71-3075

U.S. Department
of Transportation

**Pipeline and
Hazardous Materials
Safety Administration**

400 Seventh St. S.W.
Washington, D.C. 20590

JAN 9 2006

Mr. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards (NMSS)
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Brach:

On December 2, 2004 I requested that you review French Certificate of Approval No. F/379/B(U)F-96 for the TN 106 package, and make a recommendation concerning our revalidation of the package for import and export use. As a result of your ongoing review, your office issued a Request for Additional Information (RAI), which I relayed to our applicant, Packaging Technology, Inc., on September 22, 2005. The applicant has since responded to the RAI.

In accordance with the Memorandum of Understanding between our Agencies, I request that you review the enclosed answers to the items in the Request for Additional Information.

Thank you for your assistance. If you have any questions, please feel free to contact me at 202-366-4545.

Sincerely,

Fred Ferate,
for Richard W. Boyle, Chief
Radioactive Materials Branch
Office of Hazardous Materials
Technology

Enclosure

cc: Packaging Technology, Inc.

NMSS01

TN106 US Revalidation
22-Sept-05 RAI Responses

STRUCTURAL

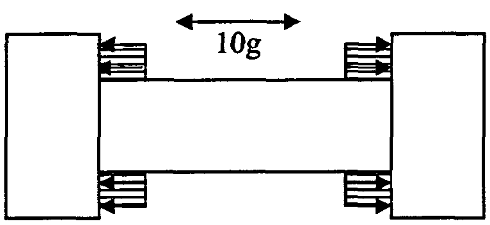
1: Provide justification for the tie-down attachments and handling devices acceleration factors used. These factors are not as recommended in IAEA Safety Guide No. TS-G-1.1 (ST-2).

The handling (trunnions or lifting lugs) evaluation is based on the accelerations factors 1,5g in vertical downward direction, and 1,5g in the longitudinal direction.

The tie-down (trunnions) evaluation contained in the SAR is based on the accelerations factors 3g in vertical downward direction, 1,5g in the lateral direction, and 2g in the longitudinal direction. These acceleration factors are approved by the French authority.

The trunnions will not be the tie-down attachments for transport in the US as they are not designed for the acceleration factors recommended for the US in table V.2 in IAEA Safety Guide No. TS-G-1.1. A transport skid which cradles the package shell will be designed for transport in theUS with the condition that longitudinal load (mass accelerated to 10g) is applied on the shock absorbers as shown by the following sketch:

Top view



The load will act directly on the balsa compartment of the shock absorbers but without crushing it (the level of compression stress is much lower than the balsa crushing stress given at around 10 MPa according to paragraph 6.6.1 of chapter 5573-Z-0 and also the steel crushing stress). It is first checked that the medium plate (item 506) of thickness 12 mm under bolt will not get sheared.

Maximal accelerated mass of the TN 106 packaging = 12 345 kg x 10 g = $1{,}21.10^6$ N
Shearing section (diameter 820 mm / thickness 12 mm) = $3{,}09.10^4$ mm²
Shearing stress = 39 MPa

This value is much lower than the allowable value (0,6 times the yield stress of the plate steel): the plate will then resist to the load.

Consequently the load will be transmitted to the bolts of the shock absorbers which constitute the only attachment points. Then it is checked that the load will not induce too excessive tensile stress in the bolt.

Maximal mass of the TN 106 packaging : 12 345 kg

Tensile stress due to acceleration in each 6 M20 screws: $F_1 = \frac{10 \times 12345 \times 9.81}{6} = 201\ 840$ N

Tensile stress area of an M20 screw: 272 mm²

Tensile strain due to acceleration in each screw M20 : $\sigma_1 = \frac{201840}{272} \approx 740$ MPa

The level of tensile strain is around 2/3 of the yield tress of the shock absorber screws (12.9 quality level – see table 0.2 of the chapter 5573-Z-0), which is acceptable.

The transverse and vertical accelerations (5g and 2g) will act on the external cylindrical surface of the packaging shell without touching the trunnions. The contact surface of the skid cradles will be large enough to induce low additional stress in the packaging components.

2 : Provide calculations demonstrating that the package is able to withstand the accelerations factors if the applicant plans to ship the package using sea/water transport mode.

The same transport skid as described above in question 1 will be used for sea/water transport. The accelerations factors during sea transport are covered by the accelerations factors considered for question 1.

3 : Provide a discussion and the implication of the negative pressure (cavity in depression before transport) and if necessary calculations to ensure that the results of ½ scale model tests performed for various regulatory drop scenarios are still valid.

As said in the paragraph 5.2.1 of the chapter 5573-Z-3A, the pressure in the cavity is defined to be 0,2 bar just after closing the package and less than 0,37 bar at thermal equilibrium.

The cavity of the ½ scale model was fixed at atmospheric pressure during drop tests.

The negative cavity pressure has a beneficial effect for the release of activity in normal and accident conditions. In comparison with the drop test model which was not depressurized, it leads to a better contact metal / metal between lid and shell and avoid a lifting off of the lid during drop test and then a possible damage of the gasket after re-crushing.

