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LIQUID WASTE TRANSPORT PACKAGES : HOW TO DEAL WITH THE SPECIFIC CONSTRAINTS GENERATED BY LIQUIDS ?

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ABSTRACT

CEA is a technological and research organisation that has an extensive experience in designing, manufacturing, licensing and operating of nuclear transport packages for its own various needs between its nuclear facilities spread all over France. Among all the nuclear material transported, liquid radioactive waste generates specific constraints at each step from the design to the final operation that have to be taken into account to allow the success of the transport in safe conditions.

This paper will present an overview of the packages and ADR tanks developed and operated by CEA for liquid waste in acidic and aqueous solutions but also in organic solutions, from low activity to high activity levels, and covering all types of transport packages from IP2 tanks to type B packages. A state of the art of the currently in-use CEA transport packages for liquid waste will be made (LR54, LR56, LR144, LR154, SORG) focusing on how their design distinctive features fit with the chemical and radiological content, with respect to the ADR or IAEA regulations.

This wide range of packages will be used to illustrate and highlight some of the specific topics due to liquid waste transport, from the design phase to operation and maintenance, such as :

- corrosion prevention : choice of tank materials (steels and gaskets) in regards to the corrosion forms, extra thickness of steels, qualification of welds, adequate rinsing
- corrosion monitoring : sample tests, periodic inspections
- safety topics during licensing process : liquid phase transformation below 0°C (32°F), how to deal with permanent operating systems during drop tests in term of mechanical behaviour or leak tightness
- precipitation and significant impurities management : radiation protection calculations, operative measures against pipe stopping up like bubbling system or sieves
- IP2 tank controls and tests: rail impact test on a tank container prototype during manufacturing, tightness and hydraulic tests during maintenance
- filling and discharging phases : accidental spillage prevention and flow rate monitoring by using a distributed control system that pilots operating safety equipments (vacuum pump, valves, liquid level and pressure sensors)

1 INTRODUCTION

CEA is the French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives). It is a public body established in October 1945 by General de Gaulle. A leader in research, development and innovation, CEA is active in four main areas: low-carbon energies, defense and security, information technologies and health technologies. In each of these fields, CEA maintains a cross-disciplinary culture of engineers and researchers, building on the synergies between fundamental and technological research.

The civil nuclear research is focused on two main fields: nuclear systems for the future and nuclear waste management.

The research studies are supported by demonstration resources and equipments using nuclear materials, which are spread all over the ten CEA research centers in France, each specialized in specific fields. Consequently, the transport of nuclear materials between its own nuclear facilities and also the waste produced by its activities, or the dismantling of old facilities, is a key issue for the good achievements of CEA programs and projects. CEA has therefore designed, licensed and manufactured a wide range of nuclear transport packages to cover its own varied needs over the last 65 years. The fleet of packages covers many kinds of nuclear materials that need to be transported:

- neutron sources and a large variety of fresh fuels,
- a wide variety of spent fuels from a large group of research reactors or laboratories, and conditioned in many forms (samples, rods, assemblies…),
- technological waste conditioned in various drums from 100l to 870l,
- liquid waste

Transport packages for radioactive liquid waste represent a specific group because of the constraints generated by the liquids at each step of the transport package lifetime, from the design to the final operation. This paper will first present an brief overview of the packages and ADR tanks developed and operated by CEA for liquid waste in acidic and aqueous solutions but also in organic solutions, and then will highlight how to deal with the specific constraints generated by the liquids in order to allow the success of the transport in safe conditions.

2 CEA TRANSPORT PACKAGES FOR RADIOACTIVE LIQUID WASTE

A brief overview of each transport package of liquid waste is presented hereafter. Please note that the chemical and physical limitations of the effluents mentioned cover CEA needs and correspond to the approval certificate at the time being, but the modification of these limits can be studied in the frame of an extension of the safety approval.

2.1 IP2 tanks

In this category, several CEA tank trucks offer the possibility to transport large quantities of Low Specific Activity (LSA-II) radioactive aqueous liquids: LR54, LR68 and LR154.

LR68 is a tank truck that can transport up to 8m^3 of effluents, while the LR54 has the capacity to transport up to 18m^3 of effluents.

