LEUPA

TypeB(U) Packageto Contain Fissile Substances

CRITICALITY ANALYSIS

Made by

INVAP

June 01, 2015

REVISION SHEET		**Document No.:**0908-LE01-3BEIN-024-B **Revision:** B **Document Title:** Criticality Analysis **Ref. No.:**			
		Name, date, signature / initials			
Revision Letter	**Description of the Revision**	**Prepared**	**Reviewed**	**Approved**	
A	Original	FDS	SBM	JCO	
B	REFERENCE	FDS	SBM	JCO	

CONTENTS

1 PURPOSE

1. Demonstrate that LEUPA package complies with Argentine Standard AR 10.16.1. Rev. 2“Transport of Radioactive Materials” for the safe transport by land, by sea or by air of fissile substances indicated in this document.

2 SCOPE

1. This document analyses and demonstrates compliance of LEUPA package with the national regulations for safe transport by land, by sea, or by air of fissile substances indicated in this document, exclusively under the viewpoint of sub-criticality.

3 REFERENCES

[1] ARN. *Transport of Radioactive Materials*. Standard AR 10.16.1. Rev. 2. Argentine Republic: ARN, 2011.

[2] BROWN, Forrest; KIEDROWSKI, Brian; BULL Jeffrey.*MCNP5-1.60 Release Notes.* LA-UR-10-06235. Hollywood: Los Alamos Laboratory, 2011.

4 ABBREVIATIONS

Abbreviation	Description
ISC	Safety Index as regards Criticality
k_{ef}	Effective Crop Factor
LEUPA	Low Enriched Uranium Package for Transport
SD	Standard Deviation

5 DESCRIPTION

1. The general assembly of LEUPA packaging can be seen in Draw. 0908-LE01-3AEIN-004.
2. The package is composed as follows:
   a. Fissile substances to be transported, packed in polyethylene bags or the similar.
   b. The package, which is a single inseparable set with enclosure systems and thermal insulation.

5.1 Fissile Substances

1. The fissile substance to transport consists of some of the following uranium composites, with an enrichment of less than 20%:
   a. Natural uranium.
   b. Metal uranium in granules or pieces.
   c. U_3Si_2in powder or pieces.
   d. $U_xAl_y$in powder or pieces.
   e. U_3O_8in powder.
2. So as to evaluate criticality, a mass of metal uramium of 50 kg is adopted.

5.2 Packaging

5.2.1 Enclosure System

1. The enclosure system is formed by steel non-airtight vessels called –in the project context–inner cans, filled with fissile substance. Each of them has an inner volume of 1.56 dm^3. LEUPA can load up to four of these inner cans, which in turn are placed in the so called container.This is a container designed according with code ASME Section III, Division 1, Sub-section NB, with an inner usable volume of around 8.25 dm^3. Pressure and temperature values considered in design are of 700 kPamanometric and 70 ºC, respectively. The container is composed of a main body and a standardized flange, both of stainless steel. The flange is fixed to the main body by means of 8 UNC ¾" screws. The joint between both is sealed by means of a graphite spiral gasket that can work with a limit temperature of up to 450 ºC. The flange has an ergonomic designed folding handle.
2. Rubber supplements eliminate the gap between the inner cans and the container, their function is to diminish dynamic effects in cases of normal or accident transport.
3. Linked to the container there is a cylindrical stainless steel double wall component. The space between walls (17 mm approximately) is filled with casted high purity cadmium. The flanged cover of the container also has a double wall inside which cadmium is filtered, so that the load of fissile substances is surrounded almost completely by the neutron absorbent material.
4. This assembly forms a compact undeformable central cell.