The negative cavity pressure creates stress in the component of the vessel containment (bending stress in the shell, in the lid and closure plate). We evaluate hereafter the level of additional stress induced by this negative pressure, assumed to 0,2 bar on a penalising assumption. The difference of pressure between cavity and ambient is then equal to 0,8 bar.

<u>Calculation of the cylindrical shell:</u>

The calculation of the inner cylindrical shell is carried out using the formula of thin walled vessels from "Roark's Formulas for Stress and Strain," 6th Edition.

$$\sigma = \frac{q \times R}{e} = 4,2 \text{ MPa}$$

With R = Medium Radius of the cylindrical shell = 125 mm
e = Thickness of the cylindrical shell = 23,5 mm
q = Pressure applied to the lid = 0,08 MPa

Calculation of the lids:

The calculation of the lids is carried out using the formula taken from "Roark's Formulas for Stress and Strain," 6th Edition, and corresponding to the calculation of circular plates of constant thickness, uniformly loaded over the whole plate, fixed edge condition (case 10b in Table 24) (same approach than described in the chapter 5573-Z-1-1 paragraph 5.2).

The moment is greatest at the periphery of the plate: $M_{max} = q\ a^2/8$

The maximum bending stress is therefore: $\sigma_{max} = 6\ q\ a^2/(8\ e_R^2)$

Where: q: Pressure applied to the lid: q = 0,08 MPa
a: Radius of the bolt circle
e_R: Thickness of the lid

The results of the calculation are set out in the following table:

Element	a mm	e_R mm	σ_{max} MPa
Front lid	340	60	0,5
Front closure plate	150	26	0,5
Back closure plate	130	30	0,3
Revolving plug closure plate	65	24	0,1
Drainage closure plate Vent closure plate	50	13*	0,2

* To ensure a conservative approach, the thickness of the closure plates at the recess is used

For all components of the shell containment, the calculated stresses are less than 5 MPa which is negligible in comparison with the level of stresses due to impact loads during drop test. The results of ½ scale model tests performed for various regulatory drop scenarios are then still valid.

MATERIALS

1: Provide manufacturing specification / data sheet for the resin F being used for neutron shield. The specification should include the useful range of operation (radiation and temperature), mechanical properties, thermal conductivity, and melting point.

The characteristics of the resin F are the following.

	Value	Location in Safety analysis report
Physical and chemical properties		
Density	1 800 kg/m^3	Table 0.5 of chapter 0
Chemical analysis : nominal mass ratio (%)	H: 4.6% B : 0.9% C : 22.6% O : 48,6% Al : 21.5% Zn : 1.8%	Table 5A-1.1 of criticality chapter 5A-1 It is also consistent with table 4A-1.2 of shielding chapter 4A-1, except the little difference on the boron and oxygen content because only the boron-10 is taken into account in the dose rate calculation and the rest is considered like oxygen (see also response 1 for criticality)
Mechanical properties		
Compression modulus at 20°C	Free : 2865 MPa Constraint : 7500 MPa	
Radiation resistance		
Critical gamma dose	10^7 Gy	
Thermal resistance		
Fire resistance	Self-extinguishing	See § 6.5 of chapter 0
Thermal conductivity (1)	1 W/m.K	Table 0.5 of chapter 0
Specific heat	1 000 J/kg.K	Table 0.5 of chapter 0
Thermal expansion coefficient	54.10^{-6} /K for T<140°C	
Temperature range	-40 / +150°C	

Note : There is no melting point for this thermoset plastic material. At high temperature, a small thickness of the resin becomes charred.

(1) The thermal conductivity is dependent of the temperature and its evolution is given in the following table

Temperature (°C)	Conductivity (W/m.K)
40	1.028
70	1.009
100	0.956
130	0.919
160	0.893
180	0.879
200	0.897

The retained value of 1 W/m.K for thermal calculations in the safety analysis report is then adequate for normal conditions (between 1.03 and 0.92) and is a penalizing value for accident conditions.

2: For the resin F, describe how excessive neutron streaming will not occur as a result of shrinkage at extreme cold temperatures such as -40°C

The following calculation evaluates the thermal shrinkage between resin F and stainless steel between temperatures of 20°C (temperature at manufacturing) and -40°C that means a difference of temperature of -60°C:

Thermal expansion coefficient of resin F = 54.10^{-6} /K
Thermal expansion coefficient of stainless steel = 16.10^{-6} /K
Maximum length of resin= 2850 mm for a length of cavity of 2500 mm (maximum value)
Thickness of resin E = 120 mm

- Radial thermal shrinkage = $\Delta E = \Delta T.E.\Delta\alpha$ = -0,3 mm

This small decrease of the thickness of the resin due to thermal expansion at low temperature has no effect on the neutron streaming all the more as the density of the resin rises while the thickness of it decreases.

- Axial thermal shrinkage = $\Delta L = \Delta T.L.\Delta\alpha$ =-6,5 mm

It is worth noting that this shrinkage divides itself on both extremities of the resin (as the geometry of the resin is symmetrical, it is reasonable to think that the shrinkage would be identical on both extremities, that means a gap of 3,2 mm). These gaps have not a significant effect on the neutron streaming at contact of the packaging as:

- they are not directly opposite to the source (the resin length is higher than the cavity length on both sides),
- and the neutron streaming increase that could appear at contact of steel shell is reduced by the presence of the shock absorbers fitted directly opposite (thickness of 310 mm of balsa).