The LR154 tank (see Figure 1) is the latest package of this category and has a compact design fitted in a 20’ ISO frame that allows easy handling on various means of transport on road or rail (its approval certificate covers ADR and RID). It can transport up to 16,3m^3 of effluents. It has a double shell that retains the liquid waste in case of leakage.

Two specimens have just been built and the first transport of radioactive waste will be realized by September 2013.

Figure 1: LR154 IP2 tank for LSA II liquids

2.2 Tank trucks for moderately radioactive effluents

LR56 (see Figure 2) is a $3m^3$ capacity tank truck designed by CEA for the transportation of moderately to highly radioactive aqueous effluents (up to 12 500 A2; 240 GBq Co-60 ; maximum content of 5,5 mol/l of nitric acid and 1,6 mol/l of sulfuric acid are allowed). The LR56 is a B type package and fissile materials are allowed with respect to maximum limits: 128g for U, 80g for Pu, 65g for Am. The thermal power of the liquids is limited to 10W. It has a double shell that retains the liquid waste in case of leakage.

CEA owns two specimens built in the 1990s and several more have been sold to US companies. There is an excellent feedback concerning the use and the maintenance of these packages.

Figure 2: LR56 tank for moderately radioactive liquids

2.3 Transport package for highly radioactive effluents

The LR144 (see Figure 3) is a tank truck which can transport up to $1m^3$ of highly radioactive aqueous effluents (up to 10^5 A2; 80 TBq Co-60; maximum content of 3 mol/l of nitric acid and 1,6 mol/l of sulfuric acid are allowed). It is a B type package and fissile materials (U and Pu) and beryllium are allowed with respect to maximum limits: 1kg for Be, 520g for U, 80g for Pu, 65g for Am, and 2,7g for Cm. It also offers the possibility to inject an inert gas in order to increase the maximum thermal power authorized (limited to 23W).

Several transports have already been realized for foreign nuclear operators like IRE in Belgium.

Figure 3: LR144 transport package for highly radioactive liquids

2.4 Transport package for organic liquids

CEA has designed and manufactured a specific transport package dedicated to the transport of organic solvents (i.e. contaminated oils), called SORG (see Figure 4).
SORG is a B type package that can transport up to 1m^3 of moderately to highly contaminated organic effluents (up to 1 000 A2; 1 750 GBq/m^3) containing fluorine, chlorine, phosphate and sulphate, with maximum content respectively of 40 mg/l, 2 g/l, 3,2 g/l and 7,3 g/l.
Fissile materials inside the effluents are limited to 15g, and thermal power of the liquids is limited to 1W.

Figure 4: SORG transport package for organic liquids

3 LIQUIDS SPECIFC CONSTRAINTS

3.1 Corrosion

3.1.1 Corrosion prevention: impact on design and manufacturing

In order to have a transport cask that can be operated in safe conditions over a long period of time, corrosion is one of the main problems that has to be tackled.

The first way to avoid corrosion problems is to select materials which have a strong resistance to this phenomenon: that's why CEA has performed dedicated corrosion studies to find out the best suitable steels that could have at the same time good mechanical properties and corrosion resistance in order to design its packages. Mechanical properties generally first drive the choice of the type of steels, especially for type B packages like LR56, LR144 and SORG with strong constraints due to accidental conditions, but radioactive liquid waste is mostly present in acidic solutions with aggressive components like chlorines, fluorine, sulfates and nitrates, that could quickly and dramatically affect the mechanical properties of the tank confining them.
Therefore, considering the envelope chemical characteristics of the materials to be transported, duplex steels made of two-phase microstructure consisting of grains of ferritic and austenitic stainless steel have been chosen because they both offer good mechanical performances and a good resistance against corrosion ; different grades can be used according to the specificities of each type of liquids transported and are presented in the table below :

