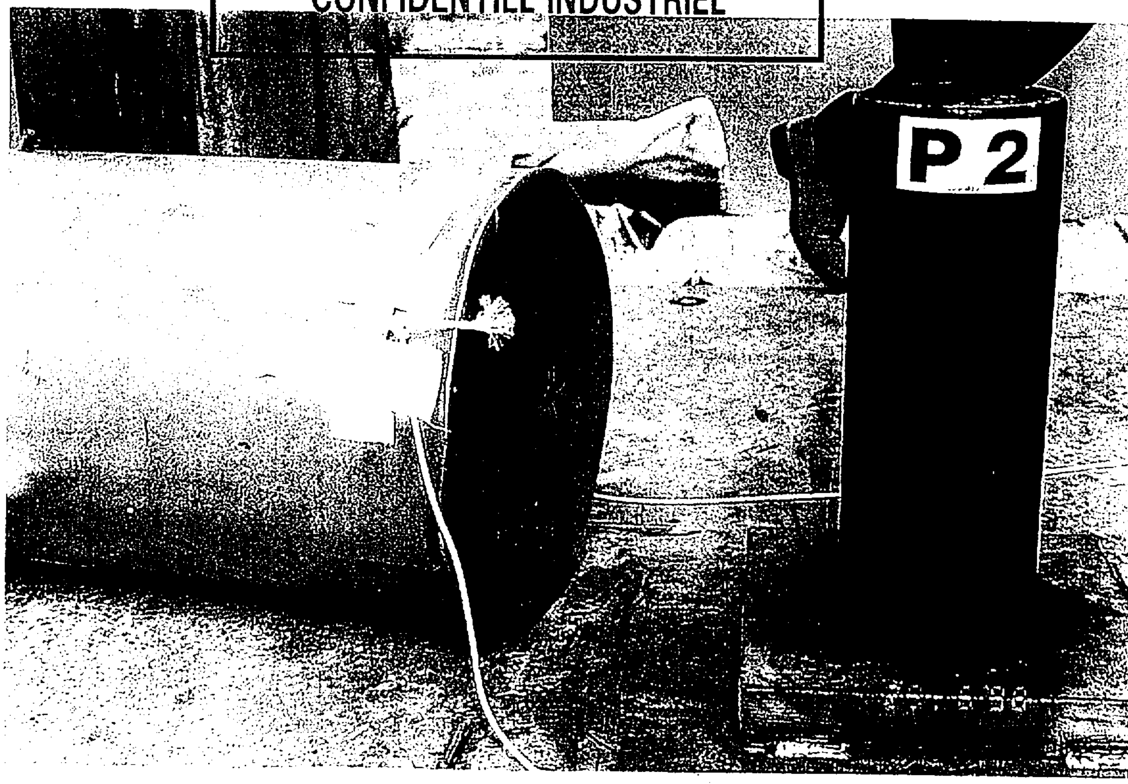
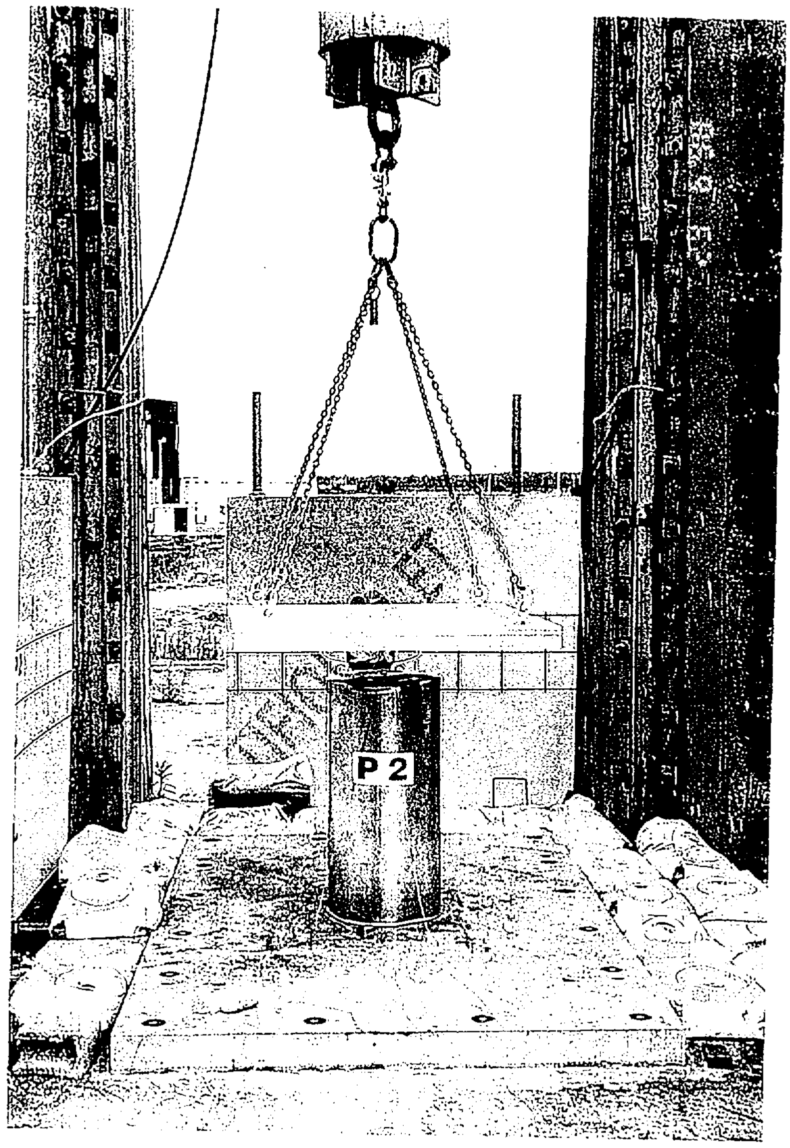


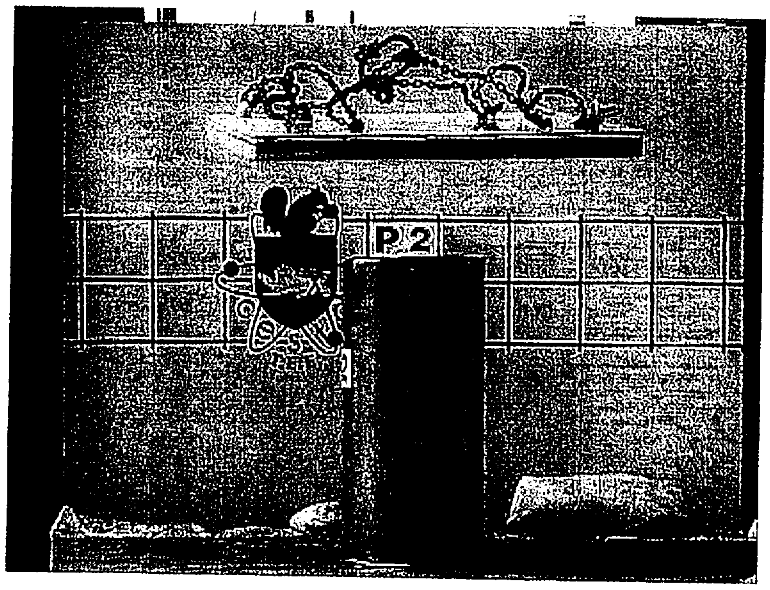
APPENDIX 4

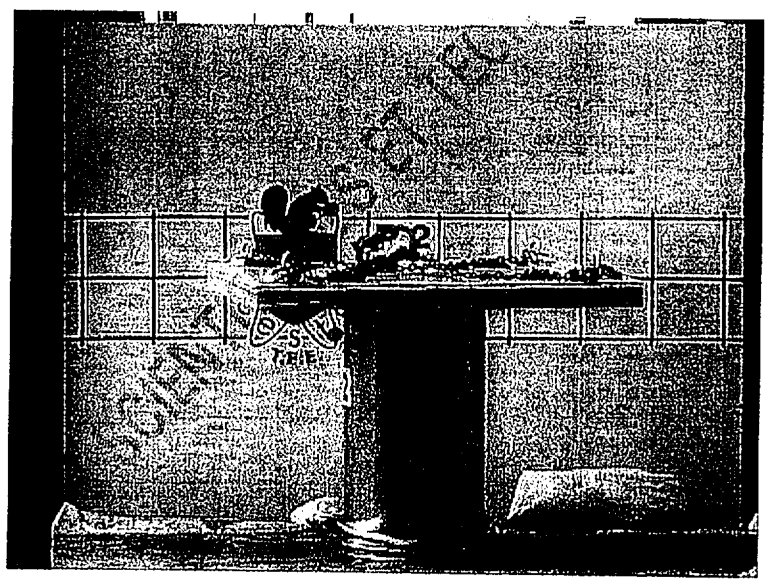
SPECIMEN P2

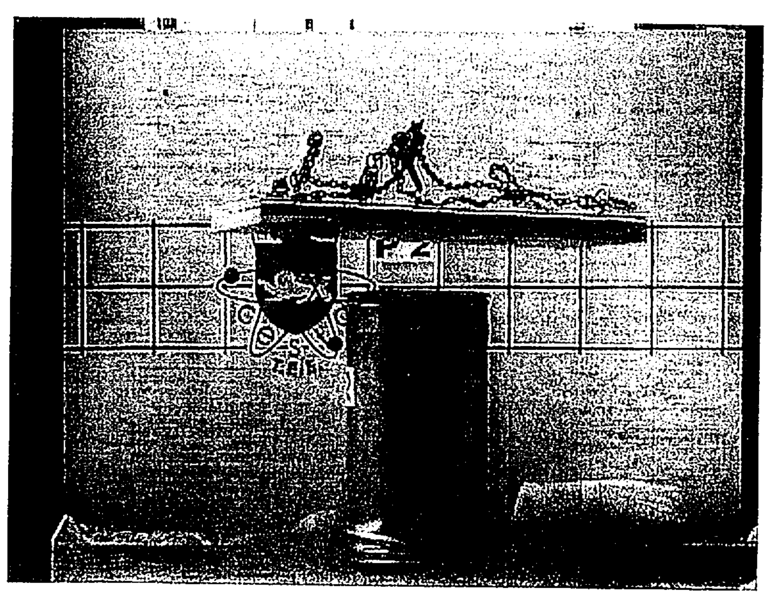
PLATE DROP TEST

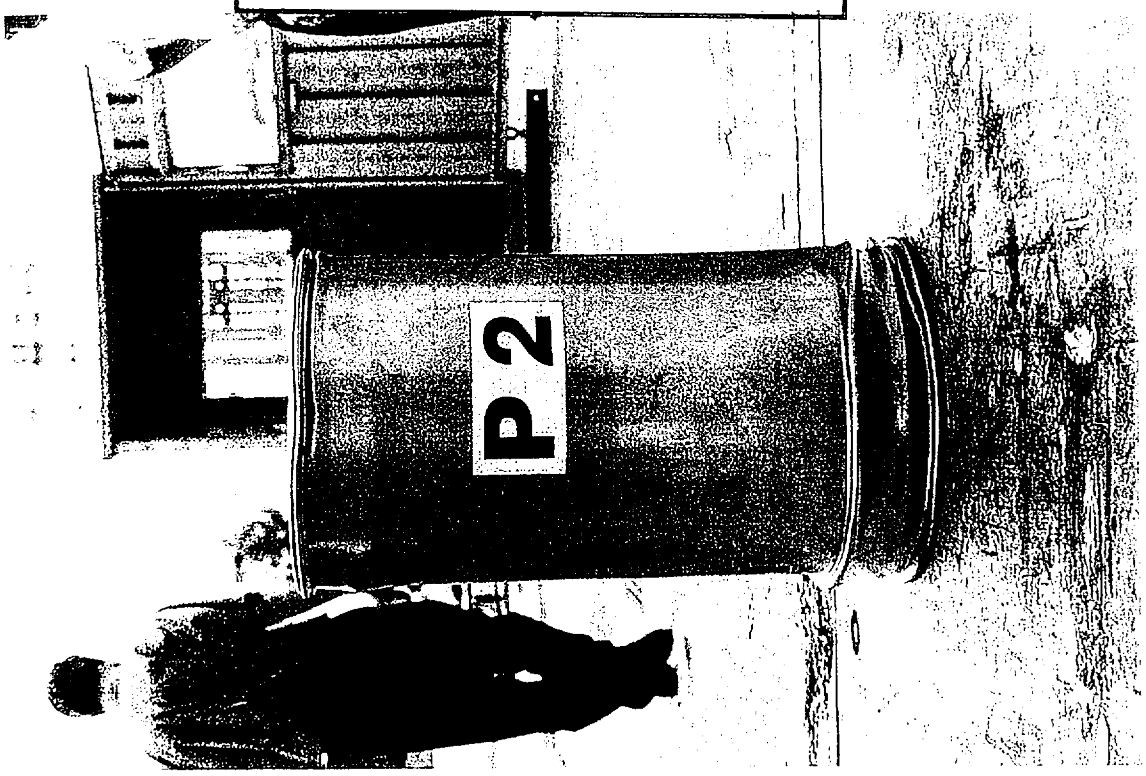

P 2

CONFIDENTIEL INDUSTRIEL





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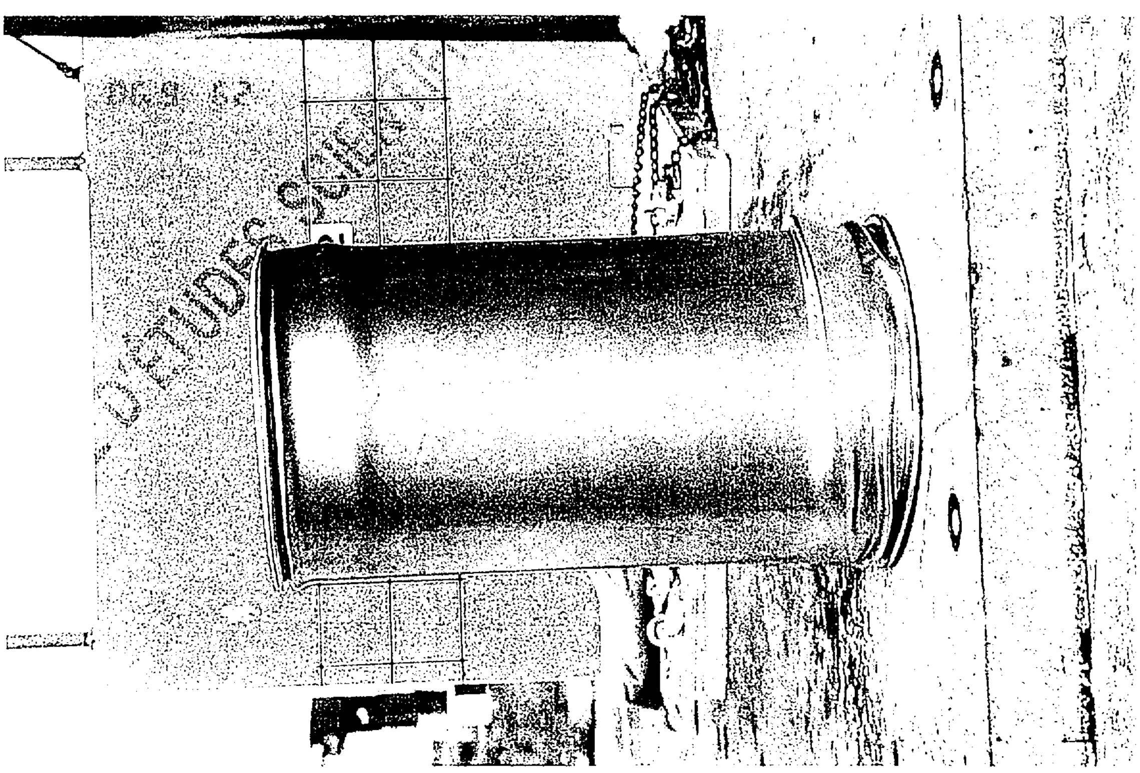
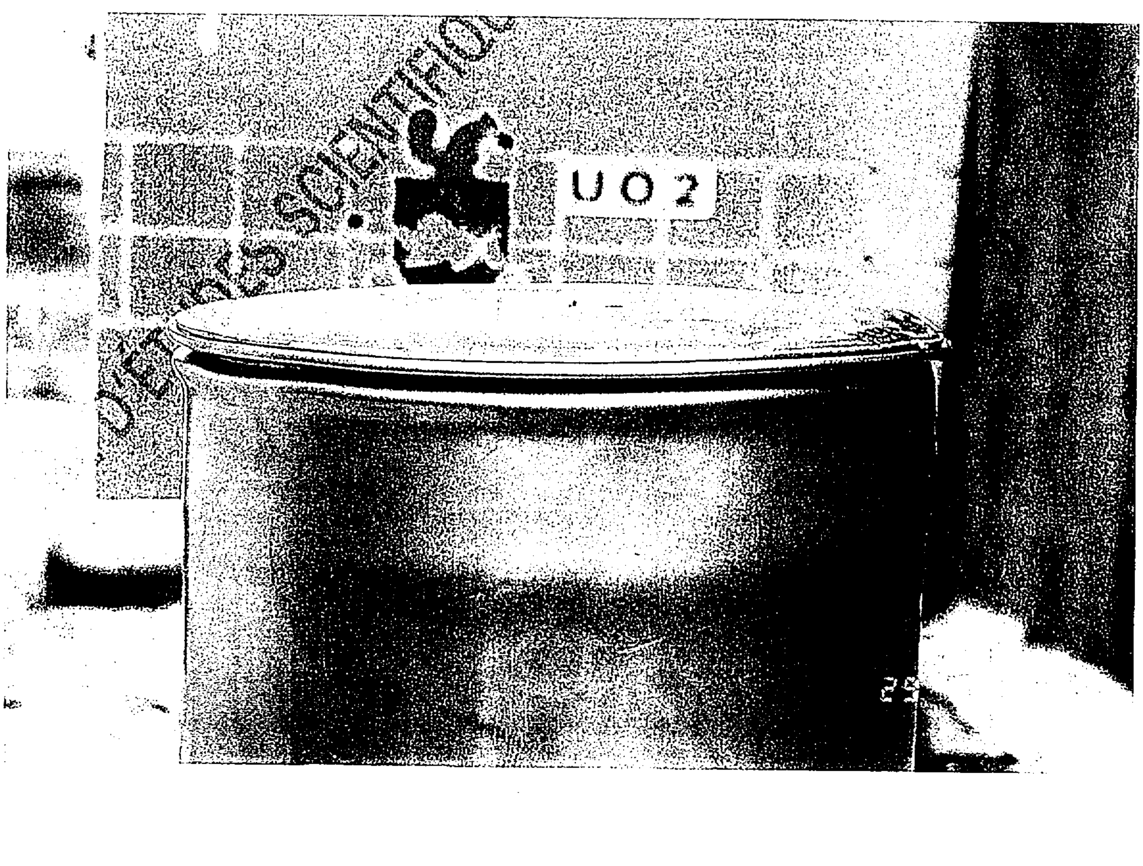


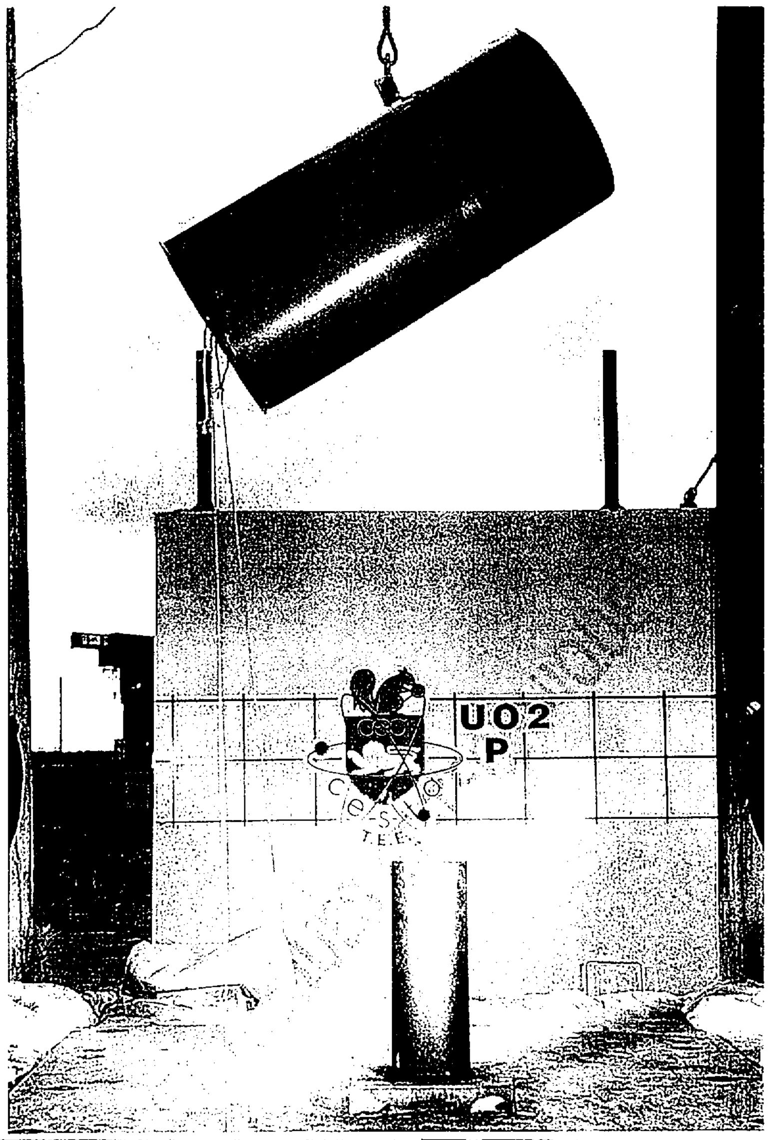

U O 2

4·

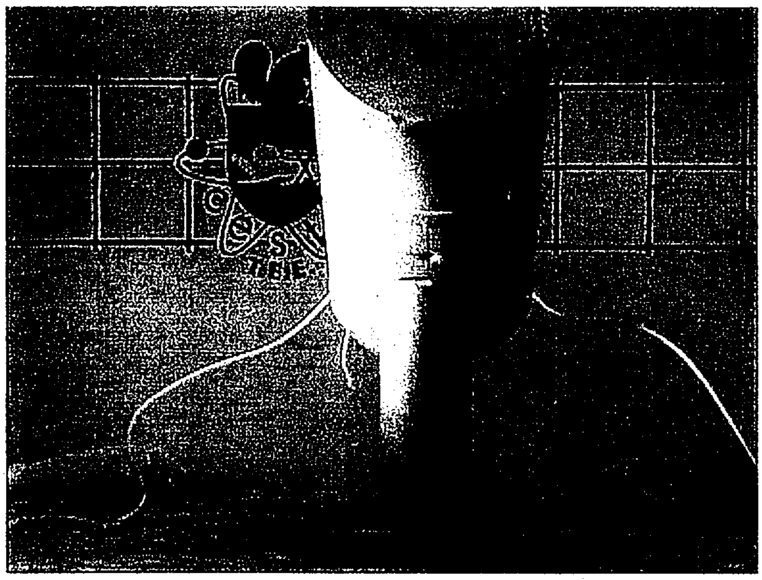
APPENDIX 5

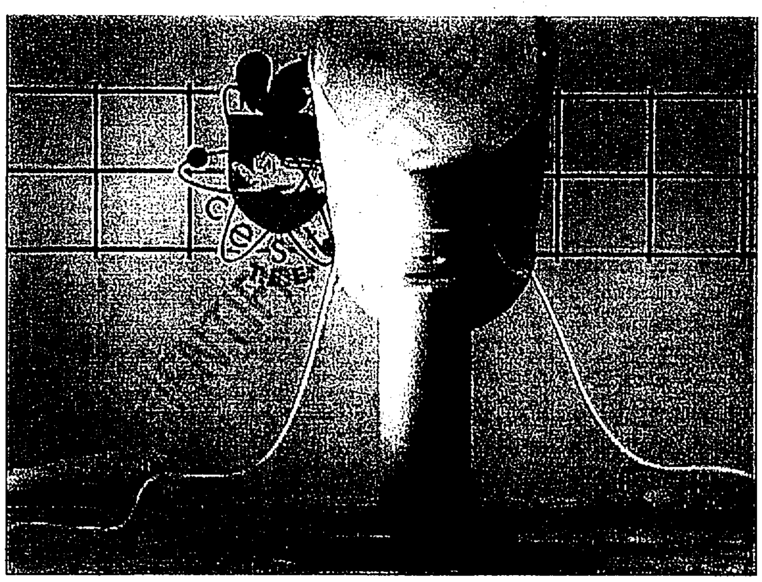
SPECIMEN P3

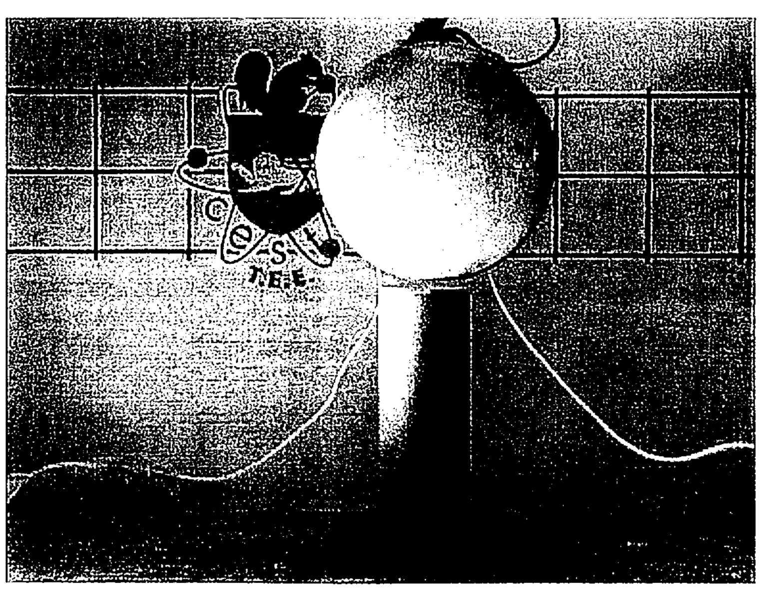
PUNCH TEST



5-1







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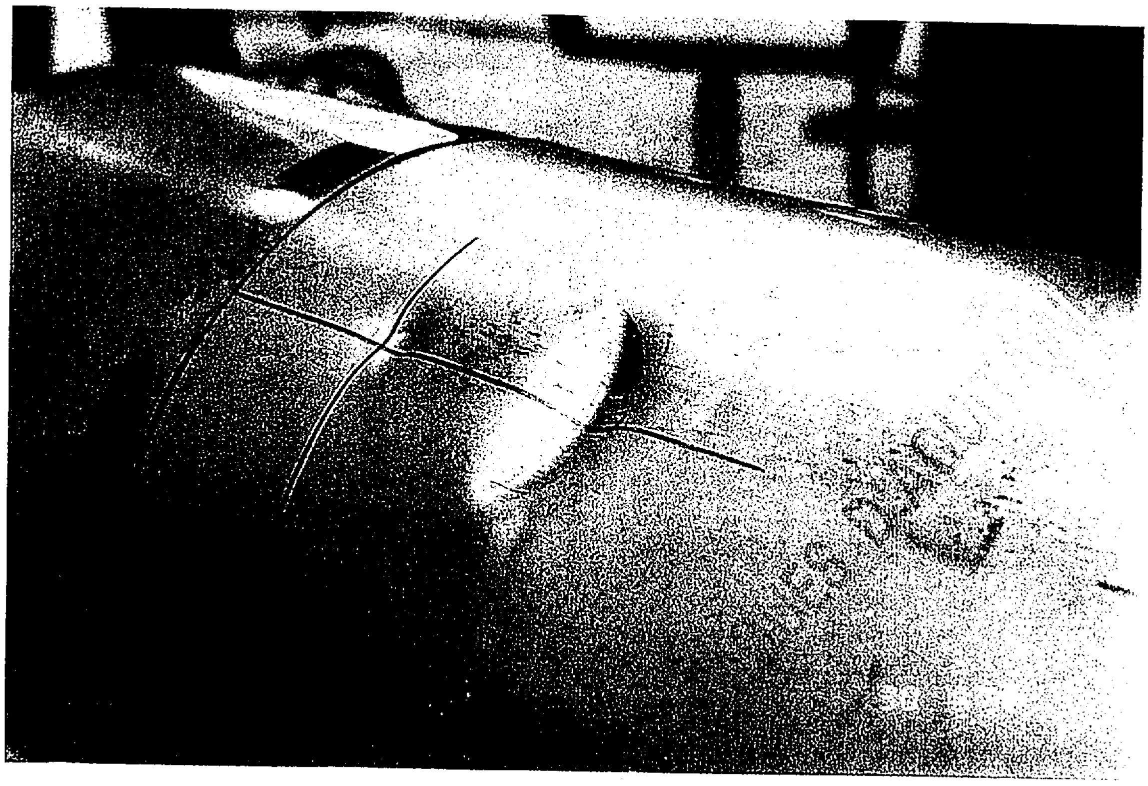
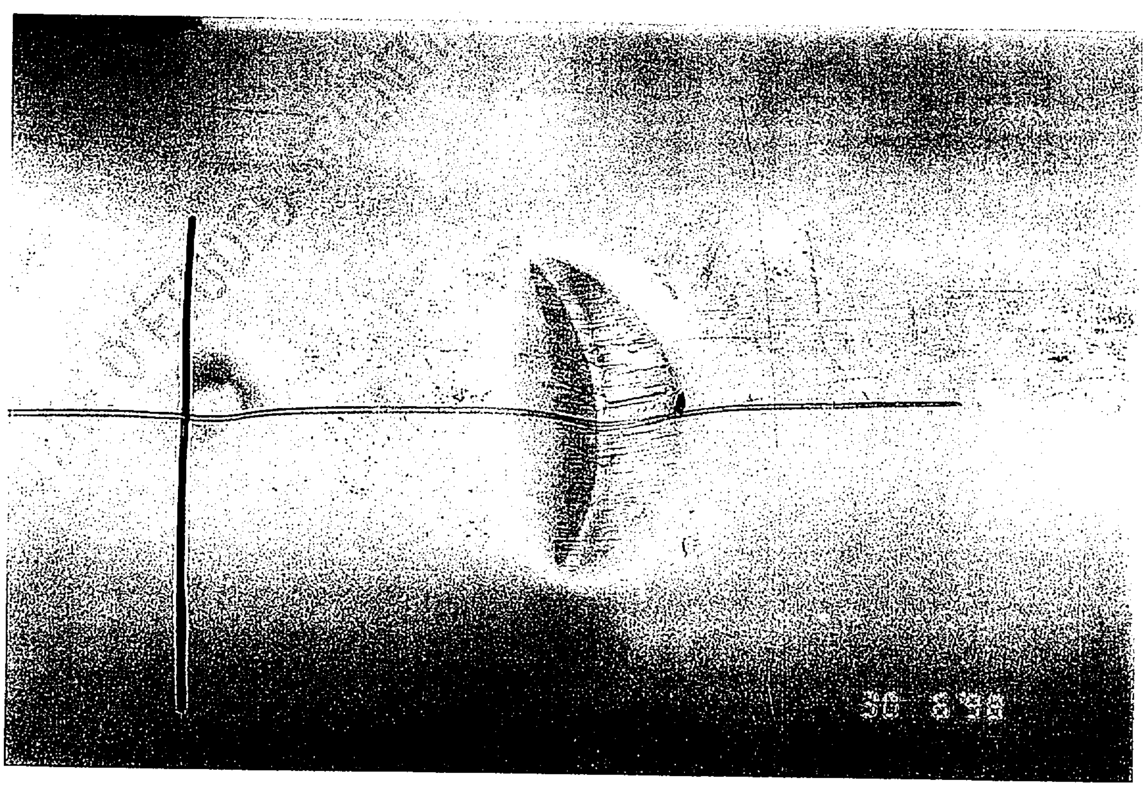


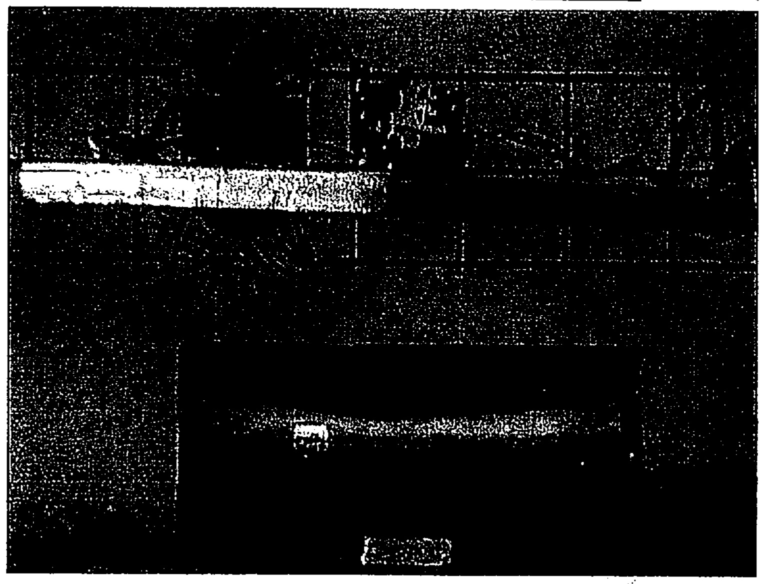


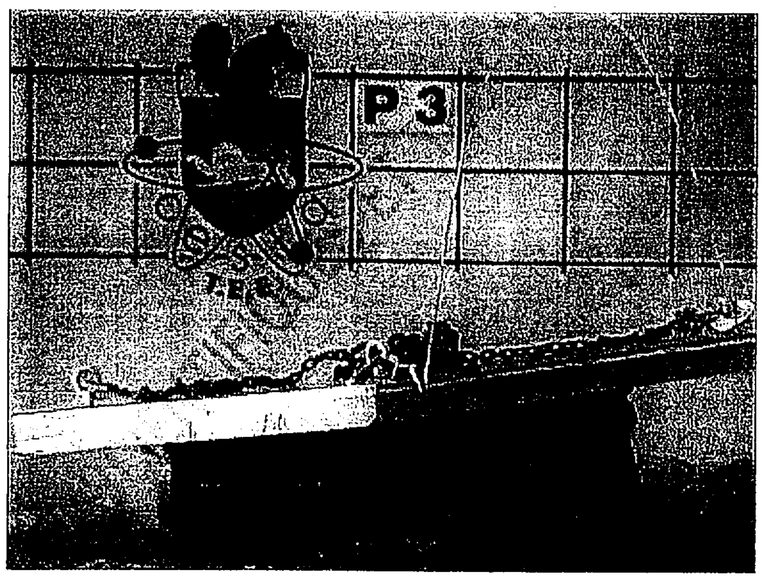
APPENDIX 6

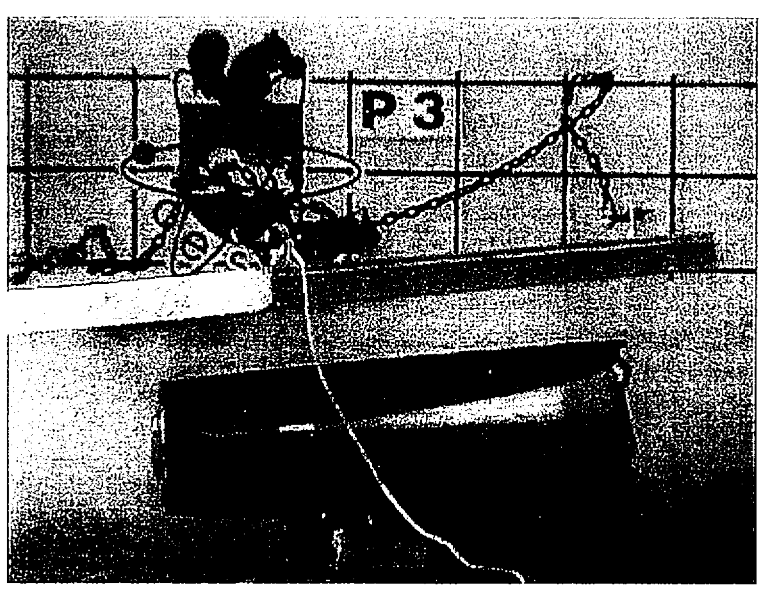
SPECIMEN P3

PLATE DROP TEST

CONFIDENTIEL INDUSTRIEL







6-1

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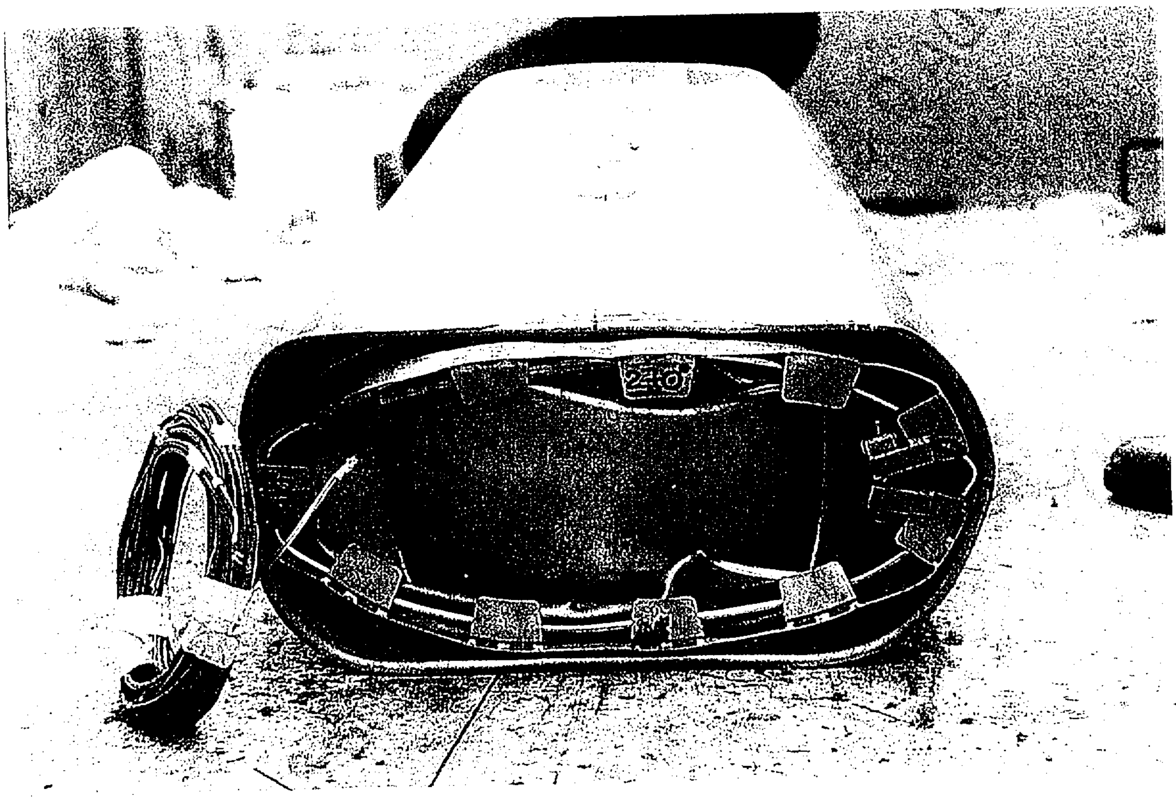

