SAFETY EVALUATION REPORT
Docket No. 71-3034
Model No. TN-BGC1
French Package Design Certificate No. F/313/B(U)F-96
Revision Jbb

## SUMMARY


On June 12, 2009, staff recommended revalidation of the Model No. TN-BGC1 package, as described in French Certificate of Approval No. F/313/B(U)F-96, Rev. No. Iak, with the condition that uranium metallic powder be prohibited under Content No. 11 as allowable contents (Agencywide Documents Access and Management System (ADAMS) Accession No. ML091660046). The justification for prohibiting uranium metallic powder was insufficient controls on leak tightness and pressure to eliminate the potential for a pyrophoric reaction. On June 30, 2015, staff recommended revalidation of the Model No. TN-BGC1 package, as described in French Certificate of Approval No. F/313/B(U)F-96, Rev. No. Jbb, with a relaxation of the prohibition on shipping uranium powder under Content No. 11 to allow the shipment of non-pyrophoric uranium powder (ADAMS Accession No. ML15182A027).

On July 9, 2015, as supplemented December 21, 2015, February 1, and March 16, 2016 (ADAMS Accession Nos. ML15208A221, ML16011A161, ML16084A171 and ML16076A294 respectively), the Department of Transportation (DOT) requested the Nuclear Regulatory Commission staff's recommendation concerning the revalidation of the Model No. TN-BGC1 package, French Package Design Certificate No. F/313/B(U)F-96, as described in French Certificate of Approval No. F/313/B(U)F-96, Rev. No. Jbb, for transport of pyrophoric powders and other contents. The package is currently licensed under International Atomic Energy Agency (IAEA) *Regulations for Safe Transport of Radioactive Material*, TS-R-1, Rev. 2009, by the French Competent authority. The package is suitable for sea, road, and air transport.

Based on the statements and representations in the application, as supplemented, staff recommends revalidation of the French Package Design Certificate No. F/313/B(U)F-96, for use in the United States, with the following conditions:

(1) Content No. 11h is prohibited;

(2) For Content Nos. 11a thru 11g transported either by land or sea, the maximum mass of uranium, the maximum enrichment in uranium-235 ($^{235}U$), the allowable containment diameter and the presence of hydrogen-bearing materials having a hydrogen content greater than water shall be as allowed in French Package Design Certificate No. F/313/B(U)F-96;

(3) For Content Nos. 11a thru 11g, the transport of reprocessed uranium is prohibited;

(4) For Content Nos. 11a thru 11g, the transport of uranium carbides (UC, $UC_2$, and $U_2C_3$) and uranium nitrides (UN, $U_2N_3$, and $UN_2$) is prohibited;

(5) For Content Nos. 11a thru 11g, the mass of water and the equivalent mass of other hydrogenous materials must not exceed 2000 grams per package;

(6) For Content Nos. 11a thru 11g, the maximum allowable fissile mass is 5 kg when transported by air;

(7) Air transport of plutonium is prohibited unless the contents meet the regulatory requirements of 10 CFR 71.88(a)(1) to (4).

(8) For Content No. 26, the maximum number of TRIGA fuel elements per package is not to exceed 5 standard elements or 23 thin elements, where standard and thin elements are defined in F/313/B(U)F-96 26bb, Appendix 26, Content No. 26. The total mass of cardboard must not exceed 1200 grams, the moisture content of the wood components must not exceed 10 percent, and the total water content (including moisture content of the wood and water equivalent in the form of cardboard) must not exceed 2900 grams per package. No other hydrogenous packaging materials are permitted within the package containment vessel.

## 1.0 GENERAL INFORMATION

The applicant requested approval to ship both unirradiated uranium enriched to less than 20 percent $^{235}U$ by weight under Content Nos. 11a, 11b, 11c and 11g and TRIGA fuel (ADAMS Accession No. ML15208A219). Previous versions of French Certificate of Approval No. F/313/B(U)F-96 described Content No. 11 in broad terms. However, in French Certificate of Approval No. F/313/B(U)F-96, Rev. No. Jbb, the applicant separated Content No. 11 into Content Nos. 11a thru 11h with each new content having well defined maximum enrichments, maximum uranium masses and maximum containment boundaries. In addition, the applicant identified for each content if packaging materials with a hydrogen content greater than that of water was allowed. The applicant also stated that the contents were not in special form and that there were no restrictions on content density (ADAMS Accession No. ML15208A219). The applicant only requested authorization to transport Content Nos. 11a, 11b, 11c and 11g because the applicant had identified that Content Nos. 11d, 11e and 11f had previously been authorized for transport (ADAMS Accession No. ML13345A107). The applicant originally requested authorization to ship unirradiated uranium having one of the following chemical forms: metallic uranium, uranium oxides, uranium tetrafluoride, uranium nitrides, uranium carbides or uranium alloyed with either silicon, molybdenum, zirconium or aluminum. However, in response to a request for additional information, the applicant amended their request to prohibit unirradiated uranium in the form of nitrides and carbides (ADAMS Accession No. ML16011A161).