5.2.2 Remainder of Packaging

1. Outside the described cell, eight (8) welded stainless steel structural plates are radially placed which link said cell with the outer wall of packaging.Furthermore, the packaging has four angle profile rings one in each end of the packaging and the other two at around one third (1/3)and two thirds (2/3)of the packaging height, respectively, as reinforcement. Each ring is welded to the radial plates, and in turn, these are welded to the central cell, thus forming an integrated unity. The external wall of the packaging is a stainless steel cylinder plate.The packaging has circular covers welded at the ends, which make, together with the external wall and the central cell, a volume where the thermal insulator, by means of gravity filtering is placed; thus, the central cell is surrounded by a thickness of thermal insulator of around 150 mm.
2. The packaging has a removable intermediate cover that is a solid construction made of cylindrical stainless steel plate and circular covers, which, as stated above, make a volume that can be filled with thermal insulator by gravity filtering technique, thus, this volume has a thickness of around 150 mm.
3. The removable intermediate cover is linked to the rest of the packaging by means of 6 M12 screws, with a rubber gasket between both.
4. Outside the removable intermediate cover, there another cover made exclusively of a stainless steel circular plate, also fixed to the rest of the packaging, by means of 6 M12 screws. Between both there is also a 5 mm rubber gasket to prevent from dirt or humidity.
5. Both, the external and the removable intermediate covers have ergonomic designed folding handles.
6. All the elements of the packaging are made to protect from impact, it is a unity that can absorb deformation mechanical energy without losing its thermal protection capacity.
7. The thermal insulator used is called in the marketKaolite 1600, a vermiculite cementitious composite in powder that must be prepared mixing it with water, and can be usedat 1600 ºF (871 ºC). It may be applied by filtering or by pressure.
8. Its mechanical properties depend on drying conditions.

9. The external cover and the rest of the packaging havepieces that allow an inviolable closureof the package by means of high resistance brass precincts, marked with permanent characters.
10. The packaging has four lifting points formed by standardized shackles with 0.5 ton. lifting capacity each, appropriately linked to the upper ring of packaging.

Table 1: LEUPA package description

System	Description
Package	Classification: TypeB(U), for transport by land, by sea or by air with fissile substances. ARN Approval Certificate: – Safety Index as regards Criticality: (SIC): 0.69. Useful Load: 50 kg of enriched uranium at 19.75% in U^{235} (limit value). Total Mass of Package: 430 kg. Dimensions: Height 1155 mil, DiameterExt. 532 mm. Lifting Points: 4 shackles with 500 kg capacity each. Clamping points for Transport: 4.
Contenido	Some of the following: a. Natural uranium. b. Metal uranium in grains or pieces. c. U_3Si_2powder or in pieces. d. $U_xAl_y$powder or pieces. e. UO_2powder. f. U_3O_8powder.
Enclosure System	Building Material: Stainless Steel. Pressure vessel, designed in accordance with code ASME Section III, Division 1, Sub-section NB. NominalDiameter: ND 125 (5”). Inner Volume: 8.25 dm^3. Design Pressure: 700 kPa (manometric). TestPressure: 875 kPa (manometric). Design Temperature: 70 ºC. Test Temperature: Ambient (20 ºC). Gasket Type: Spiral, non-reusable made of graphite and stainless steel. It accords with Standard ASME B 16.20. Type of Screws of Sealing of Flange: ASTM A 193 Gr. B7, UNC ¾” 10 HPP. Neuton Absorbent:Aprox. 58 kg high purity cadmium, in accordance with Standard ASTM B440 Grado L 01951.
Remainder of packaging	Thermal Insulator:Aprox. 85 kg ofKaolite 1600. Gaskets: 5 mm thick rubber. Cover Screws: 6 M12 in each cover, type A2-70 ISO 3506-1. Safety Precinct Type: 2 brass precincts, encoded with 6 number digits.

6 MATERIALS USED TO EVALUATE CRITICALITY

1. Table 2:describes all used materials in all performed calculations to ensure sub-criticality of the LEUPA package, under normal and accident conditions. Approximate mass involved and its composition is also detailed.