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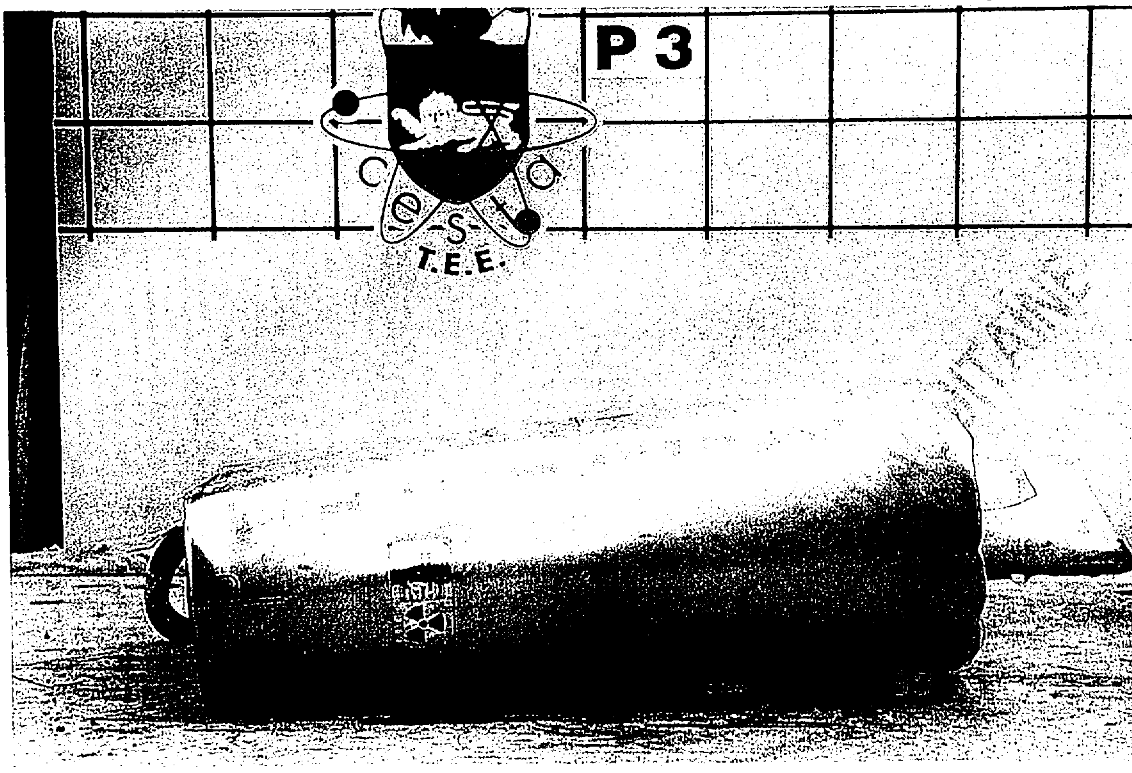
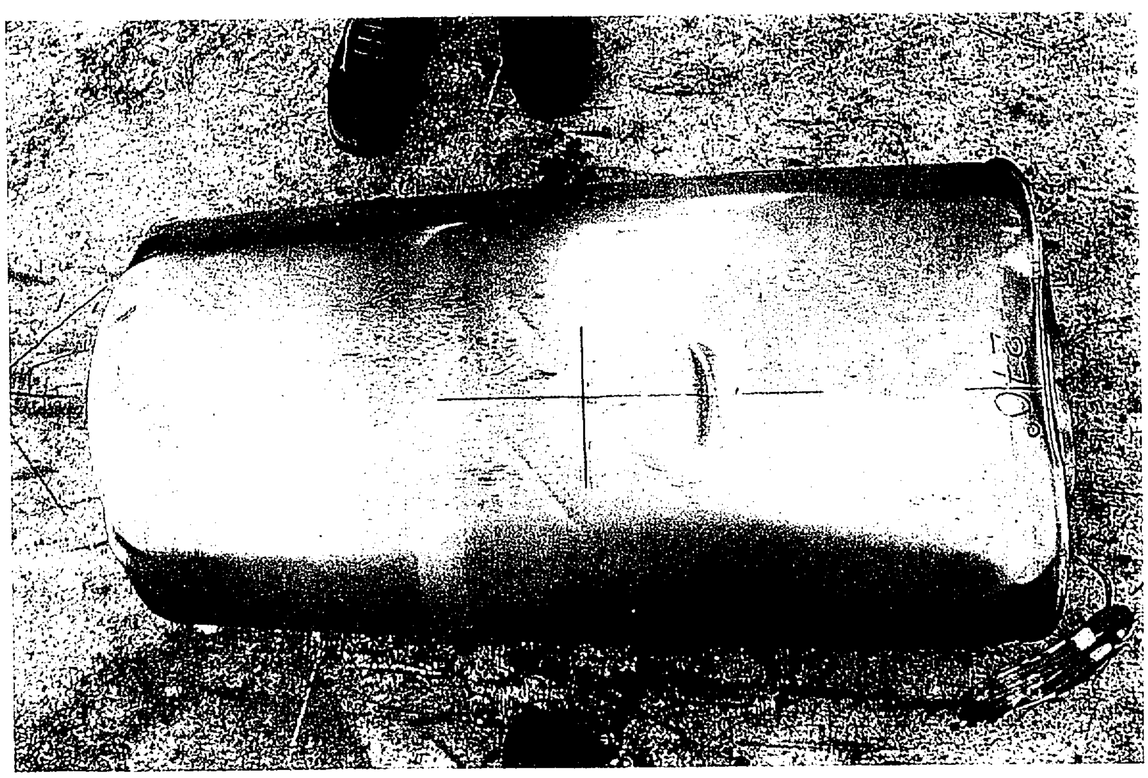

P 3
cesta
T.E.E.

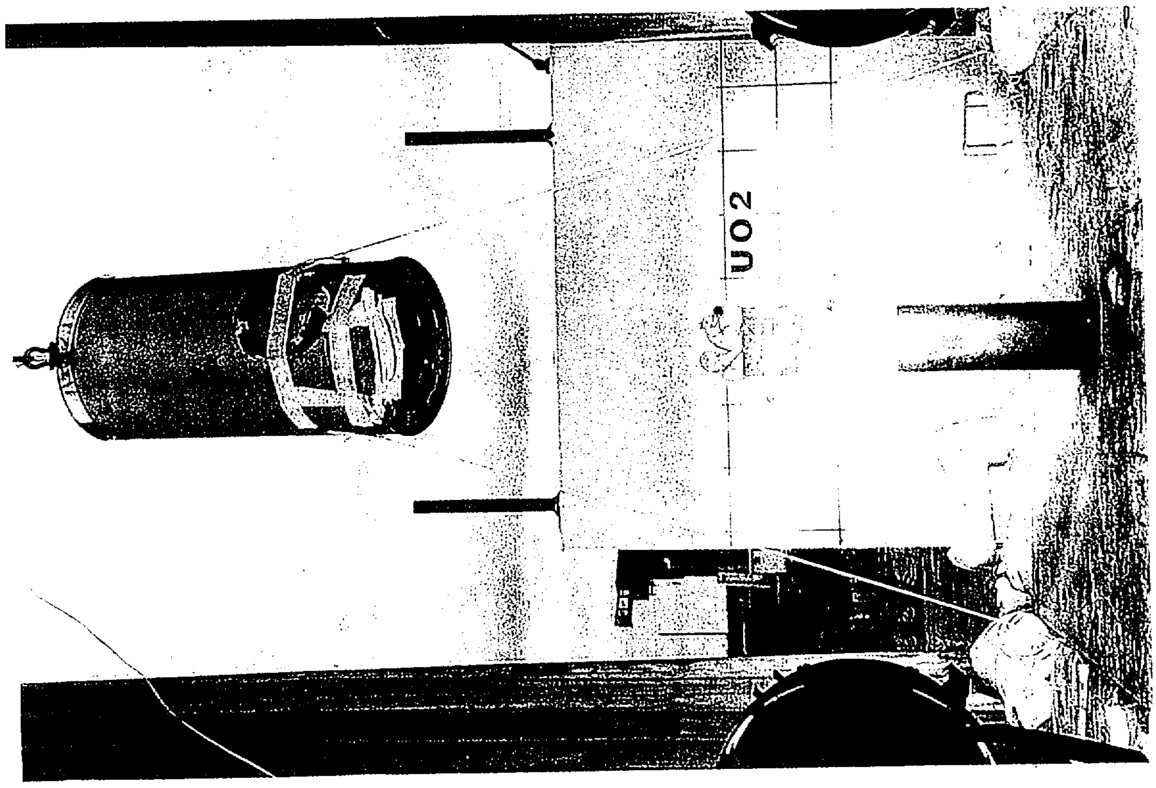


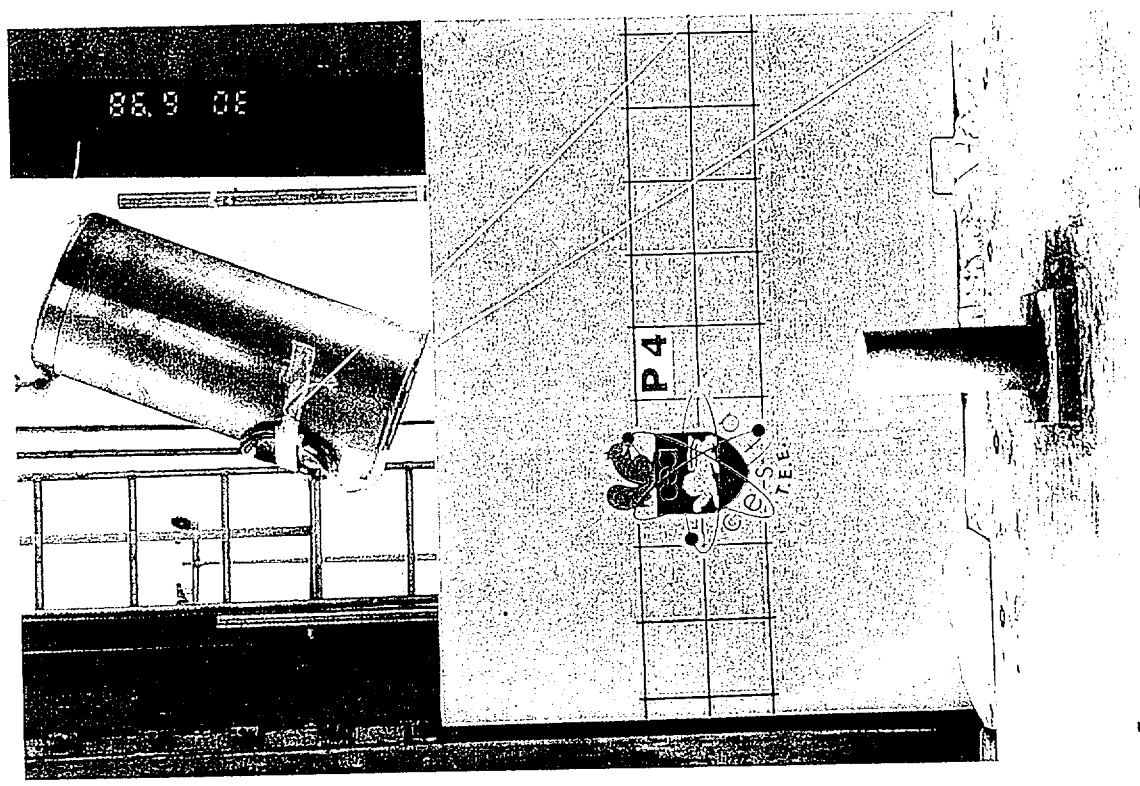
APPENDIX 7

SPECIMEN P4

PUNCH TEST

CONFIDENTIEL INDUSTRIEL

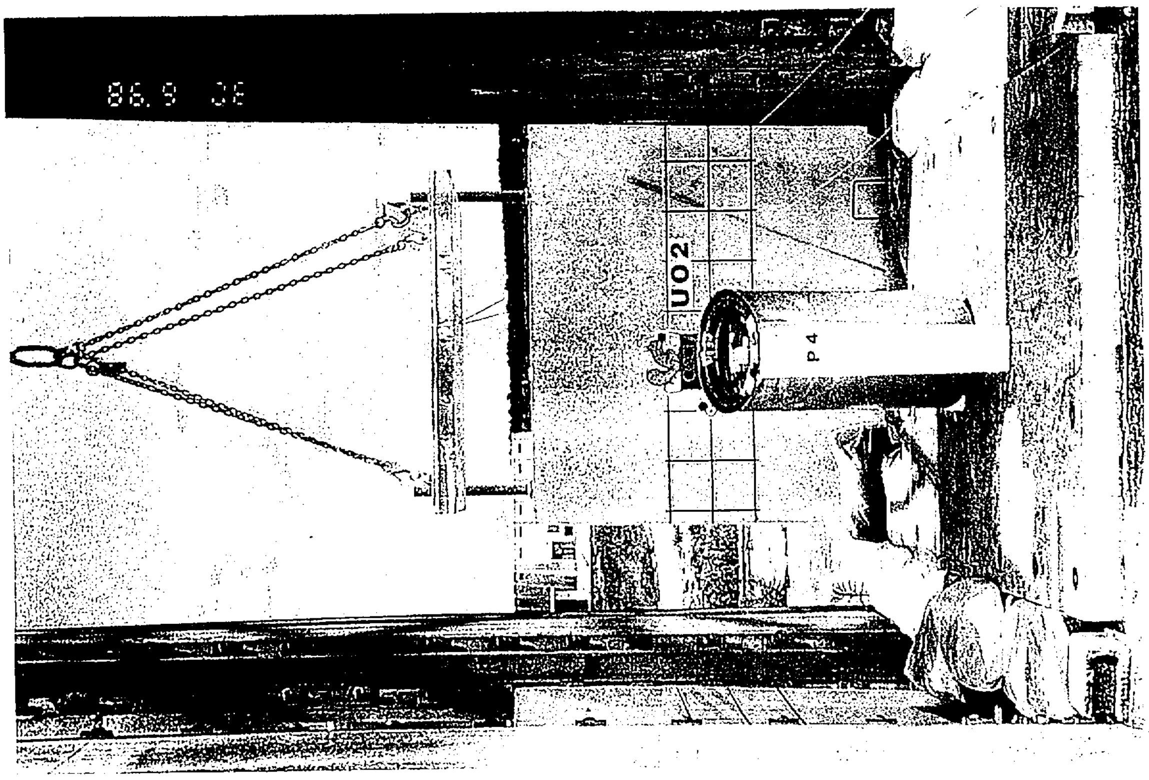


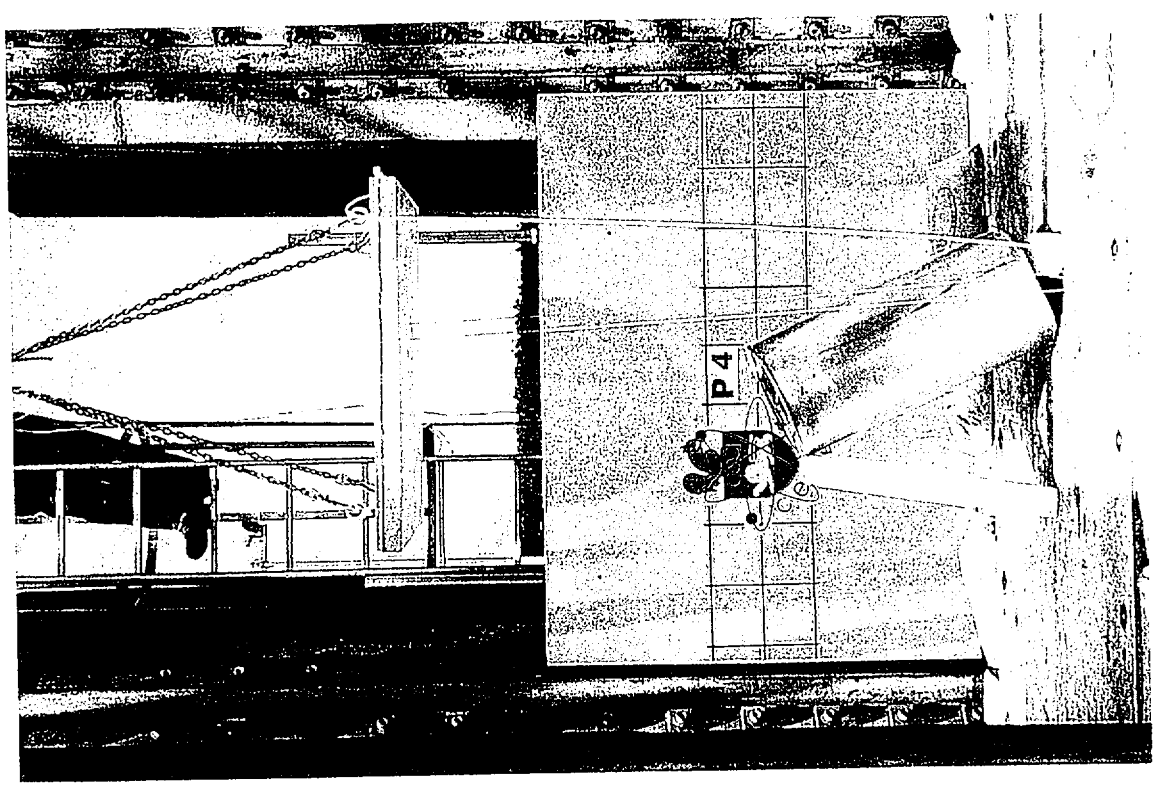


APPENDIX 8

SPECIMEN P4

PLATE DROP TEST





8-1

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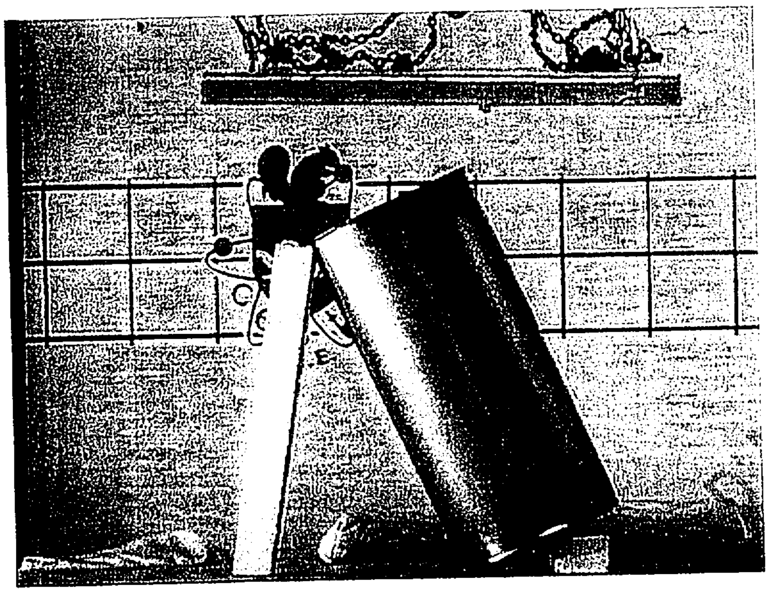

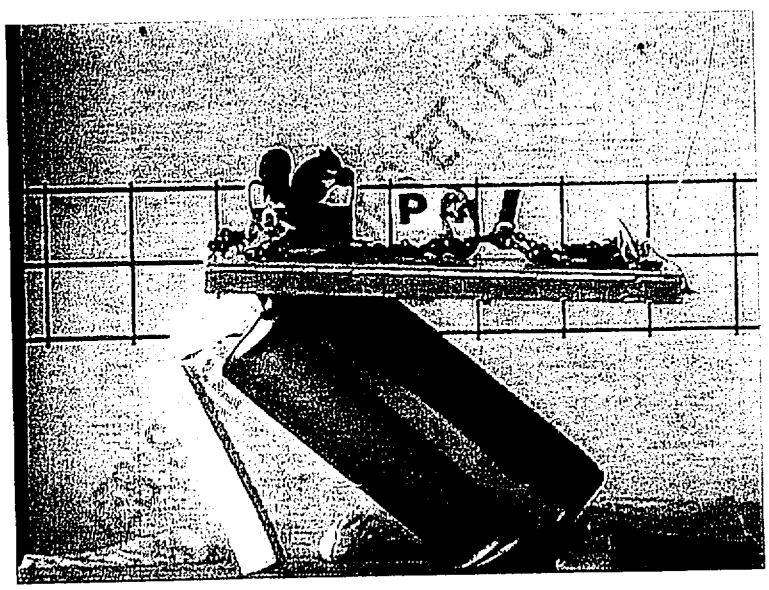

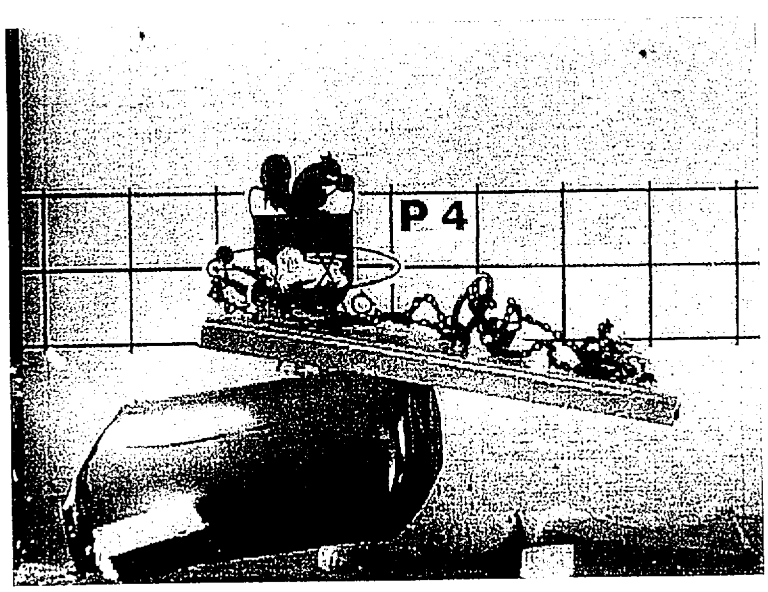

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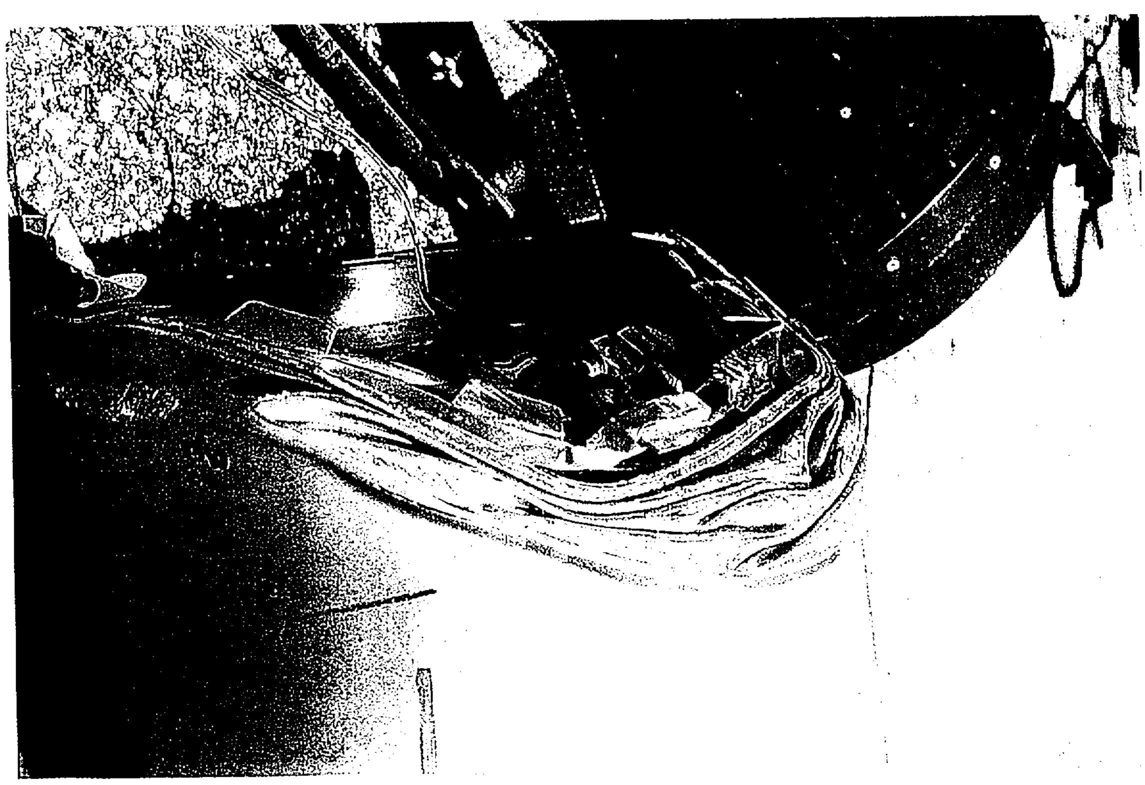

8-3

Keywords:
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TABLE OF CONTENTS

1. SUBJECT

The purpose of this document is to present the results of the regulation drop tests performed on four specimens representative of the package model comprising the TN-UO2 packaging containing a flask loaded with a maximum of 38 kg of UO2 powder.

The tests were held in two consecutive phases.

- Tests corresponding to normal transport conditions, conducted on the **LAUDUN** test site:
  - free falls of 0.30 m,
  - free falls of 1.20 m,
  - guided free falls of a 6 kg bar.

- Tests corresponding to transport accident conditions, conducted on the **CESTA/TEE** test site:
  - 1m falls onto punch bar,
  - fall by a 500 kg plate from a height of 9m,
  - free fall by the specimen from a height of 9m.

The tests were conducted in compliance with the drop test specifications <1> and the general qualification test program <2>.

2. GENERAL INFORMATION

2.1. Requesting party

DE/SAED Department

2.2. TRANSNUCLEAIRE participants

N . OUKAKI	DE/SI
D . VUILLERMOZ	DE/SI
P . MALALEL	DE/SAED

2.3. CEA/CESTA Participants

A . BOURDETTE

J : BOURSIER

3. REFERENCE DOCUMENTS

<1> 10313-A-3 Rév.0 : Specification for drop tests on TN-UO2 package.

<2> 10313-P-1 Rev.1 : IAEA qualification drop tests program;

<3> TRANSNUCLEAIRE concept drawing TN-UO2 ref. 10313-01 ind.C.

<4> Safety series n°6, IAEA Safety Standards, Regulations for the Safe Transport of Radioactive Material 1985 Edition, as amended 1990.

<5> Regulations for the Safe Transport of Radioactive Material – 1996 Edition - Requirements n°ST-1 – IAEA,Vienna.

4. TEST FACILITIES

4.1. LAUDUN test site.

The target used for the various drops comprises the following, from top to bottom:

– a steel plate

* grade	: E24
* mass	: 2 800 kg
* thickness	: 5 cm
* width and length of the plate	: 2 m x 3.5 m

The plate is drilled with 44 holes for tie-rods securing it to the concrete base.

The E24 steel tie-rods (22 of length 1.5 m and 22 of length 0.6 m) are bent into a hairpin at one end in the concrete base and threaded at the other for securing the steel plate.

– a concrete base

* height x width x length	: 2 m x 2.5 m x 4 m
* mass of base	: 49 000 kg.

The concrete is reinforced with 14 mm steel bars arranged at a 17 cm pitch.

Complete slab (steel plate + reinforced concrete base)

* mass : 53 tonnes

* height x width x length : 2 m x 2 m x 3.5 m

The specimen is dropped using a mechanical system comprising two half-hooks, which are opened via cable using a remote control device. The drop height is measured between the lowest point of impact of the specimen and the upper face of the target.

The bar used for the penetration tests has a hemispherical end 32 mm in diameter and a mass of 6 kg, with its longitudinal axis oriented vertically. It is released above the specimen and guided so that its end strikes the centre of the most fragile part of the specimen.
For a description of the bar guidance system, see drawing on figure 2.

4.2. CEA/CESTA/TEE test site.

The 30T monodirectional release gantry is positioned directly above a central target 200 mm thick and of dimensions 2mx1m juxtaposed with other steel plates 100 mm thick, constituting the whole target over a surface of about 100 m^2. This unyielding slab is anchored to a concrete reaction base with a mass of 600T.
The target used for the regulation 1 metre drop onto punch bar consists of a solid mild steel bar 150 mm in diameter. This bar is welded vertically to a horizontal steel plate, itself secured to the target defined above.

Release for the drop will be by means of a pyrotechnic shackle.

5. TEST PROCEDURE

5.1. Equipment tested

The equipment tested consisted of four full-scale prototypes of the TN-UO_2 packaging as described in <3>, containing a cylindrical flask loaded with a maximum of 38 kg of pure powdered iron with the same apparent density as UO_2 powder (about 1.7).

These prototypes, which are pre-production packagings, are thus perfectly representative of the packaging model, with the exception of elements which do not compromise package safety (instrumentation wire feed holes, ID plate).

The design of this packaging, shown in figure 1, can be summarised as being an internal flask type container with a screw-plug, enclosed inside a thermomechanical protective overpack (resistant, ductile outer envelope, and mechanical shock-absorber incorporating the heat insulation function) with simple closure systems, guaranteeing no leakage of the powder.

Overpack:

The overpack constitutes the envelope protecting the flask against external hazards (mechanical and thermal environments, normal and accident conditions according to <4> and <5>), and provides physical conditions maintaining the package sub-critical when in an array (distance between packages and neutron-poisoning protection).

Main characteristics:

- Stainless steel sheet interior and exterior lining
- Outside dia.: 380 mm
- overall height: 800 mm
- maximum mass of overpack + flask + content (38 kg) = 85 kg.

Flask

The flask is the receptacle containing the radioactive material and its main function is material containment (non-release of radioactive content) in normal transport conditions, but without specified leaktightness criterion, as the criticality study takes account of the maximum damage hypothesis leading to water penetrating the flask.
Main characteristics:

- material: high-density polythene
- maximum body diameter: 255 mm
- overall height: 550 mm
- mass of flask + powder: ≤ 40 kg.

5.2. Test program

5.2.1. TESTS ON THE AUDUN SITE

SPECIMEN P1 (content 38 kg)	
TEST DEFINITION	**ORIENTATION**
4 free fall drops of 0.30 m	Impact on each quarter of the circular base edge
1 free fall drop of 1.20 m	Impact on corner of lid ϕ opposite closure collar
Free fall drop of a 6kg bar	Bar impact on upper face 1 segment of closure collar

SPECIMEN P2 (content 38 kg)	
TEST DEFINITION	**ORIENTATION**
8 free fall drops of 0.30 m	Impact on each quarter of each of the two circular edges
1 free fall drop of 1.20 m	Axial drop onto base
Free fall drop of a 6kg bar	Bar impact in centre of base

SPECIMEN P3 (content 1 kg)	
TEST DEFINITION	**ORIENTATION**
Stacking 24 h	Axial
8 free fall drops of 0.30 m	Impact on each quarter of each of the two circular edges
1 free fall drop of 1.20 m	Lateral drop
Free fall drop of a 6kg bar	Bar impact on same lateral centreline

SPECIMEN P4 (content 38 kg)	
TEST DEFINITION	**ORIENTATION**
4 free fall drops of 0.30 m	Impact on each quarter of the base circular edge
1 free fall drop of 1.20 m	Impact on lid corner opposite closure collar
Free fall drop of a 6 kg bar	Bar impact on closure collar

5.2.2 TESTS ON CEA/CESTA SITE

SPECIMEN P1	**(content 38 kg)**
TEST DEFINITION	**ORIENTATION**
Drop N°1 of 1 m onto punch bar	Angled specimen axis, impact on closure collar (opposite 1.20 m drop impact)
Free fall drop N°2 from a height of 9 m	Specimen axis oblique with centre of gravity in vertical axis of impact

SPECIMEN P2	**(content 38 kg)**
TEST DEFINITION	**ORIENTATION**
Drop N°3 of 1 m onto punch bar	Angled specimen axis, impact on base
Free fall drop N°4 by a 500 kg plate from height of 9 m	Specimen vertical resting on head

SPECIMEN P3	**(content 1 kg)**
TEST DEFINITION	**ORIENTATION**
Drop N°5 of 1 m onto punch bar	Heavily angled specimen axis, impact on same centreline
Free fall drop N°6 by a 500 kg plate from height of 9 m	Horizontal specimen (impact on same centreline)

SPECIMEN P4	**(content 38 kg)**
TEST DEFINITION	**ORIENTATION**
Drop N°7 of 1 m onto punch bar	Angled specimen axis, impact on closure collar (opposite 1.20 m drop impact)
Free fall drop N°8 by a 500 kg plate from height of 9 m	Oblique specimen axis (wedged with polystyrene) with centre of gravity in vertical axis of impact (point of impact same as punch bar)

5.3 Measurements and checks

- Torquing of the flask plug,
- Torquing collar closure screw,
- Dimensional measurement after drop (height and crushing surface area),
- Check on condition of collar closure screw,
- Check on condition of lid fit on the body,
- Check on non-release of content (powdered iron).

5.4 Test chronology

LAUDUN:

Dated 22/06/98 drop n°1 to drop n° 20

Dated 23/06/98 drop n° 21 to drop n° 32

CEA/TEE

Dated 29/06/98 drop n°1 to drop n° 4

Dated 30/06/98 drop n°5 to drop n° 8

6. RESULTS

6.1 Tests in normal transport conditions

All the tests representative of normal transport conditions were performed on the LAUDUN test site, on the four specimens P1-P2-P3-P4.

They consisted of the following tests:

- Stacking test [24 hours],
- Free fall drop from a height of 0.30 m, onto each quarter of each of the circular edges,
- Free fall drop from a height of 1.20 m,
- Drop by a 6 kg bar, from a height of 1 m.

Note: Only specimen P3 underwent the stacking test.
This test was performed using a 500 kg plate [mass of plate > 5 times mass of package] placed on P3 for a period of 24 hours [P3 vertical resting on base]. No deformation was observed after this test.

All the tests were performed with different impact configurations (see table <5.2.1>), so as to combine the damage for each orientation with that arising from the following accident drop tests in the most penalising way possible.

After the full series of tests, we observed only minor deformation leading to no release of the powdered iron simulating the UO2 powder. For all the specimens, the collar and lid remained in place (see photographic report from LAUDUN).

6.2 Tests in transport accident conditions

The full series of tests performed at CESTA/TEE is representative of transport accident conditions

It comprised the following:

- Drop onto a punch bar from a height of 1 m,
- Free fall drop by a specimen from a height of 9 m,
- Free fall drop by a 500 kg plate, also from a height of 9 m.

Note: see table <5.2.2>

- For specimen P1 ⇒ drop onto a punch bar and free fall drop from 9 m,
- For specimens P2-P3-P4 ⇒ drop onto a punch bar and free fall drop by plate from 9 m.

