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ROBATEL-CEA'S NEW ANSWER TO THE ISSUE OF EVACUATION OF CEA'S HISTORICAL WASTE: TIRADE-R76 PACKAGE

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ABSTRACT

For the evacuation of its high and intermediate level waste drums (HILW) stored in its ancient facilities, the CEA has commissioned ROBATEL Industries to design and manufacture 4 casks of a new fissile B(M) type package (named TIRADE or R76). TIRADE/R76 transport cask shall replace the actually used DGD/R66 packaging (already designed by ROBATEL Industries for the CEA in 1996) because of increasing difficulties to obtain new certificates of approval.

The new cask has to meet two main objectives for the CEA: the transport of the primary ILW drums to CEA's reconditioning facilities before long-term storage, and secondly the transport of HLW drums to DIADEM, a new facility where all CEA's HLW waste will be collected. However, these waste drums contain organic materials thought to produce hydrogen, a highly flammable and explosive gas, by combined phenomena of radiolysis and thermolysis.

These phenomena are strongly driven by nature and residual heat of the radioactive contents as well as temperatures reached during transport. The current DGD/R66 packaging cannot meet the CEA's future transport needs because the specifications of the HILW waste drums to be transported are not compatible with the data underlying the initial safety studies, especially with respect to the residual heat to be considered. Therefore, the new TIRADE/R76 cask will present significantly increased performances especially regarding its mechanical behavior towards the risk of an internal hydrogen explosion.

The purpose of this paper is to present the original approach adopted by the CEA and ROBATEL Industries to develop this new package design. In addition to the safety justifications that aim to demonstrate the absence of risk of explosion in the package during the transport, the packaging has been nevertheless designed to withstand a possible internal explosion. These studies were conducted on the basis of physical explosion tests on an instrumented life-size model that allowed then to analyze the package's mechanical behavior by numerical simulations.

The CEA and ROBATEL Industries thus suggest a pragmatic and robust safety justification of the future TIRADE/R76 transport cask incorporating in its design an additional internal explosion test, not specifically required by the regulations.

INTRODUCTION: OVERVIEW OF THE INDUSTRIAL CONTEXT

Since its creation in 1945 the French Commission of Atomic Energy (CEA[1]) has run a large number hot labs and experimental reactors for its needs in fundamental research and R&D[2]. During six decades of nuclear research, the radioactive waste has been stored in intermediate facilities awaiting long term storage solutions. Concomitantly with the ongoing nuclear research, CEA has developed solid competences in the design of transport casks for radioactive materials to adapt the transport capacities to the demands of its research laboratories. As a result CEA disposes of an important number of type B casks for the transport of fresh fuel, irradiated fuel and all kinds of radioactive wastes. Numbers of them have been developed by CEA, others in collaboration with its partners, such as ROBATEL Industries.

Nuclear transport activity is expensive and time consuming. To keep costs and timing at a supportable level CEA has created a particular structure, the EMBAL project (transport cask = EMBALlage in french) with the main mission to ensure the scheduled replacement of transport casks in line with the evolution of transport needs and transport rules. This includes the anticipation and identification of future transport needs that cannot be covered with the existing transport casks in order to optimize the transport cask fleet. This also includes the conception/development, internally or in partnership, of new transport casks with transport authorizations corresponding to the identified transport needs.

The EMBAL project has been implanted within the Nuclear Energy Division (DEN[3]) and more precisely within the department dedicated to project management (conception and construction of new nuclear plants, renovation of existing plants) named DPIE[4].

Over the last years, CEA has started the progressive replacement of ancient nuclear facilities by modern ones adapted to future research and storage needs. In this context it became clear that the waste generated by CEA's cleaning and dismantling activities and its subsequent transport towards storage facilities could not be achieved with the existing R66[5] / DGD cask dedicated to irradiating waste transport. This is especially true for the evacuation of a large number waste drums stored in local facilities for over 10 years. In this context CEA has commissioned ROBATEL Industries to conceive a new transport cask, called TIRADE or R76[6], dedicated to irradiating waste transport with significantly increased performances.