Table 1. Grades of steel used for the design of the main tank

Packages	**Grades of steel (main tank)**	**Chemical composition of the effluents** (aqueous solution except SORG)
LR54, LR68	1.4539 X1NiCrMoCu 25-20-5 **URANUS B6**	Nitrate, fluorine, chlorine, phosphate and sulphate, with maximum content respectively of 90 g/l, 12 g/l, 4 g/l, 12g/l and 15 g/l are allowed in acidic solution
LR56	1.4539 X1NiCrMoCu 25-20-5 **URANUS B6**	5,5 mol/l of nitric acid and 1,6 mol/l of sulfuric acid are allowed
LR154	1.4462 X2NiCrMoN 22-5-3 **URANUS 45N**	Nitrate, fluorine, chlorine, phosphate and sulphate, with maximum content respectively of 90 g/l, 12 g/l, 4 g/l, 12g/l and 15 g/l are allowed in acidic solution
LR144	1.4501 X2CrNiMoCuWN 25-7-4 **URANUS 76N**	3 mol/l of nitric acid and 1,6 mol/l of sulfuric acid are allowed
SORG	1.4404 X2CrNiMo17-12 **316L**	fluorine, chlorine, phosphate and sulphate, with maximum content respectively of 40 mg/l, 2 g/l, 3,2 g/l and 7,3 g/l, in a organic solution made of TBB, TBP, TPH, TLA or nonanoic acid.

These duplex steels outperform more conventional stainless steels like 304 and 316L grades used frequently in transport cask design (for solid contents), even in very oxydizing and acidic solutions ; the drawback is that these high performance alloys are more costly and they are also more tricky to manufacture.

Corrosion can affect the whole surface of the inner wall if the material is not properly chosen against the liquid environment : this phenomenon is called general corrosion ; but welding seams for example offer a privileged zone for starting other forms of corrosion as their surface present more irregularities and their physical and chemical composition is different from the unaffected base metal : it is called local corrosion which covers different types of phenomenon like pitting, crevice, stress or fatigue corrosion. Consequently, before manufacturing, appropriate welding procedures have to be selected and qualified.
In the case of LR144 for example, once Uranus 76N grade was chosen for the tank and the welding procedure of the inner wall was defined, the next step was to check the microstructure of the welded seam through metallography and mechanical tests, in order to guarantee the absence of phase sigma precipitation or intermetallic phases or microcraks, especially in the Heat Affected Zone (HAZ).

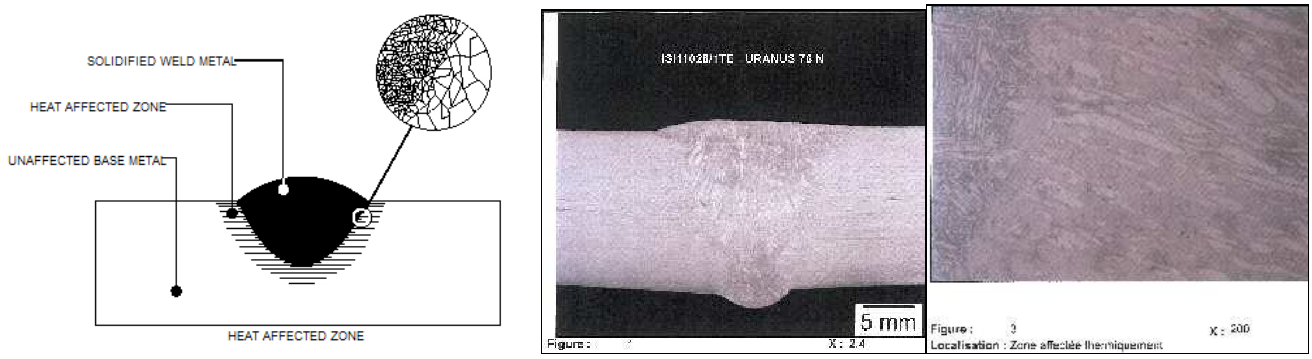

Figure 5: LR144 Uranus 76N welded coupons metallography

The impact test results (V-notch; NF EN 875/1995) at -40°C(-40 °F) are greater than 70 J, which confirms the quality of the microstructure. Finally, corrosion tests on similar coupons have been conducted at a temperature corresponding to normal and accidental conditions of transport. The results show the absence of pitting corrosion risks

But even if those specific steels offer a good resistance against corrosion, it cannot be completely avoided and degradation of the tank has to be taken into account during the design of the tank : in LR154 for example, it has been calculated that in the worst conditions, corrosion would take out approximately 1 mm of the thickness of the inner wall over the lifetime of the tank (~25 years) ; consequently, the thickness of the main tank was changed from 7 mm (due to mechanical constraints) to 10 mm in a conservative approach. For LR144 it was established that the annual corrosion rate would stay below 100 µm/year. These results are consistent with the corrosion allowance considered to cover the life span of the container and taken into account in the mechanical calculations.