6.2.1 Drop n°1 (P1): drop onto a punch bar, height 1 m, specimen axis angled by **20°.19** from the vertical, impact on collar closure (see photos n°30 and n°31; figure 3).

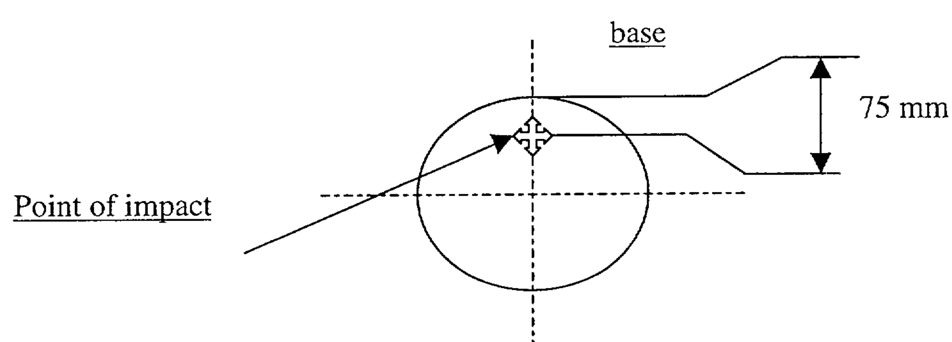
After impact on the punch bar, the collar did not move, slight twisting of the closure system was observed. The punch bar left an imprint on the lid: see figure n°2.
No cracking or opening of the lid was detected.

6.2.2 Drop n°2 (P1): free fall drop by specimen P1, top side, from a height of 9 m with an angle of **26°.5** from the vertical, impact opposite the collar closure: see photos n°32 and n°33.

This drop led to deformation of the impacted part: see photo n°33 although no opening of the lid nor release of the powder was observed.

6.2.3 Drop n°3 (P2): drop onto the punch bar, height 1 m specimen axis angled **20°.4** from the vertical, impact on base: see photos n°34 and n°35 and figure 4

This drop left only an imprint of the punch bar on the base, with no puncture.

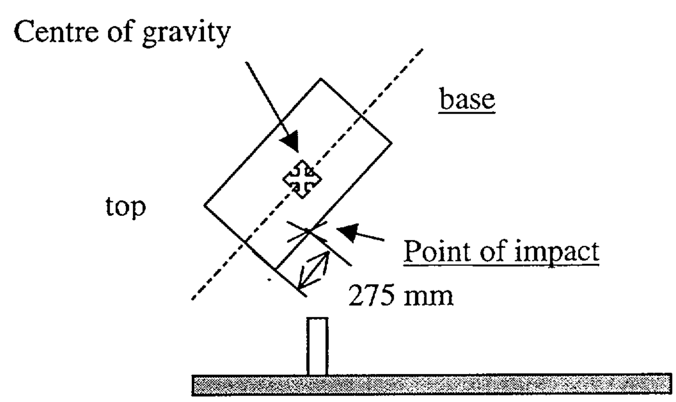


6.2.4 Drop n°4 (P2): free fall drop by a plate of 500 kg, from a height of 9 m, onto a vertical specimen resting on its top: see photos n°36 and n°37.
During this drop, the specimen was crushed an average of **104 mm** as stated in the following table:

ORIENTATION	HEIGHT (mm)
0°	709
90°	698
180°	709
270°	677

No opening of overpack or lid and no release of powder was observed.

6.1.5 Drop n°5 (P3): drop onto the punch bar, height 1 m with specimen axis angled **29°.5** from the vertical, impact onto centreline: see photos n°38 and n°39 and figure 5.



The impact left an imprint of the punch bar on the plate: (see figure 5 for the dimensions) with no puncture.

6.2.6 Drop n°6 (P3): free fall drop by a 500 kg plate, from a height of 9 m, onto a horizontal specimen, with impact on the same centreline as drop n°5:
See photos n°40 and n°41.

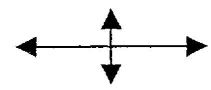
Specimen P3 was deformed over its entire length.

Overall dimensions on top side: 230 mm (Diameter before drop ϕ 380 mm)

495 mm

310 mm

Overall dimensions on base side:



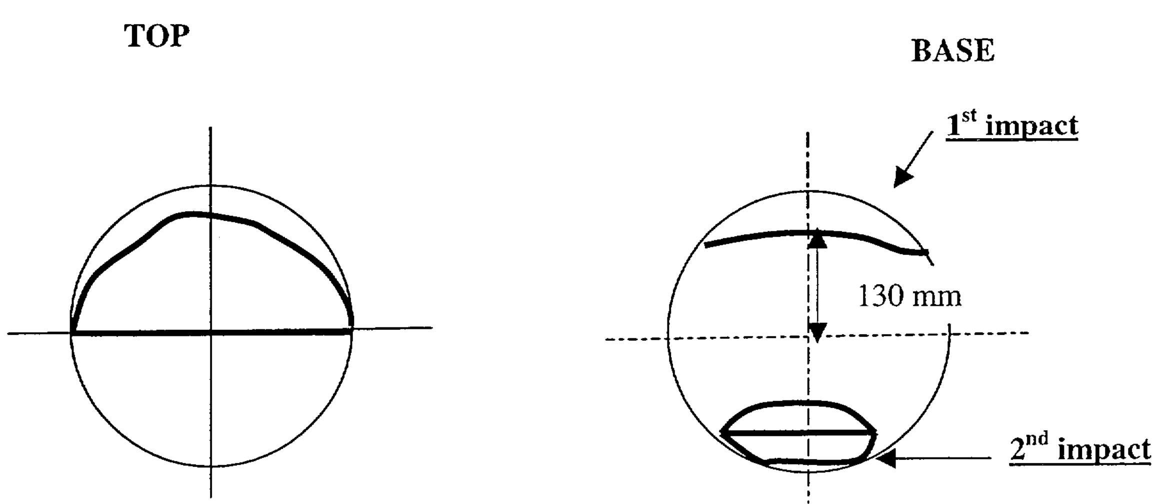
This drop led to greater deformation on the top side than on the base side. Of all the drops, this was that which led to the greatest package damage.
Although the lid remained attached to the packaging, a gap was observed at its two ends, revealing the phenolic foam shock-absorbing plug. However, no release of powder was observed.

6.1.7 Drop n°7 (P4): drop onto a punch bar, height 1 m, specimen axis angled **20°.5** from the vertical, impact onto collar closure, see photo n°42 and n°43 and figure 6.

The punch bar left an imprint on the lid (see figure 6), the collar closure was slightly bent although it remained in place. No puncture or opening of the lid was observed.

6.1.8 Drop n°8 (P4): free fall drop of a 500 kg plate from a height of 9 m, onto specimen angled **21°** from the vertical, impact on the collar closure: see photos n°44; n°45; n°46; n°47.

The deformation on the base and top was relatively significant, although the lid remained in place. The collar was also deformed but still performed its role. On the base of the packaging, two diametrically opposed impacts could be observed, as during the drop, the plate rebounded onto the packaging, hence the second impact.



No cracking of the overpack nor release of powder was observed.

▬▬ : deformation

7 CONCLUSION

The test results demonstrated that the packaging design guaranteed good package mechanical strength. The lid closure collar performed its function during all the tests. No puncture of the external plates nor weld cracking was observed.

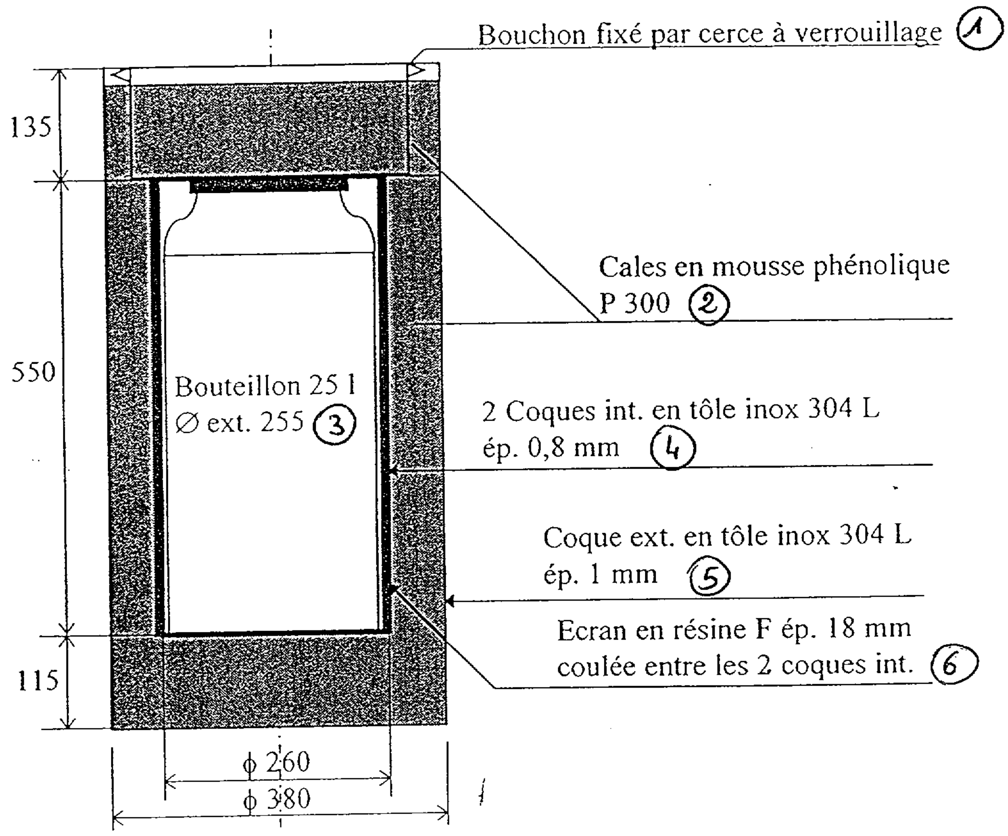
The four specimens released no powder after each of the respective test sequences. The maximum package damage was observed on specimen P3 (drop of a 500 kg plate onto specimen with horizontal axis), during which the overpack closure lid, although still in place and held by the collar, left a gap at the two ends, owing to the overpack being forced out of round by the impact.

It is therefore this drop configuration which most fragilises the package for the subsequent thermal hazard during the fire test, with these gaps in the lid creating potential paths for entry of hot gases.

LIST OF FIGURES

FIGURE 1

PACKAGING DESIGN DRAWING



Cap fixed by locking ring (1)

Phenolic foam shock (2)

24-l flask (3)

Outer dia. 255 (3)

2 inner shells in stainless steel 304 L, thickness 0.8 mm (4)

Outer shell in stainless steel 304 L, thickness 1 mm (5)

F resin shield, thickness 18 mm, poured between the two inner shells (6)

FIGURE 2

6 KG BAR GUIDE SYSTEM DRAWING

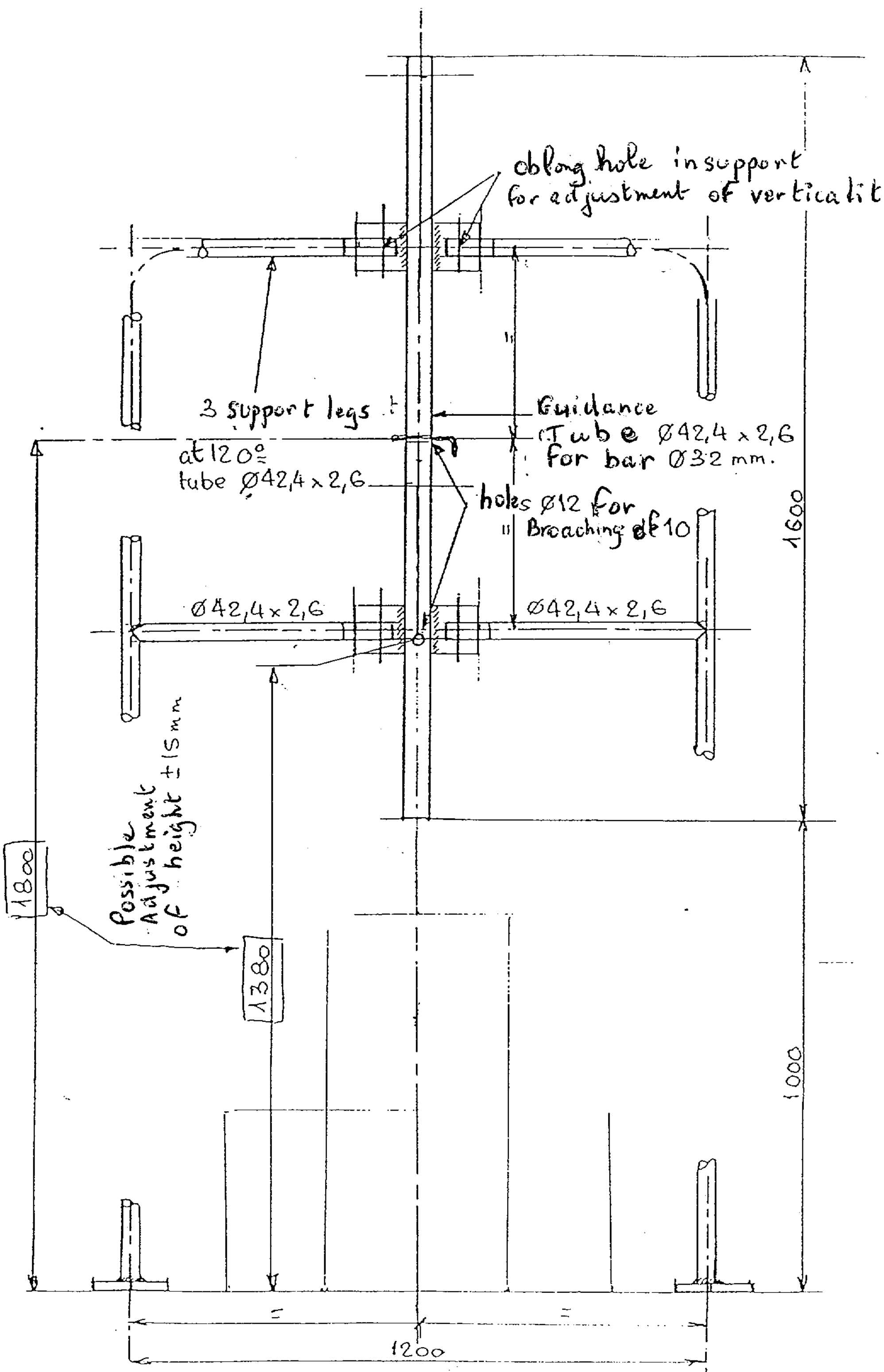
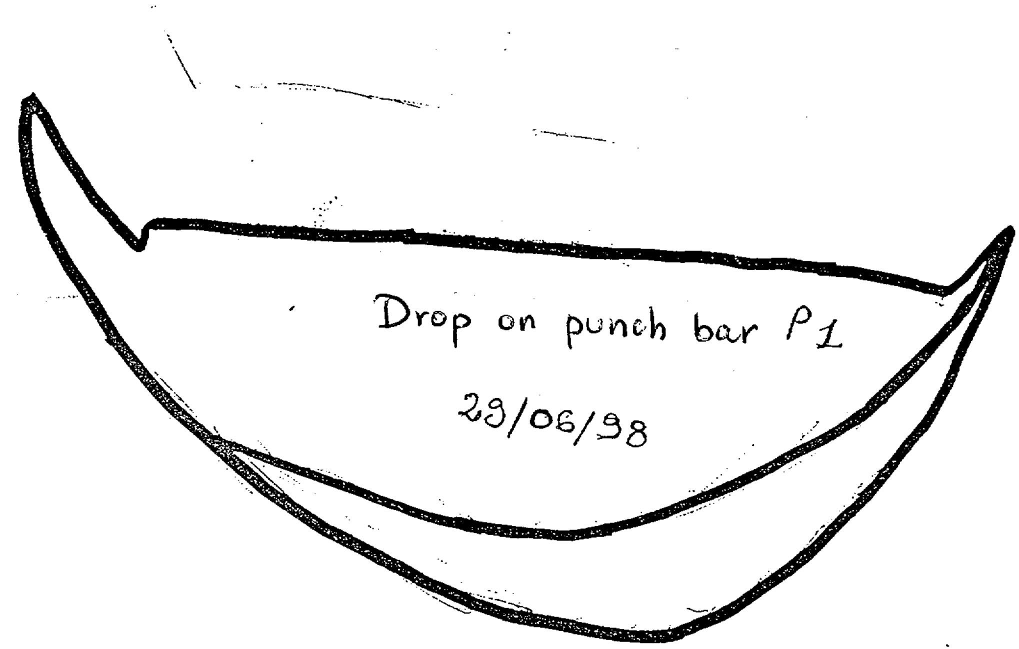


FIGURE 3

IMPRINT OF PUNCH BAR IMPACT ON P1

DROP N°1

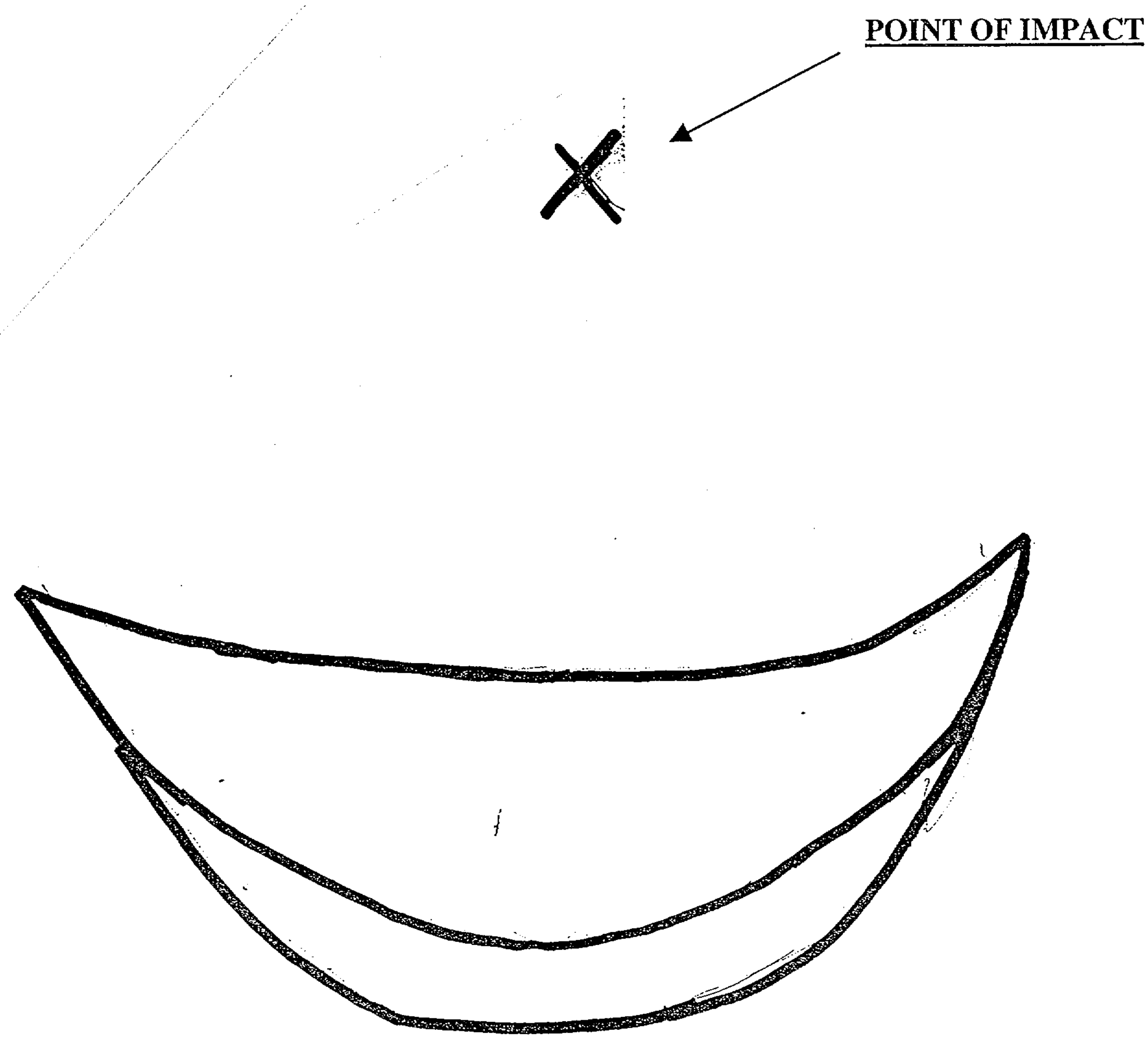


SCALE : 1

FIGURE 4

IMPRINT OF PUNCH BAR IMPACT ON P2

DROP N°3



SCALE : 1

FIGURE 5

IMPRINT OF PUNCH BAR IMPACT ON P3

DROP N°5

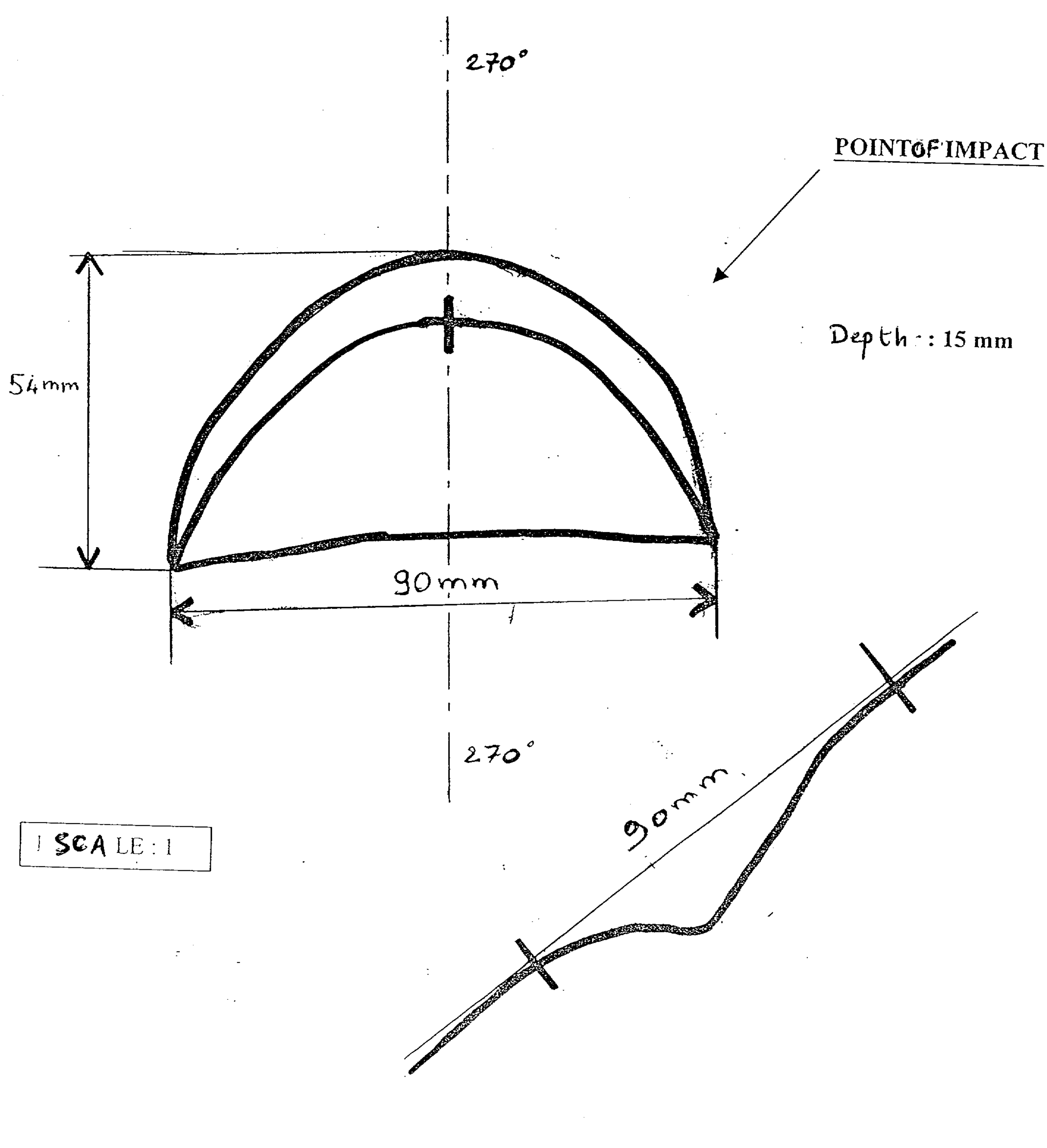
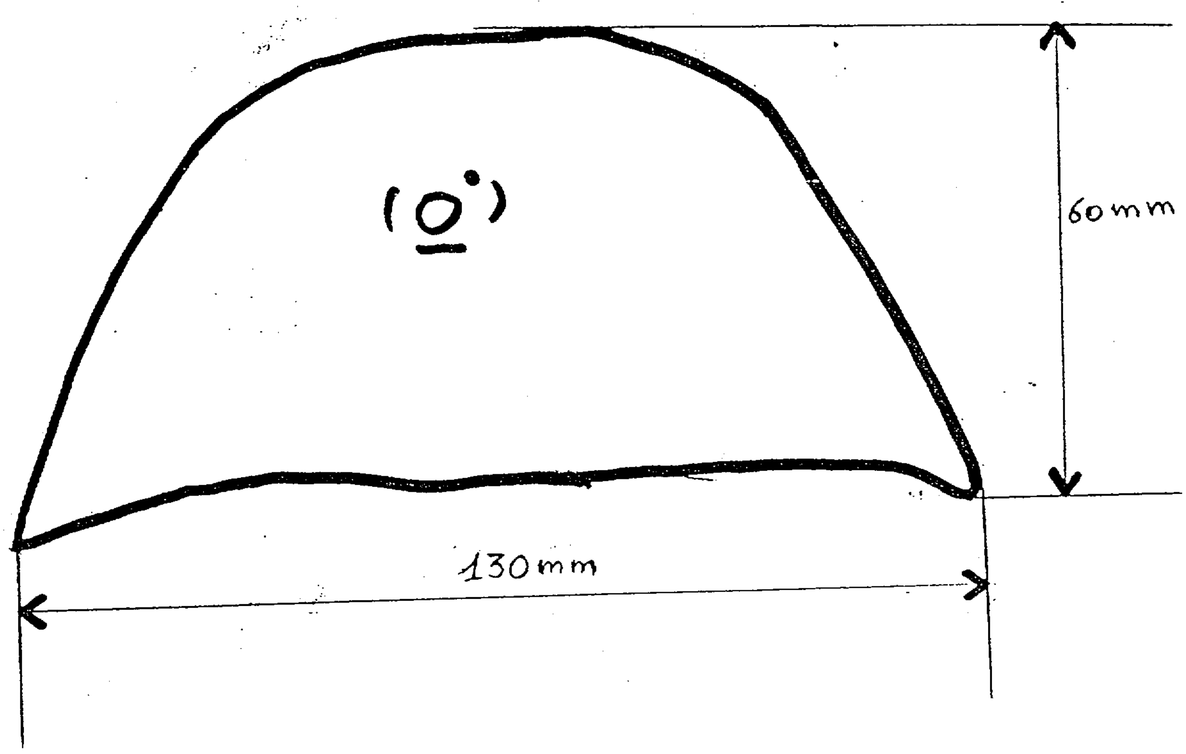


FIGURE 6

IMPRINT OF PUNCH BAR IMPACT ON P4

DROP N°7



SCALE : 1

TESTS PHOTOGRAPHIC RECORD

LAUDUN

- **Photo n° 1: Drop onto base circular edge height 0.3m, specimen P1,**
- **Photo n° 2: Deformation after the four drops onto circular edge, height: 0.30 m, specimen P1, base side,**
- **Photo n° 3: Drop height 1,2 m onto corner of lid opposite closure collar, specimen P1,**
- **Photo n° 4: Deformation after drop height 1,2 m, specimen P1,**
- **Photo n° 5: Drop of the 6 kg bar onto upper face of a collar's segment, height 1m, specimen P1,**
- **Photo n° 6: Deformation after drop of the 6 kg bar on specimen P1,**
- **Photo n° 7: Drop onto circular edge on lid side 0°, height 0,3m, specimen P2**
- **Photo n° 8: Deformation after the four drops onto circular edge, height 0,3 m, lid side, specimen P2.**
- **Photo n° 9: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P2.**
- **Photo n° 10: Axial drop height 1,2m on specimen P2, base side,**
- **Photo n° 11: Deformation after 1,2 m drop, specimen P2,**
- **Photo n° 12: Drop of the 6 kg bar onto base centre from a height of 1 m on specimen P2,**
- **Photo n° 13: Deformation after drop of the 6 kg bar on specimen P2,**
- **Photo n° 14: Stacking test on specimen P3,**
- **Photo n° 15: Drop onto circular edge on lid side 0°, height 0,3m, specimen P3,**
- **Photo n° 16: Deformation after the four drops onto circular edge, height 0,3 m, lid side, specimen P3.**

- **Photo n° 17: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P3.**

- **Photo n° 18: Lateral drop height 1,2m on specimen P3,**

- **Photo n° 19: Deformation after 1,2 m drop, specimen P3,**

- **Photo n° 20: Drop by the 6 kg bar onto 0° centreline from a height of 1 m on specimen P3,**

- **Photo n°21: Deformation after the 6 kg bar on specimen P3,**

- **Photo n°22: Drop onto base circular edge height 0.3m, specimen P4,**

- **Photo n°23: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P4.**

- **Photo n°24: Drop height 1,2 m onto corner of lid opposite closure collar, specimen P4,**

- **Photo n° 25: Deformation after drop height 1,2 m, specimen P4,**

- **Photo n°26: Drop by the 6 kg bar on onto closure cellar from a height of 1 m on specimen P4.**

- **Photo n°27: Deformation after 6kg bar drop on specimen P4.**

Photo n° 1: Drop onto base circular edge height 0.3m, specimen P1.

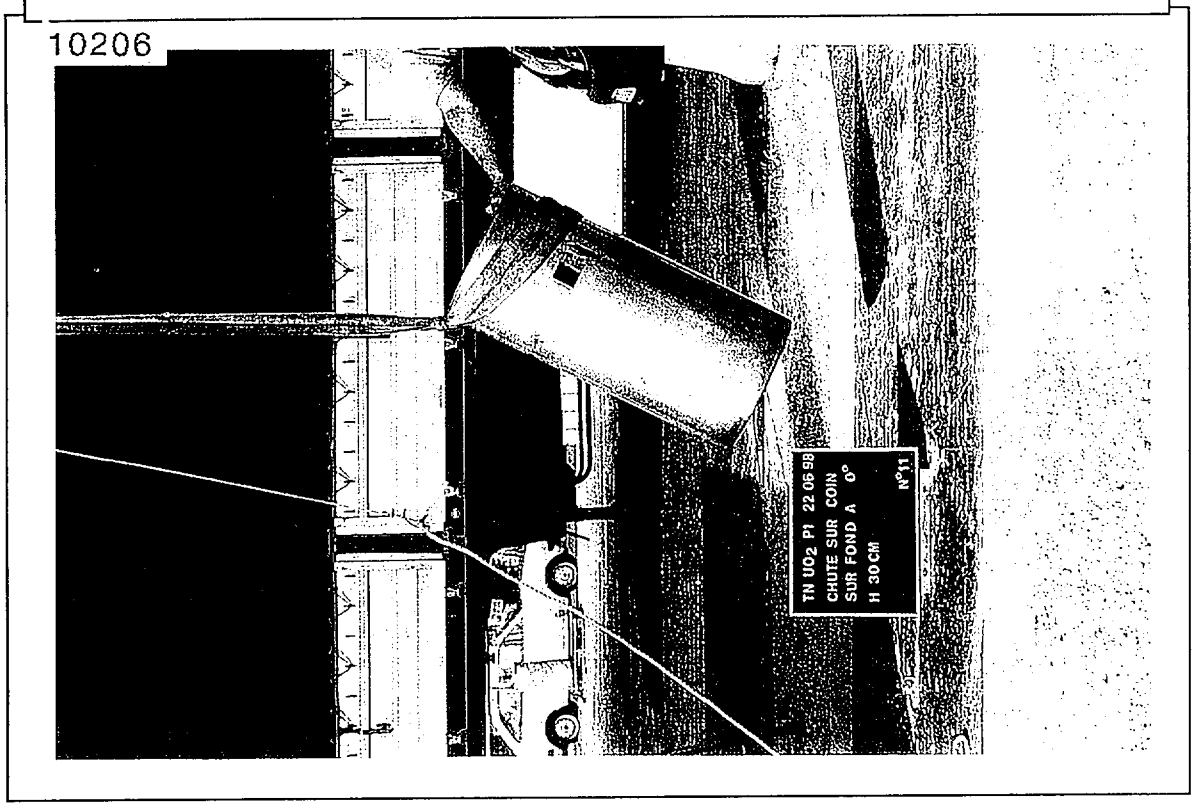


Photo n° 2: Deformation after the four drops onto circular edge, height: 0.30 m, specimen P1, base side.

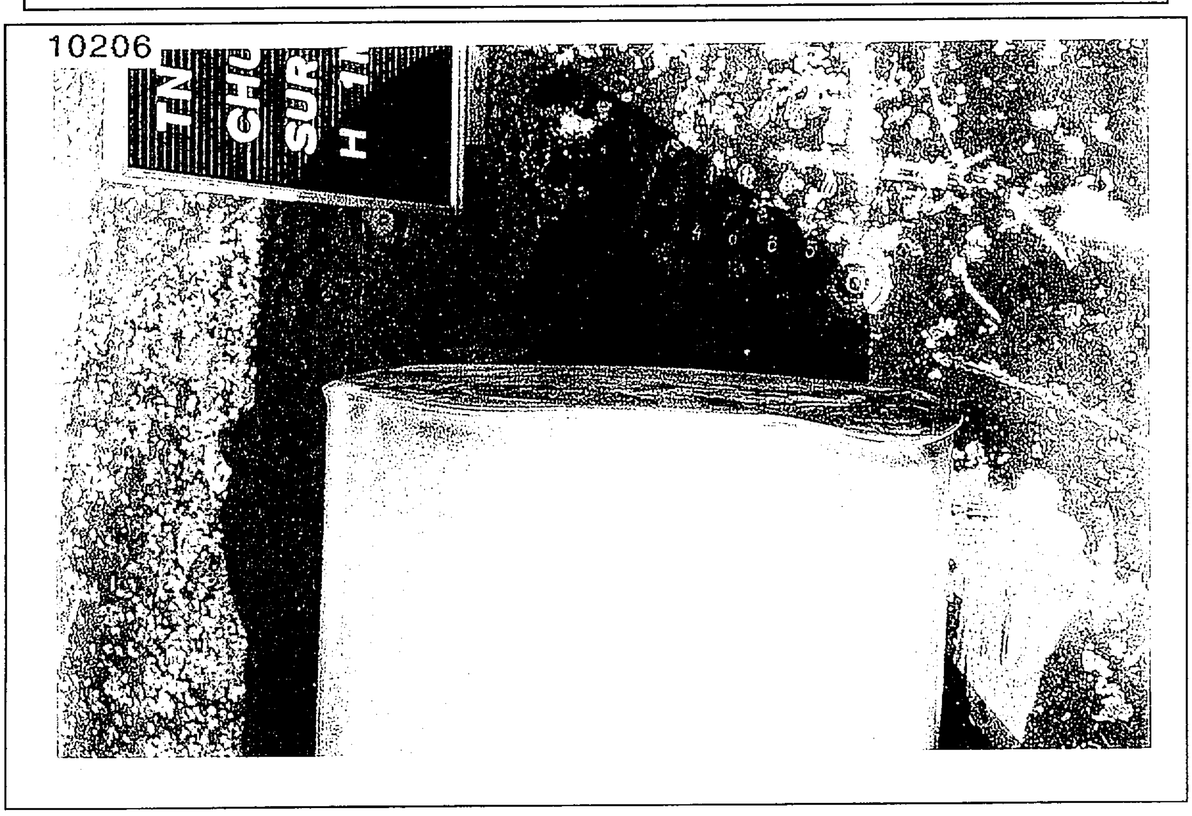


Photo n° 3: Drop height 1,2 m onto corner of lid opposite closure collar, specimen P1.

