Argentine Experience in Licensing of a Type-B(U) Package Design for the Transport of Cobalt 60

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INTRODUCTION

In addition to electric power, about 800 PBq of cobalt 60 are obtained in Argentina every year from the operation of a CANDU nuclear power reactor. Thus, this country has become an important exporter of such radionuclide and, therefore, the need arose to develop a packaging for its handling. In October 1994, the Argentine Competent Authority (ACA) issued Approval Certificate RA/0072/B(U)-85 corresponding to a Type B(U) package design for the transport of 12.95 PBq of ^{60}Co as a special form radioactive material. The certificate covers packagings with Serial Numbers 1 and 2.

This paper points out relevant technical issues related to the licensing process, mostly focused as from the Competent Authority's point of view. It basically describes the sequence of steps that led to decisions regarding the main technical areas involved and to a consensus between the applicant, INVAP SE[1] and the ACA. Such technical areas were: analysis on heat transfer, structural performance under impulsive loads, and shielding calculations, all of them under both normal and accident conditions of transport. Additionally, with regard to thermal evaluation and temperatures, radiation level, and leakage measurement, this paper summarizes the results obtained from a comparative analysis of the values obtained during design, from tests performed before first shipment of packages and from independent calculations carried out by the ACA.

Finally, the authors main conclusions concerning the experienced licensing process are provided.

DEVELOPMENT OF THE LICENSING PROCESS

At the very beginning of the licensing process, discussions were held within the ACA on how to fulfill the basic requirements established in the regulations published in its Safety Series No. 6 (SS6) by the International Atomic Energy Agency (IAEA 1990a). At that

[1] INVAP SE is a company dedicated to advanced applied research owned by the Argentine National Atomic Energy Commission (CNEA) and the Government of the Argentine Province of Río Negro.

time, the general features of the package design were analyzed and definitions were made on whether the package's structural, thermal and shielding performances would be evaluated through calculation or by means of experimental methods.

Later on, further discussions were held at the ACA concerning an experimental mechanical testing program, calculation methods, testing prior to first shipment of packages, and general procedures for manufacturing. In that stage, clear definitions were made regarding mechanical evaluation, thermal analysis, and shielding analysis. In every case, the results obtained were analyzed and validated.

Simultaneously and in a later stage, the applicant did also submit partial results of experimental tests and calculations, which were reviewed and assessed by the ACA and discussed with INVAP SE.

