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TN® Lab: Addressing the need for shipping radioactive sources and irradiated samples by making the design and licensing process more effective

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Abstract

The TN® Lab cask, the so called "Flying pig," has been developed by Orano TN to respond to the increasing demand for a cost-effective, flexible and compact solution to transport small sources and small quantities of irradiated or activated material coming from research laboratories by road, sea, and air.

A specific Working Group with different international laboratories (HOTLAB) was launched to define specifications and main characteristics of the new cask. Based on the Working Group conclusions, the following two key safety options were retained to cost effectively design and license the cask in a timely manner while still offering loading flexibility for the different users:

- the mechanical analysis in normal and accident conditions of transport was conducted exclusively with numerical simulation and without time- and cost-consuming drop tests on a scale model;
- the definition of content by inequalities was made to transport a large spectrum of nuclides with a limited level of activity. This flexible definition of the content enables a large range of user needs.

The first "Flying Pig" has been manufactured. The licensing process has been completed so that its first transportation of radioactive material is to be carried out in 2019.

This paper not only presents the characteristics of the final TN® Lab solution but mainly focuses on the implementation of the two previous key safety options used for the cask design and licensing.

Introduction

After numerous exchanges with HOTLAB (Working Group of international laboratories [1]) on both the panel of content to be transported and the operating conditions, Orano TN can now offer a new competitive cask for the transportation of small sources and small quantities of irradiated or activated material. This cask meets the laboratories' needs for a cost-effective, flexible and compact solution to transport their content throughout the world.

At the origin, this new cask was called "Flying Pig" in reference to the transfer casks used by the labs called "Pigs" as they look like a pig's head, and because of its ability to be shipped by air. As the design came to completion, the appellation "Flying Pig" evolved to become the TN® Lab.

Technical features of the cask

The TN® Lab is a Type B(U) cask that can be transported by road, rail, air, inland waterways and sea. It meets the 2012 AIEA Regulations for the Safe Transport of Radioactive Material and the requirements of applicable versions of ADR, ADN OACI, IMDG, and RID regulations.

The TN® Lab package is designed to:

- transport a large range of content
- transport more than 15 g of fissile material in a single B(U) cask in accordance with the 2012 transport regulations
- be used for international transport for ADR countries precluding the need for licensing approval by the Competent Authority of countries other than that of the country of origin (France)

Content description

A large range of content can be transported in the TN® Lab such as:

- Samples of irradiated fuel or structural materials
- Samples of activated or contaminated materials
- Radioactive sources
- Fissile material

Fuel materials can be cladded or uncladded, mounted samples, pin or plate segments. The content, in solid or powder form, is either metallic, an oxide, a carbide, a nitride or various mixtures with a matrix material.

The radioactive content is classified as one of the following regarding fissile material (in accordance with SSR-6 of the 2012 IAEA Regulations for the Safe Transport of Radioactive Material):

- Not fissile (see § 222)
- Fissile excepted from the classification as "FISSILE" (see § 417)
- Fissile excepted from the requirements of § 676 to § 686 (see § 674 or 675)

The following fissile material can be transported with the cask design approval [2]:

U enrichment	Equivalent uranium mass allowed in TN® LAB
up to 1.5%	14,666g
up to 5%	1,700g
up to 10%	660g
up to 20%	290g
up to 100%	45g

The limits for the content and its conditioning are the following:

- Maximum total thermal power: 10 W
- Gross weight: 20 kg
- Maximum volume: 4.6 L

The radionuclide activities authorized to be transported in the TN® Lab are defined by an inequality system which is described in more detail below. Regarding the shielding capabilities of the cask, the following maximum content activities can be loaded into the TN® Lab:

- ^{60}Co: $7.82 \times 10^{+10}$ Bq
- ^{137}Cs: $2.92 \times 10^{+12}$Bq
- ^{241}Am: $9.01 \times 10^{+14}$Bq

Cask description

The cask is mainly composed of the following (see Figure 1):

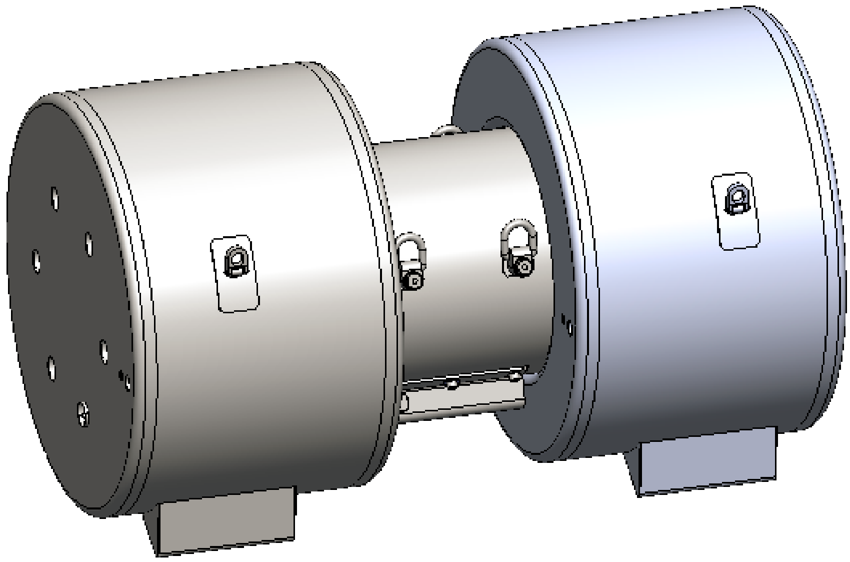
- A cylindrical forged body
- An internal revolving cylinder system
- A pushing device system
- A closure system (front, rear and radial)
- Two shock absorbers