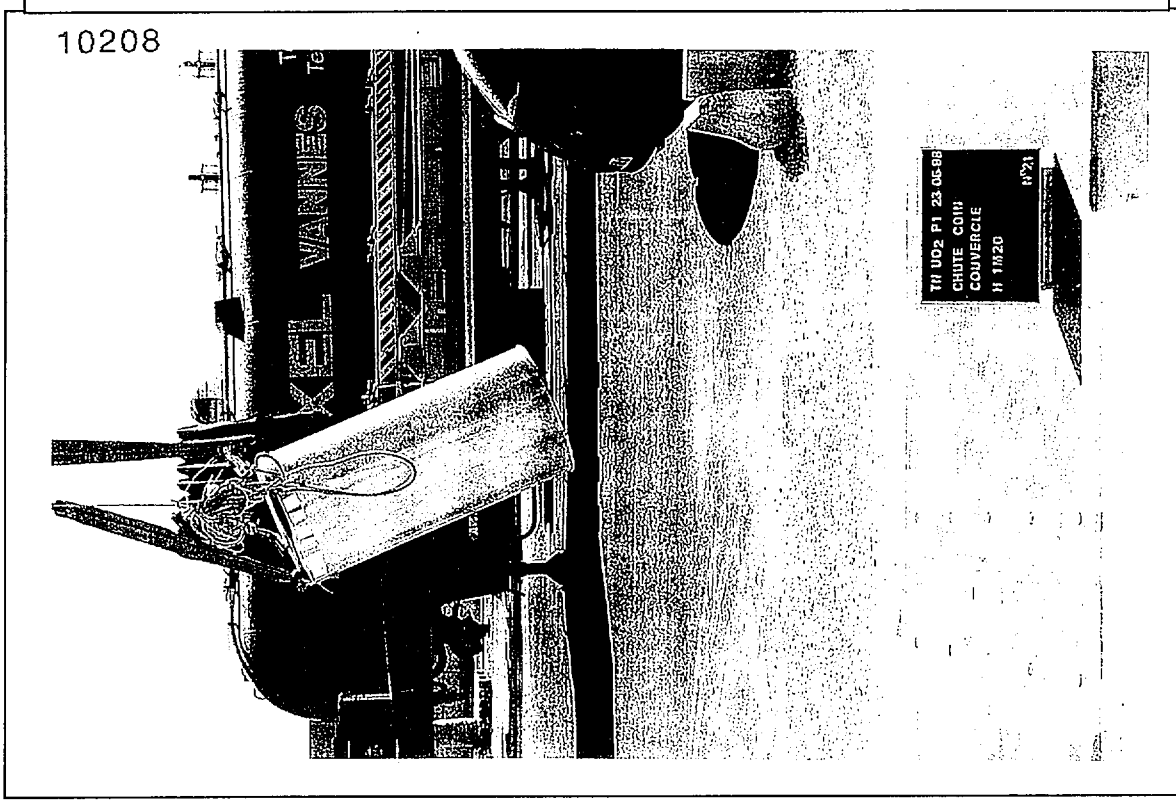


Photo n° 4: Deformation after drop height 1,2 m, specimen P1.

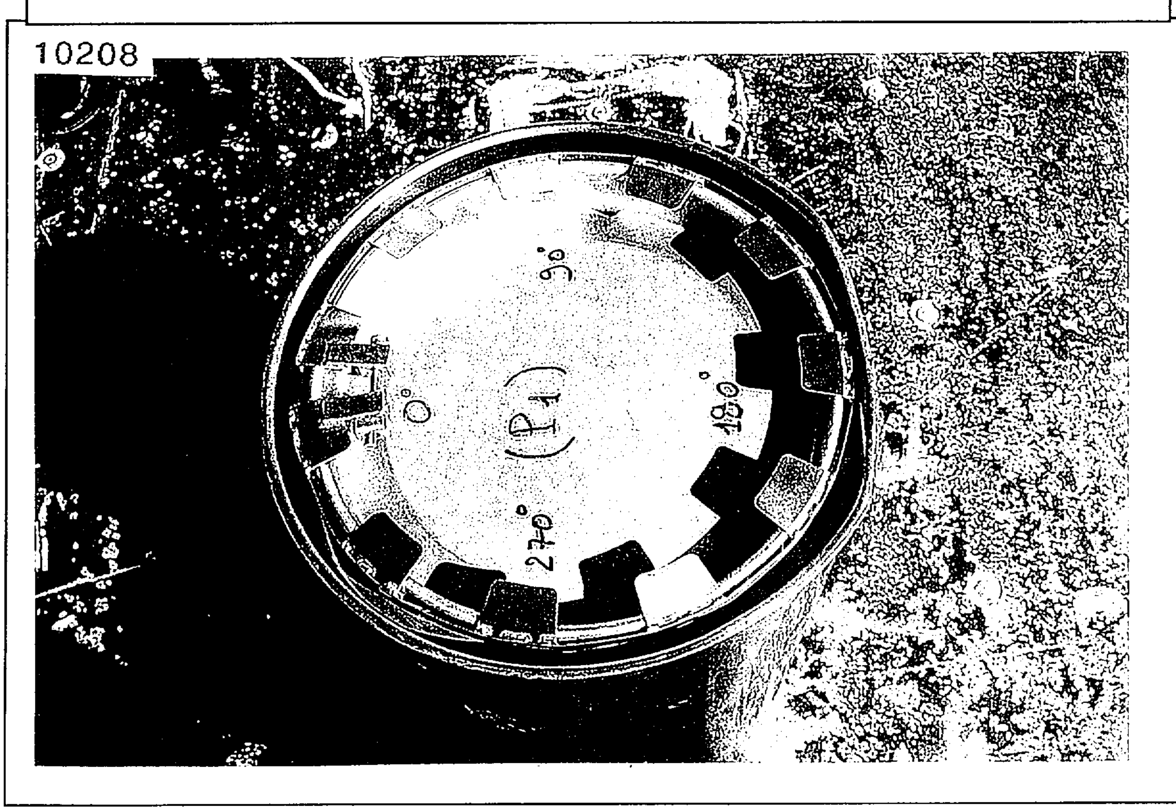


Photo n° 5: Drop of the 6 kg bar onto upper face of a collar's segment, height 1m, specimen P1.

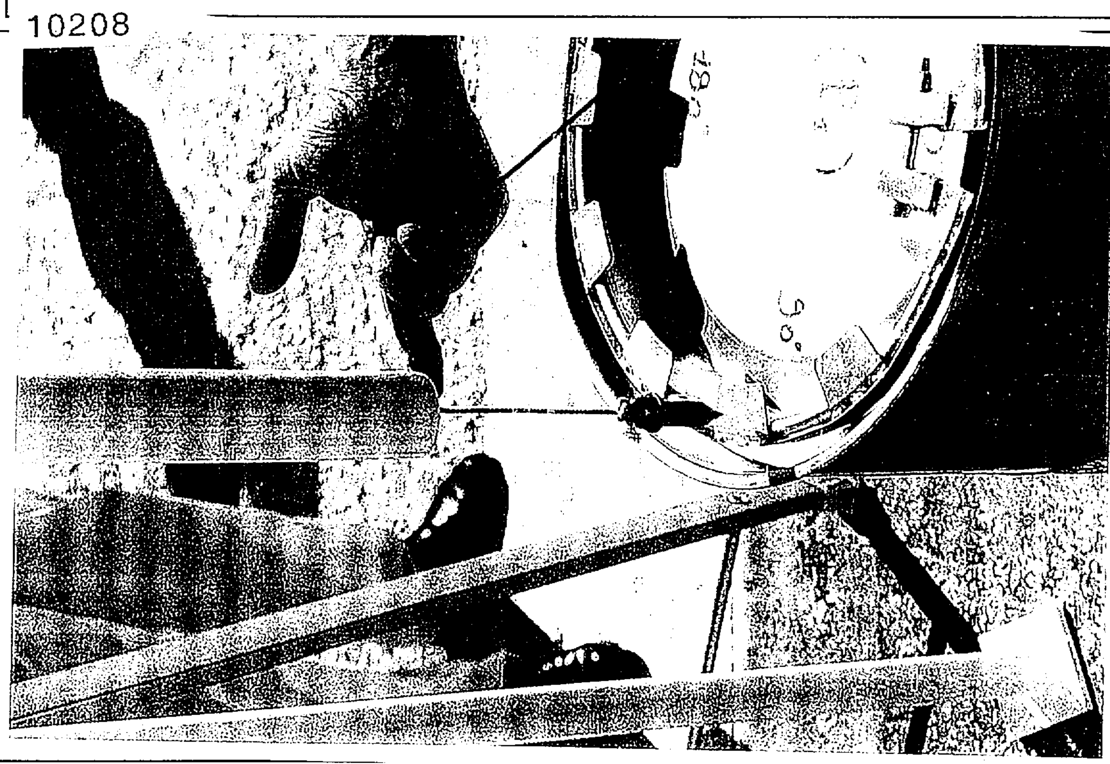


Photo n° 6: Deformation after drop of the 6 kg bar on specimen P1.

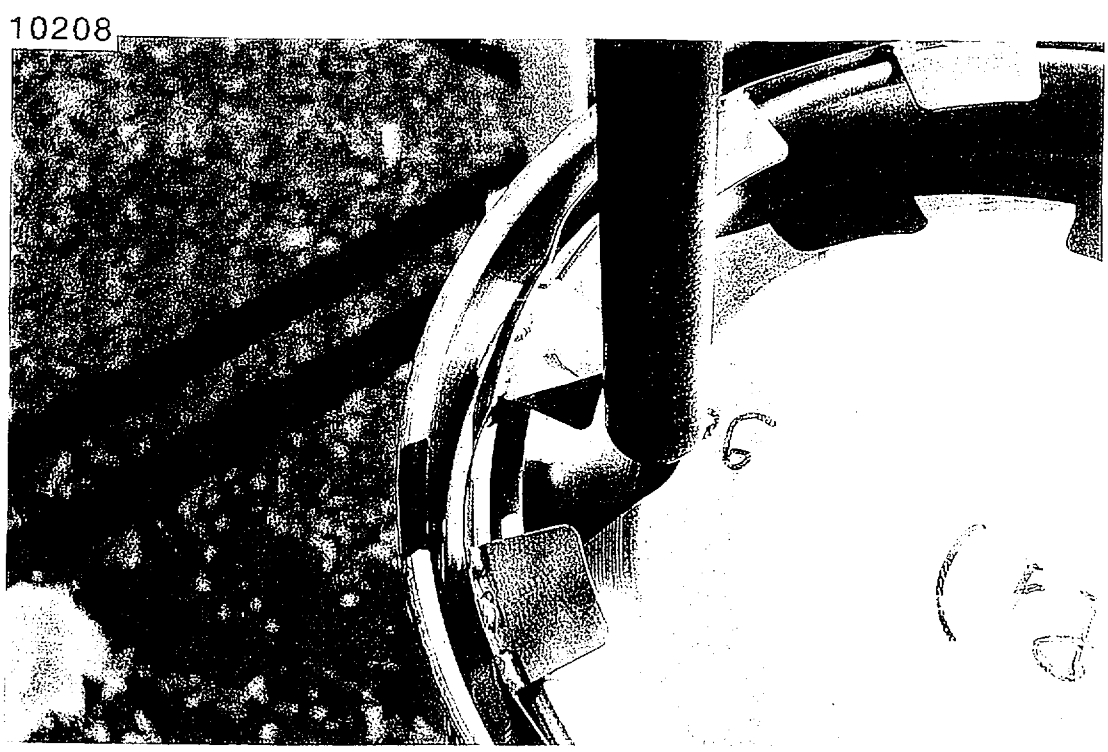


Photo n° 7: Drop onto circular edge on lid side 0°, height 0,3m, specimen P2

Photo n° 8: Deformation after the four drops onto circular edge, height 0,3 m, lid side, specimen P2.

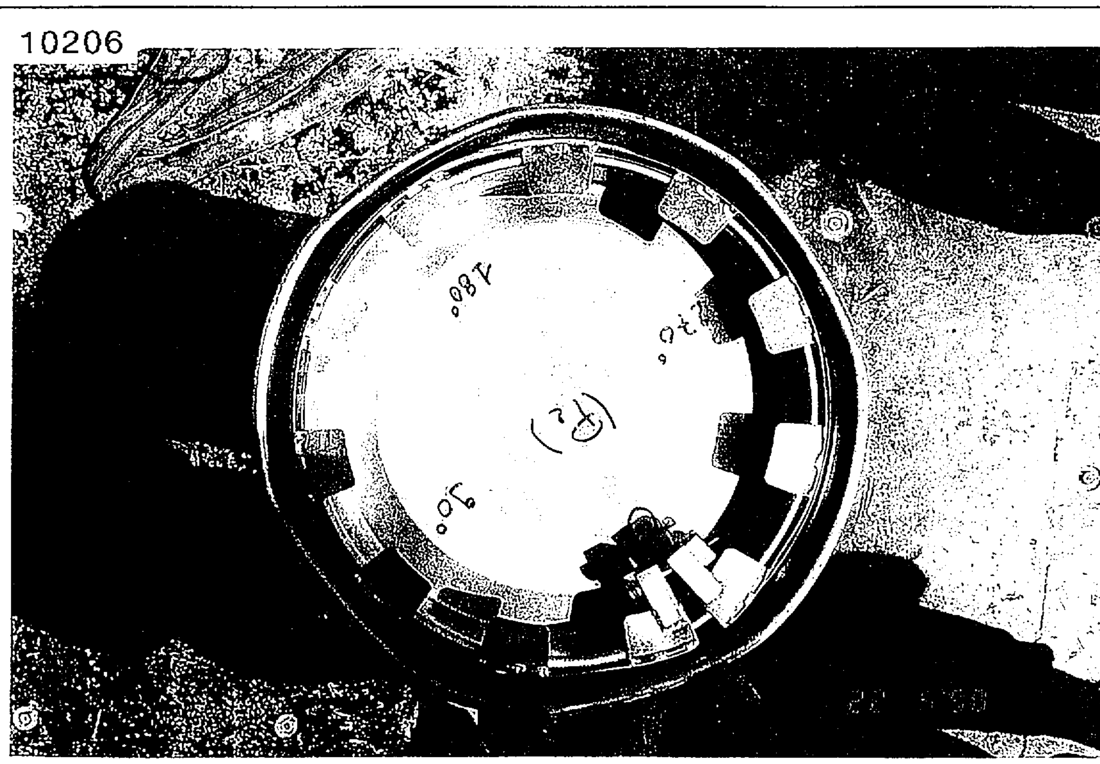


Photo n° 9: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P2.

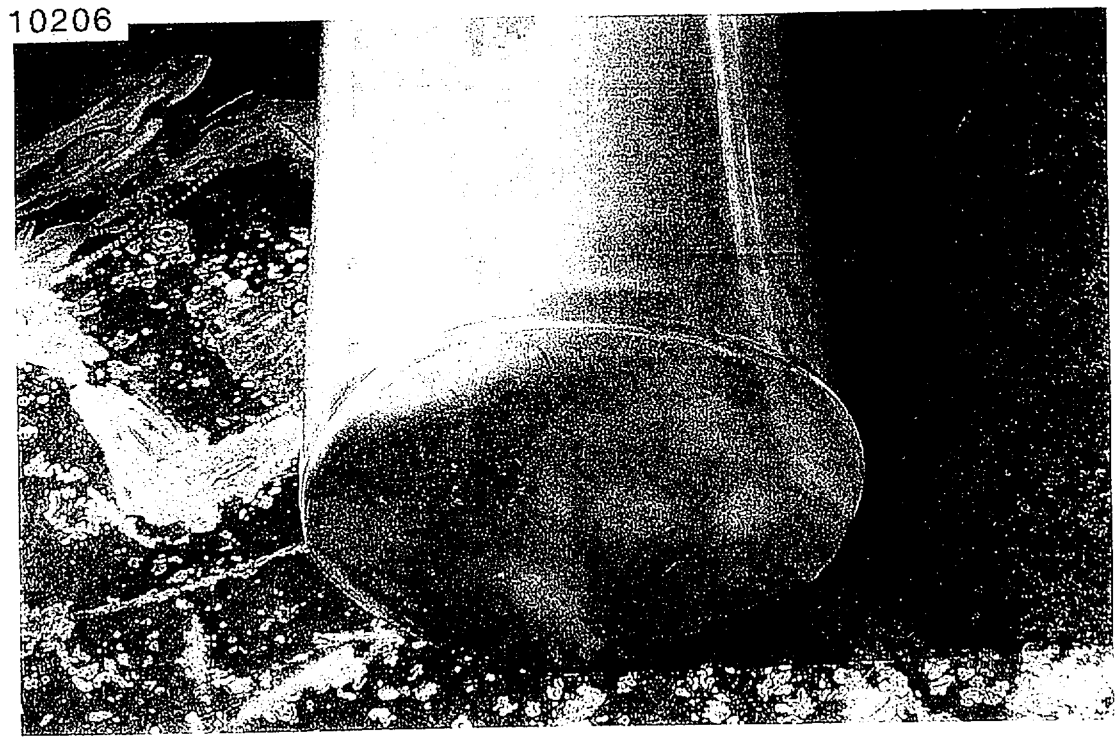


Photo n° 10: Axial drop height 1,2m on specimen P2, base side.

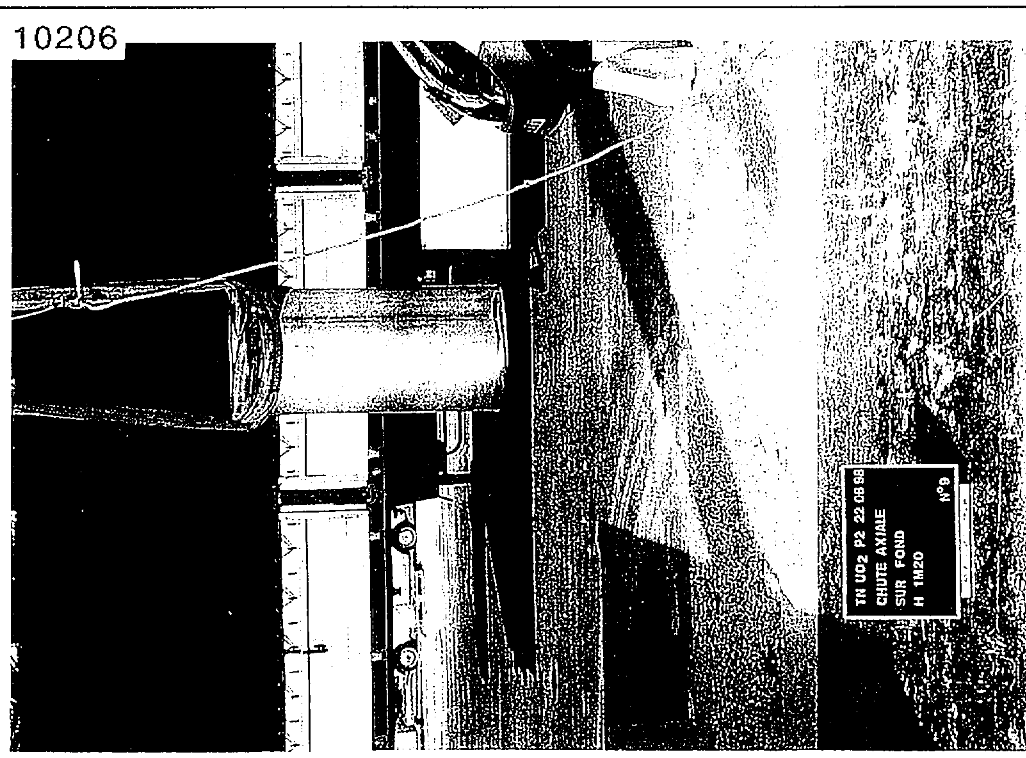


Photo n° 11: Deformation after 1,2 m drop, specimen P2.

Photo n° 12: Drop of the 6 kg bar onto base centre from a height of 1 m on specimen P2.

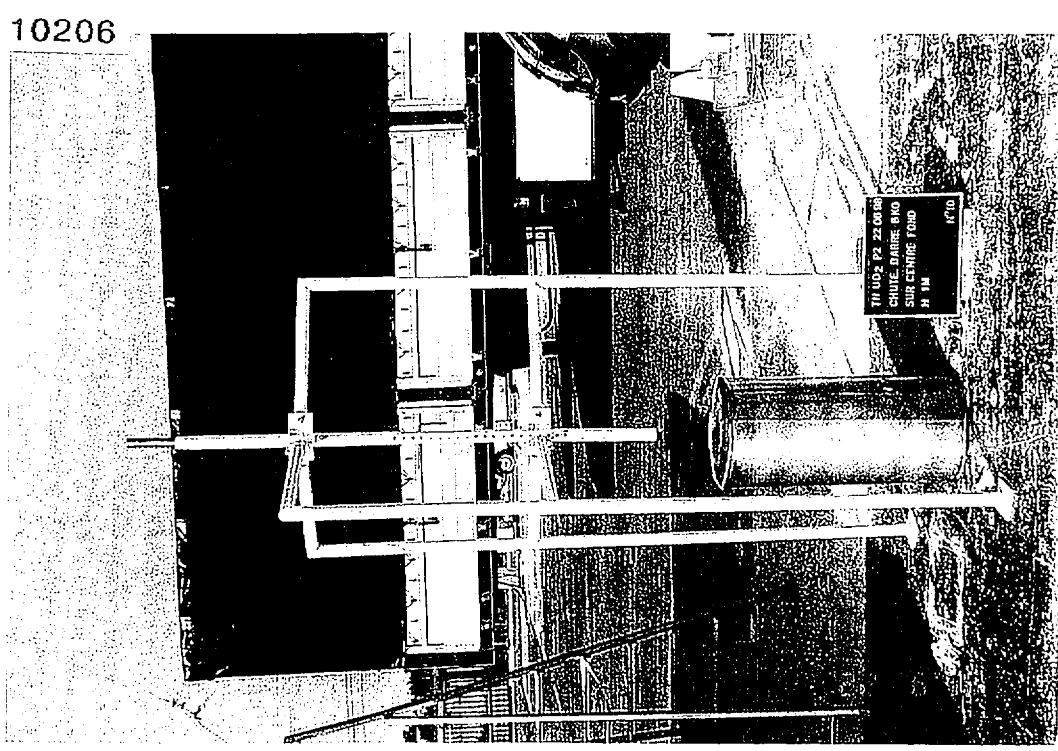


Photo n° 13: Deformation after drop of the 6 kg bar on specimen P2.

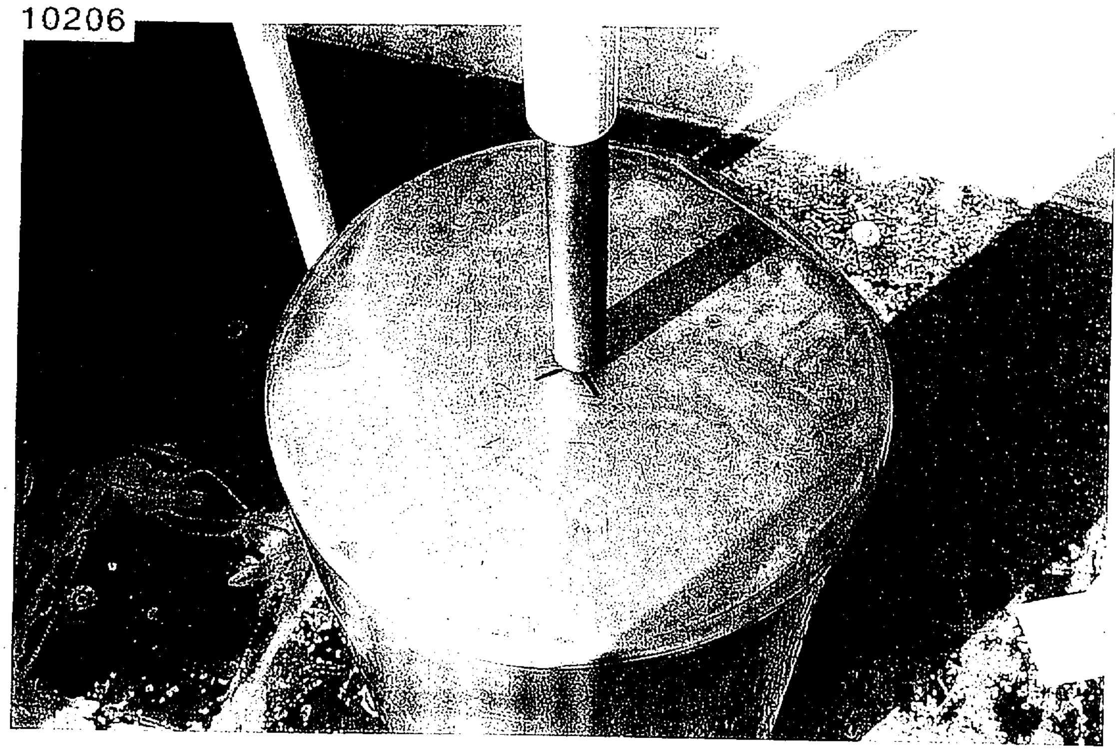


Photo n° 14: Stacking test on specimen P3.

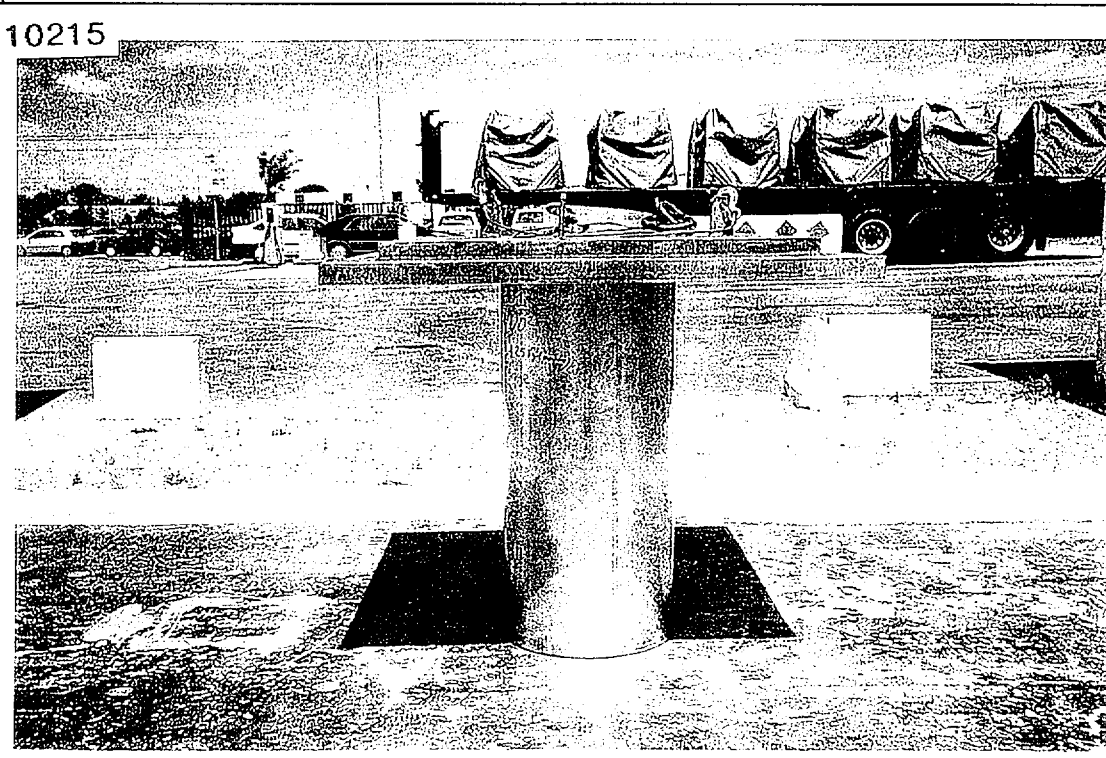


Photo n° 15: Drop onto circular edge on lid side 0°, height 0,3m, specimen P3.

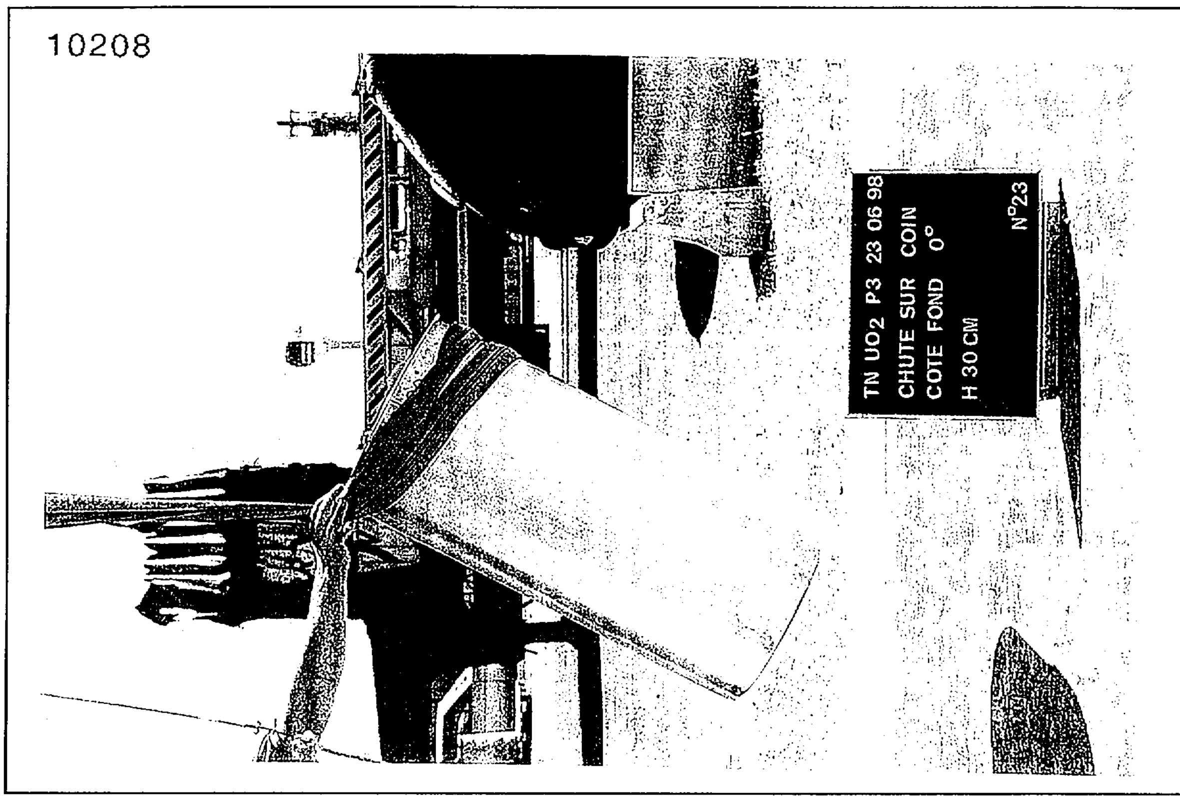


Photo n° 16: Deformation after the four drops onto circular edge, height 0,3 m, lid side, specimen P3.

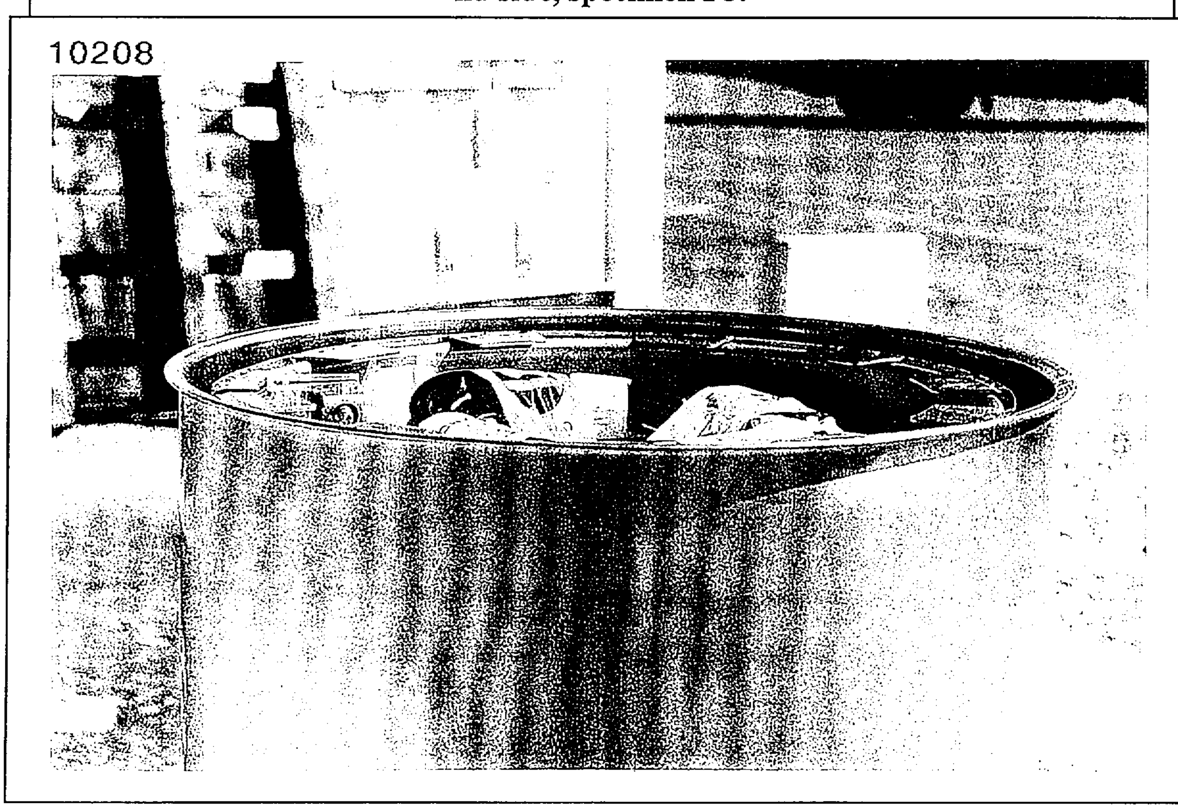


Photo n° 17: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P3.

10208

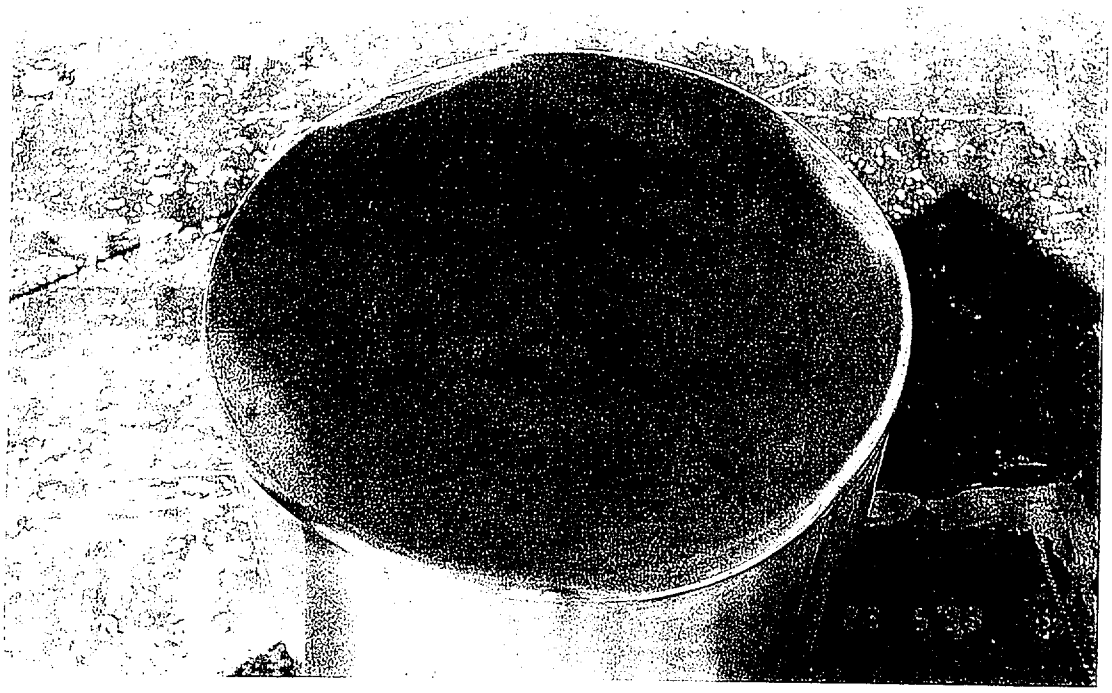


Photo n° 18: Lateral drop height 1,2m on specimen P3.