Table 2: Materials used in criticality evaluations

Material	Aprox. Mass [kg]	Density [g/cm^3]	Element	% Weight
Metal Uranium	50.0	18.9	U^{235} U^{238}	19.8 80.1
Poliethylene	0.4	–	H C	14.4 85.6
Kaolite 1600	85	0.405 (without water)	Al_2O_3 SiO_2 Fe_2O_3 TiO_2 CaO MgO Na_2O	11.0 33.0 7.9 1.4 30.0 12.1 4.6
AISI 304 L	244	7.9	Fe Cr Ni Mo Mn Si C	65.47 17.0 12.0 2.5 2.0 1.0 0.03
Cadmium	58	8.65	Cd	100.0

7 QUALIFICATION OF LEUPA PACKAGE FOR THE TRANSPORT OF FISSILE SUBSTANCES

7.1 Sub-criticality Assurance

1. According with the requirements established in paragraph 671 of the Standard AR 10.16.1 (Reference 1, as from here on named Standard), related to the assurance of sub-criticality in normal and accident conditions, calculations were carried out following conditions specified in said Standard.
2. A contingency analysis was also made to show the package sub-criticality under normal and accident conditions (see Table 3:).
3. The analysis of assurance of sub-criticality is based on the calculation of the effective crop factor, k_{ef}.Several configurations were analysed under conservative models.
4. The Standard requires the assurance of criticality of the isolated package and of the ordered set of packages, both in normal and accident conditions.
5. At the time of analysis of assurance of sub-criticality of LEUPA package, the tests specified by the Standard had not been done, due to this, the following paragraphs show the suppositions on tests results.

6. It is supposed that the inner cans containing fissile substances shall remain intact and in their position after the tests on the package. And also the inner cans and the cadmium chamber shall be intact.
7. Furthermore, it is supposed that the main impact will affect only primary containment, slightly modifying external dimensions.
8. In accordance with what had previously been said, it is appropriate to believe the damaged package is geometrically similar to the intact package. No significance will be considered to the possible variation of the effective crop factor due to deformations that might be produced during tests.
9. According with preliminary evaluations, the sub-criticality of an infinite number of packages cannot be assured. Therefore, for analysis a number "N" was considered equivalent to 72 packages piled up in 8 x 8 x 6 packages in normal conditions (five times "N") and in 6 x 6 x 4 packages in accident conditions (two times "N").
10. The difference between an intact package and a damaged one will be due to the entry of water in all empty spaces of the package, that is to say, interior of inner cans and the spaces between the cadmium chamber and the thermal insulation.
11. Given the certainty on how water may go inside the packages, analyses are made varying the density of water in a homogeneous way, with values which may go from 1.0E-7 to 1.0 g/cm^3. In this way the risk of criticality can be analysed associated to the incoming of water in the packagerelated to H/U moderation.

Table 3: Contingencies and contention barriers to assure sub-criticality (as established in paragraph 671 of the Standard)