In conclusion the shrinkage of resin at low temperatures will not induce excessive neutron streaming.

3 : Indicate the equivalent materials that could be used for resin F. Describe how the equivalent materials were tested and how that data correlated with the resin F test data regarding shielding, thermal stability, and handling properties during mixing and pouring or casting.

There are currently no equivalent materials for resin F. This sentence will be deleted in the next revision of the safety analysis report.

4 : Describe the acceptance tests that were conducted to verify that any filled channels/cavities with resin F used on casks do not have significant voids or defects that could lead to greater than calculated dose rates.

The resin F is poured by hand into the TN 106 packaging. The total mass of poured resin is measured in order to verify that the resin compartment is filled completely. This check ensures that the desired amount of resin is in the package.

Additionally the pouring is done in several times in order to have only a small quantity (40 kg) with each pour (the total weight of poured resin is around 1200 kg). By using this process, any local voids created by shrinking of one pour, which could result from resin polymerisation, are filled with the next pour. The value of the density of each pour is measured (on a small specimen besides the pour) to check the value of 1 800 kg/m^3 (tolerances are +/- 50 kg/m^3, knowing that the shielding calculation in chapter 5573-Z-4A take the minimum value 1750 kg/m^3).

5 : Discuss the acceptance tests to confirm the B-10 area density in the resin F.

It is important to note that the resin F is used as a radiological shielding for decreasing the neutron dose rates and does not ensure the sub-criticality of the package (subcriticality is mostly ensured by the geometry of the cavity and internal arrangements).

During manufacturing it is important to check the global quantity of boron (for shielding purpose). The boron content in the resin is determined by the mass of "zinc borate" which is one of the main initial components of the resin before mixing (see paragraph 6.5 of the chapter 0). The mass of zinc borate is weighed before mixing.

Additionally the numerous small resin volume per pour ensure a good homogeneity of the boron in all the volume as the polymerisation time of each pour is enough short.

As said in the previous response, the density of resin is checked for each pour. The minimum value is taken in the criticality and shielding calculations (1750 kg/m^3) that lead to the minimum boron density in the calculations which is a penalising assumption.

6 : Describe the inert matrices for the UO2 alluded to in Appendix 1a.

Inert matrices is a general expression that describes that UO2 is in the presence of material (example: metal) under conditions that this material has no influence on the safety analysis (example: not a neutron moderator, not a neutron reflector, not radiolysable, not pyrophoric, not susceptible to decomposing with heat...). One example of inert matrices is aluminum.

7 : Explain how the water is dried from the leak tight capsule. Section 2.2 of the certificate states that, "the contents can be placed in internal arrangement made from aluminium or stainless steel which may or may not be leak tight".

The TN106 can be loaded and unloaded under water or under dry conditions (hot cells).

For dry conditions, the question does not apply.

For wet conditions, the use of leak tight or non-leaktight capsule depends on the users of the plant facilities (depending on the internal plant facilities rules). If the capsule is not leak tight, it is dried with cavity drying. If the capsule is leak tight, the users design the capsule and ensure that the capsule can be dried in order to comply with the TN 106 certificate. COGEMA LOGISTICS was asked to design such leak tight capsule for the TN6/3 packaging (already used for Savannah River). A system with connections (quick disconnect couplings) that can depressurize and dry the capsule under water was developed. The same system could be adapted and used for TN 106 packaging if necessary.

8 : Provide evidence that the proposed drying procedure "the pressure is dropped between 6 and 10 mbars and held with no more than 1 mbar rise over a 5 minute period" will actually result in drying the package cavity.

For the checking of the drying quality of packaging loaded under wet conditions, the used method is a measure of pressure in closed volume. The associated criterion is a limit on the pressure increase rate that gives an indication of the remaining water quantity in the cavity. (Indeed, after the cavity is depressurized, the pressure increase rate rises as a function of the water quantity remaining in the cavity due to vaporisation).

COGEMA LOGISTICS has already performed a validation test of this procedure. The test consisted of a complete drying test of a cavity with existing experimental equipment in the most severe operations conditions, and with controls for the drying criterion. The package was cylindrical with a cavity of diameter 960 mm and length 1080 mm with a metallic basket inside.

The most severe operations conditions for this test were retained:

- No thermal power in the packaging
- Existence of point of water retention after drainage (or draining away) of the packaging
- Presence of the handling system for the basket, partly hiding the four central compartments delimited by the basket.

The main realized operations were:

- Assembly and fitting of the experimental equipment (see pictures 1 and 2)
- Filling with water followed by draining of the cavity
- First period of drying (about 3h30)
- First drying test (see table 1): the result is 10 times higher than the criterion
- Restart of the drying

- Following drying tests, until the criterion is reached (see table 1): four steps of measurement - drying were needed to reach the criterion
- Opening of the container and visual inspection of the basket, the cavity : All the accessible areas of the basket and of the cavity are completely dry. No wiping have been needed because no water was visible, included in condensate form.