ROBATEL is a French company founded in 1830 whose activity is focused exclusively on the nuclear technology since 60 years. ROBATEL Industries is well-known for its expertise in manufacturing heavy equipments for nuclear industry, nuclear research, nuclear medicine and the defense sector. It has contributed to the development of nuclear energy in France from the beginning. Thus, ROBATEL was charged by CEA in 1953 with the design of the first transport cask in France dedicated to the transport of fresh fuel rods to CEA's first experimental nuclear reactor called ZOE[7]. Since then, ROBATEL Industries has observed and accompanied the implementations and developments in nuclear technology in terms of safety requirements but also in terms of technical solutions and innovations.

In particular, ROBATEL Industries has specialized in the field of transport casks for radioactive material, providing to the nuclear industry turnkey solutions to meet the challenges of transport. Over the last 30 years, ROBATEL has designed almost 80 type B packages and produced over 1000 specimens of packages of all types and for all kinds of contents: sources, fuel rods, radioactive liquids, activated metal pieces, waste…). Among them, ROBATEL Industries has especially designed and manufactured in the 90s for the CEA the R66 / DGD transport cask. Globally, every package designed by ROBATEL is unique and specially developed to meet the applicable regulatory requirements integrating all functional specifications made by the users.

In the present paper we describe the technical improvements applied to the new R76 transport cask concept in order to integrate the specific risks during transport of irradiating waste.

PRESENTATION OF THE NEW PACKAGE R76

The R76 is a type B(M) package which may transport fissile material. It is a cylindrical package transported by road in a vertical position whose external dimensions are about Ø 2.2 m x H 2.2 m and whose total payload is around 20 tons (see Figure 1 below).

Its main strengths lie primarily in:

- its large useful volume of load (Ø 1100 mm x H 655 mm: about 620 L)
- its important biological protection (around 165 mm. minimum of lead equivalent) and
- its robust containment system with regard to its mechanical resistance: made entirely of stainless steel, it has for example a thickness of 30 mm. at its cylindrical wall and more than 100 mm. at its background and closing lid.

In addition to these special performances that its design offers, R76 packaging also includes all the elements needed for safe transport in compliance with regulatory requirements. For instance, it is equipped with specific thermal protections (in particular with PNT3™ compound which is a material specifically developed by ROBATEL Industries for these applications) allowing it to withstand the thermal regulatory test, especially in case of fire.

The R76 is made up of a body, shielded plugs, a closure lid and two shock absorbers fixed to its lower and upper faces. It can carry from one to five drums of waste according to their geometry, their physicochemical properties and their radiological features. To do this, it can be equipped with different internal devices as needed, especially with different stainless steel baskets that have cylindrical cavities to load the drums and to maintain them in the package during transport (see Figure 2 hereafter).