The surface finish of the inner wall should also be chosen as smooth as possible to limit discontinuities at the surface ; in general, a surface finish corresponding to a roughness Ra < 3,2 micrometer is imposed for these surfaces. This choice is also driven by decontamination concerns.

3.1.2 Corrosion monitoring

The second way to develop a safe approach against corrosion is to monitor how corrosion is actually developing during the real lifetime of the tanks : 2 possibilities are used by the operating teams of the transport package : first one is the direct inspection of the inner wall of the tank that can be performed in exceptional circumstances, like rehabilitation or prolongation of the life span of containers (see figure 6 of LR56 corrosion inspection). This is a costly and complex task (choice of the facility, radiation dose program, safety, security and technical issues). Here is an example of the operations that may be performed:

- visual inspection using a remote camera,
- high pressure water cleaning,
- effluents discharge,
- ultrasonic thickness measurement of the main tank wall.

The results of such inspections enable to demonstrate by direct means that the container is free of initiation of corrosion and that generalized corrosion remains within the allowable range.

Figure 6: LR56 2004 corrosion inspection

A second option is offered by another device that is sometimes used if the corrosion risk is higher and needs a strong monitoring : several sample tests of the steel used for the main tank are placed at the bottom of the tank and are removed during the maintenance campaigns in order to be analysed in a hot cell and compared with the initial sample test which has been monitored to be used as a reference (weight, thickness and surface finish).

In the case of LR144 (see figure 7) : 2 test samples are located at the bottom of the tank. On each, 3 non welded coupons in Uranus 76N steel representing the package main tank and 3 welded representing the welding seams of the confining wall. A first set of corrosion samples has just been removed from LR144 in 2013 June and will be soon analysed for controlling and analysis focusing on generalized and pitting corrosion signs and quantification. Based on preliminary studies including corrosion tests on envelope solutions (nitric, sulfuric, chlorid and fluorid), some criteria have been established with respect to the corrosion allowance. The end of maintenance will not be pronounced if the criteria are not respected. In parallel, a report is transmitted to the Safety Authority for information.