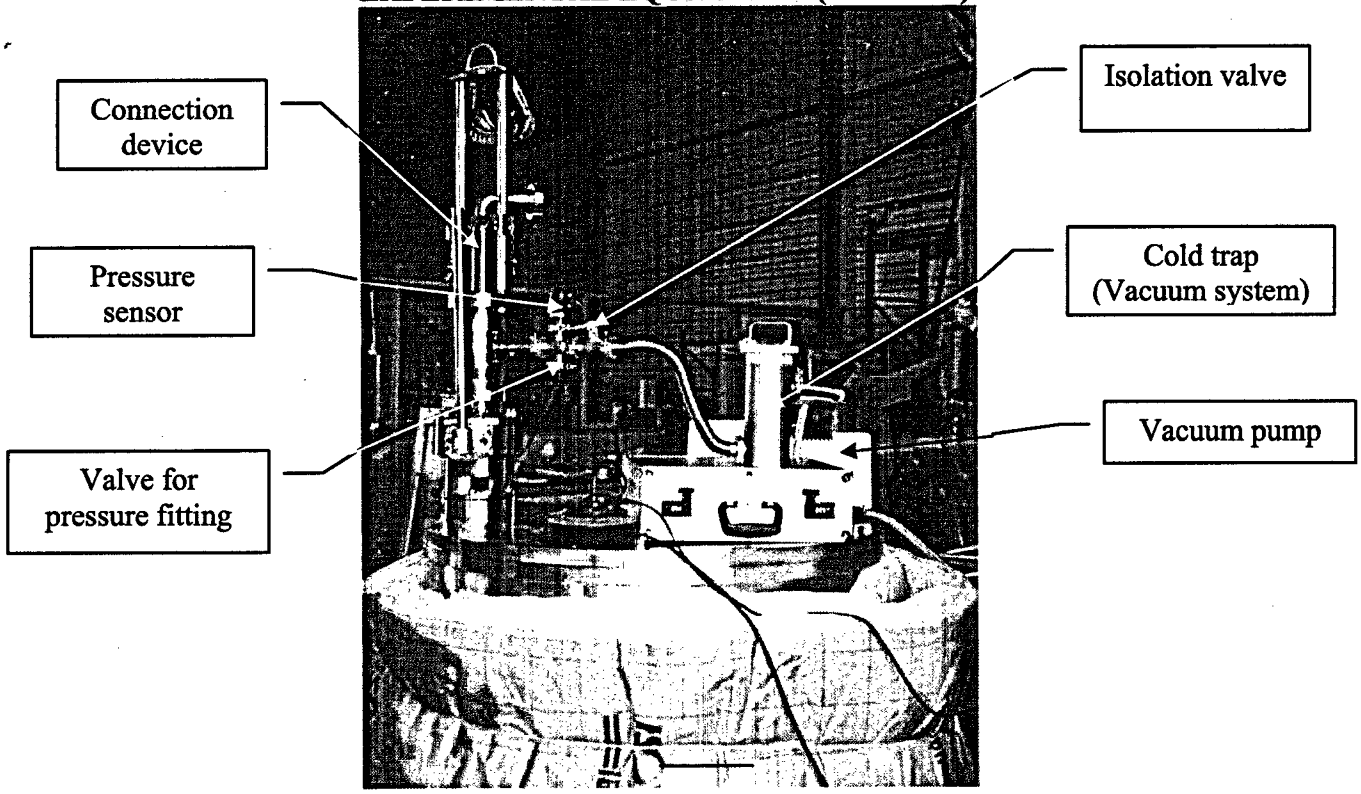
In conclusion, even in the most difficult conditions, without any internal thermal power, this test shows that all accessible areas of the cavity are completely dry as soon as the criterion of the control of the drying is reached.