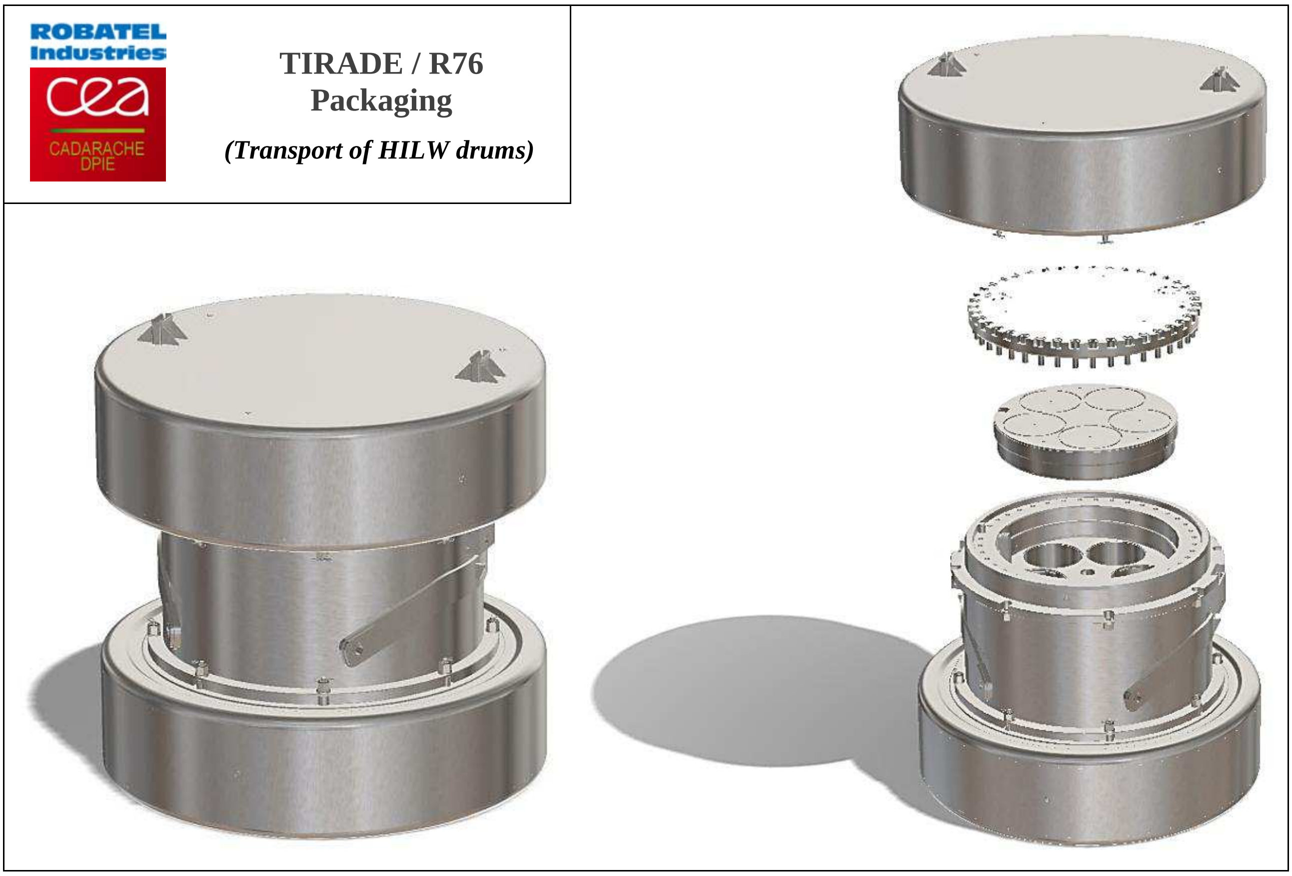

Figure 1: Overview of the TIRADE / R76 packaging

Figure 2: Overview of the various internal devices of the TIRADE / R76 packaging
(for the loading of a maximum of 2, 4 or 5 drums respectively---according to their size)

The design of the R76 package also includes all of the functional constraints concerning the specific needs of the CEA sites where it will be used. Its design and its interfaces have therefore been generally inherited from those of its grandfather, taking into account years of feedback in the operation of the R66. However, in order to integrate the current (or future) needs of the CEA best and the changes of the regulatory requirements over the last 15 years, its operating functionalities have been improved, its loading capacities have been increased and its performances (as well as the associated safety assessments) have been significantly strengthened.

To date, in terms of progress of the project, the main steps that can be underscored are as follows:

- the application for approval for the R76 package model and its associated safety report were submitted to the French Nuclear Safety Authority (ASN[8]) and are being expertised;
- in support of the various safety analyses forwarded, an internal explosion test campaign was also carried out on a full-scale model representative of the containment system of the R76;
- 4 specimens of the R76 packaging are currently being produced in the ROBATEL manufacturing workshops and should be delivered to the CEA by 2014.

The radioactive materials carried in R76 packages are HILW[9] waste from the operation or the decommissioning of CEA facilities or its research reactors (Grenoble, Fontenay-aux-Roses or Saclay, for instance). They are packed in cylindrical, metallic drums of various types and various sizes depending on their nature and their origin (mainly drums of 50, 70 or 120 L) and are scheduled to be transported either to the INB[10] n°37 and CEDRA[11] of CEA Cadarache or to the facilities of CEA Marcoule called ISAI[12] and DIADEM[13].