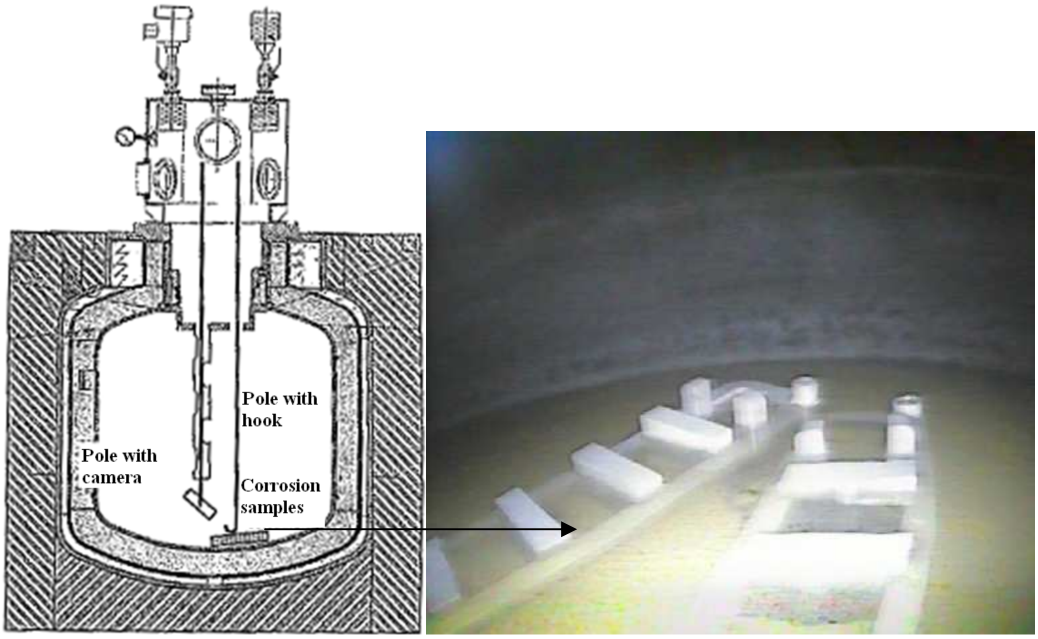

Figure 7: LR144 corrosion samples

3.2 Impact on sealing gaskets

Radioactive liquid waste can also affect the sealing gaskets used for confinement.
For example in LR144, as regards gaskets used in static stand, a double barrier has been implemented during the designing phase (see figure 8), each with a specific function generating different constraints on the gaskets.
From the outside to the inside, the first barrier is constituted by the containment gaskets that are never exposed to the potentially aggressive content, even during the regulatory drop tests; hence, the choice of material for these gaskets was driven by their leak tightness performances in an extended transport temperature range [-50°C(-58°F) ; 140°C(284°F)] and their strength against radiations. That's why EPDM gaskets were selected.

On the other hand, the second barrier may be in contact indirectly or directly with the acidic effluents, or with the tank acidic aerosols. Therefore, this constraint concentrated the choice on Kalrez® and Viton® gaskets, according to bibliography, internal feedback and also taking into account their strength against irradiation. Finally, the ability to withstand lower temperature was predominant and lead to the choice of the Viton® type, with an operation temperature range of [-20°C(-4°F); 200°C(392°F)]. This is the main reason why LR144 type B certificate of approval is not unilateral.

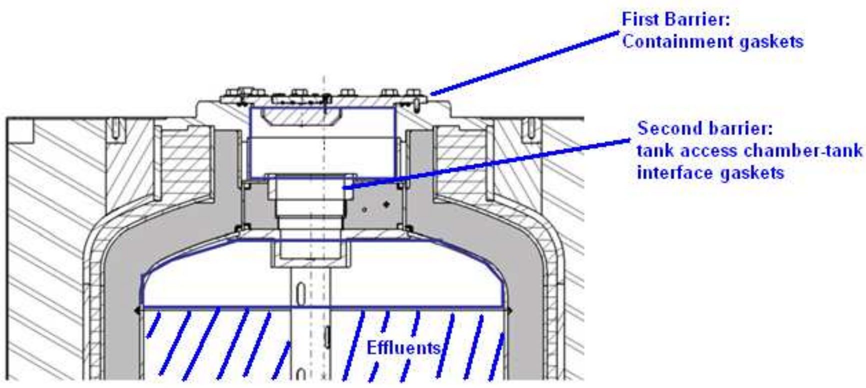

Figure 8: LR144 gaskets double barrier

3.3 Impact on permanent operating systems: LR44 compared to LR144

LR144 transport package replaces older concept of package LR44 (designed in 1973) for the transport of highly radioactive effluents. But between the 2 concepts the design has been optimized to remove from the tank access well all the equipments that could possibly break during the drop tests and let the effluents pass between the tank and the well : piping, valves and other supports have been replaced by cover plates screwed and tightened by sealing gaskets, anti-drops staubli flexible hose connectors, doubling of the tightness function of the Staubli connectors with manual valves embedded in a solid flange. The photo below gives a striking illustration of the changes between the 2 wells.

Figure 9: Tank access wells of LR44 (left) and of LR144 (right)

3.4 Specific safety topics during licensing process

In this paragraph are presented several examples of specific issues related to liquids that have been studied during the licensing process of the transport packages :

<u>Liquid phase transformation below 0°C (32°F) : LR56 example</u>

One issue is to study how to deal with permanent operating systems during drop tests in term of mechanical behaviour or leak tightness taking into account liquids. Indeed, outside temperatures of -40°C(-40°F) have to be considered and could lead to the creation of an ice cube that could affect the inner equipments of the tank or the cover plate sealing the tank.