For cost-effective and easy manufacturing, the cask body is made of a single stainless steel forged block to avoid difficult coating and welding operations. In addition, this technological option reduces the maintenance program and subsequent costs compared to a multi-layered cask.

Definition of the content by inequality

One of the main challenges of the TN® Lab was to transport a large range of content with different shapes, activity level, and radionuclides spectrum to best meet the needs of users.

For the design and licensing of the cask, the key safety option retained by Orano TN was to define the content by inequalities so as to transport a large spectrum of radionuclides with an activity limited for each radionuclide only by the package shielding capabilities.



Overall dimensions	Cavity dimensions	Mass (loaded)
• length: 1850 mm • diameter: 1100 mm	• useful length: 360 mm • useful diameter: 150 mm	3000 kg

Figure 1 TN® LAB overview

Authorized content

The content is defined by a large list of authorized radionuclides classified into 15 groups in ascending order of maximum allowed activity. For each group of radionuclides, one radionuclide, called the reference radionuclide, is chosen to represent its group. The first eight groups correspond to neutron or alpha emitters and the next seven groups correspond to gamma emitters.

Each group is defined by a leading isotope and a maximum activity. The activity of the content is limited so that the following inequality is respected:

$$\frac{1}{1-\mathrm{k_{eff}}} \times \sum_{\mathrm{i}=1}^{8} \frac{\mathrm{A_i}}{\mathrm{A_{max\,i}}}\ (\mathrm{neutron}) + \sum_{\mathrm{i}=9}^{15} \frac{\mathrm{A_i}}{\mathrm{A_{max\,i}}}\ (\mathrm{gamma}) \leq 1$$

Where:

- A_i is the total activity of the radionuclides of group i for the content in Bq
- A_{maxi} is the maximum allowed activity for group i in Bq, defined in the certificate
- $\mathrm{k_{eff}}$ is represented in dry conditions

Because quantities of radionuclide types are very important, the list of authorized radionuclides could not mention each possible radionuclide. However, nuclides not included in the previous definition can be transported under the following conditions if:

- The isotope integrates the most penalizing group for neutron emitters (group 1) and the most penalizing group for gamma emitters (group 9)
- Its activity is lower than the activity limit corresponding to an exempt consignment (according to SSR-6 of the 2012 IAEA Regulations).

Authorized list of radionuclides - methodology

The methodology used to define the 15 groups of radionuclides and their activity limit is described here below.

Verification of the reference radionuclides

For each group, one reference radionuclide was chosen to represent its group in the shielding analysis. Based on a simplified model of the TN® Lab cask, Equivalent Dose Rate (EDR) was evaluated for each significant radionuclide.

For each family, the maximal EDR was checked for the reference radionuclide. It was verified that families were classified by decreasing EDR. It was also verified that the EDR of the radionuclide of each family was greater than the EDR of the following radionuclide family.

Determination of the shielding relevant areas and the source model

The shielding relevant areas of the TN® Lab cask design were determined. These areas correspond to zones where relative maximum dose rates can occur.

The influence of the shape of the source was also studied between a volumetric source uniformly distributed into the cavity and a single source positioned in a penalizing way into the cavity.

Verification of maximum allowable activity for each radionuclide with regards to EDR criteria

This step consisted of checking the maximum allowable activity for each radionuclide group. The maximum EDR for one group was calculated with the reference radionuclide of the group and the maximum activity of the group at the shielding relevant areas.

The maximum allowable activity for the reference radionuclide of a group X was checked as follows:

$$A_{max}(X) \leq \frac{A_u(X)}{EDR(X)} \times EDR_{limit}$$

With:

- $A_{max}(X)$: the maximum allowed activity of radionuclides group X, in Bq
- $A_u(X)$: normalised activity of the radionuclideX used in the EDR calculation
- EDR(X): the EDR for the reference radionuclide of group X, of activity $A_u(X)$, in mSv/h
- EDR_{limit} : the EDR regulatory criteria, that is 2 mSv/h at any point on the external surface of the cask

This content definition covers a large spectrum of radionuclides with accurate activities and allows to transport all other radionuclides with envelope limit activity. Using inequation makes it possible to quickly estimate if a mixture of radionuclide is compatible with TN® Lab shielding capabilities.