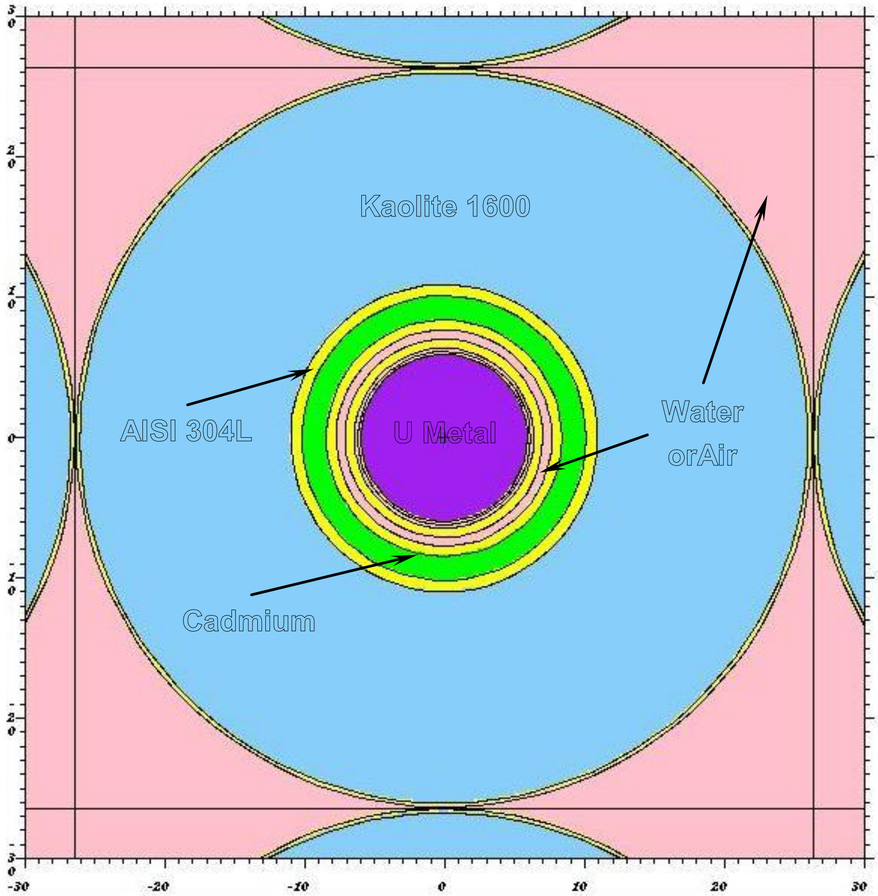
Contingencies	Protection Barriers
a. Penetration or water escape in packages.	i. Sub-criticality of a set of packages piled up 6x6x4, evaluated in Sections7.3.2and**¡Error! No se encuentra el origen de la referencia.**, **¡Error! No se encuentra el origen de la referencia.** and**¡Error! No se encuentra el origen de la referencia.**.
b. Diminishing the efficacy of neutron moderators or absorbents, the package included.	i. Sub-criticality criticality of a set of packages piled up 6x6x4, evaluated in Sections7.3.2and **¡Error! No se encuentra el origen de la referencia.**. ii. Sub-criticality inthe worst conditions analysed in a andb.i, evaluated in Section **¡Error! No se encuentra el origen de la referencia.**.
c. Modification of placement of content, inside the package or as a consequence of leakage of substances from said package.	i. It is supposed that the integrity of the package will remain after tests specified in Paragraphs719 to 724 of the Standard. ii. Sub-criticalityof a very conservative model described in Section**¡Error! No se encuentra el origen de la referencia.**.

Contingencies	Protection Barriers
d. Reducing the space within the package or between them.	i. It is supposed that the integrity of the packaging will be kept after the tests specified in Paragraphs 719 to 724 of the Standard.
e. Immersion of packages in water or into snow.	i. Sub-criticality of a set of packages piled up in 6x6x4 evaluated in Sections7.3.2 and 7.4.2.2, 7.4.2.3 and 7.4.2.4.
f. Temperature changes.	i. Sub-criticality of a set of packages piled up in 6x6x4 evaluated in Section **¡Error! No se encuentra el origen de la referencia.**.

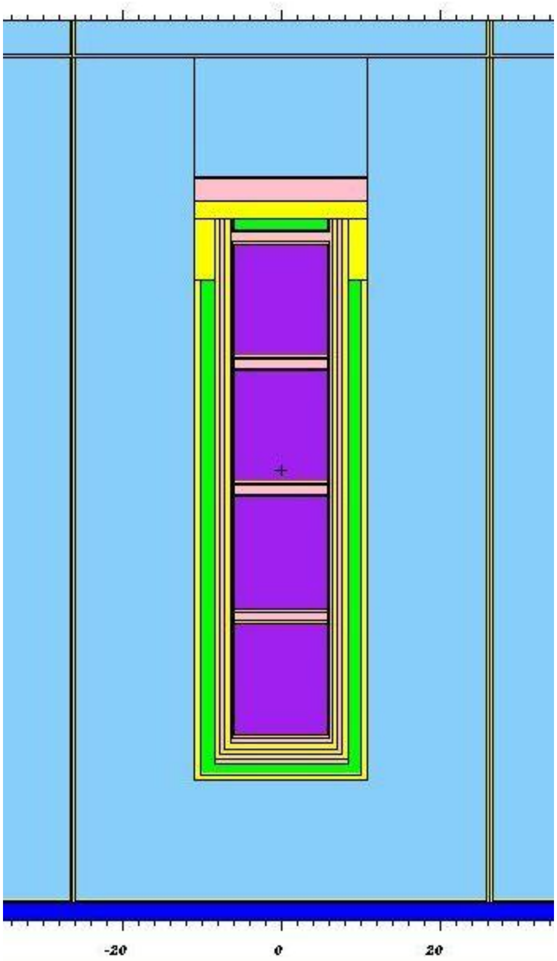
7.2 Models of Used Calculation and Codes