10207

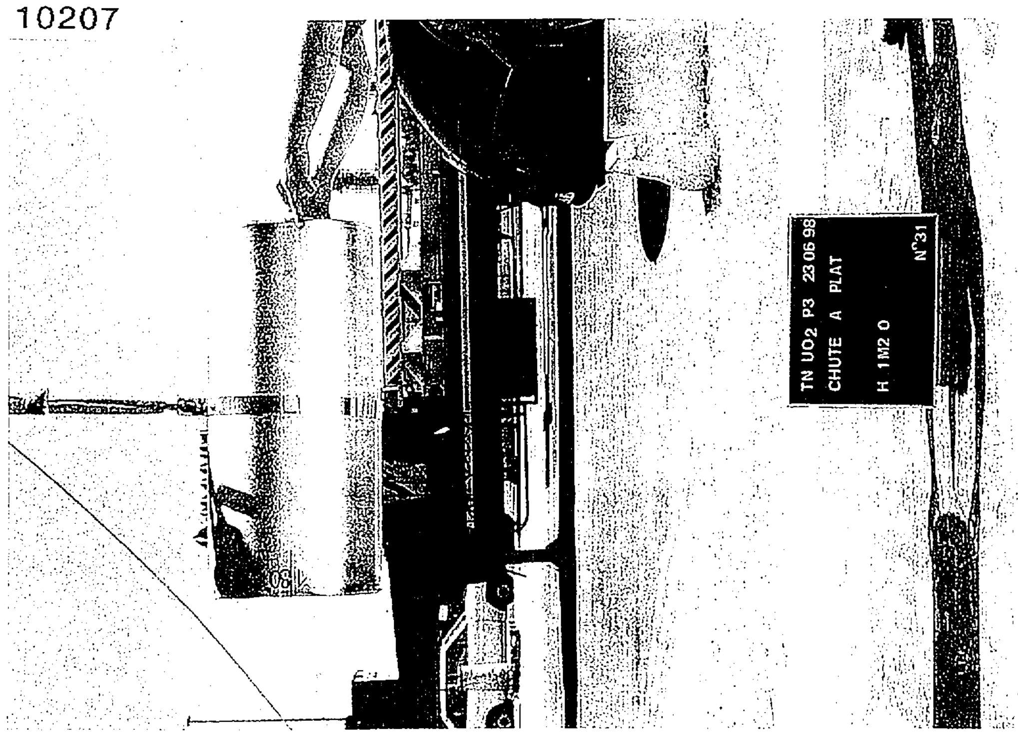


Photo n° 19: Deformation after 1,2 m drop, specimen P3.

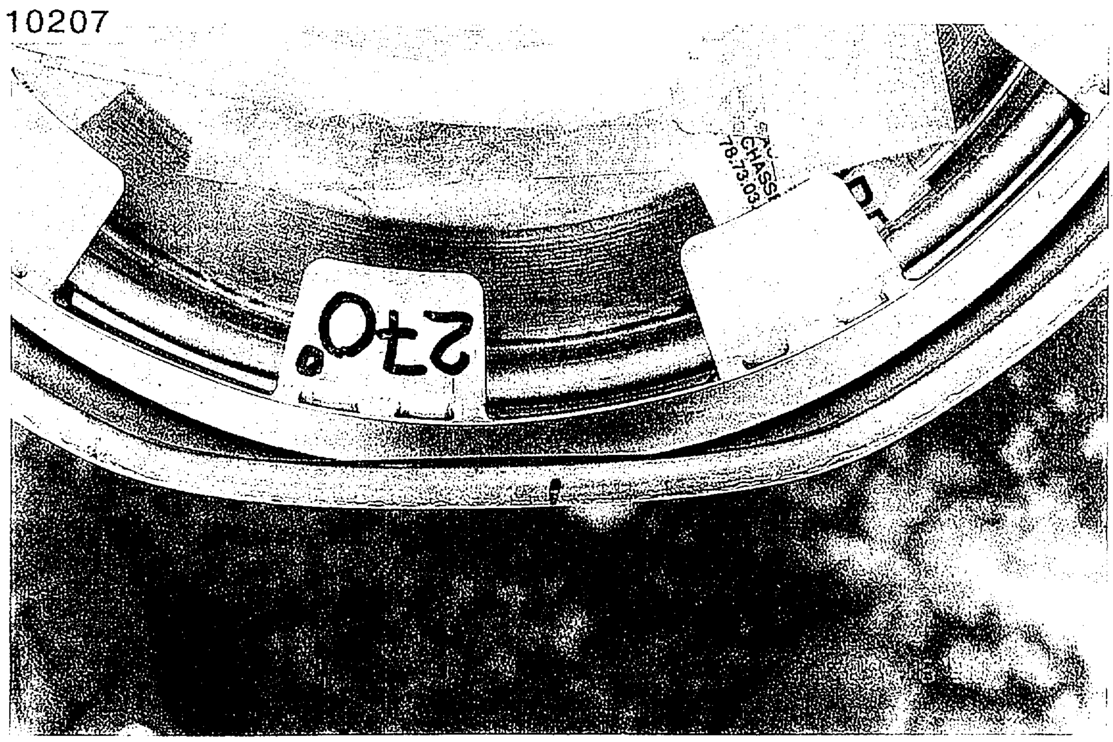


Photo n° 20: Drop by the 6 kg bar onto 0° centreline from a height of 1 m on specimen P3.

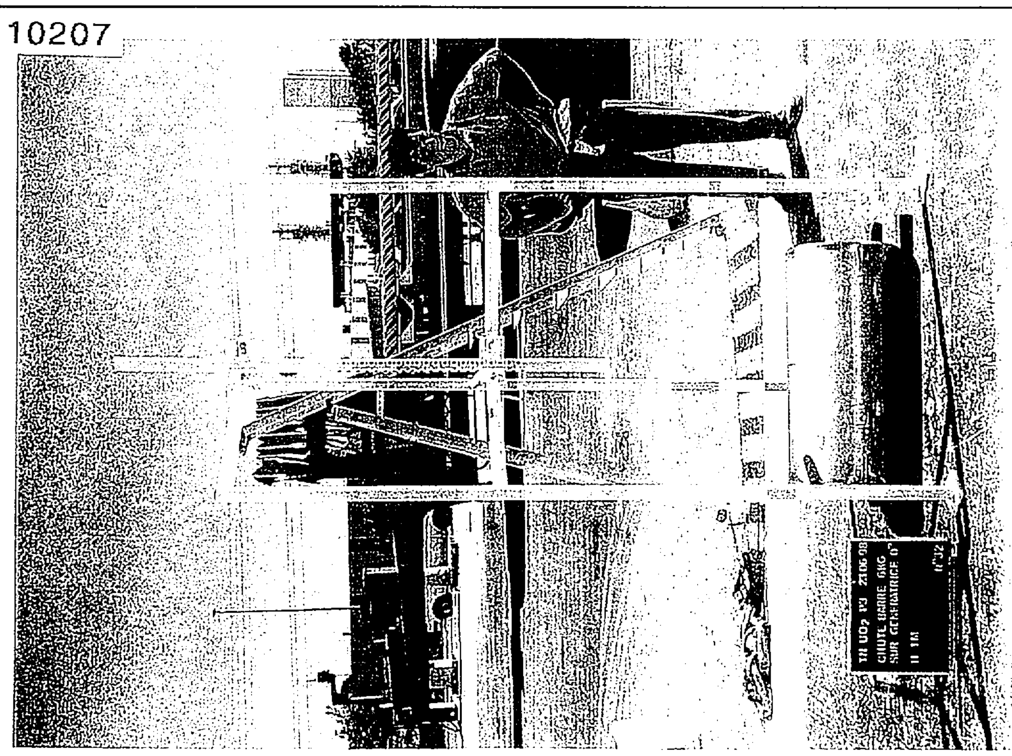


Photo n°21: Deformation after the 6 kg bar on specimen P3.

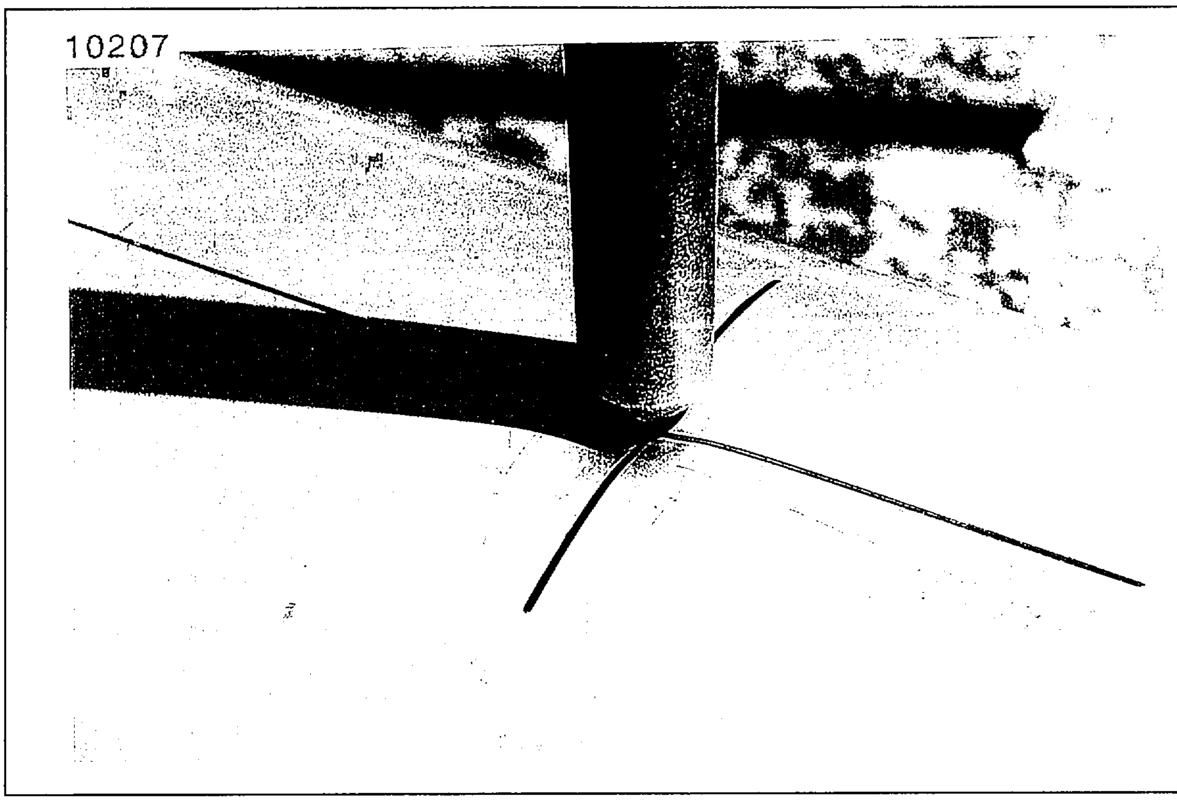


Photo n°22: Drop onto base circular edge height 0.3m, specimen P4.

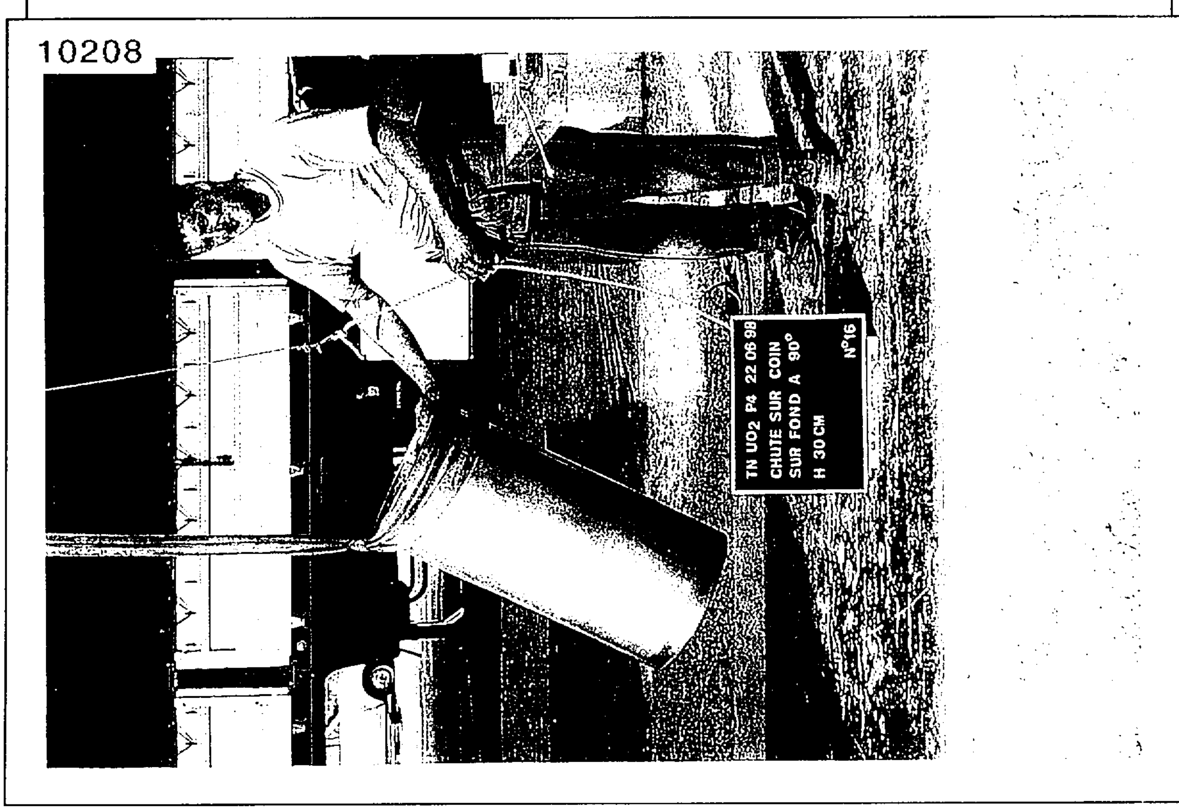


Photo n°23: Deformation after the four drops onto circular edge, height 0,3 m, base side, specimen P4.

Photo n°24: Drop height 1,2 m onto corner of lid opposite closure collar, specimen P4.

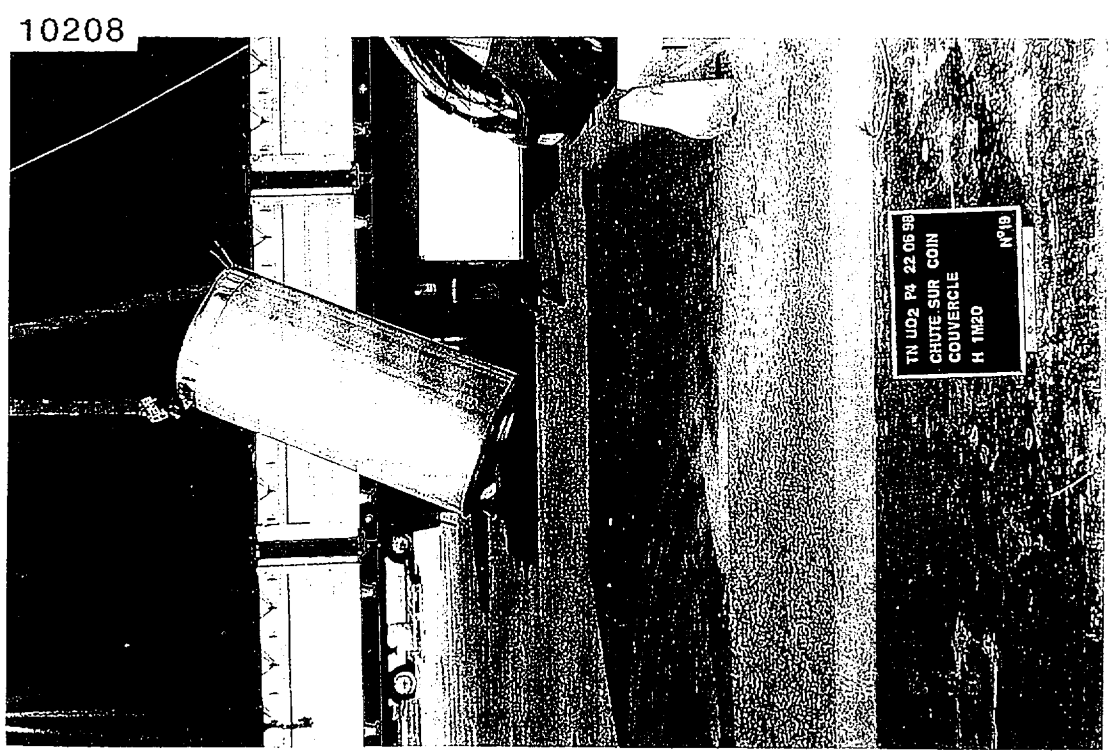


Photo n° 25: Deformation after drop height 1,2 m, specimen P4.

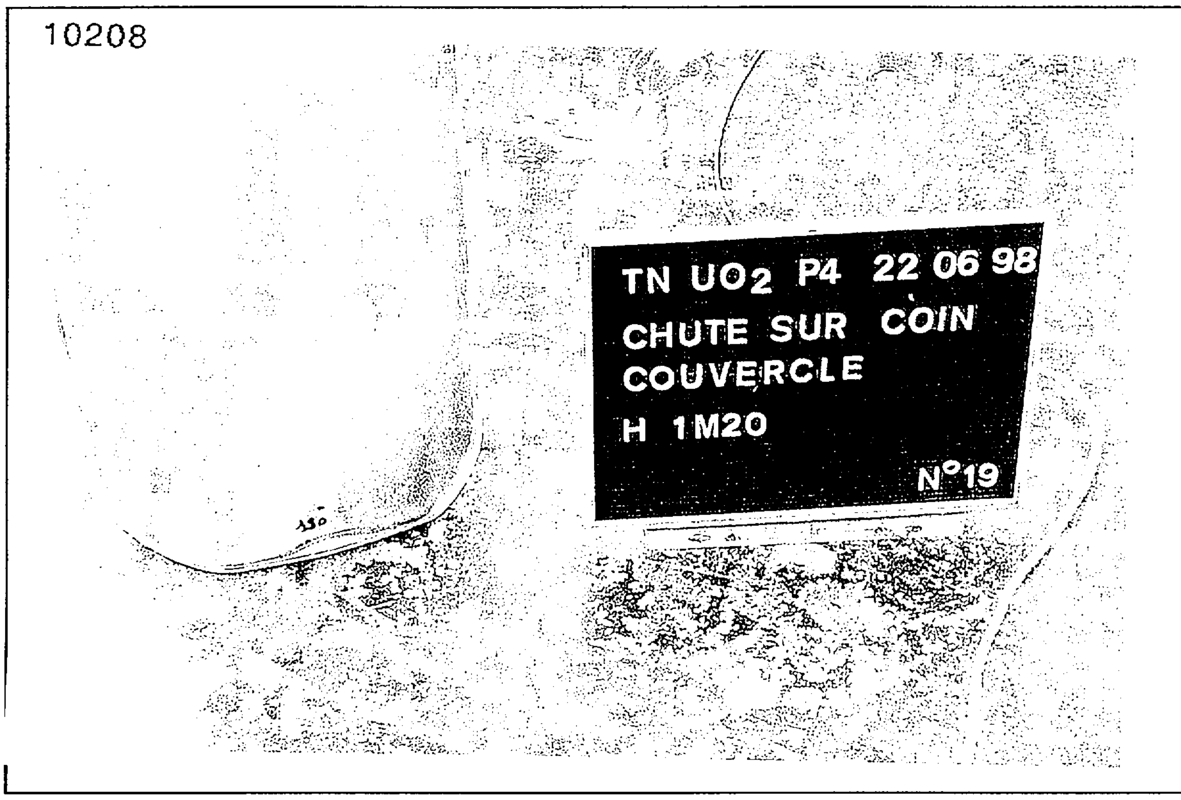
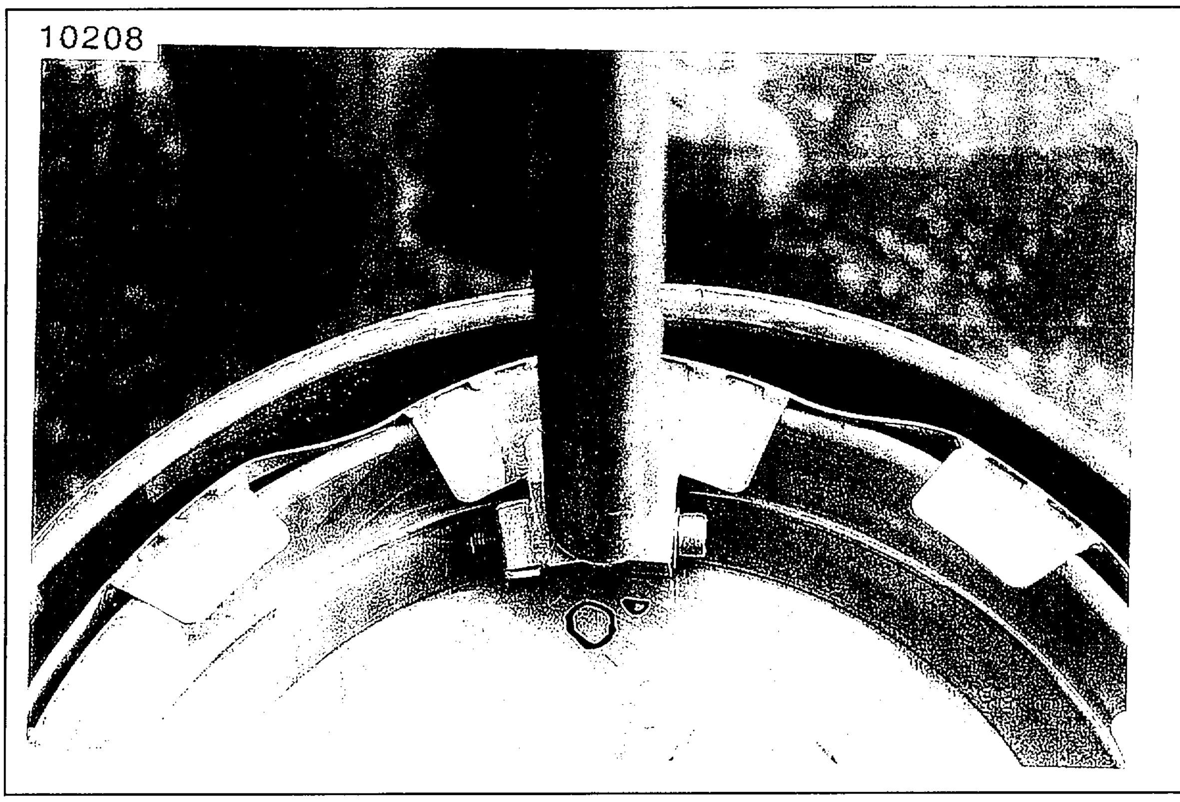


Photo n°26: Drop by the 6 kg bar on onto closure cellar from a height of 1 m on specimen P4.

Photo n°27: Deformation after 6kg bar drop on specimen P4.



TEST PHOTOGRAPHIC RECORD

CESTA

- **Photo n° 30: Mock-up P1 in drop onto punch bar position [drop n°1],**
- **Photo n° 31: Punch bar impact after drop n°1,**
- **Photo n° 32:Mock-up P1 in free fall drop position from a height of 9 m [drop n°2],**
- **Photo n° 33:Deformation of mock-up P1 after drop n°2**
- **Photo n° 34: Mock-up P2 in drop onto punch bar position [drop n°3],**
- **Photo n° 35: Punch bar impact after drop n°3,**
- **Photo n° 36: Free fall drop by a 500 kg plate from a height of 9 m onto mock-up P2 in vertical position, resting on top [drop n°4],**
- **Photo n° 37: Deformation of mock-up P2 after drop n°4,**
- **Photo n° 38: Mock-up P3 in drop onto punch bar position [drop n°5],**
- **Photo n° 39: Punch bar impact after drop n°5,**
- **Photo n° 40: Free fall drop by a 500 kg plate from a height of 9 m onto mock-up P3 in horizontal position [drop n°6],**
- **Photo n° 41: Deformation of mock-up P3 after drop n°6**
- **Photo n° 42: Mock-up P4 in drop onto punch bar position [drop n°7],**
- **Photo n° 43: Punch bar impact after drop n°7,**
- **Photo n° 44: Free fall drop by a 500 kg plate from a height of 9 m onto mock-up P4, tile angle of XX [drop n°8],**
- **Photo n° 45: Deformation of mock-up P4 top side after drop n°8,**
- **Photo n° 46: Deformation of mock-up P4 base side, first impact after drop n°8,**
- **Photo n° 47: Deformation of mock-up P4 base side, second impact after drop n°8.**

Photo n° 30: Mock-up P1 in drop onto punch bar position [drop n°1], Tilt angle 20°.19

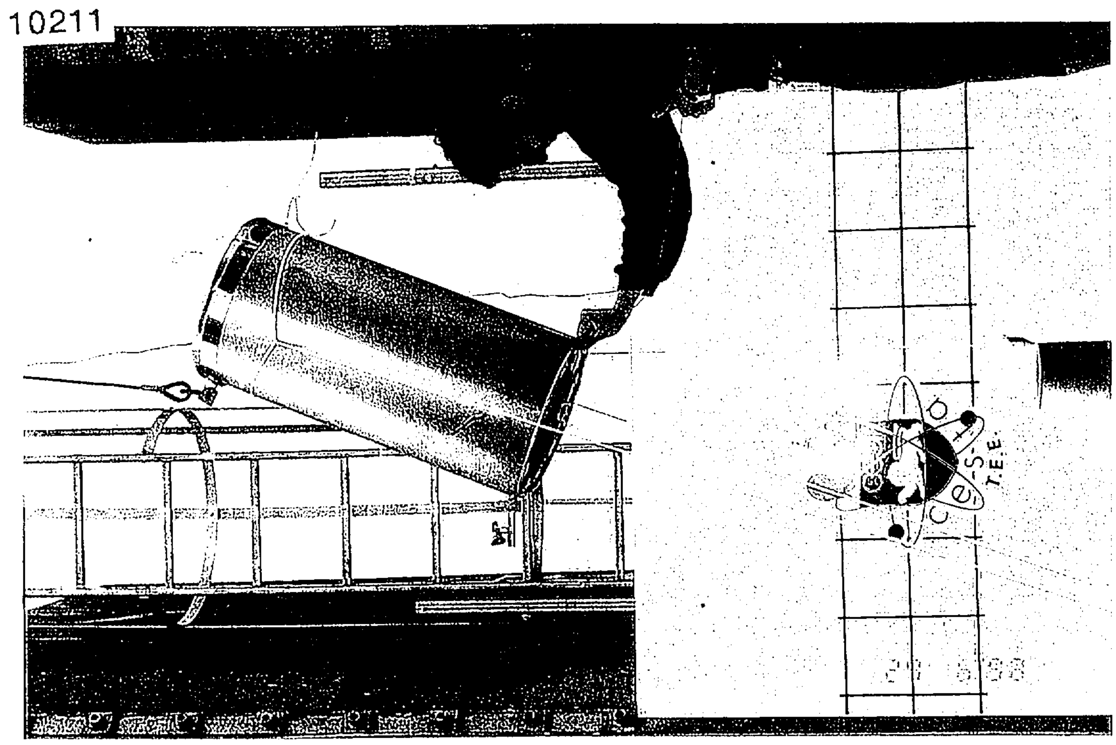


Photo n° 31: Punch bar impact after drop n°1

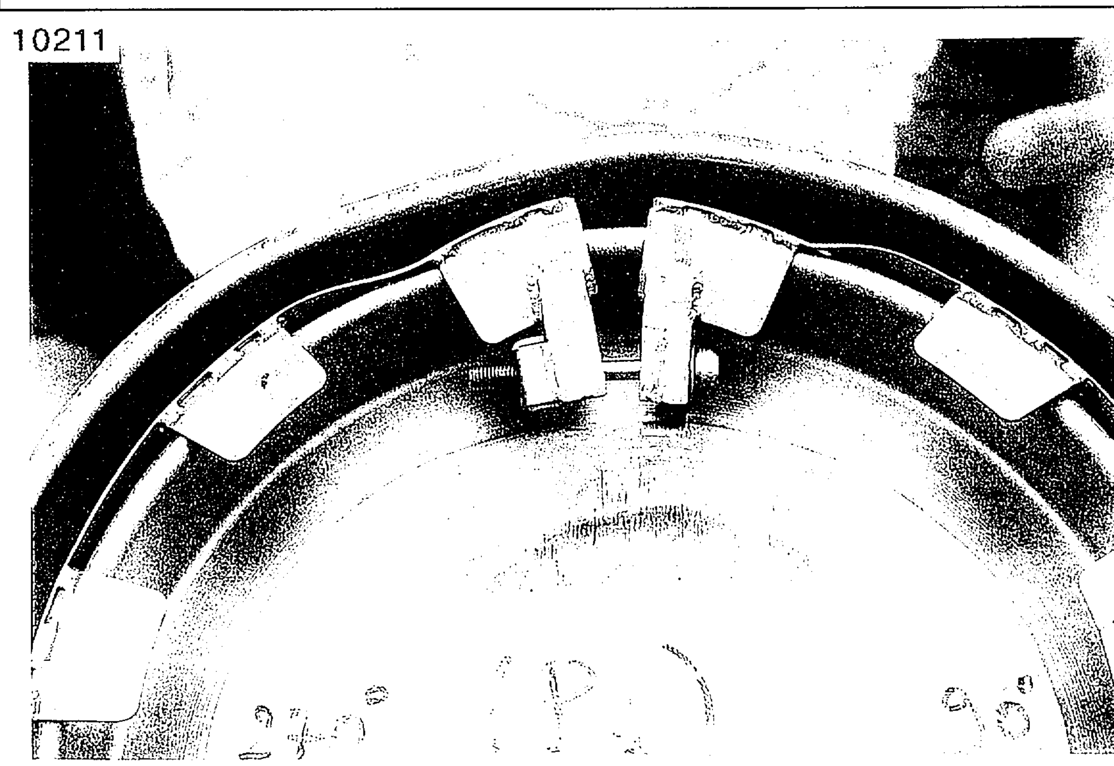


Photo n° 32:Mock-up P1 in free-fall drop position from a height of 9 m [drop n°2], tilt angle 26°.5

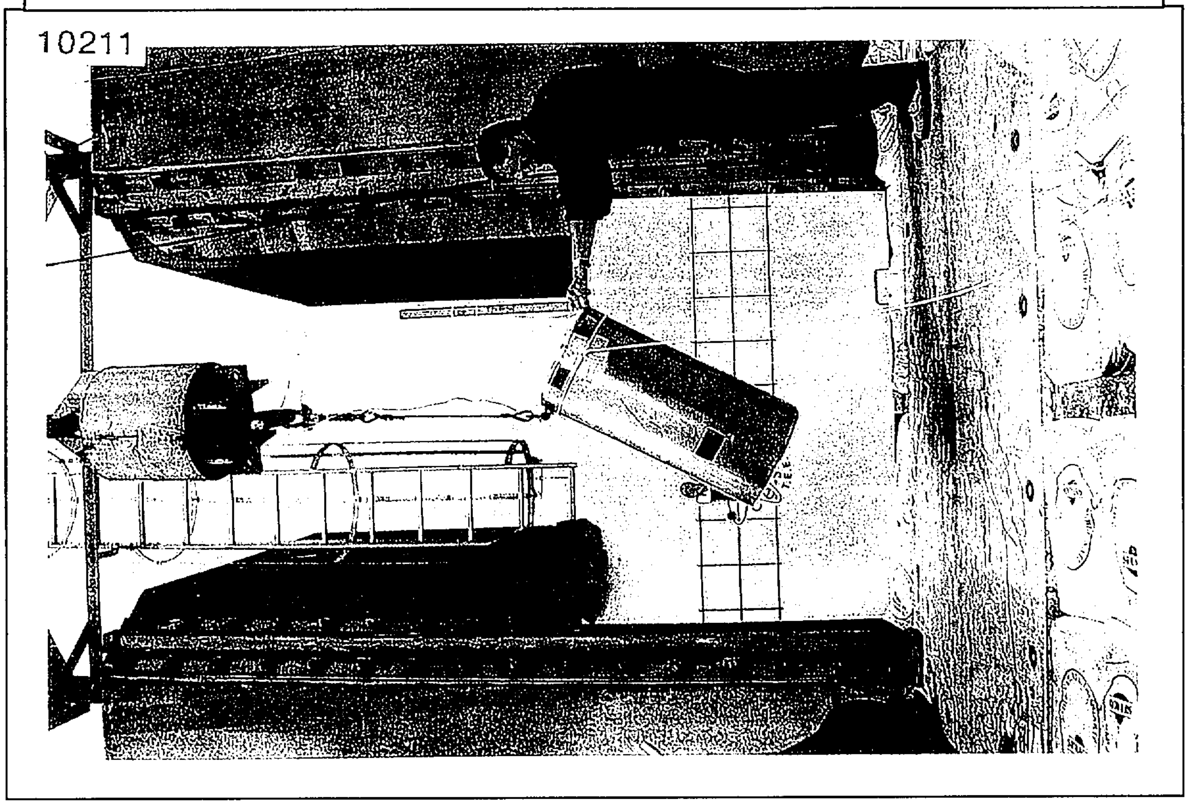


Photo n° 33: Mock-up P1 deformation after drop n°2

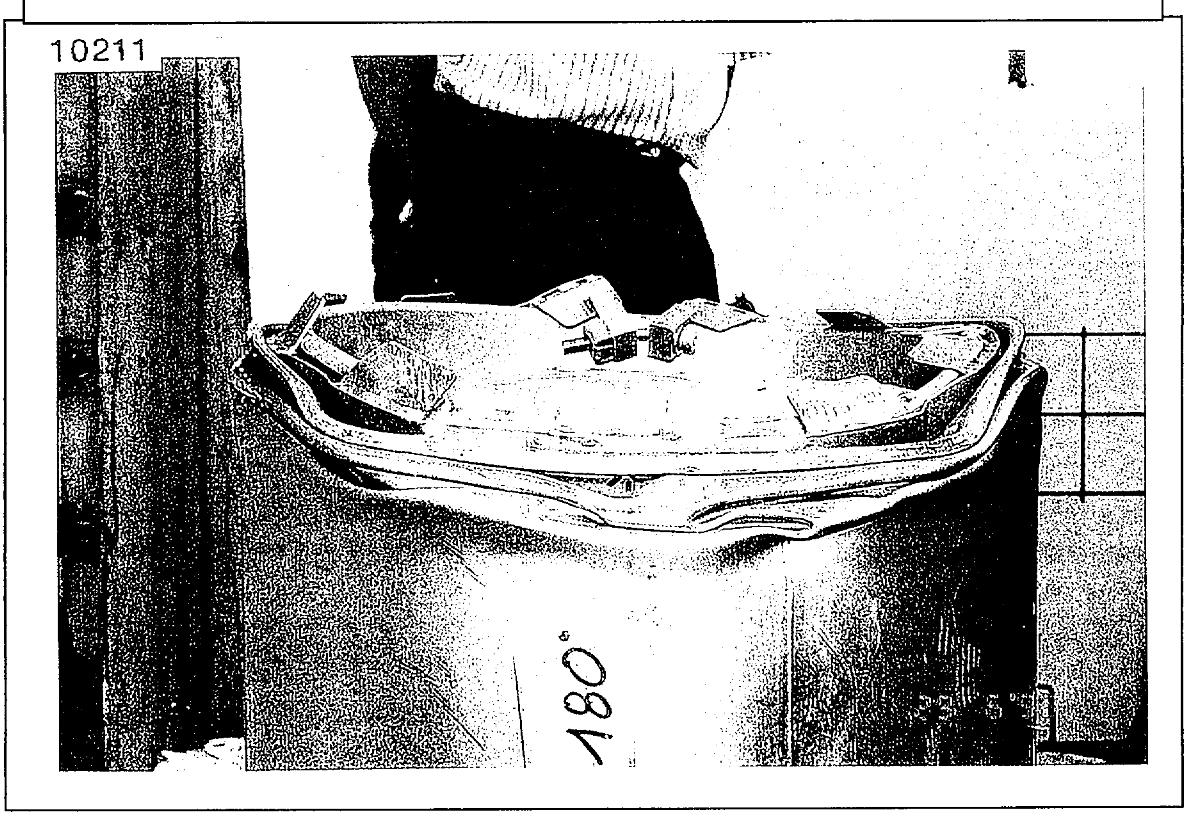


Photo n° 34: Mock-up P2 in drop onto punch bar position [drop n°3], tilt angle 20°.4