In the future, the list of authorized radionuclides can be enlarged to give even more flexibility to the content, and limit the transportability analysis (if a radionuclide is not specifically cited in the certificate of approval).

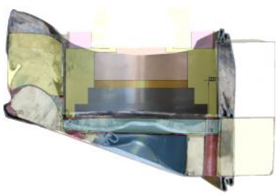
Mechanical analysis by calculations

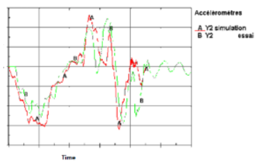
The other main challenge of the TN® Lab was to obtain the license in a short period of time. Instead of time- and cost-consuming physical drop tests on a reduced scale mock-up, numerical simulations were exclusively used for the mechanical analyses in normal and accident conditions of transport. This option was possible as Orano TN has accumulated significant information from the results of countless physical drop tests carried out on numerous types of casks in the past. During physical drop tests, the behavior of a cask model is mainly driven by the behavior of its shock absorbers. Thus, based on the feedback from several drop test campaigns, the TN® Lab shock absorbers were designed based on the TN®106 cask, the drop tests of which were conducted in the year 2000.

The methodology used in the TN® Lab Safety Analysis Report to demonstrate the mechanical behavior of the cask in normal and accident conditions of transport is as follows:

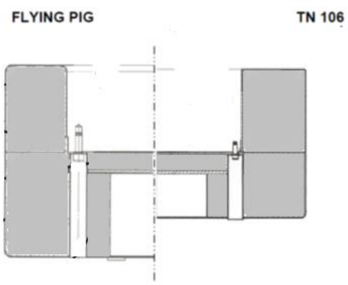
- **Step 1**: Drop tests on TN® 106 half-scale mock-up were conducted in 2000, the results of which were chosen to demonstrate the behavior of the TN® Lab.

- **Step 2**: A benchmark of deformations and accelerations of the TN®106 drop tests were carried out by numerical simulation providing a representative numerical model of the TN®106 shock absorber in testing conditions.



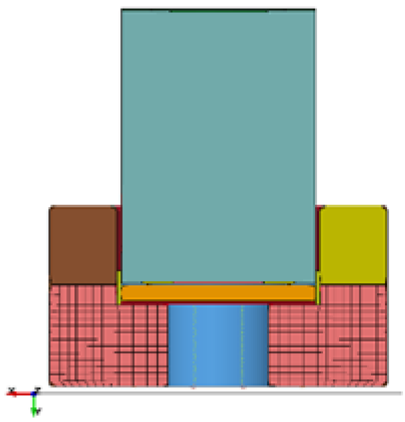


- **Step 3**: The similarity between TN® Lab and TN®106 shock absorber models was demonstrated in terms of shape, materials, characteristics of material (crushing stress), assembly, scales. Some modifications were implemented on the TN® Lab shock absorbers to improve their behavior.



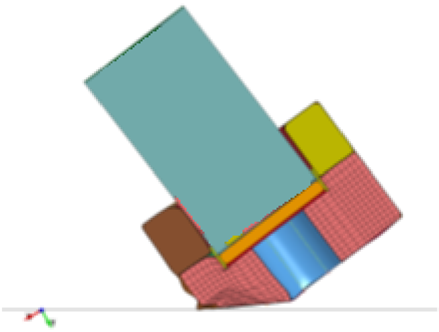
- **Step 4**: Definition of the drop test program. Based on the specificities of the TN® Lab cask model, the most penalizing drop test configurations were identified including: orientation, temperature, material properties, influence of gaps and torque.

- **Step 5**: A numerical model of the TN® Lab was created by using all the benchmarks made on the TN®106 numerical model.



- **Step 6**: TN® Lab numerical simulations were conducted for the configurations defined in step 4.

- **Step 7**: Results of numerical calculations were analyzed. The main points reviewed to validate the leak tightness of the cask are the following:
  - strain in the screws
  - openings between lids and body
  - crushing of the wood
  - strain in the containment component



The corresponding criteria were shared and validated with the Authorities during the Safety Options validation. The TN® Lab meets all mechanical criteria defined at the beginning of the project!

Conclusion

TN® Lab solution meets the needs of HOTLAB and is thus able to transport a large spectrum of contents. The licensing process has been completed, the cask is manufactured and is available to transport internationally a large variety of radioactive material and samples by air, rail, road, sea, without the need for any further approvals.

The design meets the safety options defined at the beginning of the project regarding the content definition and the mechanical demonstration. The next step, in 2021, is to obtain approval certificates from non-ADR countries, especially the US and China, to transport the same content across oceans by air.

References

[1] Transport of Small Quantities of Irradiated Materials: Flying Pig Concept Update - PATRAM 2016 - Vanessa LALOY, Fabien HUE – Areva TN

[2] New Transport Regulations on Fissile Materials following the Regulations for the Safe Transport of Radioactive Material 2012 Edition - F. DARRAS – Areva TN – Hot Lab 2015