Table 1: Results of the drying control

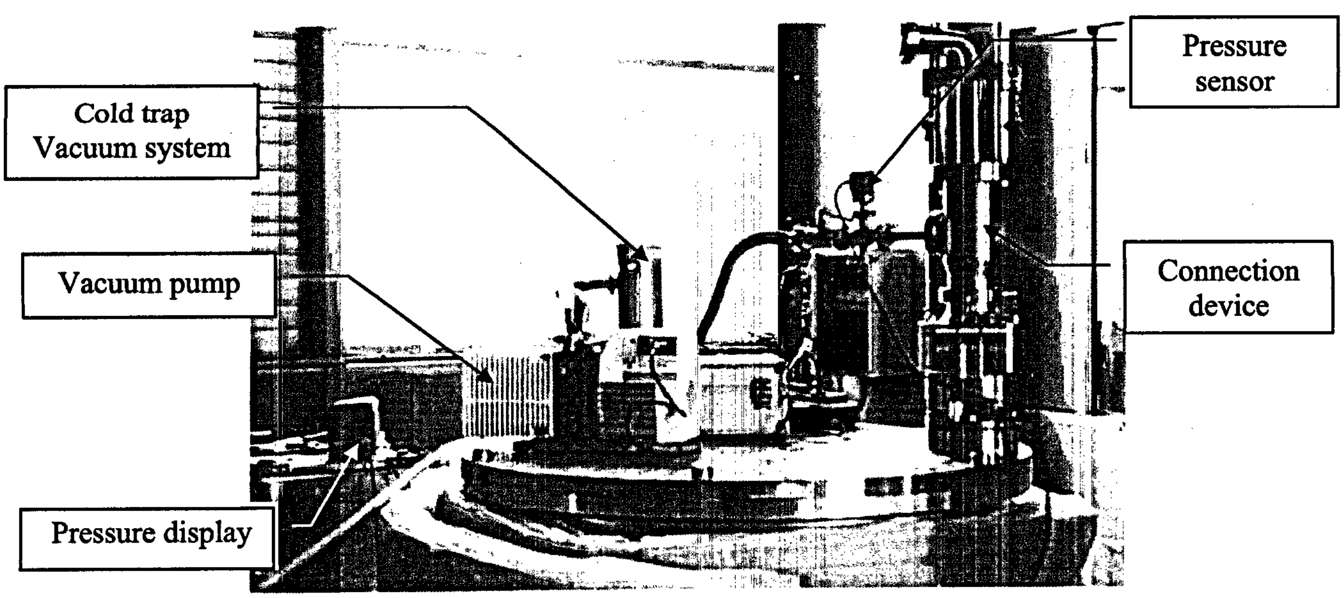
Drying criterion checking : 1 mbar over 5 minutes Pre-condition : pressure between 6 and 10 mbar			
1st measurement after 3,5 drying hours : Time Pressure	0 7 mbar	5 min. 18,2 mbar	Criterion fulfilled no
2nd measurement after new 2,5 drying hours: Time Pressure	0 6,3 mbar	5 min. 7,8 mbar	Criterion fulfilled no
3rd measurement: Time Pressure	0 6,3 mbar	5 min. 7,7 mbar	Criterion fulfilled no
4th measurement: Time Pressure	0 7,0 mbar	5 min. 8,2 mbar	Criterion fulfilled no
5th measurement: Time Pressure	0 8,1 mbar	5 min. 9,1 mbar	Criterion fulfilled yes

Nota : With the successive test we converge to the criterion. That is reached exactly for the 5th measurement (after around 7 hours of drying).

PICTURE 1
EXPERIMENTAL EQUIPMENT (front view)



PICTURE 2
EXPERIMENTAL EQUIPMENT (back view)



9 : Provide a reference for the Young's modulus of 42 GPa for Pb as presented in chapter 1, Appendix 3, Section 6.1.2.

« Données numériques sur le plomb » - M513, F. WILMOTTE – Techniques de l'Ingénieur
[« Lead Material Data », Engineering Technics]

10 : Provide a reference source for the conductivity and emissivity values of the black painted steel listed in table 2-1.1, chapter 2, appendix 1.

The translation was incorrect : it should be "white painted carbon steel".

The conductivity of carbon steel is 45 W/m.K. (reference ASME BOILER AND PRESSURE VESSEL CODE - Subpart 2 – Physical properties – Tables TE-1 and TCD, the American Society of Mechanical Engineers, New-York, 2001)

The emissivity of white paint is 0,9 (reference : PRINCIPLES OF HEAT TRANSFER, F. KREITH, 4th Edition, 1986, Ed. PWS Pub Co.)

CONTAINMENT

Containment RAIs number 1-6 is needed to show compliance with IAEA No. TS-R-1, paragraph 656.

In the revalidation application letter dated 10-Nov-2004 from PACTEC to the Department of Transportation, it was stated that for the US, the package would meet leaktight criteria. Specifically, it was stated:

The following table summarizes leak rate criteria according to the French SAR, and the values to be used in conjunction with the validation of the French CoC.

Test	French SAR		Criteria for US Validation According to ANSI N14.5-1997
	Criteria	SAR Section	
HAC tests	6.65×10^{-4} ref cc/s (a)	Ch. 1-11	1.0×10^{-7} ref cc/s
Fabrication	1.00×10^{-6} ref cc/s (b)	Ch. 7A, §3.4	1.0×10^{-7} ref cc/s
Maintenance	1.33×10^{-4} ref cc/s	Ch. 7A, §4	1.0×10^{-7} ref cc/s
Periodic	1.33×10^{-4} ref cc/s	Ch. 7A, §4	1.0×10^{-7} ref cc/s
Preshipment	6.65×10^{-4} ref cc/s	Ch. 6A	1.0×10^{-3} ref cc/s

Notes:

a) Although the post drop test leak test did not require "leaktightness," the leak test results from the drop test report (Chapter 1, Appendix 11, Test Report 5573-C-19) show that the test unit did in fact satisfy the "leaktight" criteria as defined by ANSI N14.5-1997.

b) Although the fabrication leak test did not require "leaktightness," the attached French fabrication leak test report for the one TN 106 package fabricated to date shows that the ANSI N14.5-1997 "leaktight" test criteria is satisfied for this package. The test report has been annotated with a translation of key terms from French to English.
c) The remaining test criteria will be applied as part of the US validation of the French CoC as a part of operations and maintenance.

1 : Include crud (Co-60) in the source term or justify its omission. If crud is not included in the source term, describe the administrative controls to preclude it.