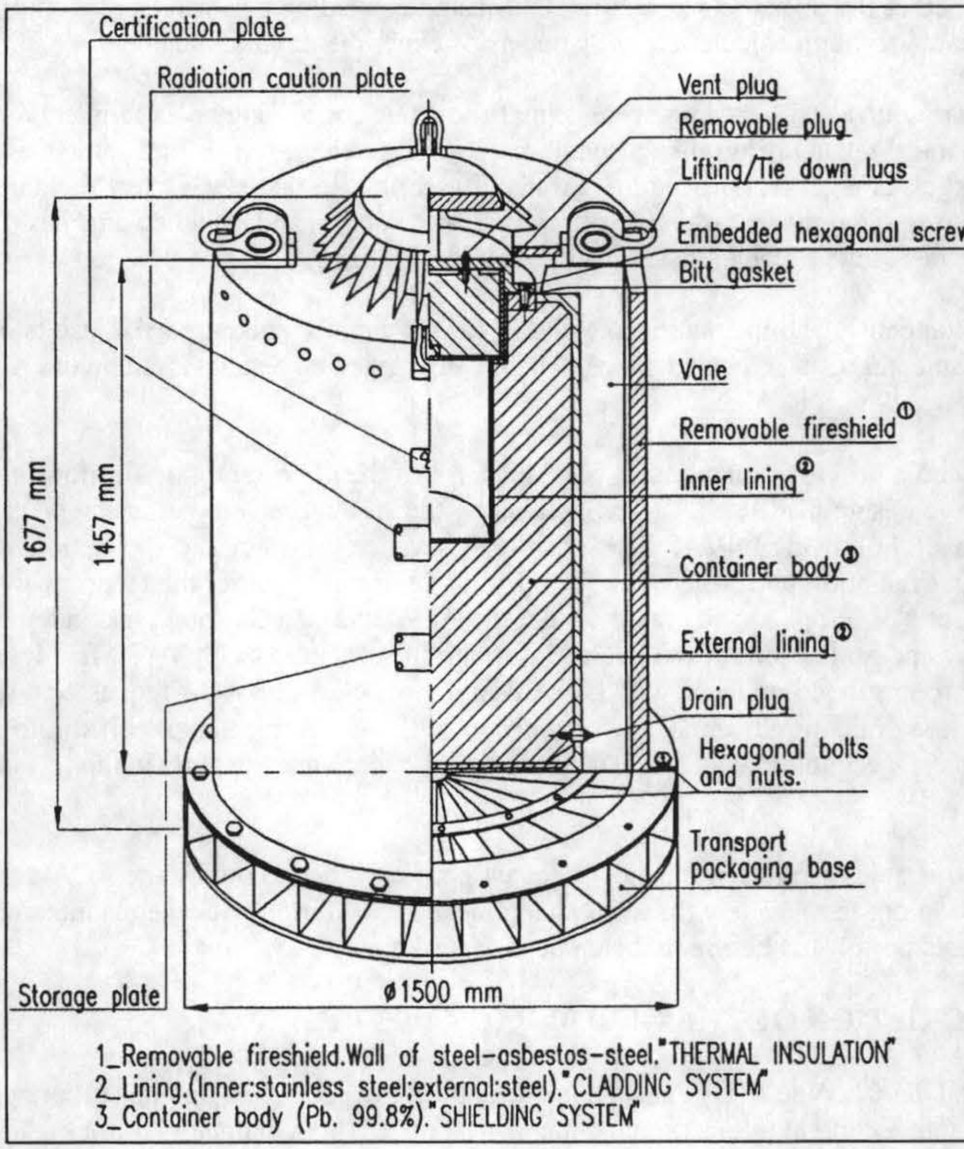
The whole process took about 5 years because of the important modifications in the package design made by INVAP SE. Finally, the ACA received the final application for approval. Following INVAP SE's Quality Assurance Program, the application included a design evaluation performed by a team from that company other than that involved in the product's development. It was then that the ACA started a thorough and independent review and assessment of the overall information submitted by INVAP SE. Moreover, in order to ensure compliance with IAEA Regulations SS6, the ACA requested a separate complete evaluation from an advisory group of the Argentine National Institute of Chemical Technology (INTEC), including long-experienced experts in the technical areas involved.

Below is a description of the most relevant activities carried out by the ACA during the licensing process, namely those involving inspections during package manufacturing and the tests performed before first shipment of packages.

DESCRIPTION OF THE GURI 01 PACKAGE DESIGN

The GURI 01 Type B(U) Package includes both the packaging and its authorized radioactive contents. Its external dimensions are: 1.5 m in diameter, 1.7 m high and a 9,400 kg mass (see Figure 1). In turn, the packaging includes three dismountable parts: a main assembly, a fireshield and a base. The main assembly is a steel-lead-steel cylinder designed for an efficient containment of radioactive material and for controlling the radiation level. Its external surface is equipped with fins that allow for an adequate dissipation of the heat generated by its contents (12.95 PBq of ^{60}Co generate 5.4 kW heat energy) and serve as energy absorbers in case of an impact. It is also equipped with drainage and venting ducts that facilitate its wet loading. The fireshield is an asbestos layer jacketed between two steel walls surrounding the main assembly. It is aimed at reducing heat entrance in case of a fire. It is bolt-anchored to a bladed steel base. The maximum authorized radioactive contents, 12.95 PBq of ^{60}Co, is in the form of 86 pencils (special form radioactive material), carried on the periphery of a pencil-holding grid located within the inner container of the main assembly. The external dimensions of each pencil are 8 mm in diameter and 285 to 450 mm in length. Their maximum activities are between 370 and 518 TBq.