For LR56, a study was carried out to estimate the time that would lead to the glaciation of the content in the worst conditions and with a simplified model. Outside temperature considered is -20°C(-4°F) which gives good operation margins (in France). Estimated time to get an ice cube (37 days, see figure 10) is far above the classical time needed to perform the transport, even including hazards.

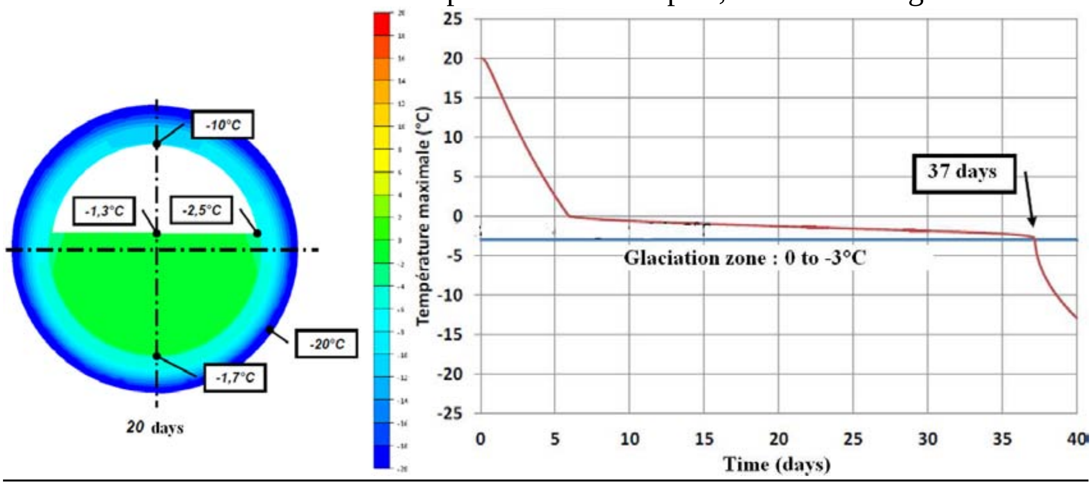

Figure 10: Numerical calculation of the glaciation of the liquid content with time

Radiological protection calculations to check local concentration of activity by precipitates
For LR144, the gamma radiation activity is defined by 1 m^3 homogeneous of :

- 3.10^4 TBq at 0,8 MeV of gamma emission for ^{137}Cs ;
- 80 TBq at 1,17 MeV (100 %) and 1,33 MeV (100 %) of gamma emission for ^{60}Co.

To take into account a potential activity concentration due to precipitation, the activity is concentrated in 60 L and different configurations of the tank have been studied (see figure 11), taking into account the effects of the regulatory drop tests (in particular the damages caused by a puncture bar). The respect of the regulatory radiological criteria has been checked.