See response above.

2 : Include an assessment under the Normal Conditions of Transport (NCT) of the effect of aerosols and volitiles from the damaged fuel which would be assumed to be 100% failed at the time of loading.

See response above.

3 : Justify the source term presented in Chapter 0A, Section 5.1, by describing how it was calculated and include identification of the parameters upon which it was determined (e.g., maximum burnup, enrichment, cooling time, average power, geometry). Specifically justify how the values associated with 100 GWD/MTU were determined.

See response above.

4 : Calculate and submit the maximum permissible leakage rate for the NCT and accident conditions of transport using the methods described in ANSI 14.5 for the source term associated with Contents No. 1.

See response above.

5 : Provide reference no. <3> as indicated in Chapter 0A, Section 7, page 22.
In Chapter 0A, Section 5.1.4, it is assumed that only 5% of the fission gases are released from a fail fuel rod. The NRC assumes 30% of the fission gases are released.

See response above.

6 : Justify the practice of transport under vacuum to minimize the calculated release. Describe the controls in place to prevent a single failure from losing vacuum in the package or falsely indicating vacuum conditions in the package.

The vacuum in the cavity is a usual practice at COGEMA LOGISTICS. It is an additional safety measure (no release of activity during one year) that is independent of the calculations. The criteria of release of activity are not proved thanks to this vacuum (see response above).

SHIELDING

The information is needed to show compliance with IAEA No.TS-R-1, paragraphs 531 and 532 for normal conditions of operation and with paragraph 656 for accident conditions.

1) **Provide the geometric properties for Contents No. 1, "Fuel Pins or Rods Consisting of Uranium Oxide", states "the geometric properties (diameter, thickness and nature of the cladding, etc) do not matter". To do a confirmatory calculation for the source term, basic fuel parameters such as pitch, pellet diameter, cladding material and thickness, etc, are needed.**

   The definition of the geometric properties for content No. 1 in the certificate comes from the assumptions taken in the shielding calculations (see chapter 4A appendix 1 paragraph 4). For the study of the shielding, the source volume is considered as a cylinder whose radius and density are variable parameters. The most disadvantageous source volume is sought producing the highest dose rate for the calculation points situated at mid-height in contact with the packaging and at a distance of 2 m from the transport vehicle. For the axial sides (back and front of the packaging) the source is placed at the ends of the cavity and takes up the whole diameter of the TN 106 cavity.

   In conclusion the shielding study is not linked to the exact geometry as a homogeneous model (for content and cladding) is taken into account. The aim is to cover the numerous possibilities of content which are transported in the TN 106 packaging.

2) **Explain how the generic gamma and neutron source term described in Chapter 4A, Appendix 1, "Study of the shielding of TN-106 Packaging", can be considered representative of irradiated UOx fuel rods and pins.**
   A cooling time of 4 years appears to be considered in the calculations. However a minimum time of 3 months is indicated in the description for Contents No. 1 which is the only content considered in this review. Fuel with a shorter cooling time would have a greater amount of short-lived fission products which would contribute to the gamma dose. The dose rate from fuel with a shorter cooling time may have a significantly higher dose.

   The shielding calculations are done for a typical content, defined in Chapter 4A, whose parameters (mass, burn-up rate, cooling time, enrichment) are chosen from among the most common (here a cooling time of 4 years). This means that they are not restrictive : all other group of values (mass of heavy metal, burn-up rate, cooling time, enrichment) are acceptable provided that the dose rates measurements taken prior to shipment comply with regulatory criteria, as specified in the certificate.

   Moreover, the equivalent dose rate criterion is always fulfilled with in accident conditions of transport provided that the regulatory criterion in normal conditions of transport is fulfilled (the allowable activity amount is at least 6 times higher in accident conditions than in normal conditions).

For information, the characteristics of the Content No. 1 presented in Chapter 0A and the certificate are coming from the study of the release of activity. Indeed the activity release study gives the allowable mass of heavy metal in the cavity by combination of all most penalizing parameters of the content which are indicated in the certificate (the maximum burn-up (100 000 MWJ/ton of heavy metal), the minimum cooling time (3 months) and the maximum enrichment (10%)).

In conclusion the acceptance criteria for the content are :

- a maximum burn-up (100 000 MWJ/ton of heavy metal), a minimum cooling time (3 months) and a maximum enrichment (10%),
- <u>and</u> the dose rates measurements taken prior to shipment comply with regulatory criteria.

3) Provide the maximum activity in Becquerels for the neutron source. In Chapter 4A, Appendix 1, Section 3.2, there is a generalized explanation of how the neutron source term was determine using Am-241 but no activity amount was included.

The Section 3.2, of the Chapter 4A, Appendix 1, concerns only the neutron source that is not part of our validation application.

The shielding of Content No.1, which is the subject of our application is studied in Section 4.

<u>CRITICALITY</u>

1: Provide the correct material specification of the resin. Both Table 5A-1.1 in chapter 6 (criticality) and page 10 of attachment 6 (TN106 criticality analysis, calc 41199-02) state that the resin contains zinc. However table 4A-1.2 states that the resin contains copper.