Figure 1. Type B(U) Package Design - GURI 01



DESIGN AND TEST DEVELOPMENT

Primarily, Type B(U) packages must comply with functional design requirements and, especially, must be fit to maintain the containment and shielding integrity against radiation after being submitted to tests simulating both normal and accident conditions of transport. Particularly, during the design of the GURI 01, solutions were found to the following counteracting design conditions: under normal conditions, the package must dissipate the heat generated by its radioactive contents adequately, so that the latter does not deteriorate during transport (zircaloy hydrides at 500°C) or, in case of a fire, preventing the heat from entering the main body, considering that a loss of shielding could take place due to the hydraulic breakage of the main body if lead fusion occurs (327°C).

The ACA decided that the verification of compliance with the requirements in the IAEA's Regulations SS6 (IAEA 1990a) and in the documents of the IAEA's Safety Series No. 7

and 37 (IAEA 1990b; IAEA 1990c) would be carried out following the guidelines shown in the IAEA's TECDOC-413 (IAEA 1987) and Safety Series No. 112 (IAEA 1994). On the other hand, INVAP SE had the required technical capacity to demonstrate compliance with the applicable IAEA's SS6 Regulations.

Mechanical Test Under Accident Conditions of Transport

The ACA decided to perform this text experimentally, considering that validated computation models for their simulation or results from tests with similar package models were not available in the country. This is why, in order to perform the test, INVAP SE designed and built an impact platform (target) consisting of a 3-m edge cube of reinforced concrete anchored to basaltic rock by means of pedestal piles, with a 5-mm thick massive steel plate anchored to its upper face (López-Vietri et al. 1991).

Due to the high cost involved in the preparation of the testing specimens, two of them were built at a 1:3 scale and, consequently, their escalation, requirements and specifications had to be defined. No significant differences were found between the model and the testing specimens.

For this test, INVAP SE and the ACA defined the dropping sequence and orientation, so as to obtain the greatest specimen damage, and its number, the deceleration measuring methods, and the stress-deformation ratio. Twenty one drops were performed with the cylinder axis in a normal, oblique, and horizontal angle with respect to the target; 11 were free drops from 9 m height producing general deformation effects on the structure of the specimens and 10 were punched from 1 m height and caused punctual effects upon the impact area. The ACA witnessed the drops and provided its advice during their performance and during the further evaluation. On the other hand, an analytical evaluation was performed in order to confirm that after the test there was no significant damage on the grid and the cobalt bars and that no increase could be detected in the deformations of the structure due to the increase in lead temperature, considering the lead's support to the steel carcass.

After the most unfavorable testing sequence and orientation, (1) free drop in horizontal position and (2) punching on the same area, the integrity of the containment and of the shielding was verified, considering that the cover remained in its fixed position, there were no important deformations or fissures in the primary containment, the fireshield had not lost its efficacy in its thermal protection of the main body, there was a scarce section reduction among the coolant channels caused by the flattening of the fins (the tests proved that the fins are excellent impact absorbers), and the cobalt bars suffered no damage.

Thermal Analysis Under Normal and Accident Conditions of Transport

Considering the fact that INVAP SE already had independent duly-validated computation models, TAP 6 and CATE, the thermal analysis under normal conditions of transport was modeled on the basis of aximetric calculations, assuming an 0.99 W/cm^2 uniform flow on the whole surface of the inner container, and that heat is transferred out by conduction, convection and radiation. The most significant temperature figures obtained are summarized in Table 1.

Table 1. Temperatures (T) for Normal Conditions of Transport

Temperature measure point	T (calculated) [°C]		T (tests)	T (IAEA SS6)
	INVAP SE	INTEC	[°C]	[°C]
External lateral wall of main assembly, T_{max}.	118	122	115	Not specified
Main assembly, T_{min}.	77	81	65	
Internal wall of main assembly, T_{max}.	289	302	211	
External wall of fireshield, T_{max}.	62	68	53	50 - 85 (1)
Lifting/tie down lugs, T_{max}.	80	74	67	50 - 85 (1)
Outlet air of ventilation channels, T_{max}.	61	55	59	50 - 85 (1)

(1) Paras 544 and 555 of IAEA SS6 require that maximum temperature on external surface of the package during transport shall not exceed 50°C, and for transports under exclusive use such temperature shall not exceed 85°C.