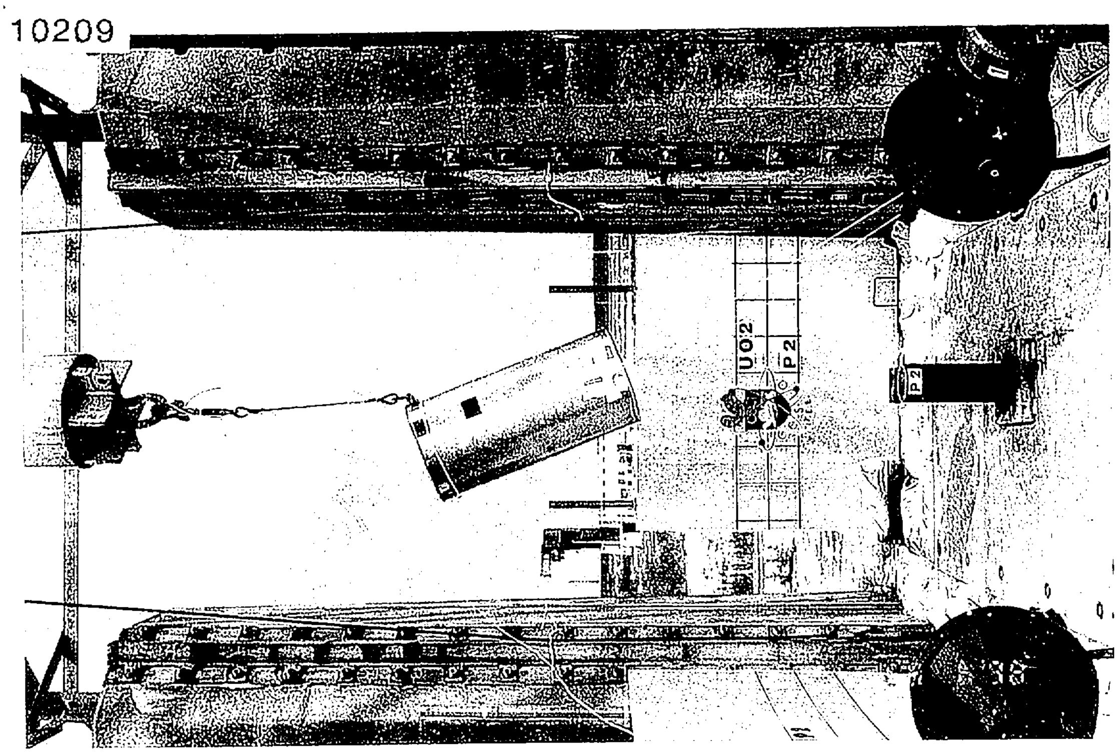


Photo n°35: Punch bar impact after drop n°3,

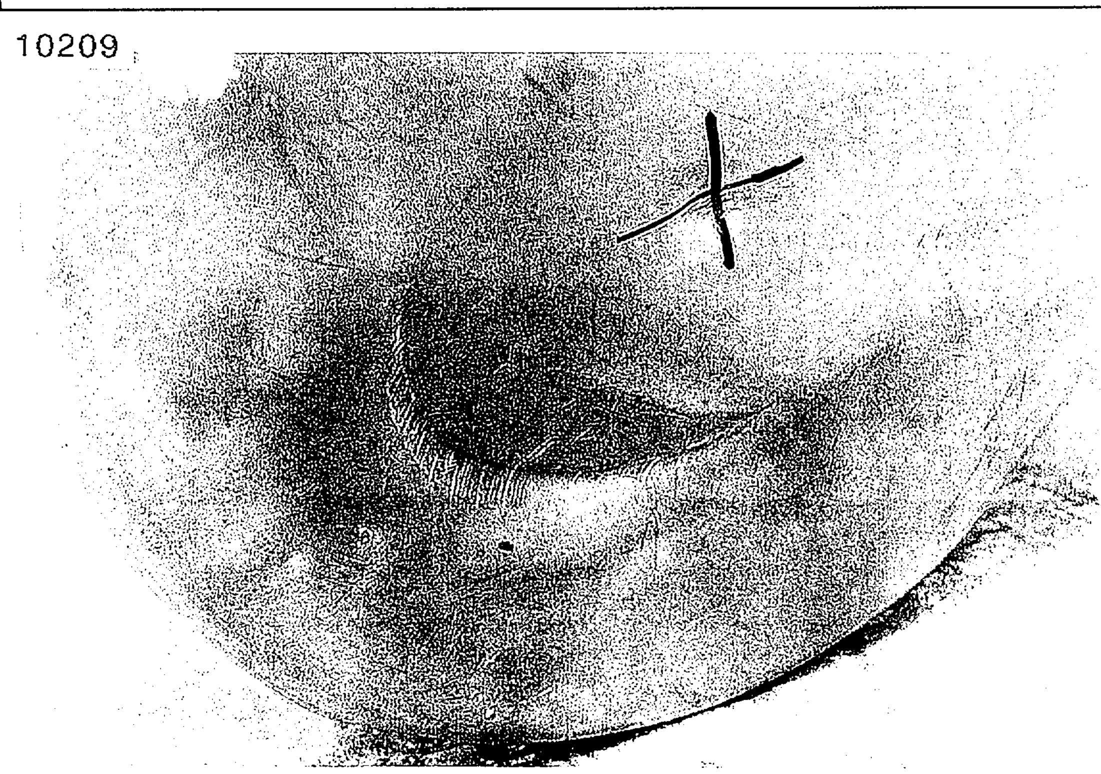


Photo n° 36: Mock-up P2 in free fall drop position from a height of 9 m [drop n°4], P2 vertical resting on top

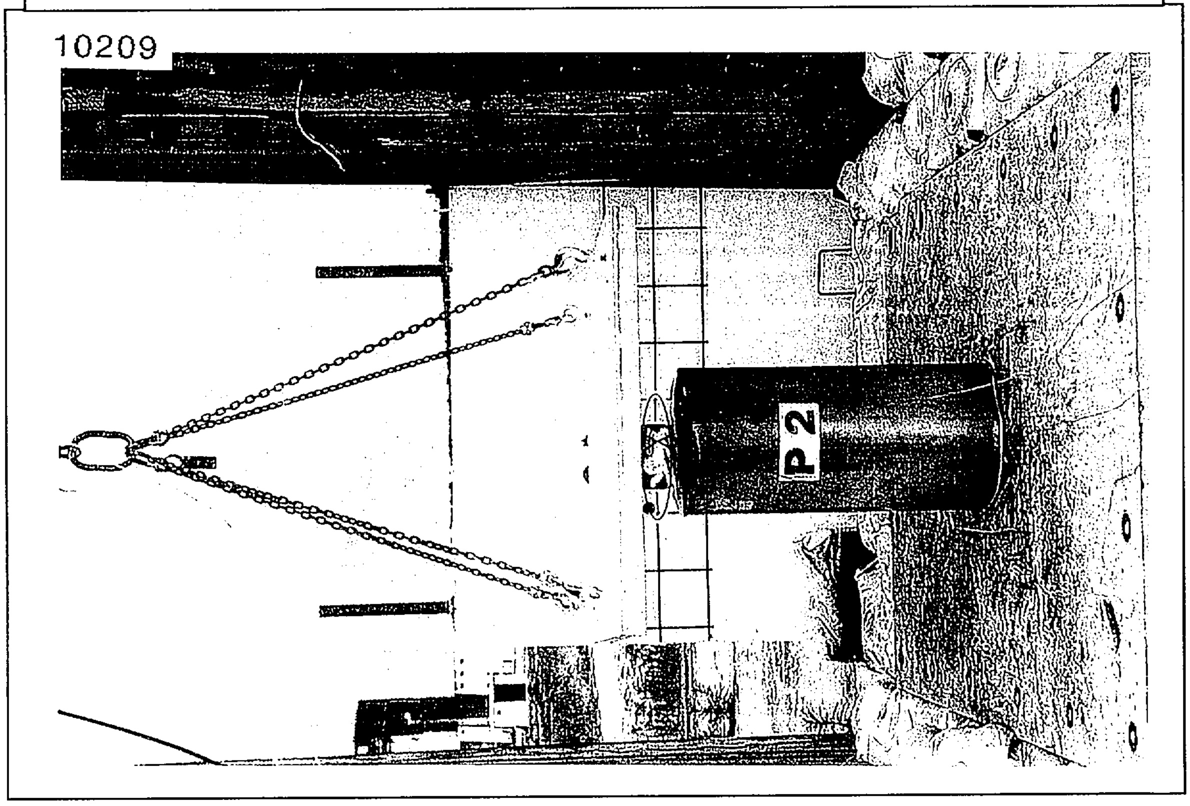


Photo n° 37: Deformation of mock-up P2 after drop n°4,

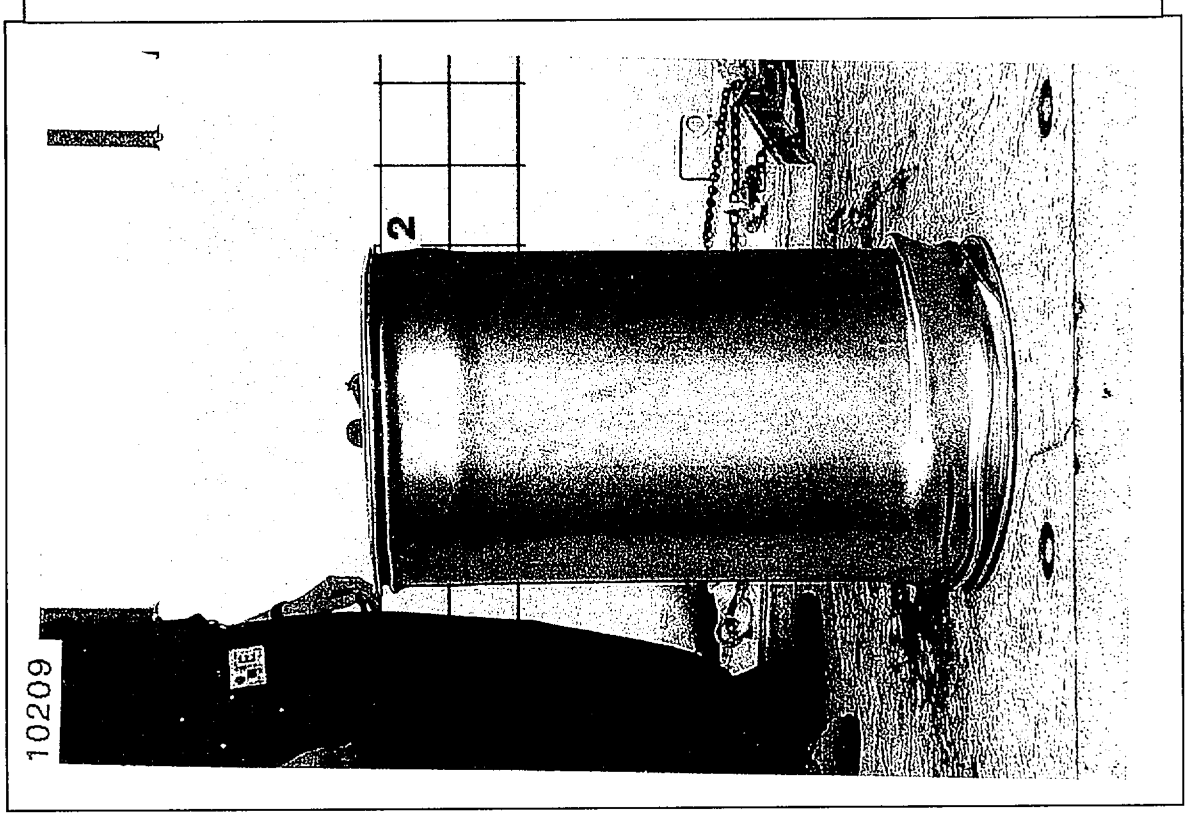


Photo n° 38: Mock-up P3 in drop onto punch bar position [drop n°5], Tilt angle 29°.5

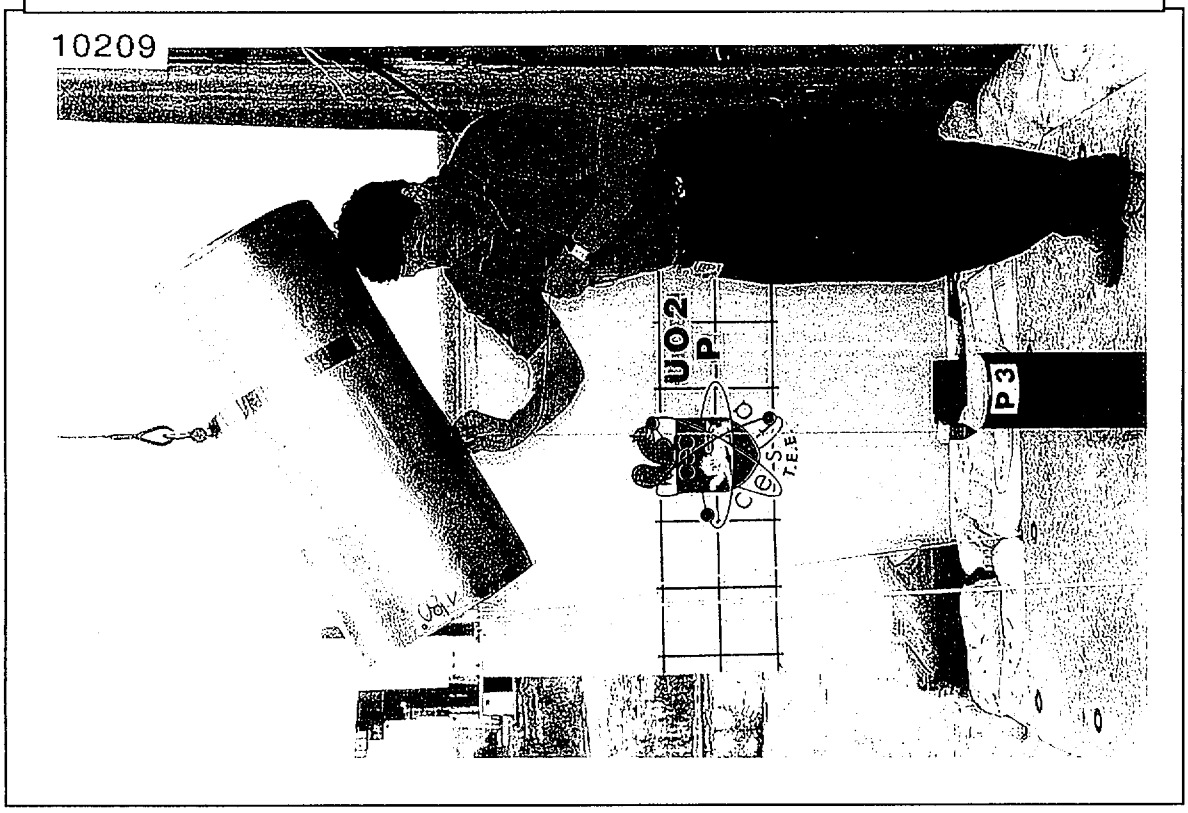


Photo n° 39: Punch bar impact after drop n°5,

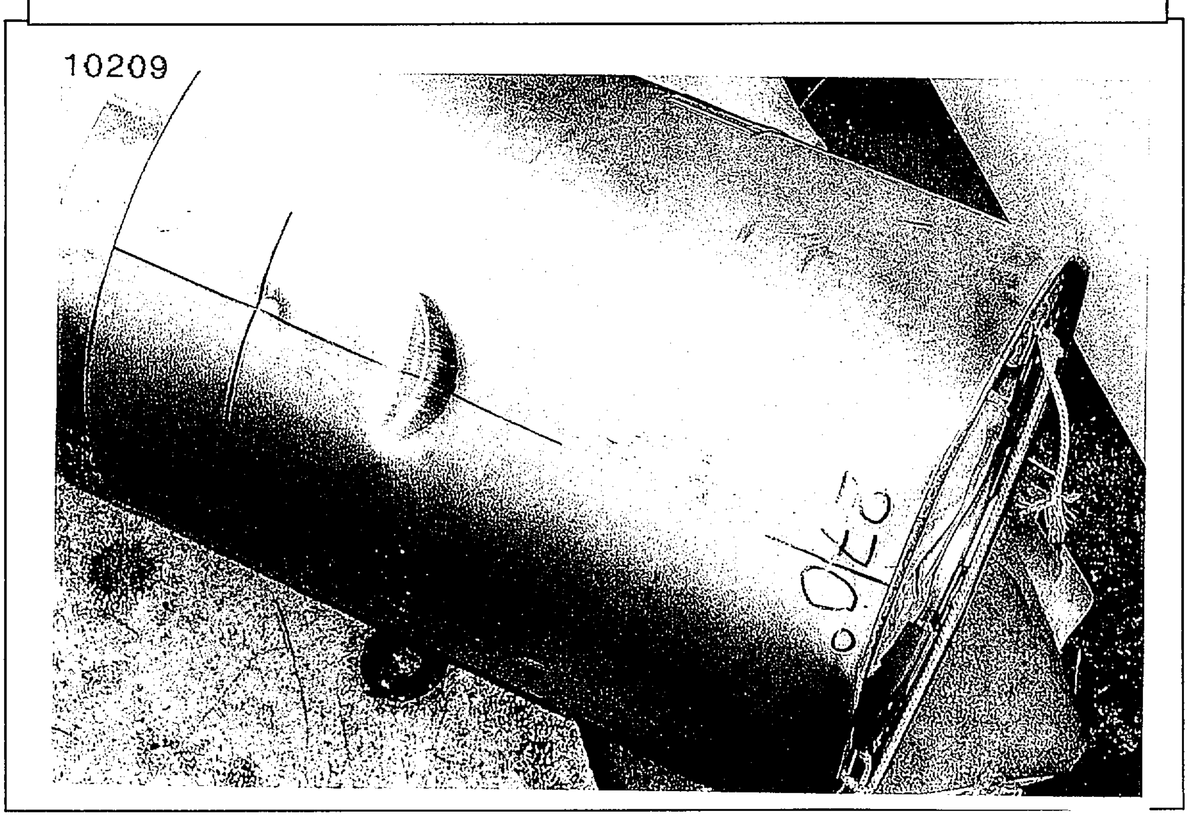


Photo n° 40: Free fall drop by a 500 kg plate from a height of 9 m onto mock-up P3 in horizontal position [drop n°6],

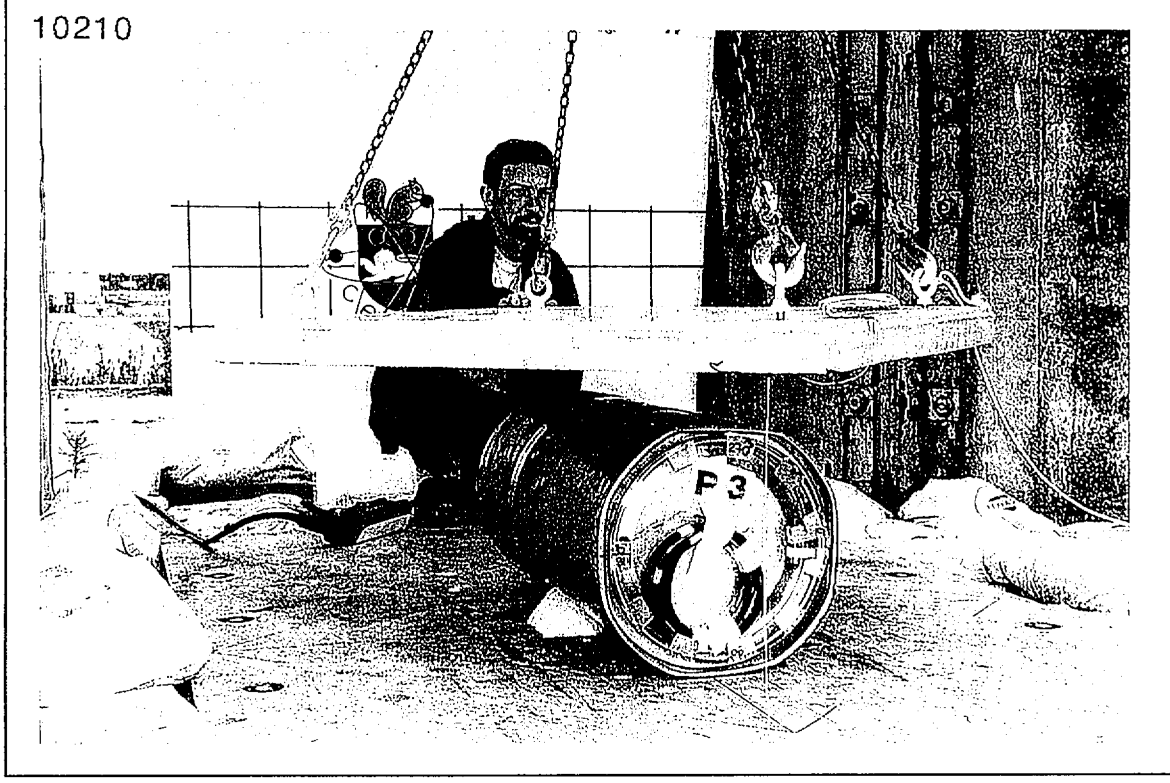


Photo n° 41: Deformation of mock-up P3 after drop n°6

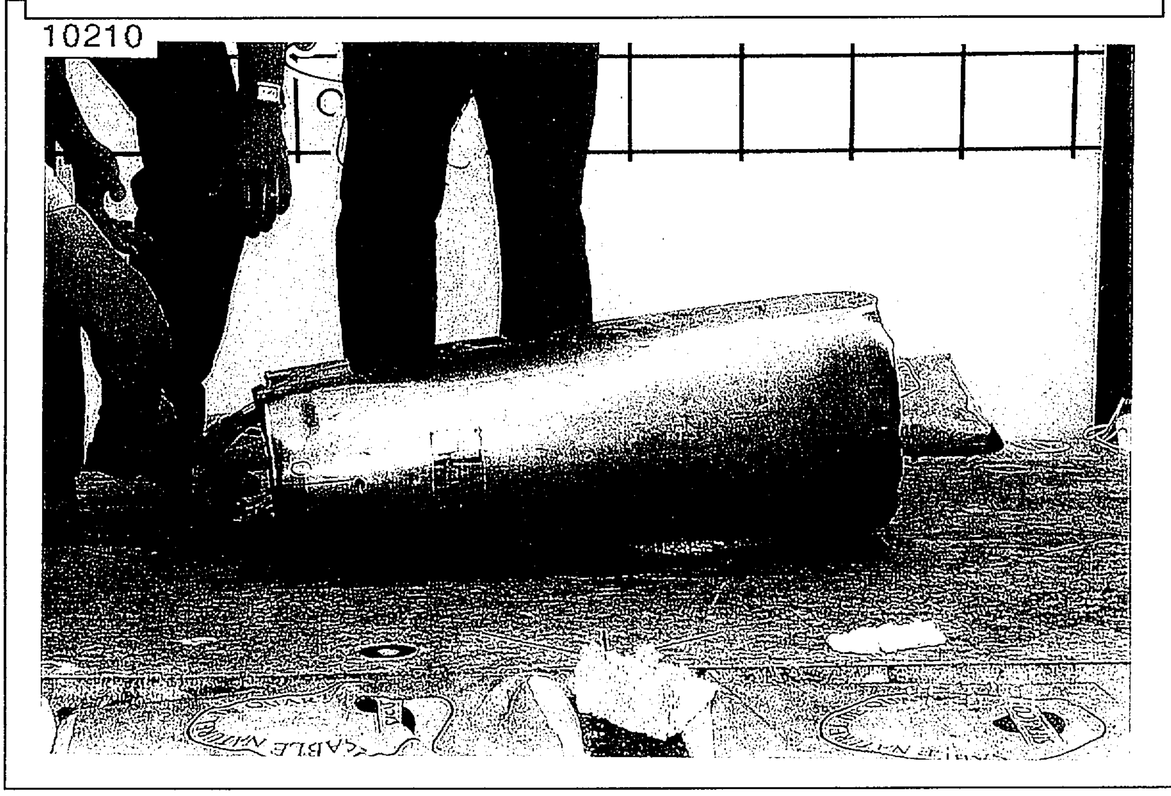


Photo n° 42: Mock-up P4 in drop onto punch bar position, tilt angle of 20°.5 [drop n°7],

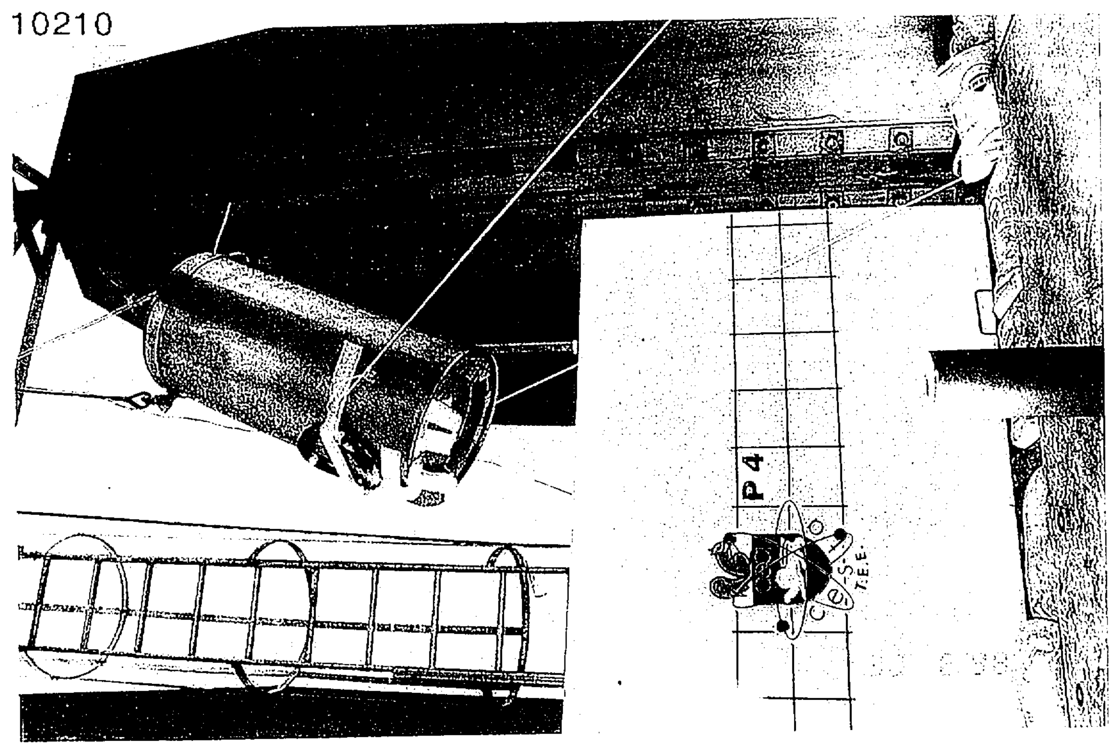


Photo n° 43: Punch bar impact after drop n°7,

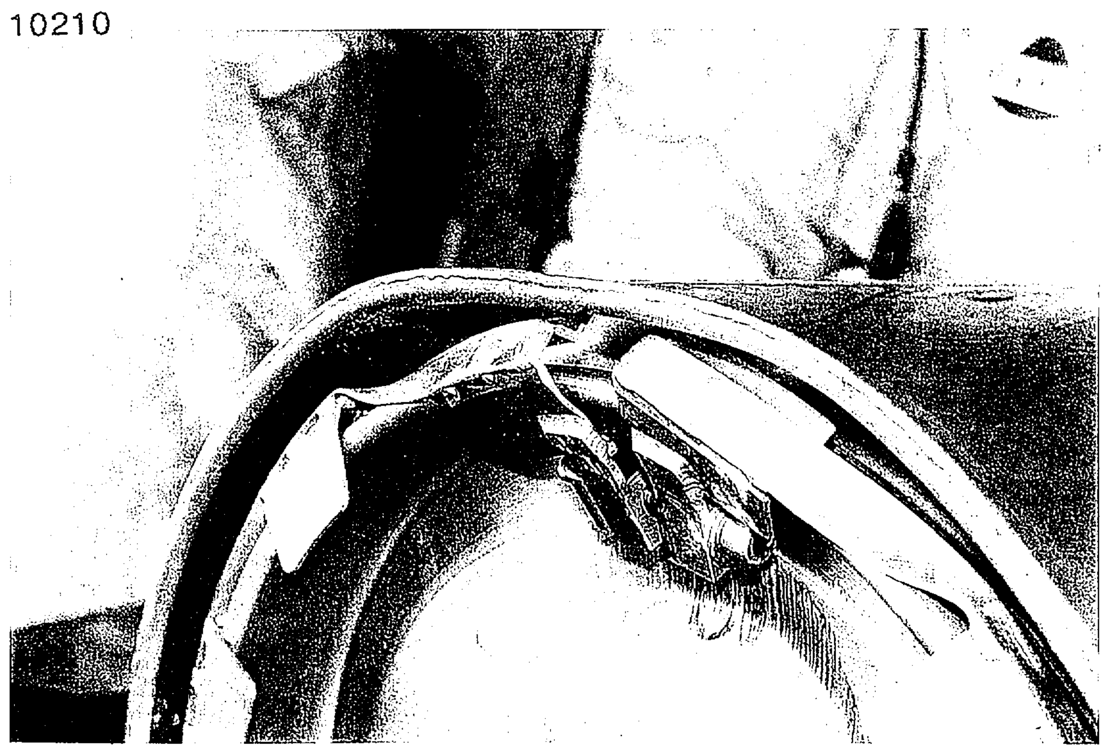


Photo n° 44: Free fall drop by a 500 kg plate from a height of 9 m onto mock-up P4 with a tilt angle of 21° [drop n°8],

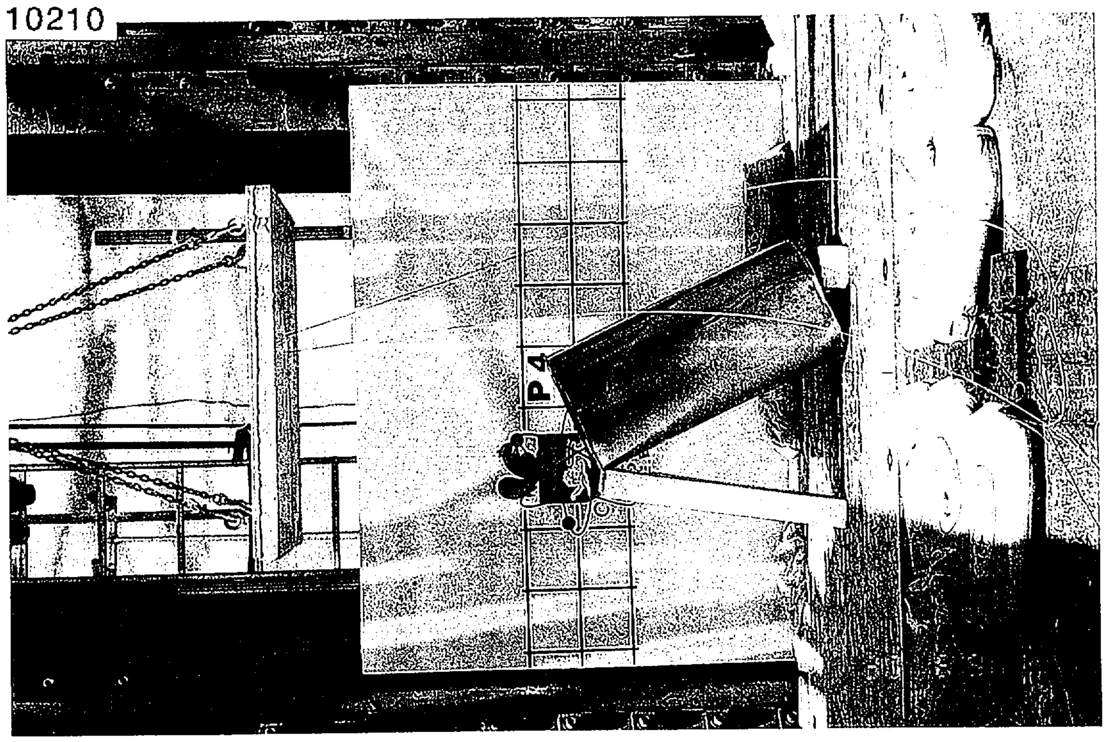


Photo n° 45: Deformation of mock-up P4 on top side after drop n°8,

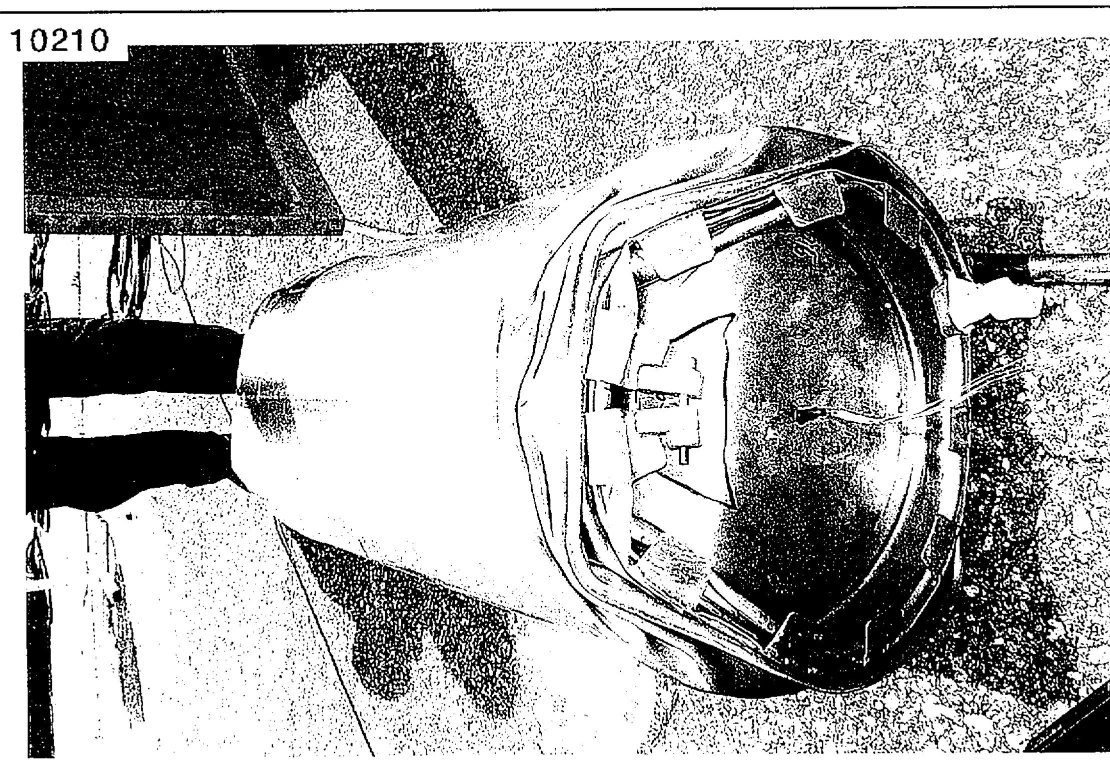


Photo n° 46: Deformation of mock-up P4 on base side, first impact after drop n°8,

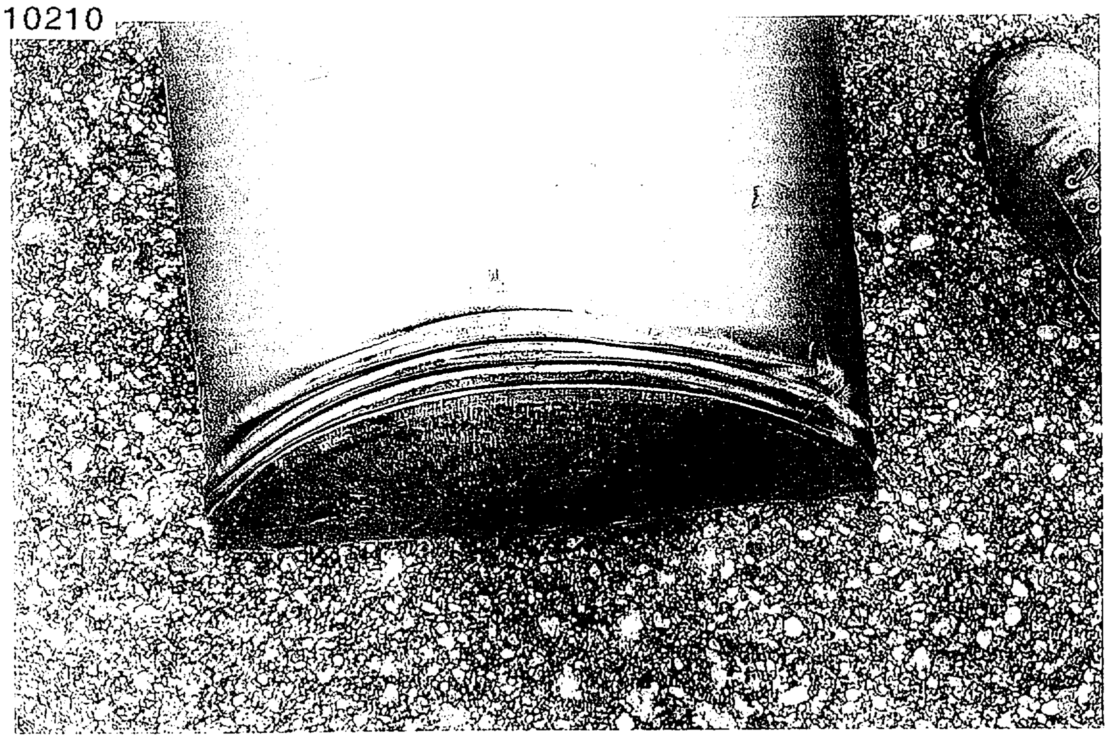
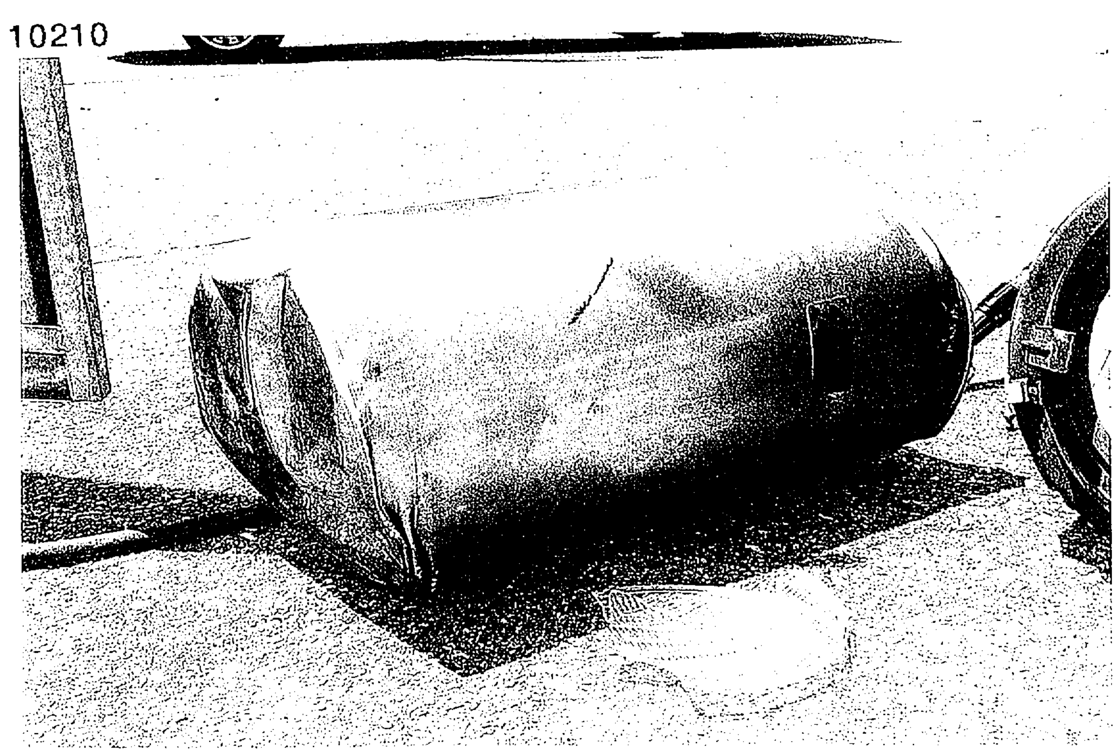


Photo n° 47: Deformation of mock-up P4 on base side, second impact after drop n°8.