Based on a review of the statements and representations in the application the staff concludes the contents have been adequately described and evaluated to meet the TS-R-1 requirements, Rev. 2009.

## 2.0 MATERIALS

The applicant requested approval to transport both non-irradiated solid uranium (Content Nos. 11a, 11b, 11c and 11g), and TRIGA fuel (Content No. 26) in the TN-BGC1 package. The staff reviewed information presented by the applicant for a maximum mass of uranium as it relates to gas generation by radiolysis and thermolysis of packaging material containing hydrogen present in the container. The staff also reviewed information presented by the applicant regarding minimization of gas generation during the transport of TRIGA fuel by minimizing the amount of cardboard packaging during transportation. The staff accepts that gas generation due to radiolysis and thermolysis during transport of solid uranium and TRIGA fuel will be minimal based on the above discussion, review of the previous revalidation findings and review of additional literature.

Pyrophoricity of Metallic Powder

The staff also reviewed as part of this revalidation two powder contents: metallic powder and uranium tetrafluoride ($UF_4$). In previous revalidations, these powders were prohibited because controls on leak tightness and pressure were insufficient to prevent oxygen and water vapor intrusion. However, improved controls on leak tightness and pressure allowed revalidation of $UF_4$ powder stored in either stainless steel or aluminum boxes and then placed in a stainless steel container. Staff reevaluated these two powder for this revalidation.

The applicant presented pyrophoricity analyses for metallic powders in response to the staff's request for additional information (ADAMS Accession No. ML16011A161). Although the metallic powders will be transported in an inert atmosphere, these pyrophoricity analyses assumed the metallic powder was in contact with both oxygen and water vapor within the package, and also assumed that the amount of oxygen and water vapor within the package was identical to the ambient air conditions outside the package. The applicant also provided literature showing that the ignition temperature of uranium powders in an inert gas is above 200 degrees Celsius (approximately) and that such temperatures are not credible under all conditions of transport. Staff also requested additional information on metallic powder dryness. The applicant stated that water is not used in the manufacturing process of metallic powder. Therefore, drying the metallic powder is not required prior to loading (ADAMS Accession No. ML16011A161). Staff performed an independent analysis using the following assumptions: (i) oxygen and water vapor are present within the package, and (ii), oxygen and water vapor can enter the package at the pre-shipment leak rate of $6.65 \times 10^{-4}$ Pascals (Pa)-$m^3$/s ($1.3 \times 10^{4}$ ref $cm^3$/s) specified in Certificate USA/0492/B(U)F-96, DOT, Rev. 16. Using a leak rate of $6.65 \times 10^{-4}$ Pa-$m^3$/s ($1.3 \times 10^{-4}$ ref $cm^3$/s) is conservative compared to applicant's analysis because it allowed replenishment of the oxygen consumed by the pyrophoric reaction. In both the applicant's analysis and the staff's analysis, neither the amount of combustible gases nor the heat necessary to cause a pyrophoric reaction were generated. In addition, staff reviewed the applicant's operating and maintenance procedures. Staff determined that the operating procedures adequately evacuated the package internals of oxygen and water vapor prior to backfilling the package with an inert atmosphere. Staff also determined that the package maintenance tests ensure the package will meet a leak rate of $1 \times 10^{-7}$ Pa-$m^3$/s ($1 \times 10^{-6}$ ref $cm^3$/s).

Therefore, staff accepts that metallic powders can be safely transported based on a review of (i) statements of material dryness following the manufacturing process, (ii) operating instructions which evacuate the package internal environment to remove oxygen and water vapor prior to backfilling with an inert atmosphere, (iii) statements that ignition temperatures are not reached, and (iv) the amount of uranium available for reaction is minimized.