Analytical models and hypothesis conservatism were assessed in order to model the thermal test. The hypotheses considered by INVAP SE were intact package after the (most conservative) mechanic test, initial temperature distribution at a steady state same as that calculated under normal conditions; T_{amb} = 800°C, emissivity 0.9, and exterior hot gas speed between 5 and 10 $m.s^{-1}$ were assumed during the 30 minutes heating period; while, during the 3 hour natural cooling time, T_{amb} was assumed to be 38°C. For fires, the thermal analysis was modeled as equivalent to that under normal conditions, considering that the heat traverses the fireshield by radiation and that, by conduction, there is a constant flux of 0.3 W/cm^2. The most important results obtained were those indicating that T_{max} on the inner wall was 301°C, that the amount of melted lead is 9.7% of the total after two minutes cooling, that the energy entering the package during the fire is 256 MJ, that temperature is 445°C at the ^{60}Co bars and 373°C for the internal gas, that internal pressure is below 700 kPa and that stress due to internal pressure and to differential and thermal expansion is 5% of that admitted for the steel. That was how the thermal test served to verify integrity in both the containment and the shielding.

Immersion Test, Shielding Evaluation, and Normal Conditions of Transport

After the water immersion test, INVAP SE demonstrated the integrity of the package through calculations, since hydrostatic pressure does not affect its external components and its inner environment (designed for a 1 MPa differential pressure) remains waterproof.

Concerning shielding under normal and accident conditions of transport, the technical problem and its evaluation by means of empirical formulas and computational calculation tools, MERCURE IV code, were assessed. The rods' activation were analyzed using the ORIGEN code and assuming that they only contained ^{60}Co, ^{95}Zr, and ^{95}Nb. The source was considered to be integrated by 86 ^{60}Co rods with maximum activity (12.95 PBq) and located within an annular cylinder, assuming that in every decay ^{60}Co emits two 1.332 MeV gammas, thus overestimating the equivalent dose by a factor of 2, since the contribution of the 1.173 MeV gamma is disregarded. Tables 2 and 3 show a summary of the radiation values and their compliance with the acceptation criteria in IAEA's Regulations SS6 (IAEA 1990a).

Concerning compliance with tests for normal conditions of transport, INVAP SE demonstrated that the one related to water aspersion was not relevant and that those referred to free drops and penetration can be disregarded when compared with those for accident conditions, while the stacking test is not applicable because, for operational reasons, these packages are not supposed to be stacked on each other. The lifting eyebolts and the tie-up systems were calculated in accordance with IAEA SS37 (IAEA 1990c).

Table 2. Radiation Levels (RL) for Normal Conditions of Transport

Radiation Level measure point	NR on external surface of main body [mSv/h]			NR at 1 m of external surface of main body [mSv/h]		
	Calculus	Tests	IAEA SS6	Calculus	Tests	IAEA SS6
Basis, $NR_{max.}$	0.17	0.080	2.00 (1)	0.065	---------	0.10 (1)
Basis, $NR_{min.}$	0.11	0.060		0.037	---------	
Lateral zone, $NR_{max.}$	0.29	0.300		0.055	0.03	
Lateral zone, $NR_{min.}$	0.20	0.030		0.035	0.02	
Cover, $NR_{max.}$	0.17	1.000		0.065	0.06	
Cover, $NR_{min.}$	0.12	0.060		0.045	0.04	

(1) These radiation level conditions correspond to a package category III-YELLOW.

Table 3. Accepting Criteria for Normal and Accident Conditions of Transport

Accepting criterion considered	Calculus / Tests	IAEA SS6
Radiation shielding behavior after tests for normal conditions of transport (NCT)		
- Radiation Level on package external surface	1.00 mSv/h (1)	2.00 mSv/h
- Radiation Level at 1 m of package external surface	0.06 mSv/h (1)	0.10 mSv/h
Radiation shielding behavior after tests for accident conditions of transport (ACT)		
- Radiation Level at 1 m of package external surface	8.00 mSv/h (2)	10.0 mSv/h
Containment behavior after tests		
- Loss of radioactive contents after NCT	$5.9 \cdot 10^{-12}$ TBq/s (3)	$1.11 \cdot 10^{-10}$ TBq/s
- Loss of radioactive contents after ACT	$3.9 \cdot 10^{-11}$ TBq/s (3)	$6.61 \cdot 10^{-7}$ TBq/s

(1) Values obtained during tests before first shipment of packages.