1. The evaluations of the effective crop factor were done following the calculation code Monte Carlo MCNP5, version 1.6, internationally known and accepted as appropriate for this type of evaluations (see Reference[2]).
2. The efficient sections of the majority of materials involved in analysis are based on the data library ENDF/B-VII.
3. Pictures 1 and 2 show horizontal and vertical sectionsof the simulated model in piling up and used as enter to code MCNP.

Picture 1: LEUPA horizontal section showing one of the packages in piling up



Picture 2: LEUPA vertical section showing one of the packages in piling up



7.3 Description of Analysis

7.3.1 Normal Conditions

1. According to paragraph**681**of the Standard:

   681. An "N" number shall be established so that a number of packages equal to five times "N", with the placement and conditions that allow the maximum multiplying of neutrons, shall be sub-critical, considering the following requirements:

   a. There will be nothing between packages and the latter shall be surrounded on all their sides by a water reflection of 20 cm minimum; and

   b. The state of packages shall be the condition evaluated, or demonstrated if they had been subject to tests specified in paragraphs719 to 724.

2. To verify the compliance of paragraph 681, 384 packages were evaluated, piled up 8 x 6 and the whole set surrounded by 30 cm of water (higher than the 20 cm established in Standard).
3. As indicated in section 7.1, the damaged package is considered to have the same geometry as the intact package.

7.3.2 Accident Conditions

1. Following paragraph **682**of the Standard:

682. An “N” number shall be established so that a number of packages equal to double “N”, with the placement and conditions that allow the maximum multiplying of neutrons, shall be sub-critical, considering the following:

A hydrogenation moderated between packages and a reflection of water of 20 cm as minimum, on all its sides, and

a. *The tests specified in paragraphs 719 to 724 followed by any of the tests that proves to be more rigorous than any of the following,*
   i. *Tests specified in section b) of paragraph 727 and, otherwise those specified in section c) of paragraph 727 for packages with a mass not exceeding 500 kg and a total density not exceeding 1000 kg/m^{3}on account of its external dimensions, or the ones stated in section a) of paragraph 727 for all other packages; followed by test specified in paragraph 728 and, lastly, by tests specified in paragraphs 731 to 733, or*
   ii. *Test specified in paragraph 729, and*
b. *In case any of the parts of the fissile substance escapes from the containment system after the tests specified in section b) of paragraph 682, it is to be supposed that fissile substances escape from each ordered package and all fissile substance shall be organized in the way and with the due moderation which allows the maximum neutron multiplication with a reflection of complete and direct water of 20 cm minimum.*

2. To verify compliance with paragraph 682, 144 packages shall be evaluated, said packages piled up 6 x 6 x 4 and the whole unity surrounded by 30 cm of water.
3. As established in section 7.1, it is considered that the damaged package has geometry similar to the intact one.
4. Due to the geometry and materials of the package, there are several possibilities of water coming into the piled sets, which may be considered as abnormal situations:
   a. Variation of quantity of water in the thermal insulatorKaolite 1600:
      i. This material is a cementitious composite prepared by adding water. Most water is retained in the mixture, but proportion is uncertain and depends on ambient conditions.
      ii. The quantity of hydrogenated material in the mixture may vary as a consequence of temperature changes due to processes such as drying and ignition.
   b. As the worst evaluated case is that, in which the insulation has no hydrogen in the mixture, variation of the crop factor with the quantity of water added to the mixtures was studied as “abnormal” cases.
   c. Water entering the inner empty spaces of the inner container (that is to say, the inside of the can that carries the mass of metal uranium);
   d. Water entering the empty spaces between the inner cans container and the cadmium chamber and into empty spaces between packages (signalled as “water or air” in Picture 1:).
   e. Combinations of all of the above cases.
   f. Abnormal case is an error in manufacturing where cadmium is not filtered in the cadmium chamber.