The resin contains zinc. The database for criticality analysis is correct.

The shielding calculation takes into account copper instead zinc as the data base of the shielding software does not know zinc. It is worth noting that zinc does not have any influence of neutron and gamma dose rates. In the data base of the shielding software, copper has the nearest atomic weight to the zinc one that justifies this choice.

2: Provide justification for the use of lattice cross-sections with homogenized geometry. Section 5.2 of attachment 6 states that in order to simplify the calculations cell weighted cross-sections were generated considering heterogeneous fuel pellets and moderator and these cross sections were then applied to a homogeneous fuel/moderator volume. Further explanation is needed to determine the implications of this simplification.

In the 4% and 5% enriched models, the fuel is assumed to exist as pellets. The most rigorous manner in which to model the fuel region would be as arrays of fuel pins. Due to the geometry limitations of KENO-V.a, such a modeling approach would be tedious because there is no simple means to place an array of pins into a cylindrical cavity. A combination of arrays and cylindrical holes could be used, but such an approach would prove to be impractical given the large numbers of runs needed in order to demonstrate criticality safety.

In order to simplify the approach, lattice cross-sections are utilized with homogenized geometry. XSDRN generates a homogenized mixture of fuel and water as "mixture 500," which is then used to fill the cylindrical cavity. In this manner, the response of the physical system is duplicated without the need to model arrays of individual pins.

To estimate the effect of this modeling approach, both explicit and homogenized models are developed and compared. Case D203E5X320R15 from Table 5.2-1 is used as the base case. Enrichment is 5% U-235, the pitch is 0.6512 cm, the pellet radius is 0.15 cm, and the fuel height is 89.647 cm.

To simplify the comparison, the explicit pin array is modeled as the largest square array (21x21) which will fit inside the cylindrical cavity of diameter 20.3 cm, see Figure 1. Note that this results in radial water gaps in the cavity and a loss of fuel mass when compared to the base case. The equivalent case is modeled using the homogenized "material 500" approach, see Figure 2. The results are as follows:

21x21 pin array, explicit:	$k = 0.7883 \pm 0.0005$, $k_s = 0.7893$
21x21 pin array, homogenized:	$k = 0.7900 \pm 0.0005$, $k_s = 0.7910$

The homogenized method results in a 1.7 milli-k (mk) increase in reactivity when compared to the explicit method, which is within the expected statistical fluctuation. The two methods are therefore statistically equivalent. The reactivity is significantly lower than the base case (0.9223) simply because the mass has been reduced.

To obtain k-eff values comparable to the values listed in the criticality analysis, the numerical experiment is repeated using a 29x29 array. Because this square lattice geometry will not fit within a cylindrical cavity, the cavity is modified to a square geometry, see Figures 3 and 4. While this geometrical modification is non-physical, it is sufficient to demonstrate the accuracy of the homogenization method. The results are as follows:

29x29 pin array, explicit:	$k = 0.9349 \pm 0.0005$, $k_s = 0.9359$
29x29 pin array, homogenized:	$k = 0.9361 \pm 0.0004$, $k_s = 0.9369$

The homogenized method results in a 1.0 mk increase in reactivity when compared to the explicit method, which again is within the expected statistical fluctuation. The reactivity is higher than the base case simply because the mass has been increased.

Based on the results of these numerical experiments, using lattice cross-sections with homogenized geometry is statistically equivalent to modeling the pins explicitly. Therefore, the modeling technique used in the criticality analysis is acceptable.