(2) Values obtained by calculus on top package points when melted lead reaches 22%, and totally escape from the cover, implying a 7 cm shielding diminution.

(3) Values obtained by calculus using the standard ISO/DIS 12807 (ISO 1995).

FABRICATION OF SPECIMENS AND DEVELOPMENT OF TESTS BEFORE FIRST SHIPMENT OF PACKAGES

The ACA performed inspections so as to verify that the fabrication of packagings were performed in a controlled manner and in agreement with the design specifications of INVAP SE's Quality Assurance Program. The most important procedures to be assessed were the welding of the fins, since the latter are excellent impact absorbers, and the lead melting, because its design requires lead-steel adherence above 40%. The performance of non-destructive tests was also relevant in order to verify the adequacy of the above-mentioned welding and adherence. On the other hand, control over adequate material purchasing, especially to verify their ductility even at –40°C.

The ACA performed evaluations and inspections over the tests performed before first shipment of packages, verifying their handling, their thermal and shielding behavior, and their leakages, so as to validate theoretical results and assess the general performance of the package design. Four tests were carried out to verify the behavior of the containment and shielding calculated in the design: two thermal tests, with simulated radioactive load and with radioactive contents, for verifying packages handling and temperature values; a shielding test with radioactive load for verifying radiation level values; and a leakage test for verifying the loss of radioactive contents (López-Vietri and Novo 1995). Tables 1, 2, and 3 summarize the values obtained in these tests.

The importance of performing these tests is to be noted, considering that they allowed to detect anomalies in the manufactured packagings and to propose engineering modifications for the final design of GURI 01 package, such as those involving supplements to the cover, where radiation levels higher than design were found, replacing the eyebolts of the fire–shield by stronger grousers and the location of identification plates and of a cover strap.

EVALUATION BY THE ARGENTINE COMPETENT AUTHORITY

Personnel from ACA and from the foreign consulting group INTEC performed an independent analysis and re-calculation of the documents presented by INVAP SE: Final Safety Analysis Report, Operation Manual (INVAP SE 1994a), Inspection and Maintenance Manual (INVAP SE 1994b), Quality Assurance Manual, Production and Inspection Program and Procedures, Emergency Procedures, Program of Tests before the First Shipment, and protocols and results from manufacturing controls and tests. These analyses confirmed that INVAP SE has developed the GURI 01 design using sufficiently consevative criteria, so as to ensure a high level of compliance with IAEA Regulations SS6.

Tables 1, 2, and 3 show a summarized comparison of the results obtained by calculation and from the tests, as well as those required by IAEA's Regulations SS6. As it may be seen, both the design and the postulated hypotheses have been conservative.

CONCLUSIONS

The following conclusions were reached after the licensing process for the Type B(U) package called GURI 01:

- Even, the ACA did provide it officious advice without any commitment, independence between the applicant and the Competent Authority was maintained all the time.

- The ACA was fully satisfied by the compliance with IAEA's Regulations SS6 by means of its own verifications and those performed by the contracted consulting group, INTEC, which reviewed and, in several cases, re-calculated the design using different methods.

- It was verified that the calculated design values are adequately conservative, since they are 20% safer than those measured during tests before first shipment of packages.

- The fundamental importance of tests before shipment of packages was revalued, since they allowed to detect anomalies in the manufactured packagings and to propose engineering modifications to the package design.

- Presently, the impact platform built allows for performing mechanical tests for specimens below 6,000 kg or 2.5 m.

- The performance of this Type B(U) package development in Argentina was the starting point for other designs, such as the Type B(U) package, approved by the ACA for transport purposes and for the transfer of cobalt therapy sealed sources.

- Benefits were obtained for the development and experience of the local nuclear industry, resulting in a product with excellent quality and comparable at an international level.

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