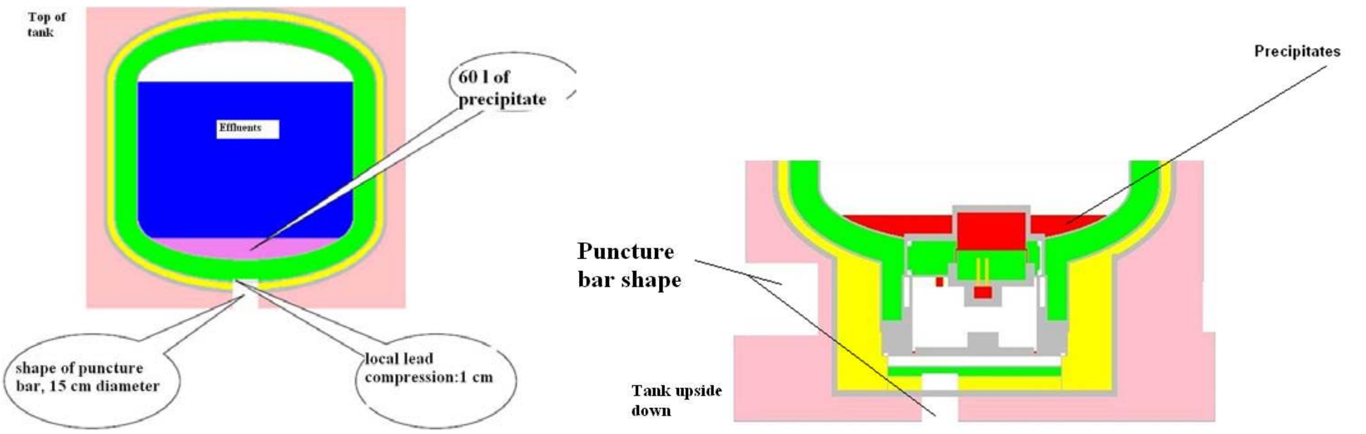

Figure 11: 2 configurations of LR144 radiological protection calculation

Impact test on IP2 tanks :
While for B type liquid transport package, drop tests are similar to other B type transport package, IP2 tanks like LR154, mounted on a 20'' frame, have to undergo specific dynamic test to qualify the mechanical behaviour of the structure and this test is part of the mandatory elements to get the IP-2 approval certificate (§6.4.5.4 of ADR specifications).
This dynamic test follows the ISO 1496-3/A1 norm and consists of an impact test of the tank fully filled with water, mounted on a wagon and hit by another wagon loaded with 80 tons at a 12,4 km/h (7,7 mph) speed (see figure 12) ; the acceptance criterium is that local deformation of the structure of the 20'' ISO frame does not exceed 5 mm.

Figure 12: Dynamic test campaign of LR154 tank

After the impact test, LR154 maximum deformation of the frame was limited to 3 mm.

3.5 Operation constraints: filling and discharging phases

During operation of the packages, the main specificity of the liquids transport is illustrated by filling and discharging phases of the content which are totally different from those for solid contents. Indeed, to transfer the liquids from the facility where they are stored, in general in fixed tanks, into the main tank of the package (and back to another fixed tank), a complete tight and radiologically protected circuit of pipes is needed. This circuit is divided into several parts, some flexible and some fixed, connected between each other by valves.

The safest way to fill in the transport package tank is to create a low pressure in the tank using a vacuum pump, in order to suck the liquids from the storage tank in a passive way : if for any reason the tightness of the circuit is lost during transfer, the pressure difference between the two tanks disappear and the transfer automatically stops. For all CEA liquid transport packages, the vacuum pump is strong enough to create a low pressure of 0,2 bar, which means that it is possible to suck the liquids from an underground tank that is located down to 5 m below the level of the transport package (top of the tank is approximately at +3 m above ground).

Discharging of the loaded package tank is done in the same way by creating a low pressure in the tank that will receive the liquid effluents. The connection between the tank and the facility is done by flexible hoses equipped at both ends with specific connectors that limits the spillage of effluents (initially these connectors were ZENITH® connectors used for fuel filling of airplanes, but more recent packages like LR144 and LR154 use STAUBLI® connectors; adaptors exist to assure a compatibility between the 2 types of connectors). The diameter of the flexible hoses and the lowest pression that can be created into the main tank drive the flow rate of transfer of effluents that can be obtained (see table 2).

Table 2. Overview of main characteristics of CEA transport packages for liquid waste

Packages	Type of effluents (aqueous solutions except SORG)	Capacity of the main tank	Flow rate for filling
LR54, LR68	LSA-II	**18 m^3 for LR54** **8 m^3 for LR68**	**~10 m^3/h**
LR154	LSA-II	**16,3 m^3**	**~18 m^3/h**
LR56	moderately radioactive effluents (240 GBq Co60)	**3 m^3**	**~ 3 m^3/h**
LR144	Highly radioactive effluents (80 TBq Co60)	**1 m^3**	**~ 250 l/h**
SORG	Highly radioactive organic effluents (1,75 TBq Co60)	**1 m^3**	**~ 650 l/h**

All these tanks (except SORG) have been designed as autonomous systems where the tank truck driver is perfectly trained to pilot all the equipments needed to manage the operations related to the filling or the discharge of the effluents, which can be performed easily within a half day period.