The types of waste contained in the drums are in solid form and consist of contaminated or irradiated miscellaneous materials (such as plastics and rubbers, cellulosic materials, metallic pieces, glass or rubble for instance). They can thus possibly induce radiolytic or thermolytic phenomena but are however chemically inert. They may also contain any type of radionuclides (alpha, beta or gamma emitters) as well as fissile material. The main characteristics of the different types of loading and contents of the R76 are briefly presented in Table 1 hereafter.

In total, several thousand ILW or HLW drums will have to be removed during the next fifteen years using the R76 packagings.

Table 1: Overview of the main characteristics of the R76 package contents

Main properties of the waste drums :	Maximum number of drums that can be loaded in the packaging : ≤ 5 drums max	≤ 4 drums max	≤ 2 drums max
Geometric properties:			
Volume of the drums:	≈ 50 L/drum	≈ 70 L/drum	≈ 120 L/drum
Maximum weight of a drum (filled with waste):	≈ 80 kg/drum	≈ 100 kg/drum	≈ 200 kg/drum
Maximum diameter of a drum:	≈ Ø 370 mm	≈ Ø 385 mm	≈ Ø 500 mm
Maximum height of a drum:	≈ h 490 mm	≈ h 625 mm	≈ h 625 mm
Physical and chemical properties:			
Physical state of contents:		Solid	
Maximum weight of thermolysable material per drum:	≤ 17 kg/drum	-	≤ 17 kg/drum
Maximum total thermal power of the contents loaded in the packaging:	≤ 19 W (total)	≤ 150 W (total)	≤ 17 W (total)
Radiological properties:			
Maximum total weight of fissile material in the contents:		≤ 210 g (total)	
Maximum γ dose rate at the surface of a drum:	≤ 30 Sv/h	≤ 260 Sv/h	≤ 260 Sv/h
Maximum activity of a drum:	200 TBq/drum	200 TBq/drum	200 TBq/drum
Maximum total activity loaded in the packaging (in A2):	≤ 35 500 A2 (total)	≤ 34 000 A2 (total)	≤ 36 000 A2 (total)

OVERVIEW OF THE SPECIFIC TECHNICAL AND INDUSTRIAL ISSUES

The need for a new R76 packaging to replace the existing one for the removal of waste drums refers among other things to the fact that the CEA must remove waste drums with residual powers that are beyond the scope of the safety studies conducted at the time for the R66 packaging. But due to the presence of organic material in the drums (either in the loaded waste or inside the conditioning devices which equip the metallic drums), these residual powers can lead to radiolytic or thermolytic decomposition of hydrogenated materials that generate a gas production in the packaging during its transport, among which hydrogen which is especially flammable or even explosive. As radiolysis and thermolysis phenomena are highly dependent on thermal power and temperature, the transports of these drums can then become problematic.

In any case, such gas production shall be taken into account in the safety analysis of the package and its transports. The main risks incurred involve the increase of the internal pressure and the potential inflammation or even the explosion of the gases produced.

From a regulatory point of view, the presence of hydrogen in a package is not prohibited as long as it does not affect the safety of transport. However, if the regulations actually specify that these phenomena shall be taken into account, they do not particularly specify how or according to which criterion *(cf. [1] §644: "The design of any component of the containment system shall take into account, where applicable, the radiolytic decomposition of liquids and other vulnerable materials and the generation of gas by chemical reaction and radiolysis." and [2] §642.1: "Certain materials may react chemically or radiolytically with some of the substances intended to be carried (…). (…) ensure that the containment system is neither susceptible to deterioration caused by the reactions themselves nor damaged by the pressure increase consequent upon those reactions.")*.

PRESENTATION OF THE SAFETY APPROACH ADOPTED

In the case of R76, in order to avoid reducing the loading capacities of the packaging too drastically, the CEA and ROBATEL chose to approach the problem from two angles simultaneously:

- on the one hand, the decision was made to take into account and analyze the risks associated with the presence of hydrogen in the packaging in view of the impact on their compliance with safety regulatory requirements;

- on the other hand, a solution was found which consists in controlling and limiting the total amount of hydrogen potentially produced during transport with limitations being imposed on both the power carried and on the transport time.