TRANSNUCLEAIRE	REPORT ON DROP TESTS IN TRANSPORT ACCIDENT CONDITIONS			Page 1 of 10
$TN\text{-}UO_2$ SAFETY FILE		Name	Signature	Date
	Preparation	P. MALALEL		
	Checked by	F. POTELLE		
Ref. 10313-C-16 / Rev. 0				
Key words : Réf informatique : S:\Dac\Commun\Dossiers de Sûreté\TN-UO2\USA\10313C16E.doc				

CONTENTS

REVISION SHEET

Revision	Date	MODIFICATIONS	Author / Verified by
0	16/9/99	Creation of document	PML / FPL

1. PURPOSE

The purpose of this document is to present results relating to regulation drop tests in transport accident conditions performed on two specimens (named P11 and P15) representative of the final model of the TN-UO_2.package

The drop sequences used comprised the drop configurations which had resulted in the most damage to the package during the first test series (see <1>).

The normal-condition tests were not repeated, as they caused only insignificant damage to the packaging (see <1>).

The test were performed in compliance with the drop test specifications <3> and with the general qualification test program <2>.

The measurement of deformations on specimens was carried out after the full sequence of regulation tests, or after the thermal tests (see <4>).

Photographs of prototypes were taken at various stages of the drop test program, and some of these are included below. A video film was made of each drop (except for P15) and has been retained for possible examination in the "Documentation" room of the Interfaces and Tests department in the Development and Support division.

2. GENERAL INFORMATION

2.1. Participants from FBFC - Romans

C. BONNOT	Technical Direction
T. TAILLANDIER	Technical Direction

2.2. Participants from IPSN

A. LEROY	SSTR

2.3. 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. REFERENCE DOCUMENTS

<1> 10313-C-7 rév.0 : Drop tests report on TN-UO_2 packaging.

<2> 10313-P-3 rév.1 : IAEA qualification tests program.

<3> 10313-A-7 rév.0 : Drop tests specification on TN-UO_2 packaging.

<4> 10313-Z-1-7 rév.0 : Report on post-tests P1+P2/P11+P15 assessments.

<5> TRANSNUCLEAIRE TN-UO_2 drawing ref. 10313-05 ind.A.

<6> TRANSNUCLEAIRE TN-UO_2 drawing ref. 10313-05 ind.B.

<7> PPE non-conformity letter ref. 99109-MF/JPC of 21/04/99.

<8> Safety series n°6, IAEA Safety Standards, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (as amended 1990), Vien.

<9> Regulations for the Safe Transport of Radioactive Material – 1996 Edition - Requirements n°ST-1 – IAEA,Vienna.

4. DEFINITION OF TEST SPECIMENS

The equipment tested consisted of two full-scale prototypes of the TN-UO_2. packaging each containing a flask filled with pure iron powder with the same bulk density as UO_2 powder (see Appendix 1-5 of this safety file):

- specimen P11: sequence including dropping of plate through 9 meters at a slant onto the upper corner of the packaging, with maximum contents (38 kg).
- specimen P15: sequence including dropping of plate through 9 meters laterally onto the centerline of the packaging with minimum contents (1 kg).

The high-degree of representativeness of the prototypes, of which the execution drawings are presented in <5> for P11. and <6> for P15 respectively, is justified in the descriptive note on prototypes (Annex 1-5 of this safety file).

5. TEST MEANS

The tests were performed on the test site of the Celestin de Laudin facility.

5.1. The drop installation

The drop installation used consisted of an unyielding target and a hoist of which the block was equipped with a hook with a mechanical release device.

The target used for the various drops consisted, from top downwards, of:

- a steel plate:

  – grade : E24

- weight : 2 800 kg
- thickness : 5 cm
- width and length of plate: 2 m x 3.5 m.

The plate has 44 holes allowing passage of tie rods attaching it to the concrete base block.

The tie rods, in E24 steel (22 with length of 1.5 m and 22 with length of 0.6 m) have a "hairpin" bend at one end in the concrete block and are threaded at the other end, embedded for attachment of the steel plate.

- a concrete base block:
  - height x width x length : 2 m x 2.5 m x 4 m
  - weight of base block : 49 000 kg.

The concrete is reinforced with 14-mm steel hoops spaced at 17 cm.

Complete slab (steel plate + reinforced concrete block):
- weight : 53 tons
- height x width x length : 2 m x 2 m x 3.5 m.

Release of the specimen is achieved by means of a mechanical device with two demi-hooks of which the opening is controlled remotely by a cable. The drop height is measured from the lowest point of impact of the specimen and the upper surface of the target.

5.2. Special means

5.2.1. *Punch tests*

The target used for the regulation drop test through 1 meter onto a punch is a solid mild steel bar (E 24) with a diameter of 150 mm. This bar is welded vertically to a horizontal steel plate, itself welded to the steel plate described above.

5.2.2. *Plate drop test*

The plate used for the regulation drop test consisted of a flat, solid, mild steel plate (E 24), with dimensions of 1 m x 1 m and a real weight of 501 kg.
The plate is lifted using a four-branched metal sling.

6. PERFORMING THE TESTS

The tests were performed on 27 January 1999 for prototype and on 30 August 1999 for prototype P15 (postponement due to defect in initial prototype P12, linked to lack of homogeneity of inner ring of neutron-absorbing resin: non conformity in process of pouring of material: see <7>).

The list of drops performed in compliance with specifications described in <2> and <3> is given below:

TEST	SPECIMEN	TEST DEFINITION	ORIENTATION	Area of package tested
<9> 727 c)	P 11 Contents 38 kg	Free fall of a 500-kg plate through 9 m	Specimen axis at a slant with center of gravity vertical to impact (inclination of around 25°, Figure 1)	Entire package
<8> 627 b) <9> 727 b)	P 11	Drop through 1 m onto punch bar	Specimen axis with inclination of around 25°, impact on edge of lid at point of widest opening (Figure 2)	Locking device and bayonet operated lid
<9> 727 c)	P 15 Contents 1 kg	Free fall of 500-kg plate through 9 m	Specimen horizontal, center of plate vertical to specimen center,(Figure 3)	Entire package
<8> 627 b) <9> 727 b)	P 15	Drop through 1 m onto punch bar	Specimen axis with inclination of around 25°, impact on edge of lid at point of maximum opening (Figure 2)	Locking device and bayonet operated lid

Measurements and monitoring:

- Weighing of quantity of powder in flasks.
- Torquing of flask cap.
- Closing of lid.
- Measuring of dimensions after drop (height of crushing).
- Checking of fitting of lid onto body.
- Checking of outer shell and welds.
- Checking that there is no dispersion of contents.

7. RESULTS

7.1. Drop n°1 (P11)

- Free drop of 500-kg plate through 9 meters onto specimen with angle of inclination of **25°** in relation to vertical (specimen immobilized by polystyrene chock), impact on lid closing device: see photographs 1 to 8.
- Deformation on the base side and on head side was fairly severe. However, the lid remained in place. The bayonet closing system was also deformed, but still fulfilled its function. A corner impact was observed on the body of the packaging, as the plate rebounded after its fall onto the packaging, causing the second impact.
- No cracking of shell, nor dispersion of contents was observed.

7.2. Drop n°2 (P11)

- Drop onto punch bar, height of 1 meter, axis of specimen at angle of **25°** in relation to vertical, impact on edge of lid at point of maximum opening caused by drop no. 1: see photographs 9 to 12.
- The punch left an imprint on the lid (see photograph no. 12), the lid remained in place.
- No perforation, opening of the lid, or dispersion of contents was observed.

7.3. Drop n°3 (P15)

- Free fall of 500-kg plate through a height of 9 meters onto horizontal specimen (specimen immobilized by polystyrene chocks) with lid locking devices horizontal: see photographs 13 to 18.
- The specimen is deformed (flattened) over its entire length.

<u>Overall dimensions, head side</u>

300 mm (vertical) *(Diameter before drop: 380 mm)*

435 mm (horizontal)

<u>Overall dimensions, base side:</u>

325 mm (vertical)

402 mm (horizontal)

- This drop caused greater deformation on the head than on the base, after initial impact and flattening of the package, the plate rebounded and impacted the head of the specimen a second time leaving an imprint in the outer shell (see photograph 18).

- The lid remained fitted to the packaging, opening was observed at both of its ends (see photograph 16).
- No cracking of the shell nor dispersion of the contents was observed.

7.4. Drop n°4 (P15)

- Drop onto punch bar, height 1 meter with inclination of **25°** in relation to vertical, impact on edge of lid at point of maximum opening (photograph 21) caused by drop no. 3: see photographs 19 to 23.
- The punch slid on the edge of the lid, then impacted the swivel (see photograph no. 23), the lid remained in place.
- No perforation, opening of the lid nor dispersion of contents was observed.

8. CONCLUSION

The tests on the various specimens were performed in compliance with the specifications.

The test results showed that the design of the packaging was such that its mechanical strength is adequate. The closing and locking system of the lid fulfilled its function during all tests. No perforation of the outer sheet metal nor cracking of welds was observed.

The two specimens did not show dispersion of the iron powder contained after each of the respective test sequences.

They were therefore declared suitable to undergo the final thermal qualification test as per <8> and <9>.

LIST OF FIGURES

LIST OF TEST PHOTOGRAPHS

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3 4	A A	Specimen P11 after plate impact ditto view of packaging base	1
5 6	A A	Specimen P11 after plate impact, head view ditto view of second plate impact	1
7 8	A A	Lid, specimen P11 after plate impact ditto detail	1
9 10	A A	Specimen P11 in position for fall onto punch bar (drop n°2) ditto after impact	1
11 12	A A	Detail impact area with punch bar ditto	1
13 14	A A	Specimen P15 in horizontal position for drop n°3 ditto	1
15 16	A A	Specimen P15 after plate impact ditto view of packaging head	1
17 18	A A	Base, specimen P15 after plate impact Top view with second plate impact	1
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		TOTAL	12

FIGURE 1

STRESS OF PACKAGING DURING 500-KG PLATE FALL THROUGH 9 METERS (INCLINATION 25°)

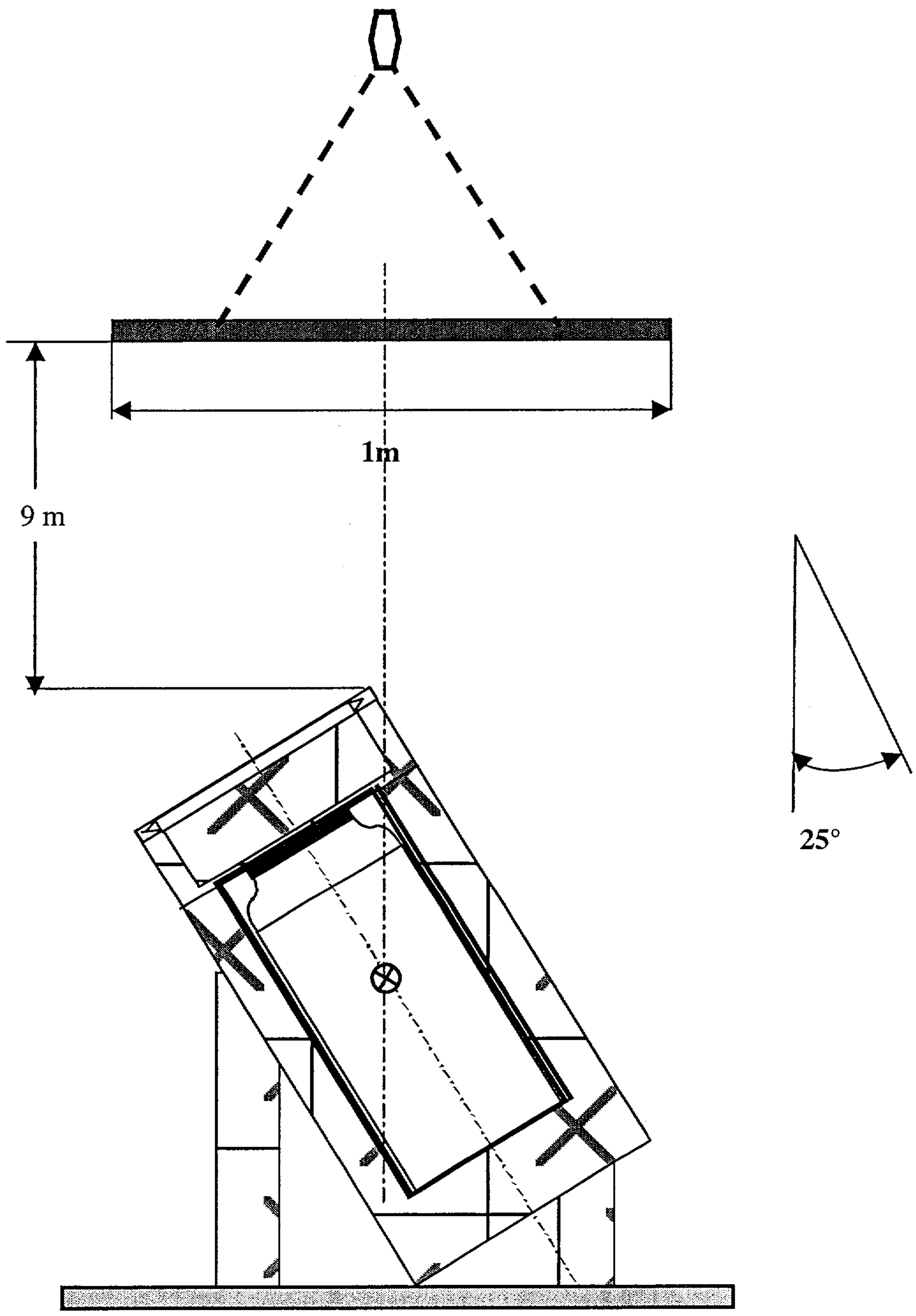

FIGURE 2

STRESS OF PACKAGING DURING DROP ONTO PUNCH BAR

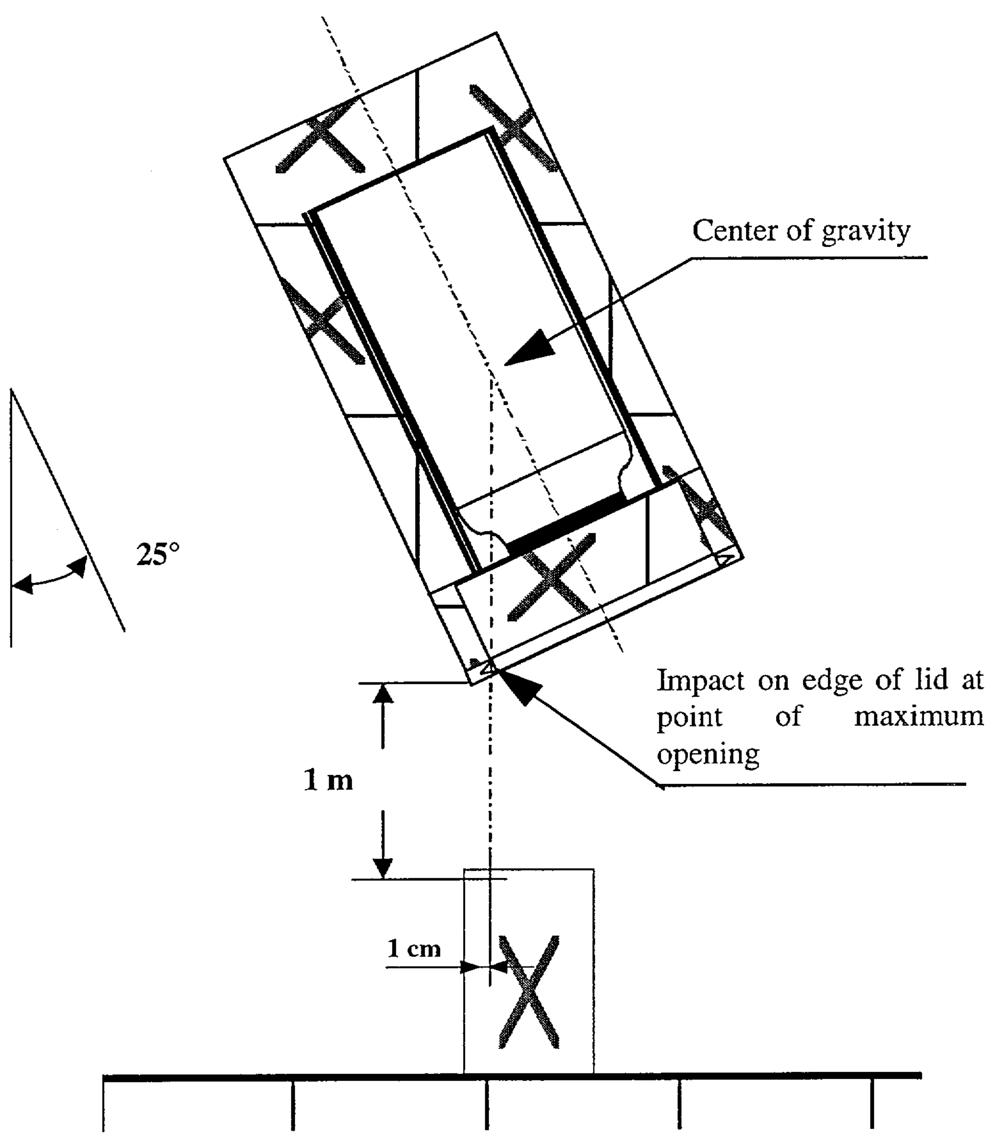

FIGURE 3

STRESS OF PACKAGING DURING LATERAL DROP OF 500-KG PLATE

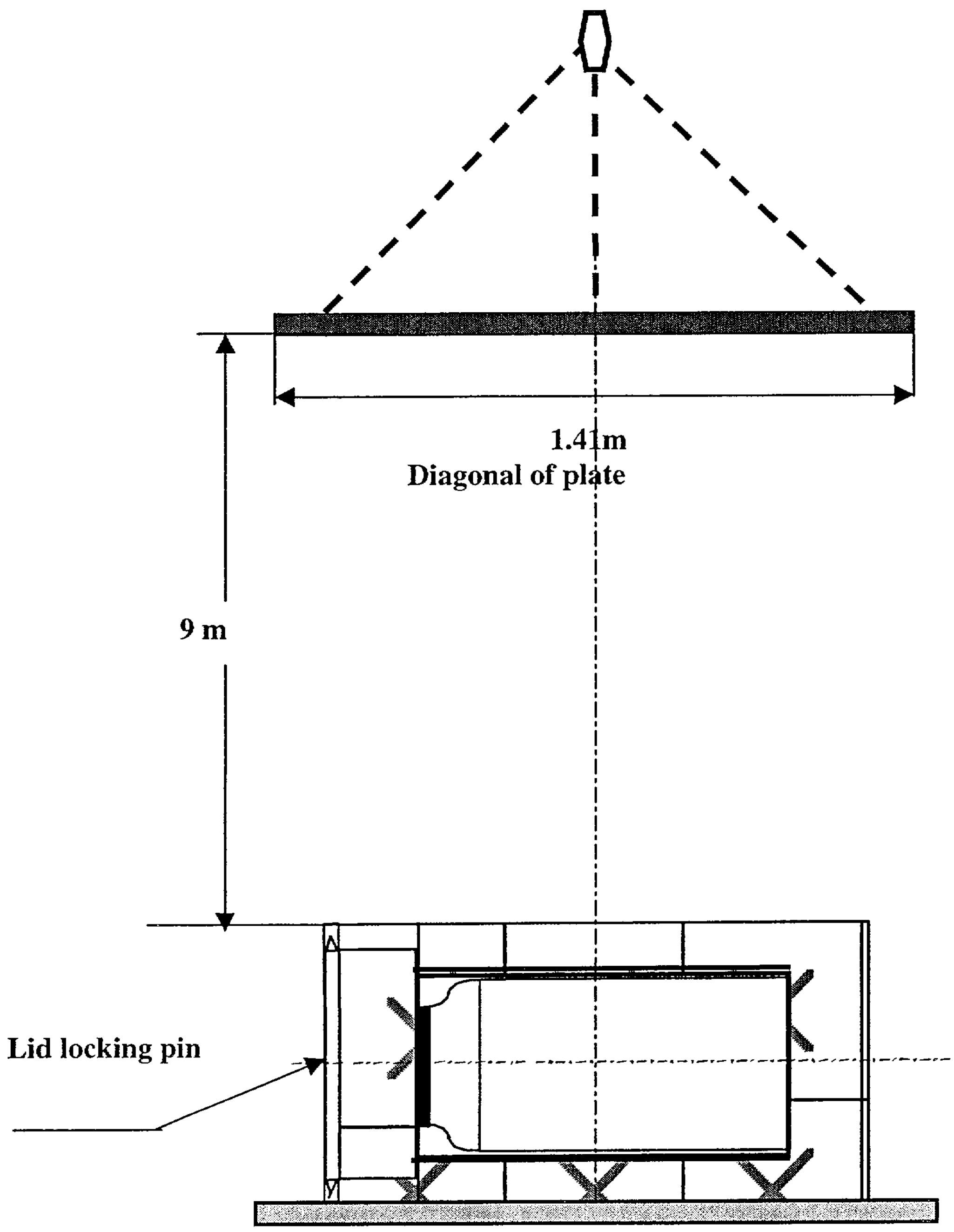

Photo n° 1: Specimen P11 in slant position for drop n°1

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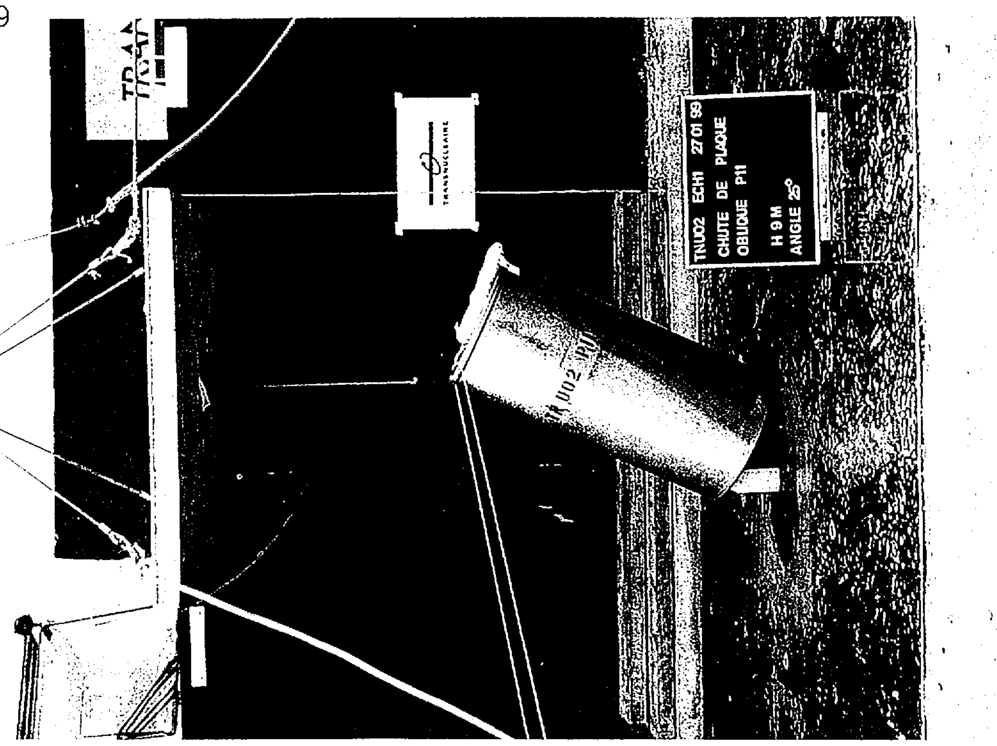

Photo n° 2: ditto

10269

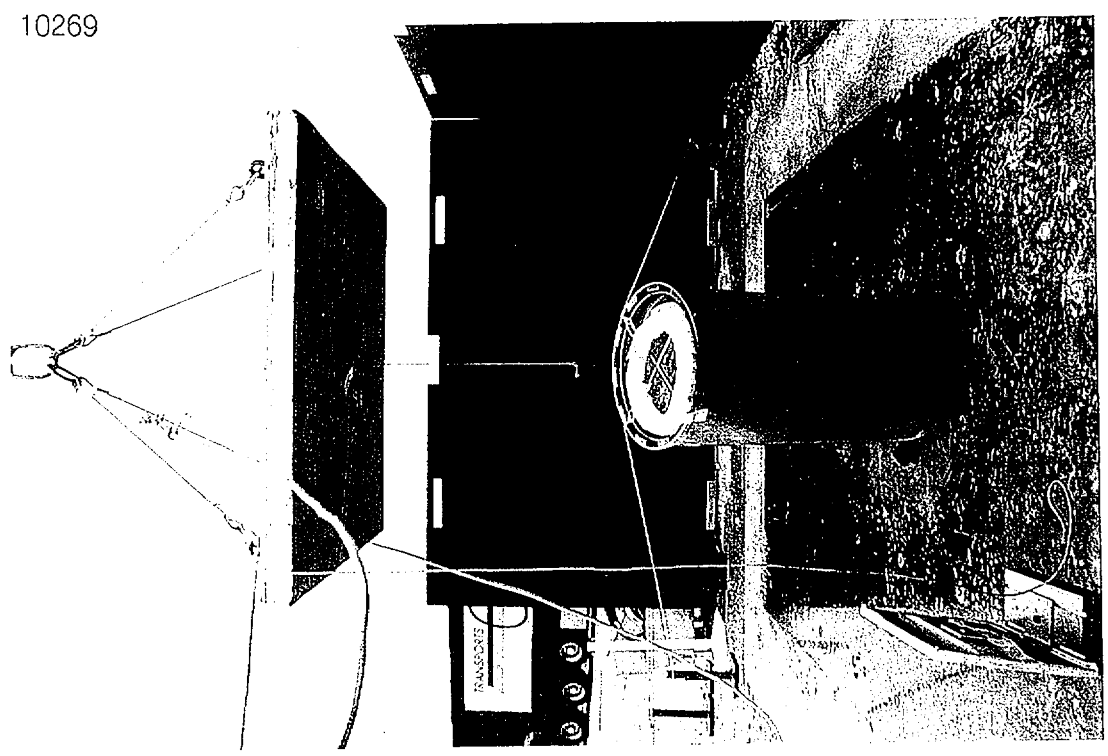

Photo n° 3: Specimen P11 after plate impact

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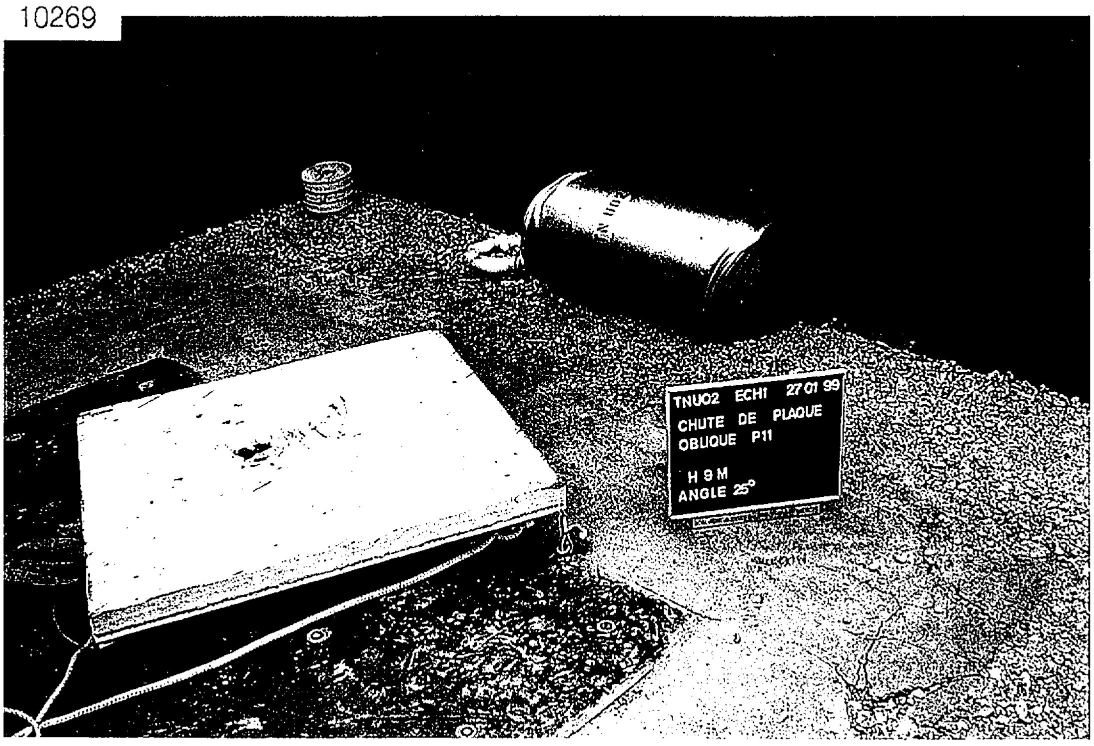

Photo n° 4: ditto view of packaging base

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Photo n° 5: Specimen P11 after plate impact, head view

Photo n° 6: ditto second plate impact

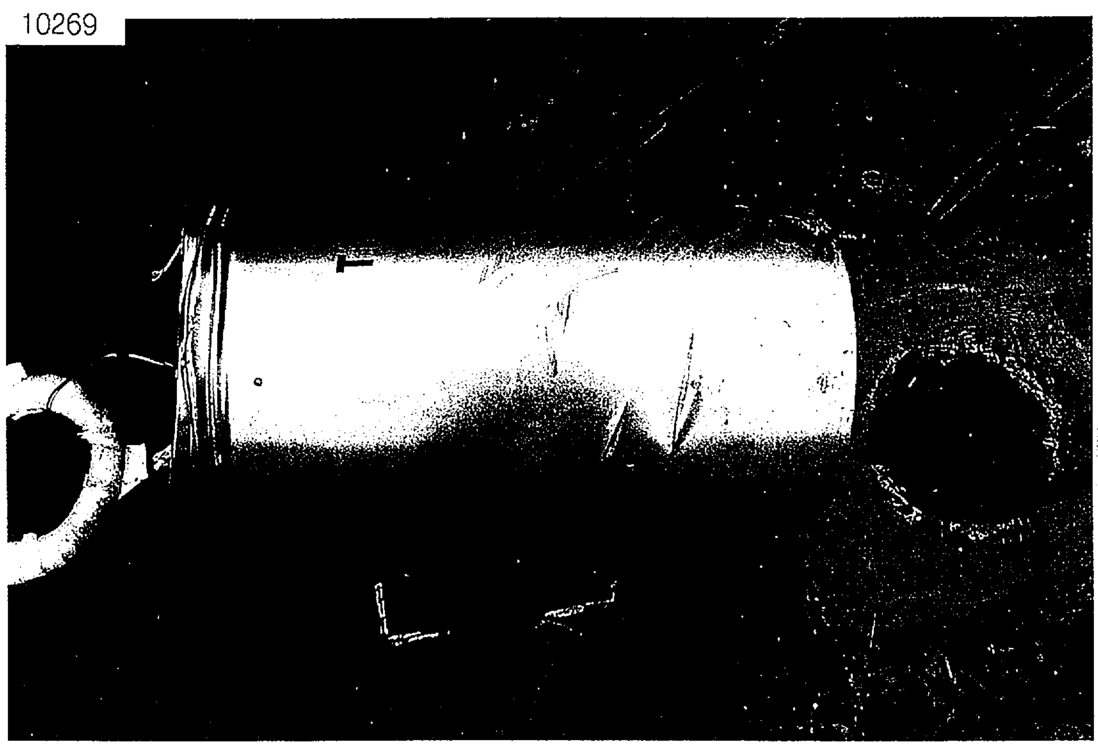

Photo n° 7: Lid, specimen P11 after plate impact

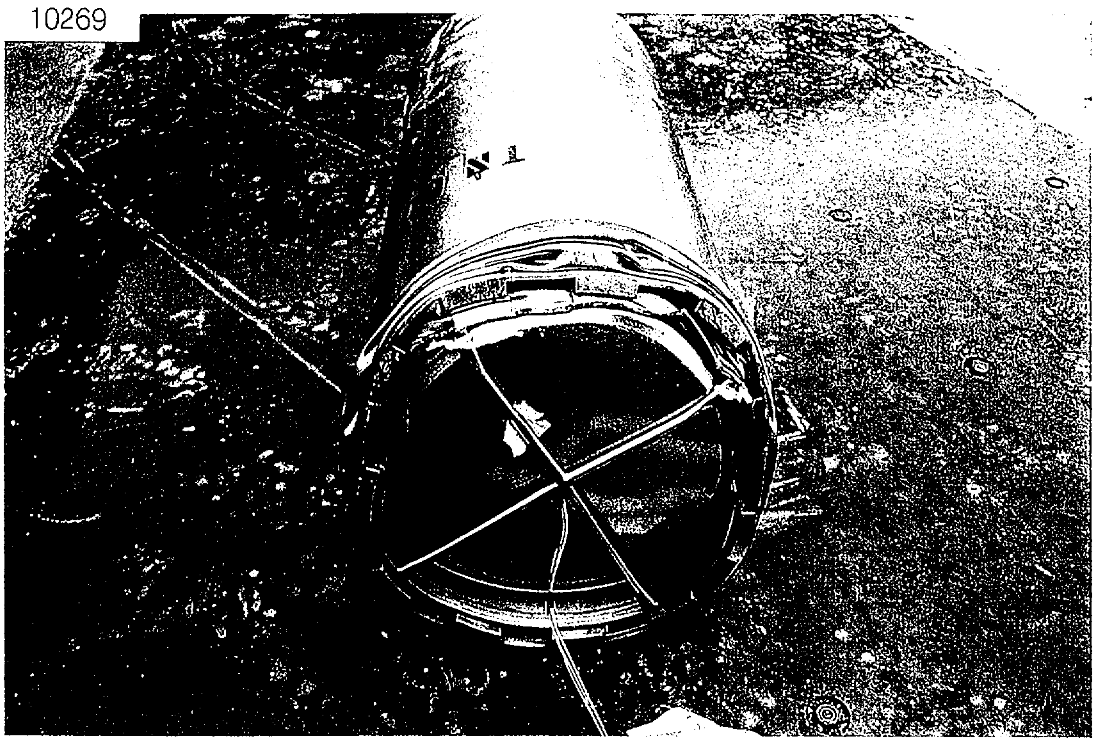

Photo n° 8: ditto detail

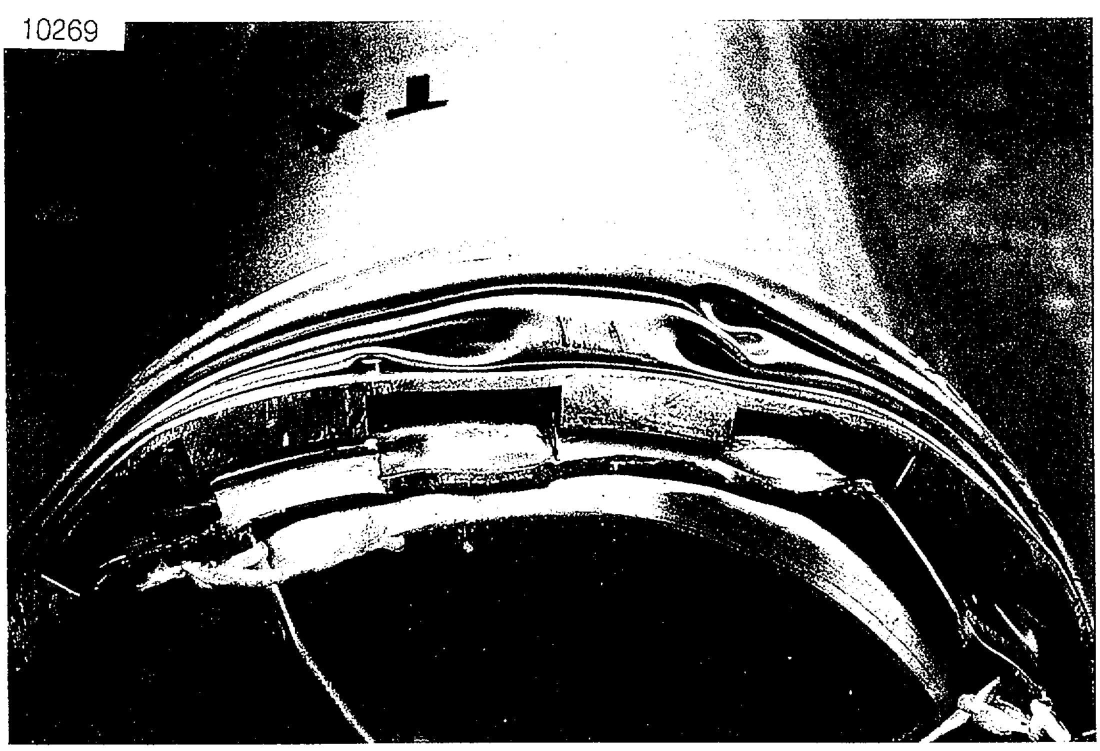

Photo n° 9: Specimen P11 in position for drop onto punch bar (drop n°2)