Corrosion of $UF_4$ Powder

In a 2012 revalidation request, the applicant calculated the amount of corrosion which would result from residual water vapor in the package during transport. The applicant's calculation assumed the corrosion occurred uniformly (ADAMS Accession No. ML16083A385). Staff reviewed the calculation, and although staff disagreed with the applicant's determination of uniform corrosion, staff determined that the leak tightness capabilities of the containment boundary sufficiently limited moisture ingress during transportation. Staff also reviewed literature and domestic accident databases to determine whether corrosion issues due either to the transportation or storage of $UF_4$ powder had occurred. Staff found no supporting data. Staff also reviewed the pre-shipment inspections, pre-shipment leak tests and maintenance leak tests which ensured the package maintained a leak tight condition (ADAMS Accession No. ML12362A412).

In the current application, staff independently assessed the amount of corrosion assuming moisture intrusion by mass balance analysis using both a pre-shipment leak rate of $6.65 \times 10^{-4}$ Pa.m$^3$/s ($6.6 \times 10^{-3}$ ref cm$^3$/s) and a maintenance leak rate of $1 \times 10^{-7}$ Pa-m$^3$/s ($1 \times 10^{-6}$ ref cm$^3$/s). The staff determined that the associated corrosion rates result in no credible alteration of the BGC-1 package.

Materials Review of Resin Shield

Staff reviewed information provided by the applicant to determine how temperature impacted the neutron shield resin material properties. Relevant information provided by the applicant is summarized as follows:

(i) Tests carried out by the owner of this resin demonstrate that, when subjected to an external flame of 800°C for thirty minutes, the resin carbonizes on the surface to a maximum depth of 4 mm; the owner also subjected the resin to an 800°C furnace test for thirty minutes which degraded the neutron absorbing properties to a depth of approximately 10 mm.

(ii) Data on the chemical composition of resin is specified following the ACT fire and indicates that the neutron shielding capability of resin, which depends on hydrogen and boron contents, is equivalent to a neutron shield layer of 33 mm which is the thickness used in criticality safety analyses for the remaining resin (ADAMS Accession No. ML16011A161).

(iii) The resin is a thermoset material which does not melt or lose its average structural properties under ACT fire conditions (ADAMS Accession No. ML16011A168).

(iv) Proprietary test data indicated the resin density remains constant during normal conditions of transport (NCT) since a constant temperature of 125 degrees Celsius over a 100 day period (conditions representative of NCT) results in a negligible mass loss of 0.7 %.

Based on a review of the literature provided by the applicant, staff finds that the neutron shield resin performance is not significantly degraded by temperatures associated with transportation.

## 3.0 CONTAINMENT

The BGC1 packaging was previously revalidated; there were no changes in the packaging design indicated in the application letter. For the current BGC1 revalidation, the applicant requested authorization to ship non-irradiated solid uranium-bearing materials (Content Nos. 11a, 11b, 11c, and 11g), and fresh TRIGA fuel (Content No. 26). The focus of this evaluation is on the containment boundary and leakage testing of the package.

According to the safety analysis report (SAR) Chapter 2, external valves are not associated with the package. In addition, the French certificate indicated that a quick-disconnect is covered with a cap (ADAMS Accession No. ML15208A219). According to SAR Chapter 5, the package and O-ring seal temperatures will remain below their maximum allowable value because the non-irradiated content has only minor decay heat. SAR Chapter 6 specified that the stainless steel containment boundary is resistant to a -40 degree Celsius temperature and that the seals have an operating range between -70 and 300 degrees Celsius. According to SAR Chapter 6, the package has a maximum normal operating pressure between $1.2 \times 10^5$ Pa and $2.63 \times 10^5$ Pa and an ACT pressure between $2.04 \times 10^5$ Pa and $3.78 \times 10^5$ Pa, depending on content. SAR Chapter 6 also indicated that the containment boundary would not result in the loss or dispersion of contents above the regulatory limits if the external air pressure was reduced to 5000 Pa. Likewise, SAR Chapters 3, 4, and 6 indicated that the package's containment boundary would prevent the loss or dispersion of contents above the regulatory limits if the package was subjected to the NCT and ACT tests. Staff concludes that the information presented in the application shows that the BGC1 package meets the temperature and pressure related TS-R-1 requirements.