ROBATEL Industries has therefore set up and implemented an explosion tests campaign. These tests were performed on an instrumented full scale model that was representative of the inner enclosure of the R76 package (especially in terms of geometry). This model, equipped with various sensors (thermocouples, pressure gauges or photodiodes for instance), was filled with different types of flammable gas mixtures in order to observe and measure the development of pressure waves caused by an internal explosion. The overall objective was to look for configurations inducing the most severe mechanical loads to check the mechanical strength of the packaging through calculations and numerical simulations performed on the basis of collected data.

During the explosion tests, various setups of internal inflammation were tested in order to observe the impact of various parameters. These include in particular:

- Analysis of the influence of the nature of the flammable gas mixture in the inner enclosure:
  - the flammable mixture used for the tests was a mixture of hydrogen and oxygen in stoichiometric proportions;
    → i.e.: gas mixture = $\{⅔\ H_2 + ⅓\ O_2\}$
  - this flammable mixture was tested either neat or diluted in other inert gases (such as air, nitrogen or helium);
    → i.e.: gas mixture = $\{[(1 – x\%) \cdot (⅔\ H_2 + ⅓\ O_2)] + [x\% \cdot IG]\}$
    (where IG means Inert Gas, i.e. here: air, N_2 or He)
- Analysis of the influence of the amount of flammable gas mixture in the internal enclosure:
  - Tests were performed in an empty cavity of 620L (representative and on the scale of the packaging); in other words: without considering the presence of the internal arrangements or of the content which in a real transport situation, takes up space in the inner enclosure of the package and thus reduces all the remaining free space. Throughout the explosion tests, the total amount of flammable mixture in the inner enclosure had been therefore maximized with respect to the actual transport conditions. For testing, the whole volume of 620 L was thus filled with gas when in reality, the volume available in the package varies somewhere between 260 and 590L depending on the loading typologies.
  - In this volume, different amounts of gas were generated: from 0.5 to 1.2 bars of a stoichiometric mixture of H_2/O_2 in the presence (or not) of 0 to 1 bar of inert gas (for an initial total pressure before ignition ranging from about 0.5 to 2 bars). As an indication, for the most severe configurations, this corresponds to an amount of explosive mixture equivalent to more than 1 kg of TNT[14].
- Analysis of the influence of the position of the reaction ignition point in the enclosure on the internal propagation of the explosion and on the induced response at the inner walls of the structure. Two remarkable configurations given the geometry of the enclosure were thus observed (see Figure 3 hereafter):
  - Ignition of the explosion at the center of the plane face of the enclosure;
  - Ignition of the explosion at the middle of the cylindrical wall of the enclosure.
  - In addition, as mentioned above, the tests were conducted in an empty enclosure (without internal arrangement and without content). Besides maximizing the quantities of combustible / combustive, this allows the flame front (and reflection waves induced) to spread freely in the cavity without being disrupted or slowed by any obstacles that could diminish their power or even break a potentially detonating wave to transform it in a deflagrating one.

These different test configurations were therefore conducted to observe the behavior of propagation of an internal explosion in the most severe and most penalizing conditions compared with the actual transport conditions. Based on the results obtained from these tests, for a given amount of flammable mixture, we therefore sought to determine the maximum mechanical loads induced (i.e.: spatial and temporal profiles of pressure sustained by the inner walls). For information: in the most severe conditions, velocities of flame fronts exceeding 3 000 m/s were observed inducing peaks of pressure of about a hundred bars (both highly localized spatially and very limited temporally: some tens of microseconds).