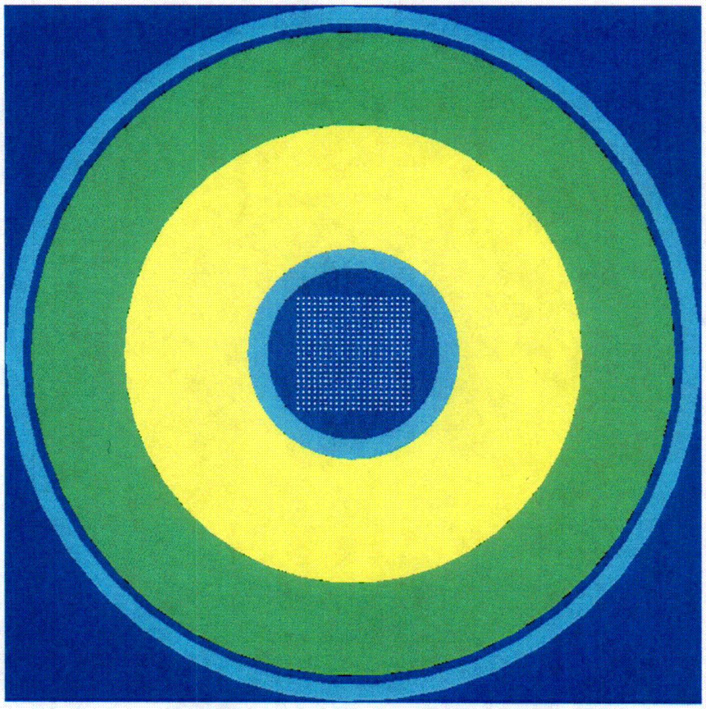


Figure 1. Explicit 21x21 Pin Model

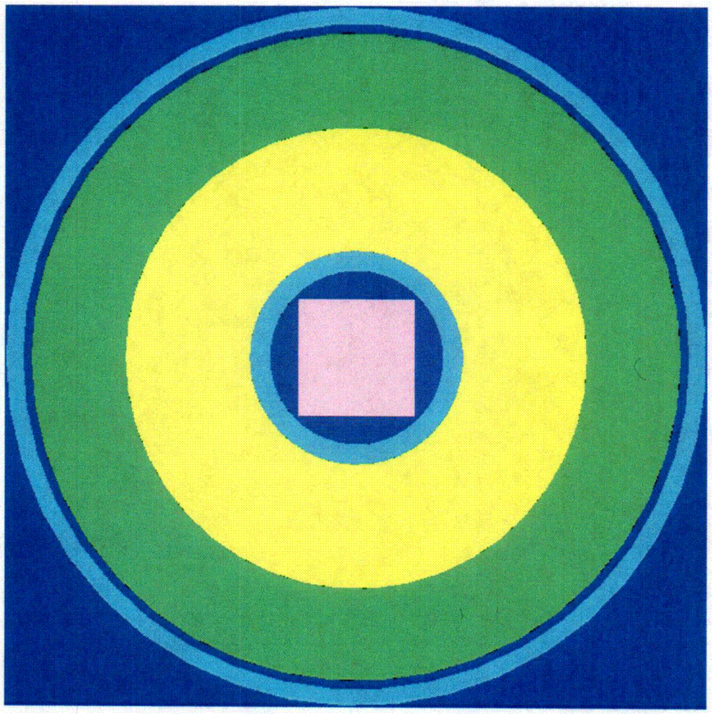


Figure 2. Homogenized 21x21 Pin Model

C01

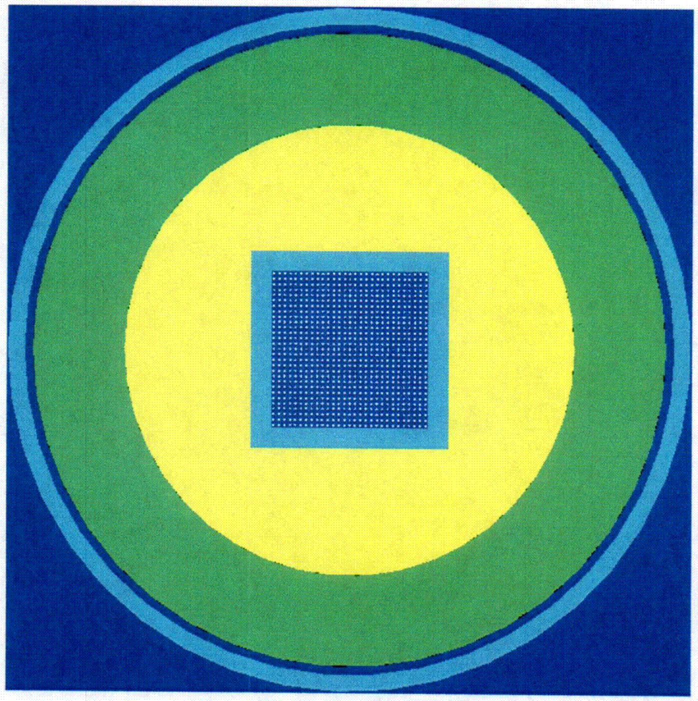


Figure 3. Explicit 29x29 Pin Model

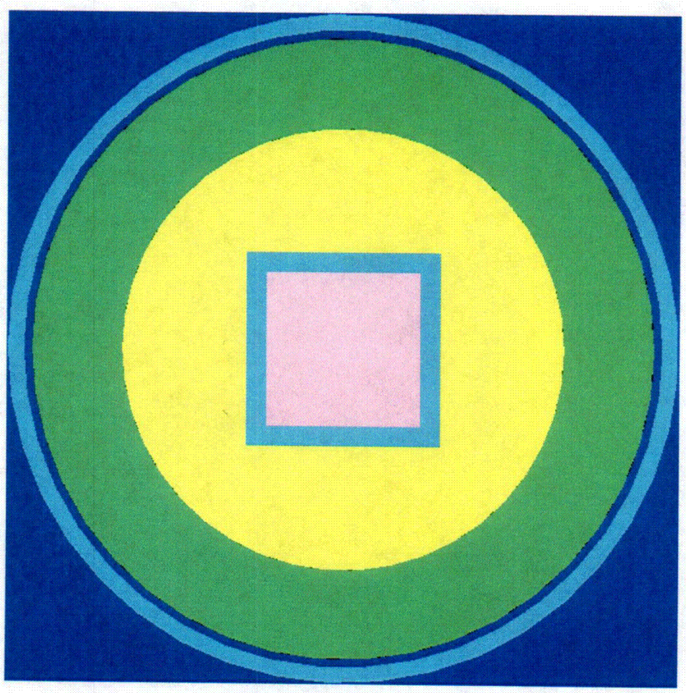


Figure 4. Homogenized 29x29 Pin Model

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