7.4 Results

7.4.1 Normal Conditions

1. The crop factor for five times “N” packages (384 in this case), without water, is the following:

$$k_{ef} + 3\sigma\ (\sigma < 0.0002) = 0.45798$$

7.4.2 Accident Conditions

7.4.2.1 Content of Water in Thermal Insulator

1. An analysis took place studying several mixtures ofKaolite 1600 and water. The mass of the thermal insulation kept constant at a value of 84.4 kg.
2. Table 4: shows the evaluated cases, the name of the data file entry to MCNP (as a reference), the effective crop factor (k_{ef}) obtained together with its standard deviation (SD) and the final result as k_{ef}plus three times the SD.
3. The first column shows the relation between the insulating mass and the water considered in the mixture.For example, 100/0 considers thedry insulator, while a value 100/180 indicates a relation 1.8 between the mass of water and the thermal insulator.
4. The column identified as "# Cycles" is the total number of cycles KCODE done, each of them issuing two thousand five hundred (2500) fission neutrons.

Table 4: Crop factor for several water mass

Case	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
100/0	lp-0050	1500	0.40055	0.0002	0.40115
100/50	lp-0051	1500	0.28566	0.0002	0.28626
100/100	lp-0052	1500	0.27829	0.0002	0.27889
100/141	lp-0053	1500	0.27834	0.0002	0.27894
100/180	lp-0054	1500	0.27871	0.0002	0.27931
100/250	lp-0055	1500	0.27960	0.0002	0.28020

5. The most unfavorable situation is that of the dry thermal insulator, which is not real since the composite will always retain water after preparation and even after a possible drying.

7.4.2.2 Variation of Water Density in Empty Spaces

1. Due to the uncertainty of the way water would enter into packages, several analysis were made in which density of homogenous water was varied, with values which went from 1.0E-7 a 1.0 g/cm^3. Thus, criticality risk can be analysed, associated with the water in the package, as regards the H/U moderation of the package.
2. In a conservative way, the thermal insulator was considered without water.
3. **¡Error! No se encuentra el origen de la referencia.**shows the evaluated cases, the name of the data file entry to MCNP (as reference), and the effective crop factor (k_{ef}) obtained together with its SD, and the final result obtained as k_{ef}plus three times ofSD.
4. The first column shows density of water in empty spaces. Empty spaces can be seen in Picture 1:, indicated as "water or air".
5. The column identified as "# Cycles" is the total number of cycles KCODE done, each of them issuing two thousand five hundred (2500) fission neutrons.
6. It can be seen that the crop factor does not modify with the adding of water in empty spaces.

Table 5: Crop factor for several water densities

Density	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
1.E-07	Ip-0001	2000	0.40251	0.0002	0.40311
1.E-05	Ip-0002	1500	0.39586	0.0002	0.39649
1.E-03	Ip-0003	1500	0.39604	0.0002	0.39670
1.E-02	Ip-0004	1500	0.39780	0.0002	0.39846
0.1	Ip-0005	1500	0.36919	0.0002	0.36985
0.2	Ip-0006	1500	0.35335	0.0002	0.35401
0.4	Ip-0007	1500	0.35630	0.0002	0.35699
0.6	Ip-0008	1500	0.37306	0.0003	0.37381
0.8	Ip-0009	1500	0.39363	0.0003	0.39441
1.0	Ip-0010	1500	0.41528	0.0003	0.41612

7.4.2.3 Variation of the Water Mass introduced in Inner Cans

1. The variation of the effective crop factor with the adding of different water mass inside the inner cans was studied.
2. The mixture of water and metal uranium was supposed homogenous inside the inner can.
3. In a conservative way, the thermal insulator was taken without water.
4. Table 6: shows the cases evaluated, the name of the data file entry to MCNP (as reference), and the effective crop factor (k_{ef}) obtained together with its SD, and the final result obtained as k_{ef} plus three times of SD.
5. The first column shows the water mass mixed with metal uranium.
6. The column identified as "# Cycles" is the total number of cycles KCODE done, each of them issuing two thousand five hundred (2500) fission neutrons.
7. It can be seen that the crop factor does not vary much with the additional water mass to the metal uranium, which grows monotonously, and the worst case is a mass water of 1000 g. Due to volume the metal uranium takes in the inner can, not more than 900 g of water can be added.