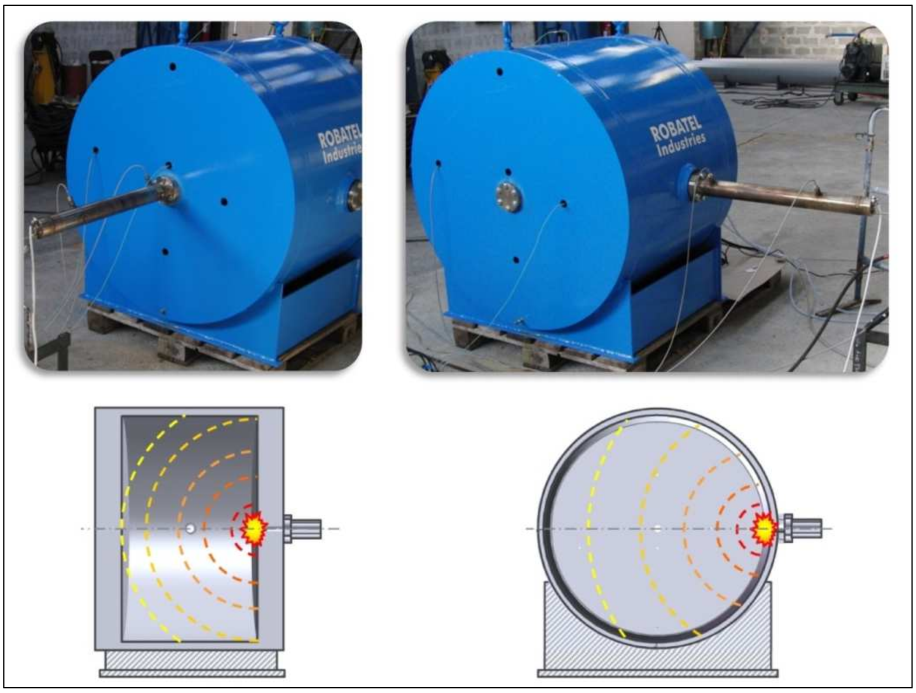

Figure 3: Explosion tests performed on an instrumented full scale model representative of the inner shell of the R76 cask *(on the left: axial ignition configuration – on the right: radial ignition configuration)*

These solicitations, having been observed and measured, were introduced in a finite element model of the package to perform high speed dynamic simulations of its mechanical behavior (see Figure 4 below). The objective was to verify, depending on initial conditions in the package, if a possible internal explosion wouldn't call into question its mechanical strength, particularly with regard to its containment or closure system.

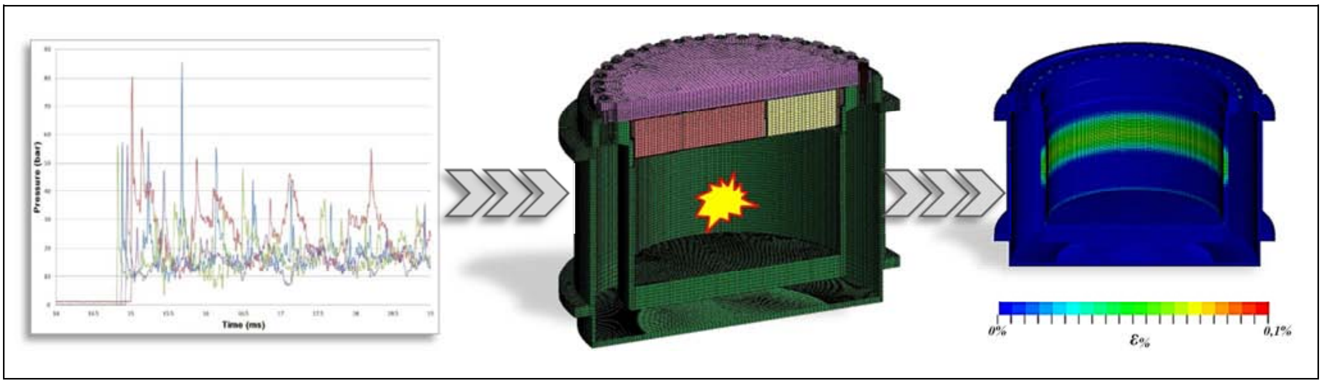

Figure 4: Measurement carried out during the explosion tests: constitute the input data for the numerical simulations to assess the mechanical behavior of the cask

The CEA and ROBATEL have therefore preferred a scenario of justification jointly based on tests and calculations rather than one that would have been only based on the observation of the mechanical resistance of the model during testing (a method of justification that is nevertheless widely used for regulatory drop testing, for instance). This option was chosen especially for issues related to the safety of the tests but also, given the atypical nature of these kinds of tests, for reasons of rationalization of experiments and studies that ultimately fall almost within R&D.