The applicant indicated in their December 21, 2015, response to a request for additional information the maximum activity for Content Nos. 11a thru 11g was 9.27 TBq (255 Ci) (ADAMS Accession No. ML16011A161). SAR Chapter 6 indicated that prior to shipment, the package would be leak tested with an acceptance criteria of $6.65 \times 10^{-4}$ Pa-m$^3$/sec to ensure that regulatory release values for NCT and ACT would be met. This acceptance criteria was based on a content specific activity of 46 $A_2$/g uranium which, as noted in the December 21, 2015, response to a request for additional information, is conservative relative to the 0.04 $A_2$/g uranium that would actually be transported. SAR Chapter 10 stated an acceptance criterion of $1 \times 10^{-7}$ Pa-m$^3$/sec SHeLR (standard helium conditions as per ISO 12807) for a maintenance helium leakage test of the containment system (closure system and body). SAR Chapter 10 also indicated an acceptance criteria for the acceptance helium leakage test of the entire containment system (global) would not exceed $1 \times 10^{-8}$ Pa-m$^3$/sec SHeLR (standard conditions for helium as per ISO 12 807). Staff notes that $1 \times 10^{-8}$ Pa-m$^3$/sec is approximately $1 \times 10^{-7}$ ref-cm$^3$/sec, which is considered 'leaktight' per ANSI N14.5. SAR Chapter 10 indicated that helium leakage testing would be performed by those with COFREND certification. The staff concludes that the information presented in the application shows that the multiple leakage tests would provide reasonable assurance that the BGC1 package would meet TS-R-1 release values for NCT and ACT.

Based on the statements and representations in the application and the French certificate, the staff concludes with reasonable assurance that the BGC1 package for the current revalidation meets the TS-R-1 containment requirements.

## 4.0 CRITICALITY

The applicant requested adding Contents 11a, 11b, 11c, and 11g in various forms of highly enriched uranium bearing materials as allowable contents of the TN-BGC1 package. The content forms are metallic uranium, uranium oxides ($UO_2$, $UO_3$, $U_3O_8$), uranium tetrafluoride ($UF_4$), and uranium alloyed with aluminum (Al), molybdenum (Mo), silicon (Si), and zirconium (Zr). However, the French Certificate for the TN-BGC1 authorizes other contents, such as plutonium dioxide, in both metallic and powder form, as well as mixed uranium and plutonium dioxide, which were not requested as authorized contents for this revalidation (ADAMS Accession No. ML15208A219). The U.S. regulations specifically prohibit air transport of plutonium inside the U.S. unless it meets the requirements of 10 CFR 71.88.

The applicant provided criticality safety analyses for the TN-BGC1 package with the requested contents. The applicant used the SCALE 6.0 computer code and 238-group ENDF/B-V cross section library in these analyses. The applicant provided code benchmarking analyses and determined the Upper Subcriticality Limit (USL) which included code biases for criticality safety analyses associated with these types of material compositions. The selected critical experiments included systems with various enrichment of uranium homogeneously mixed with water. The USL for the content was 0.9384 and the applicant used 0.9370 as its acceptance criterion to include additional safety margin (ADAMS Accession No. ML16084A084).

The applicant calculated the effective neutron multiplication factor, $k_{eff}$, for a single package as loaded with these various contents to demonstrate that the package met the requirements of para. 677 of TS-R-1, 2009 edition. The applicant searched for the optimal moderator/fuel concentration with the given container geometry. The applicant calculated the $k_{eff}$ of a single package under ACT to demonstrate compliance with the requirements of para. 671-673 of TS-R-1, 2009 edition. Based on the applicant's calculation, the maximum $k_{eff}$ of a single package as loaded and flooded with water is 0.9008 (0.9002 + 2σ, σ=0.0003) for Content No. 11b, which bounds Content Nos 11a, 11c, and 11g. The maximum fissile mass limit is 1.65 kg, 15 kg, 40 kg, and 40 kg for content 11a, 11b, 11c, and 11g respectively (ADAMS Accession No. ML16084A084).

The applicant calculated the $k_{eff}$ for an array of packages loaded with these various contents under NCT and ACT separately to demonstrate compliance with the requirements of para. 681-682 of TS-R-1, 2009 edition. The applicant used 5N packages stacked together for NCT and 5N for ACT. For packages with Content Nos. 11a, 11b, and 11c, the number N used was 10. For Content No. 11g, the number N used is 50. The difference between these models is that a square array was used for NCT while a hexagonal array of array of cylinders was used for ACT. This approach was consistent with the geometric form of the package. The maximum $k_{eff}$ of the array of 50 (Content Nos. 11a, 11b, and 11c) or 250 (for Content No. 11g) packages under NCT and ACT is 0.9052 and 0.9238 respectively, which corresponds to a package loaded with 16 kg of $^{235}U$ as Content No. 11b (ADAMS Accession No. ML16084A084). The Criticality Safety Index was 5.0 for Content Nos. 11a, 11b and 11c. The Criticality Safety Index was 1 for Content No. 11g.