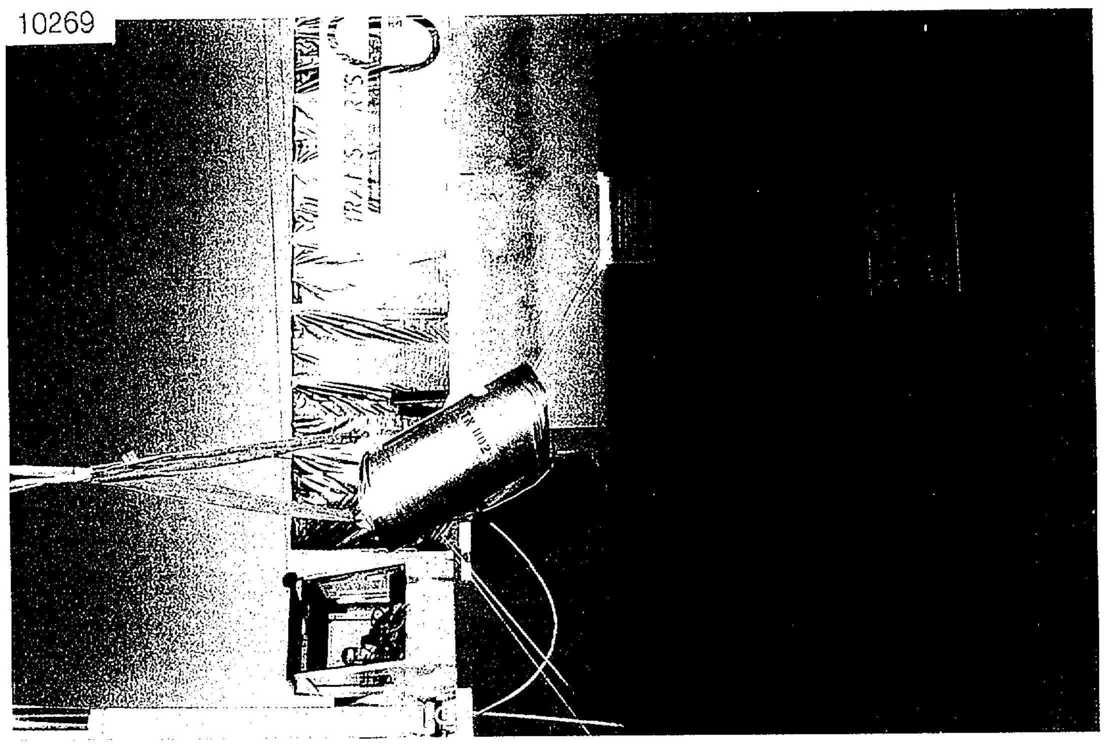

Photo n° 10: ditto after impact

Photo n° 11: Detail of punch bar impact area

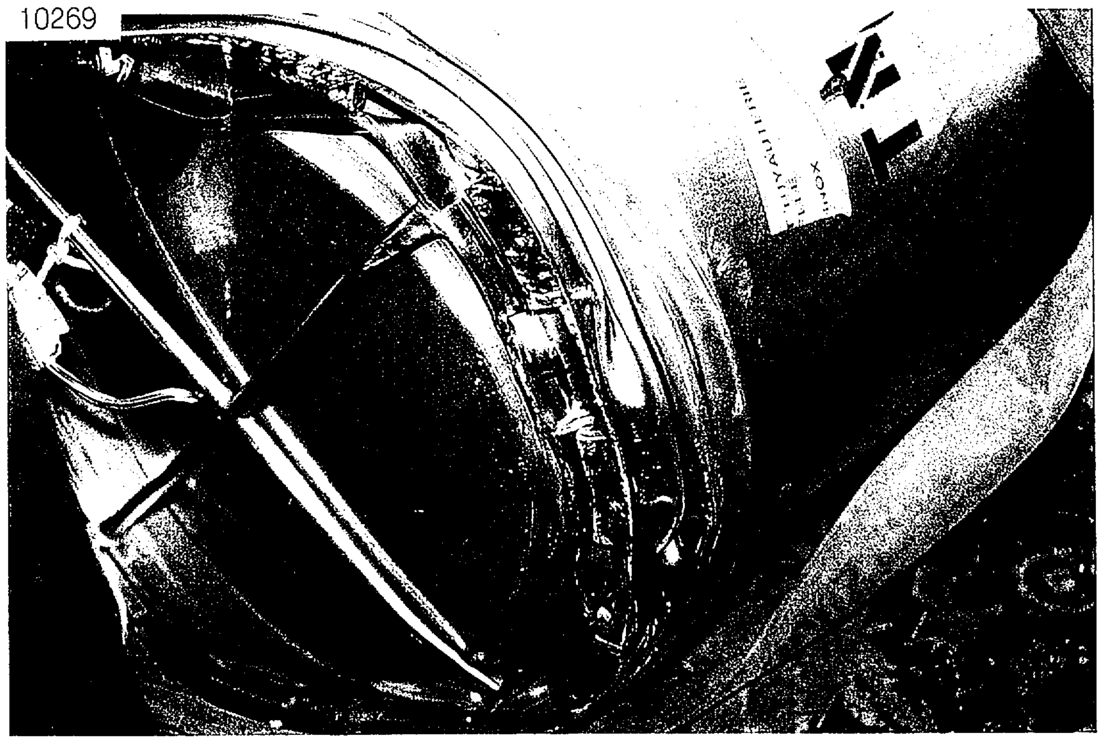

Photo n° 12: ditto

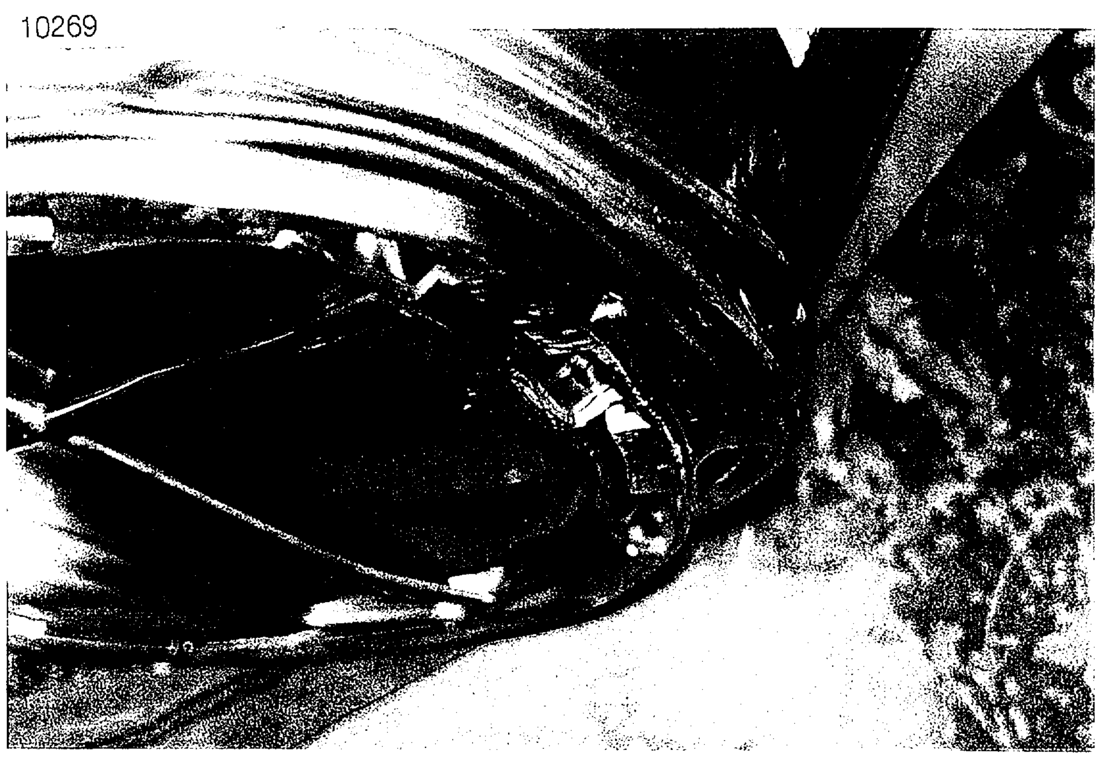

Photo n° 13: Specimen P15 in horizontal position for drop n°3

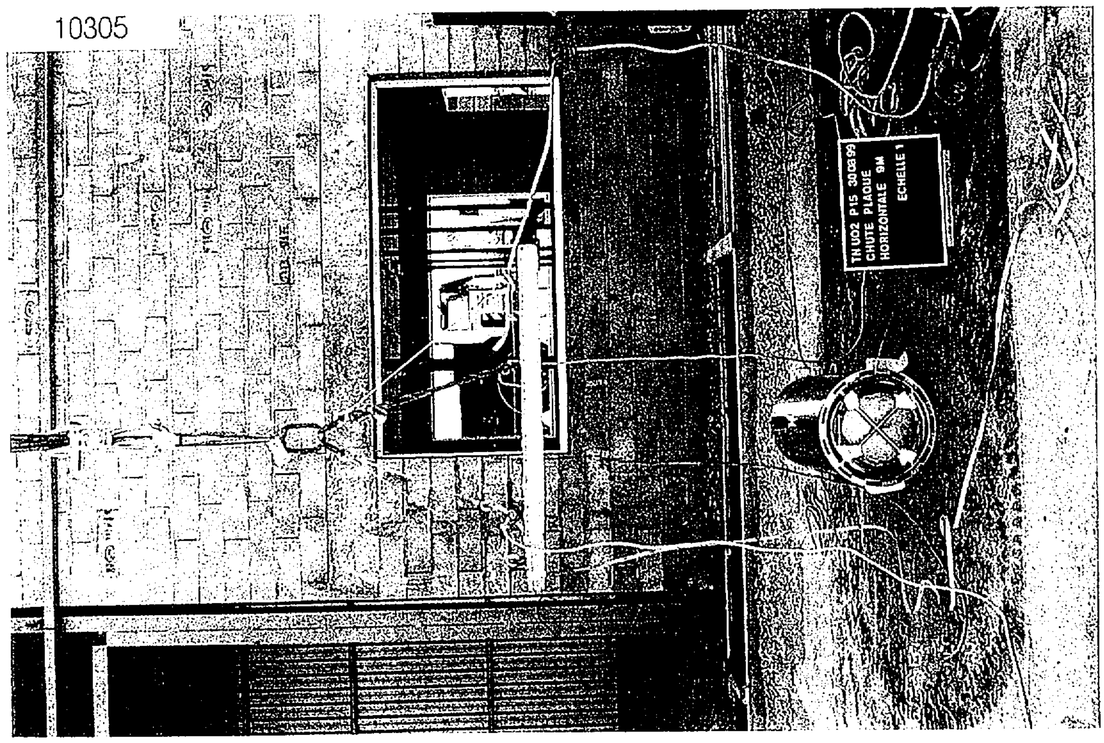

Photo n° 14 : ditto

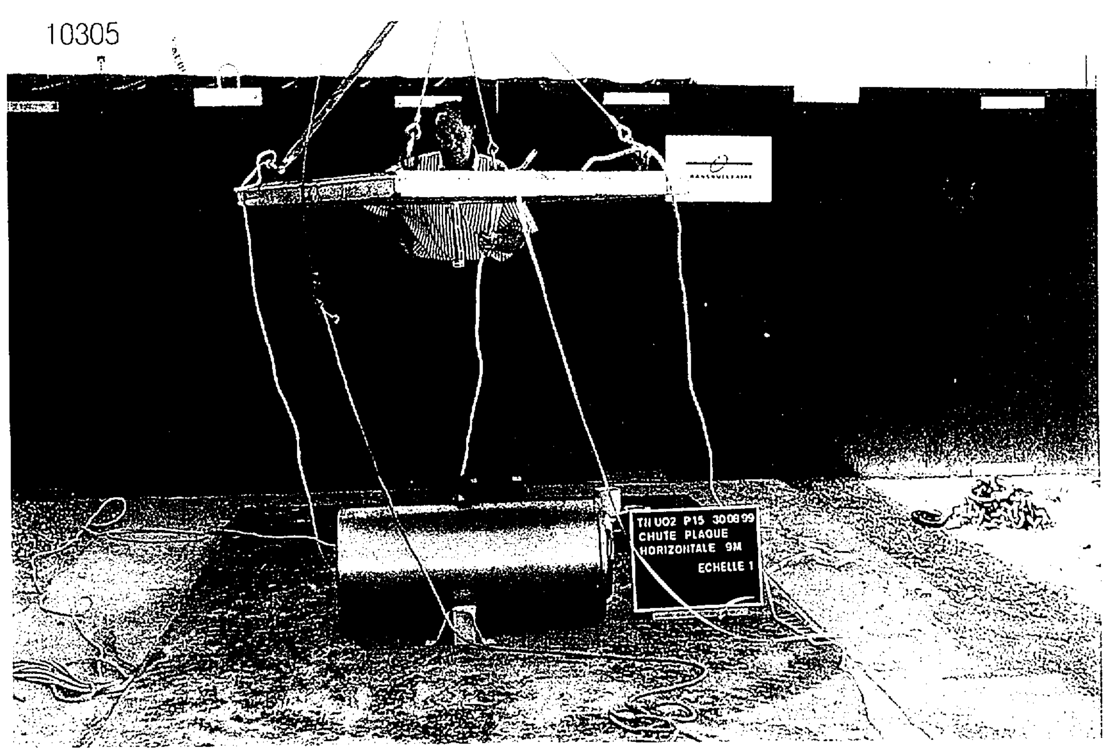

Photo n° 15: Specimen P15 after plate impact

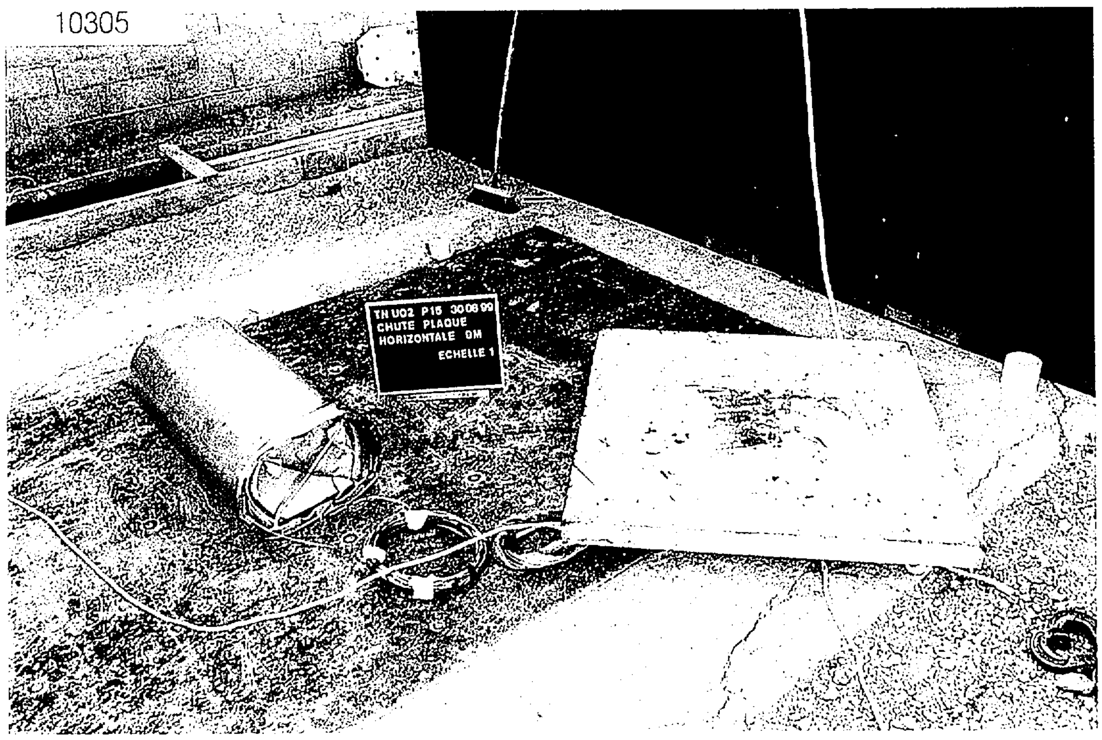

Photo n° 16: ditto packaging head view

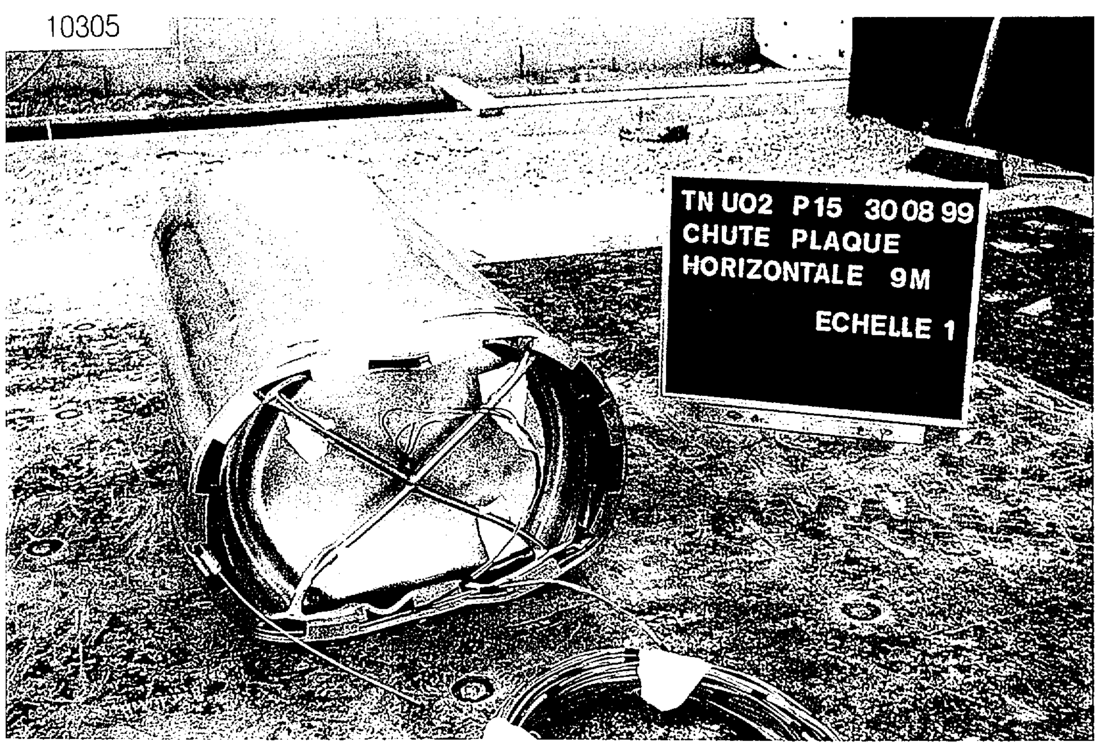

Photo n° 17: Base view, specimen P15 after plate impact

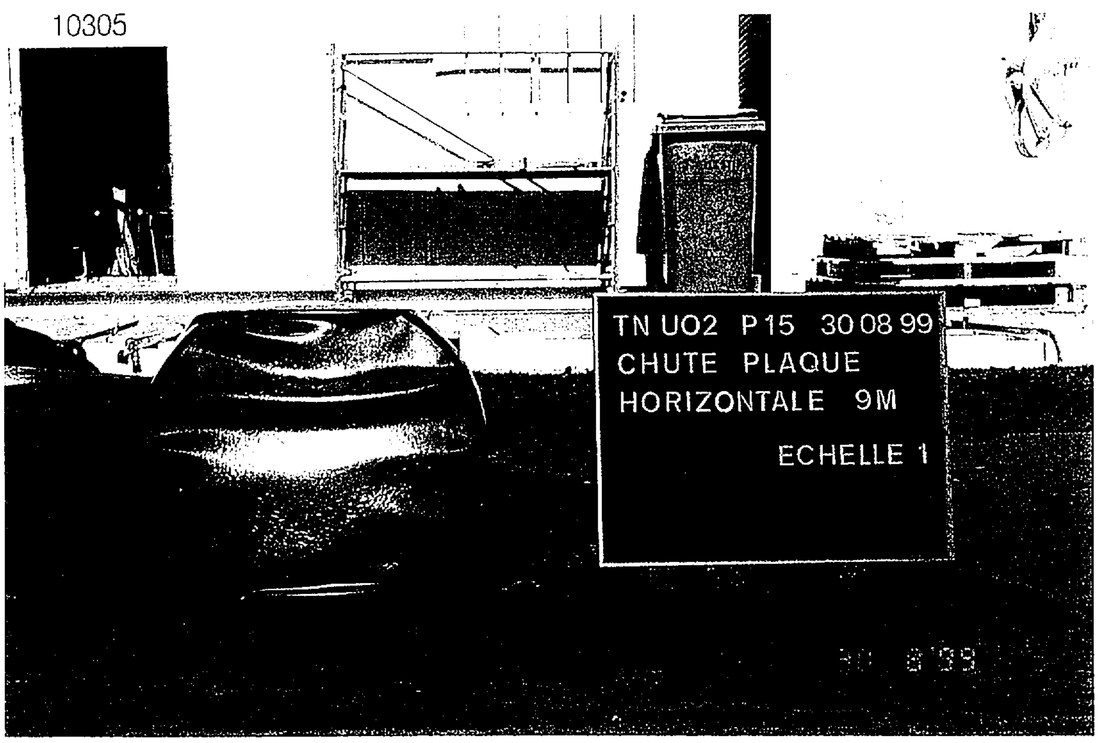

Photo n° 18: Top view after second plate impact

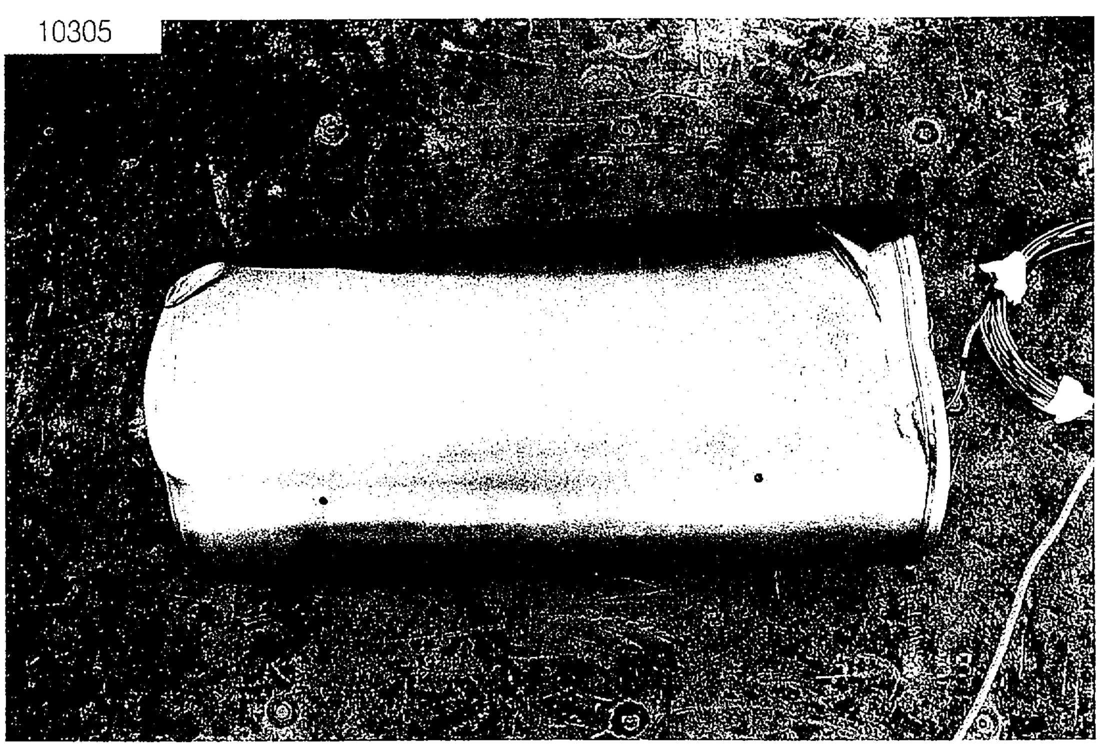

Photo n° 19: Specimen P11 in position for drop onto punch bar (drop n°4)

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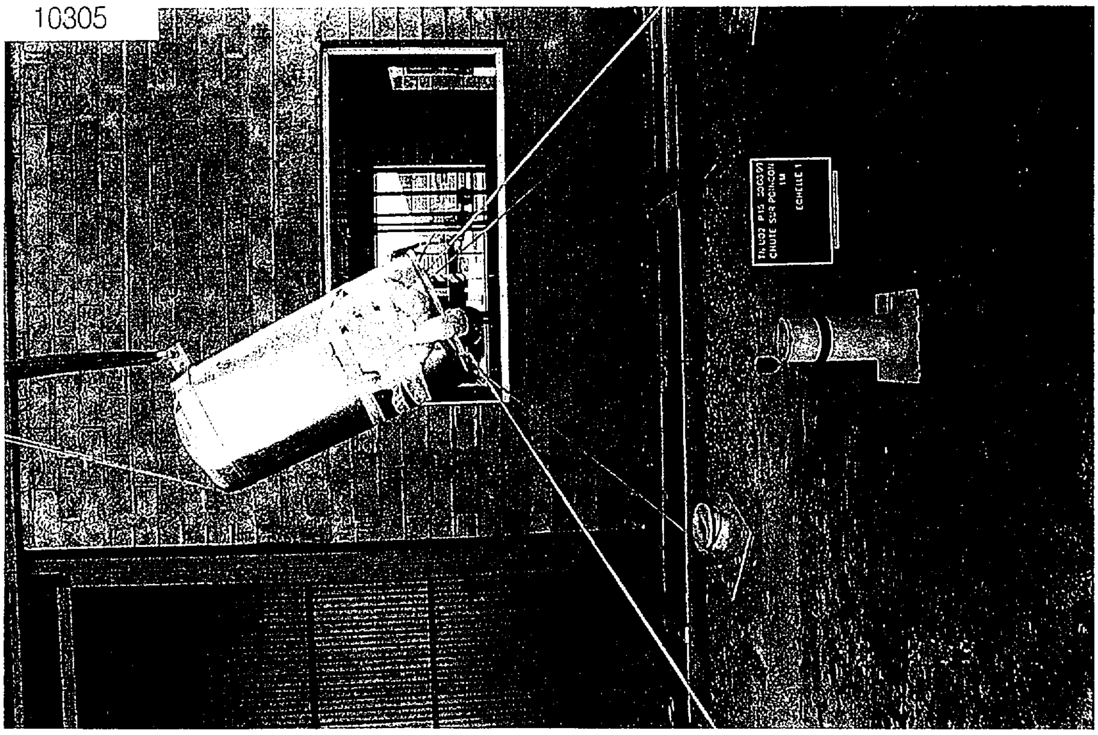

Photo n° 20: ditto

10305

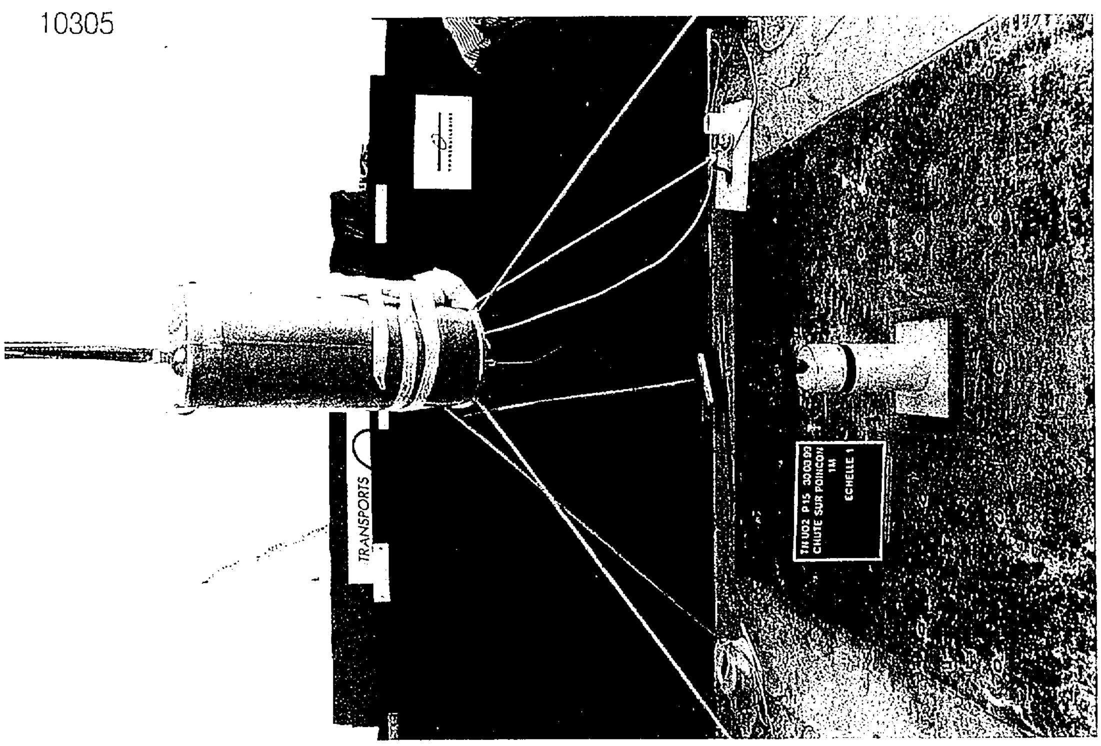

Photo n° 21: Detail of punch bar impact area before fall

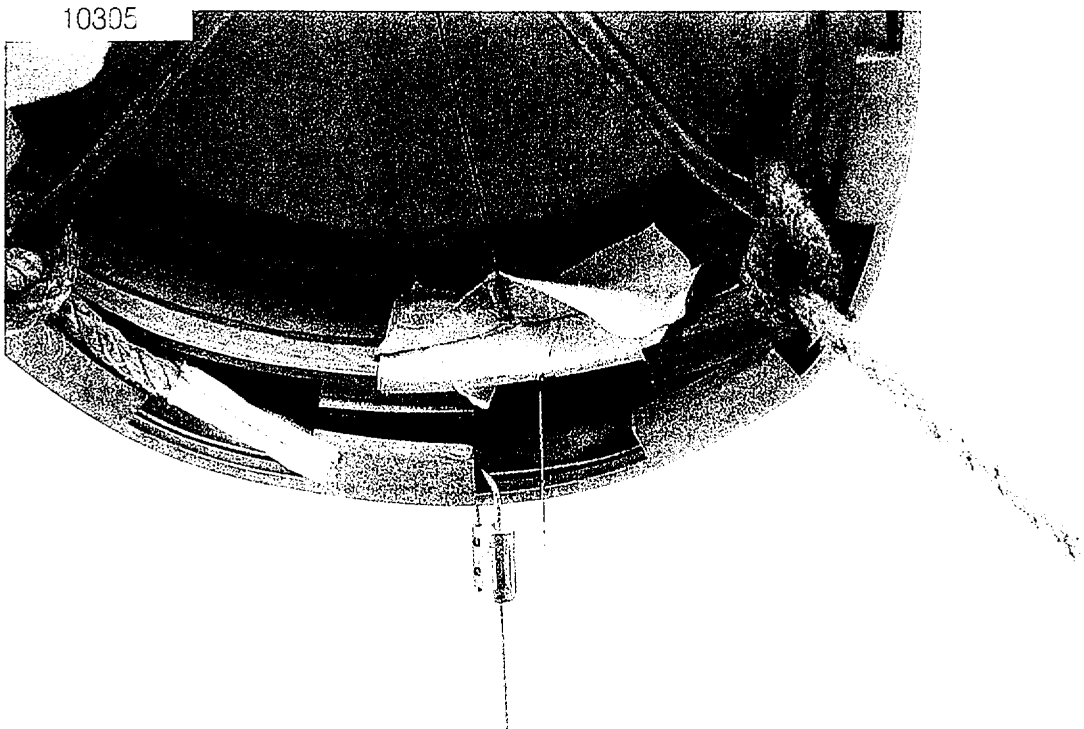

Photo n° 22: Specimen P15 after impact

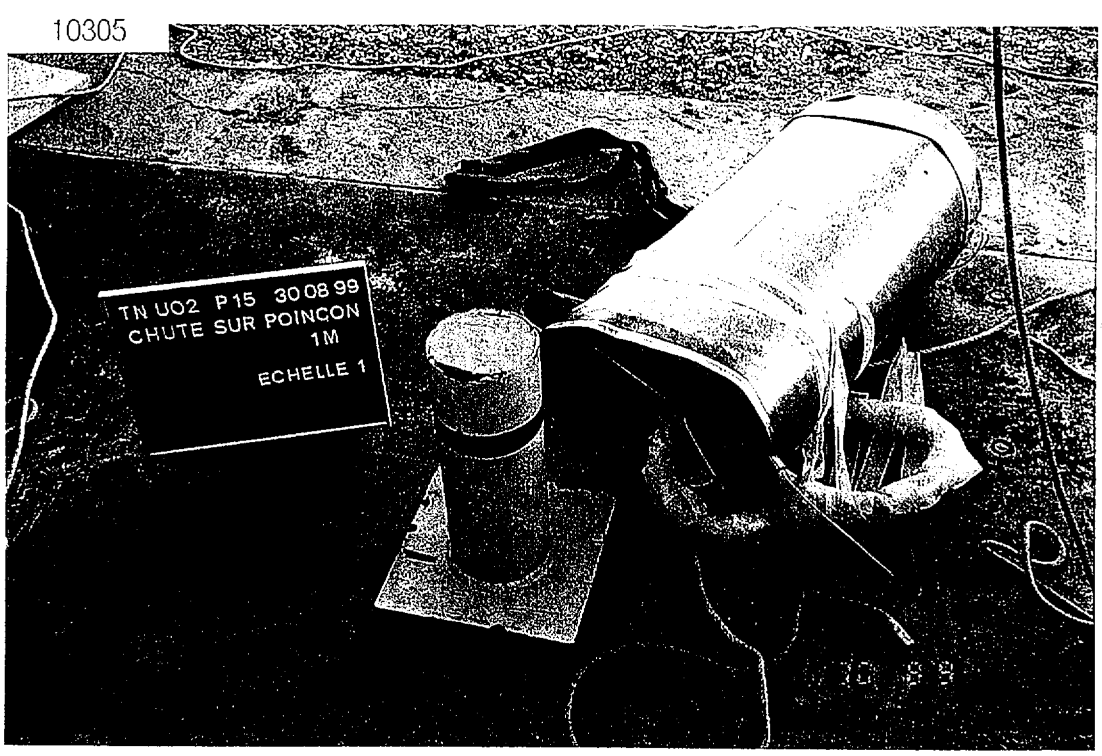

Photo n° 23: Lid, specimen P15 after punch bar impact