Safety analyses of the R76 package were then performed jointly based on the collected data and on various related analyses. Studies of gas production by radiolysis and thermolysis have enabled us to determine the maximum quantities of flammable gas mixtures potentially generated in the package during transport. Given the limitations specified on the content of the package, special attention was given to:

- the adequacy between their findings, i.e. the initial test conditions and the results of numerical simulations in terms of mechanical strength of the package,
- the compliance of the package regarding its release of activity,

in a case where an internal combustion of gases might occur during transport, whether in normal or accidental conditions. Indeed, as this scenario (i.e. an internal explosion) is not explicitly specified by regulations, it was conservatively decided to consider that this "test" could not be excluded from normal conditions of transport. The package must therefore be able to guarantee the safety of its transport with a performance level corresponding to the regulatory requirements under normal conditions.

CONCLUSION

With the development of this new R76 packaging, the CEA and ROBATEL have thus proposed a new approach that is certainly unusual but that aims to be safe in any case. If this approach, combined with a specifically adapted package design, must first ensure its compliance with regulatory requirements, it also aims to optimize the capabilities of loading and transport. Thus, taking into account the risks associated with the potential presence of hydrogen, the R76 packages are aiming to ensure the safe transport of radiolysable waste that may have thermal power up to about twenty watts for normal transport times of about five days (excluding contingencies that may occur during transport and for which additional security measures have been included in analyses).

The designers of the R76 packagings therefore want to provide a solution to deal with these kinds of issues that are today, for many players in the sector, a major and recurring challenge: on one hand they concern the needs of material transport in the presence of radioactive and radiolysable materials, but they must also consider the viewpoint of the safety requirements inherent in them.

REFERENCES

[1] IAEA Safety Standards - Regulations for the Safe Transport of Radioactive Material, 2012 Edition – Specific Safety Requirements n°SSR-6

[2] IAEA Safety Standards - Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, 2008 Edition – Safety Guide n°TS-G-1.1 (Rev.1)

NOTES

[1] CEA: Commissariat à l'Energie Atomique et aux Energies Alternatives
(The French Commission of Atomic and Alternative Energies)

[2] R&D: Research and Development

[3] DEN: Direction de l'Energie Nucléaire – CEA
(Division of Nuclear Energy)

[4] DPIE: Département des Projets d'Installation et d'Emballage – CEA
(Department of Projects for facilities and packages)

[5] R66: Type B(M)F package also called « DGD »
(66th ROBATEL design of type B package)

[6] R76: Type B(M)F package also called « TIRADE »
(76th ROBATEL design of type B package)

[7] ZOE: First nuclear research reactor in France (CEA Fontenay-aux Roses: 1948 - 1974)
ZOE stands for: « Zéro émission d'énergie – Oxyde d'uranium – Eau lourde »
(Zero energy emission – uranium Oxide – Heavy water)

[8] ASN: Autorité de Sûreté Nucléaire (the French Nuclear Safety Authority)

[9] HILW: High and Intermediate Level Waste

[10] INB: Installation Nucléaire de Base
(Licensed Facility)

[11] CEDRA: Centre d'Entreposage de Déchets RAdioactifs – CEA Cadarache
(Storage Center for Radioactive Waste)

[12] ISAI: Installation de Surveillance des Assemblages Irradiés – CEA Marcoule
(Monitoring Facility of Irradiated Assemblies)

[13] DIADEM: Déchets Irradiants ou Alpha et de DEMantèlement – CEA Marcoule
(Facility for Irradiated, Alpha and Decommissioning Waste)

[14] TNT: Trinitrotoluene: one of the most commonly used explosive materials