Table 6: Crop factor for several water mass mixed with metal uranium

Water Mass [g]	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
100.0	Ip-0030	2000	0.44283	0.0002	0.44343
200.0	Ip-0031	2000	0.48738	0.0002	0.48798
300.0	Ip-0032	2000	0.53067	0.0003	0.53160
400.0	Ip-0033	2000	0.57112	0.0003	0.57205
500.0	Ip-0034	2000	0.61012	0.0003	0.61105
600.0	Ip-0035	2000	0.64669	0.0003	0.64762
700.0	Ip-0036	2000	0.68170	0.0003	0.68263
800.0	Ip-0037	2000	0.71448	0.0003	0.71541
900.0	Ip-0038	2000	0.74619	0.0003	0.74712

Water Mass [g]	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
1000.0	Ip-0039	2000	0.77632	0.0003	0.77722

7.4.2.4 Variation of Water Mass Introduced simultaneously in Several Compartments

1. The effective crop factor was studied when added different water mass inside the inner cans and the empty spaces and the water caught in the thermal insulation.
2. In a conservative way, it was considered, in all cases, a mixture of 1000 g of water and metal uranium inside the inner can. The mixture was supposed to be homogenous inside the inner can.
3. **¡Error! No se encuentra el origen de la referencia.**shows the cases evaluated, the name of the data file entry to MCNP (as reference), and the effective crop factor (k_{ef}) obtained together with its SD and the final result obtained as k_{ef} plus three times of SD.
4. The first column shows the water mass mixed with thermal insulation, keeping the same names as in Table 4:.
5. The second column is density of water that entered in empty spaces.
6. The column identified as "# Cycles" is the total number of cycles KCODE done, each of them issuing two thousand five hundred (2500) fission neutrons.
7. It can be seen that the worst case is that in which inner cans are flooded with water (1000 g), the thermal insulator is dry (100/0) and the density of water in empty spaces is insignificant..

Table 7: Variation of quantities of water in combined form

Water Mass [g]	Density of water in Empty Spaces	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
100/0	1.E-05	Ip-0511	2000	0.77868	0.0003	0.77958
	1.E-02	Ip-0512	2000	0.77305	0.0003	0.77395
	0.3	Ip-0513	2000	0.69997	0.0004	0.70117
	0.8	Ip-0514	2000	0.71455	0.0004	0.71575
	1.0	Ip-0515	2000	0.72481	0.0004	0.72601
100/50	1.E-05	Ip-0611	2000	0.64305	0.0003	0.64395
	1.E-02	Ip-0612	2000	0.64378	0.0004	0.64498
	0.3	Ip-0613	2000	0.66060	0.0004	0.66180
	0.8	Ip-0614	2000	0.69571	0.0004	0.69691
	1.0	Ip-0615	2000	0.70948	0.0004	0.71068
100/100	1.E-05	Ip-0711	2000	0.63410	0.0003	0.63500
	1.E-02	Ip-0712	2000	0.63569	0.0003	0.63659
	0.3	Ip-0713	2000	0.65609	0.0003	0.65699
	0.8	Ip-0714	2000	0.69406	0.0004	0.69526
	1.0	Ip-0715	2000	0.70738	0.0004	0.70858