Remote control of these transfers is done by the operator using a distributed control system (DCS) ; the DCS pilots all operating safety equipments (vacuum pump, valves, liquid level and pressure sensors) and offer the operator a constant monitoring of the process. Manual operations have been reduced to the minimum in order to offer the operator the highest level of safety and security.

3.6 Precipitation and significant impurities management

The diameters of the pipes have to be chosen according to the liquid viscosity and should also take into account the presence of significant impurities and precipitates coming from the facilities where the liquid waste is extracted, in order to avoid blocking the pipes which can become a problem very tricky and costly to solve during operation or maintenance, due to the radioactivity of the liquids.
Bubbling system like the one installed on LR154 can help preventing the formation of precipitates (see photo), and helps the global homogenization of the effluents.
A filtration sieve can also be required on the facility circuit to limit the risk of blocking the pipes by significant impurities. For LR144 (see figure 13), the maximum particles size authorized is 1 mm and a security bypass was added.

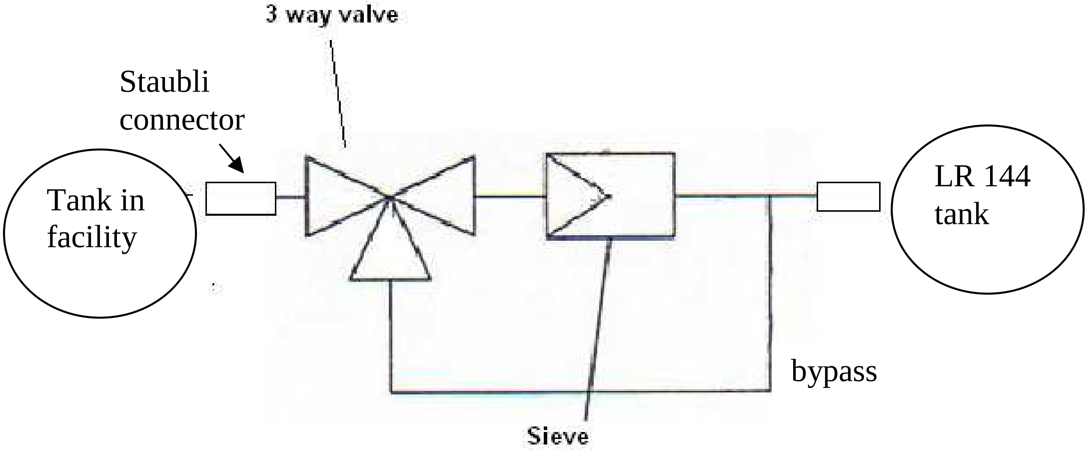

Figure 13: Principle of the filtration sieve for LR144

For SORG, organic effluents are filtered before filling in order to allow particles with maximum size of 0,2 mm.

3.7 Conformity of the liquid content to be transported

In the approval certificate of the transport package, characteristics of the liquids to be respected are given for a homogeneous content; therefore, especially when only some part of a tank is evacuated, the operator has to guaranty that what is sent into the transport package is conform to the approval certificate.
That’s why two operations are coupled: homogenization first and then sampling of the content are realized in order to get a sample that will be analysed to check the conformity.
These two operations can be realized in the nuclear facility or directly into the transport package like in LR154 which is equipped with a bubbling system and a sampling system.

4 CONCLUSIONS

CEA owns and operates a series of packages dedicated to the transport of a wide range of radioactive liquids (aqueous and organics) due to its various needs over the years, from IP-2 tanks to B-type tanks. Having also designed, manufactured and licensed those tanks is a main asset for CEA to tackle successfully all the issues related to the transport of this specific type of waste, such as :

- Corrosion prevention and monitoring
- Design constraints on materials and equipments
- Specific safety topics during licensing
- Operational constraints

This feedback from many years in liquid waste transport packages has resulted, for the latest packages of its fleet, in solid concepts that are at the forefront of the latest changes in international transport regulation, using for example high-performance steels or double-shell concepts. Therefore, CEA is in the position to propose a set of liquid transport packages fully operational and user friendly to perform the transports of liquid waste in all safety and security conditions.