For array of packages under hypothetical accident conditions, the applicant took partial credit for neutron shield; i.e., the applicant assumed 33 mm of the 48 mm neutron shield was present and able to perform its safety function under ACT. The applicant made this assumption based upon ACT drop test and fire test results (ADAMS Accession No. ML16076A294). Based on its review, staff determined that the applicant used the test results to inform the assumption of a uniform damage layer of 15mm over the entire surface of the neutron shield. Staff accepted this approach because, while this approach would be slightly non-conservative when compared to the maximum damage of 20mm at the puncture location, it is functionally conservative with respect to criticality safety when considering the effectiveness of the entire neutron shield.

Staff also performed confirmatory calculations for surface transport mode. Staff used SCALE 6.0, 238 group ENDF/B-V cross section library. In the models, optimally moderated,100% enriched uranium/water solutions were evaluated at varying heights of cylindrical columns limited by the constraints of the confinement diameters specified in the supplemented criticality safety evaluation report TN-BGC1-0601. The confirmatory analyses showed that the applicant's calculations, results, and conclusions are acceptable.

The staff reviewed the application and the applicant's responses to the staff's requests for additional information following the regulations of IAEA TS-R-1, 2009 Edition as well as the guidance provided in TS-G-1. Based on the information provided in the SAR, the applicant's additional information request responses, teleconferences, and the revised calculations for forms of highly enriched uranium, uranium oxides ($UO_2$, $UO_3$, $U_3O_8$), uranium tetrafluoride ($UF_4$), and uranium alloyed with aluminum (Al), molybdenum (Mo), silicon (Si), and zirconium (Zr) as well as staff's confirmatory calculations, staff finds with reasonable assurance that the addition of powder form of these materials as allowable contents in the TN-BGC1 package meets the regulatory requirements of TS-R-1 for surface transportation provided that the following limitations are maintained.

**CONDITIONS**

The NRC recommends revalidation of French Competent Authority Certificate F/313/B(U)F-96, for use in the United States with the following conditions:

(9) Content No. 11h is prohibited;

(10) For Content Nos. 11a thru 11g transported either by land or sea, the maximum mass of uranium, the maximum enrichment in uranium-235 ($^{235}U$), the allowable containment diameter and the presence of hydrogen-bearing materials having a hydrogen content greater than water shall be as allowed in French Package Design Certificate No. F/313/B(U)F-96;

(11) For Content Nos. 11a thru 11g, the transport of reprocessed uranium is prohibited;

(12) For Content Nos. 11a thru 11g, the transport of uranium carbides (UC, $UC_2$, and $U_2C_3$) and uranium nitrides (UN, $U_2N_3$, and $UN_2$) is prohibited;

(13) For Content Nos. 11a thru 11g, the mass of water and the equivalent mass of other hydrogenous materials must not exceed 2000 grams per package;

(14) For Content Nos. 11a thru 11g, the maximum allowable fissile mass is 5 kg when transported by air;

(15) Air transport of plutonium is prohibited unless the contents meet the regulatory requirements of 10 CFR 71.88(a)(1) to (4).

(16) For Content No. 26, the maximum number of TRIGA fuel elements per package is not to exceed 5 standard elements or 23 thin elements, where standard and thin elements are defined in F/313/B(U)F-96 26bb, Appendix 26, Content No. 26. The total mass of cardboard must not exceed 1200 grams, the moisture content of the wood components must not exceed 10 percent, and the total water content (including moisture content of the wood and water equivalent in the form of cardboard) must not exceed 2900 grams per package. No other hydrogenous packaging materials are permitted within the package containment vessel.

**CONCLUSIONS**

Based on the statements and representations contained in the application, as supplemented, the staff concludes the Model No. TN-BGC1 package design, with the above stated conditions meets the IAEA requirements of TS-R-1, Rev. 2009. Therefore, the staff recommends revalidation of French Competent Authority Certificate F/313/B(U)F-96, for use in the United States with these conditions.

Issued with letter to R. Boyle, Department of Transportation, on April 15, 2016.