Water Mass [g]	Density of water in Empty Spaces	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
100/141 (nominal)	1.E-05	Ip-0411	2000	0.63343	0.0003	0.63433
	1.E-02	Ip-0412	2000	0.63461	0.0003	0.63551
	0.3	Ip-0413	2000	0.65656	0.0003	0.65746
	0.8	Ip-0414	2000	0.69300	0.0004	0.69420
	1.0	Ip-0415	2000	0.70701	0.0004	0.70821
100/180	1.E-05	Ip-0811	2000	0.63379	0.0003	0.63469
	1.E-02	Ip-0812	2000	0.63463	0.0003	0.63553
	0.3	Ip-0813	2000	0.65638	0.0003	0.65728
	0.8	Ip-0814	2000	0.69345	0.0003	0.69435
	1.0	Ip-0815	2000	0.70751	0.0004	0.70871

7.4.2.5 Manufacturing Error: Cadmium is not filtered in Cadmium Chamber

1. The variation of the effective crop factor was studied in the extreme cases analyzed in previous sections, considering that cadmium, due to an unseen error in manufacturing, does not filter into the cadmium chamber.
2. Table 8: shows the cases evaluated, the name of the data file entry to MCNP (as reference), and the effective crop factor (k_{ef}) obtained together with its SD, and the final result obtained as k_{ef} plus three times of SD.
3. The column identified as “# Cycles” is the total number of cycles KCODE done, each of them issuing two thousand five hundred (2500) fission neutrons.
4. It can be seen that the worst case is again that in which the inner cans are flooded with water (1000 g), the thermal insulator is dry (100/0) and the density of water in the empty spaces is insignificant. This case, with which the highest infinite crop factor was obtained, shows sub-criticality is assured by large.

Table 8: Several cases without cadmium in the cadmium chamber

Case	Reference Name	Name	# Cycles	k_{ef}	SD	k_{ef}+3SD
100/0	Ip-0050	Ip-0060	2000	0.44659	0.0003	0.44749
1.0	Ip-0010	Ip-0061	2000	0.41667	0.0003	0.41757
1000.0	Ip-0039	Ip-0062	2000	0.81006	0.0004	0.81126
100/0 - 1E-5	Ip-0511	Ip-0063	2000	0.81428	0.0004	0.81548

8 CLASSIFICATION OF LEUPA PACKAGE FOR TRANSPORT BY AIR

8.1 Requirements in accordance with the Standard

1. According with paragraph**680** of the Standard, the packages for transport by air must fulfil the following requirements (a) and (b):

   680.*In the case of packages to be transported by air:*

a. *The packages must be sub-critical in conditions compatible with the prescribed tests in paragraph 734, considering a minimum water reflection of 20 cm, but without water penetration; and*
b. *The special characteristics mentioned in paragraph 677 shall not be taken into account, unless the water from empty spaces is blocked after tests specified in paragraph 734 and afterwards, in the ones specified in paragraph 733.*

8.1.1 Conformity with Paragraph 680 a) and b)

8.1.1.1 Considered Setting

1. To demonstrate conformity with paragraph 680 a), the following setting is supposed:
   a. Once tests required by Standard are finished, the package is completely damaged.
   b. The four inner cans are out of the cadmium chamber. The 50 kg of metal uranium spill and form a homogenous sphere.
   c. The absorbent material (cadmium, steel) is not taken into account, neither moderation of the thermal insulation or hydrogenated material (polyethylene bags).
   d. The homogenous sphere is placed in direct contact with 30 cm of water (higher than the minimum 20 cm established in Standard) with 1.0 g/cm^3density.

8.1.1.2 Results

1. The crop factor for the above setting is the following:

$$k_{ef} + 3\sigma \ (\sigma < 0.0004) = 0.69758$$

2. Suppositions considered in the sample are very conservative. It is highly unlikely that the 50 kg of metal uranium, which are normally in four steel inner cans, may spill and make a sphere, and all this without considering the cadmium chamber that contains a great quantity of absorbent.
3. This being considered, and in accordance with the evaluations performed, the package shows compliance with paragraph 680 a) of the Standard.

9 CONCLUSIONS

1. This document demonstrated that the LEUPA packagecomplies with Argentine regulations for the safe transport of50 kgof metal uranium, by land, by sea and by air, as regards sub-criticality assurance.
2. Since the number of packages considered in the analysis was N=72, the Safety Index as regards Criticality (SIC) is:

$$\mathbf{SIC} = 0.69$$