NRC-94-011

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U. S. Nuclear Regulatory Commission
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Subject: Docket 71-5450: Application for Approval of Packaging, RCC Shipping Containers.

Gentlemen:

The Westinghouse Electric Corporation hereby submits six (6) copies of revised and additional pages to an application for approval of packaging of fissile radioactive material (RCC Shipping Containers) -- package identification number USA/5450/AF. Pages 2, 3, 8, and 9 are revised from the February 11 submittal; pages 13-18 are added, and should be inserted just prior to the KENO tables.

If you have any questions concerning this submittal, please write to me at the above address; telephone (803) 776-2610, extension 3426; or fax (803) 695-3964.

C.F. Sanders

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Nuclear Material Management & Product Records

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APPLICATION DETAILS

February 11, 1994

1. The shipments shall consist of Westinghouse-designed 14x14 OFA fuel assemblies.

2. The fuel stack will consist of 144 inches (nominal) of UO_2 enriched to 4.95% (nominal) ^{235}U, with the top six inches of the fuel made of annular pellets; the middle 132 inches of fuel made of solid pellets; and the bottom six inches of fuel made of annular pellets. Figure 1 shows the annular pellet; Figure 2 shows the fuel stack in the rod. The solid pellets are the same length and OD as the annular pellets.

3. All parameters for this fuel are the same as those listed in Certificate of Compliance 5450, Paragraph 5.b.iii, column 1, except that the top and bottom six inches of the fuel stack has annular pellets; due to the smaller amount of UO_2 in the annular pellets, the maximum ^{235}U per fuel assembly (for the largest rod diameter) is reduced from 22.1 to 21.6 kgs. For the smallest diameter rod, the use of annular pellets in the end zones results in a weight reduction from 18.5 kgs per assembly to 18.1 kgs per assembly. The weight difference was calculated using the formula

$$W_{new} = (W_s + W_a(\frac{N_a}{N_s}))W_{old}$$

where

W_{new} = the new maximum ^{235}U weight per assembly with annular blankets,

W_s = the portion of the stack which is solid pellets, or 11/12 of the stack,

W_a = the portion of the stack which is annular pellets, or 1/12 of the stack,

N_a = the nominal weight of one annular pellet, or 0.0107 lbs.,

N_s = the nominal weight of one solid pellet, or 0.0143 lbs., and

W_{old} = the maximum ^{235}U weight per assembly with all solid pellets.

4. Figure 3 illustrates the KENO model used for the HAC.

5. Reactivity differences are discussed in a following page.

6. Clamping frames are positioned at each grid, and the 14x14 OFA assembly has seven (7) grids. Figure 4 illustrates the positions of the clamping frame arms along the assembly's length.

7. The configuration of the 14x14 OFA assembly is as follows:

Pellet OD	0.3444 in. nominal
Rod OD	0.4000 in. nominal
Clad thickness	0.0225 in. minimum
^{235}U/assembly	18.5 kgs. maximum (all solid pellets) 18.1 kgs. maximum (annular end zones)

REACTIVITY DIFFERENCES

Calculations have been performed using the KENO Va criticality code to evaluate the reactivity of the Westinghouse RCC shipping container when loaded with NSP 14x14 OFA fuel assemblies. The NSP assemblies include six inch, enriched, annular axial blankets on both the top and bottom ends of the active fuel zone. Fuel assembly enrichment was assumed to be 5.0 wt% for both the solid center pellets and the annular axial blanket pellets.

Five cases were modeled. Table A describes each case and the resultant reactivity. The KENO decks for each of the five cases are listed in Tables B through F. The water density at which optimum moderation occurs, 0.02 g/cm^3, was determined by making multiple KENO runs. The data from these runs are presented in Figure 4. All cases were modeled under the Hypothetical Accident Condition (HAC) scenario.

Case 1 evaluates the RCC cask reactivity under the same bases and assumptions applied to all previous Westinghouse cask evaluations - namely, that the insides of the fuel rods are dry and are not subject to the water which is assumed to flood the open areas within the cask. The model is three-dimensional and does not take into account any of the cask materials of construction.

Case 2 is identical to the first, except that the water is assumed also to penetrate into the inside of each fuel rod and flood the pellet-to-clad gap areas and the annulus of the annular blanket pellets.

Case 3 is a two-dimensional model. Assumptions modeled are as follows: the entire pellet stack is solid, there is optimum moderation around the assembly, the inside of the rod remains dry, and approximately 50% of the materials of construction are taken into account. The clamping arms are assumed to be separated by 25 inches from center-of-arm to center-of-arm. This is slightly smaller than the grid locations shown for the 14x14 OFA fuel assembly. Slight changes in the arm center-to-center spacing will have negligible effect on reactivity due to the small size of the clamping arm itself and the relatively large arm center-to-center spacing.

Case 3* was originally analyzed in 1985 (Table 8, Page 19-20, dated 12/20/85) and is included here for reference. It assumes a solid pellet stack, full density water around the assembly, no water inside the rod, and no container construction materials taken into account. It is also a two-dimensional model.

Case 4 is again a three-dimensional model. It is identical to Case 2 except that partial density water around the assembly is postulated. Full density water is assumed to be inside the rod in the annulus and pellet-to-clad gap.

Case 5 is also three-dimensional, and is identical to Case 4 except that the pellet stack is assumed to be solid along its entire length.

Note the ΔK_{eff} between Cases 1 and 2, and between Cases 4 and 5. This increase in reactivity is on the order of the uncertainty of KENO (≈ 0.005). Comparing Cases 1 and 2, we can see that introducing water inside the rod containing annular pellets does not significantly increase reactivity. Comparing Cases 4 and 5, we see that introducing annular pellets at reduced water density also does not significantly increase reactivity. Comparing Cases 1 and 5, and Cases 2 and 4, shows that the effect of reducing water density from full density to optimum moderation outside the rods produces a slightly larger ΔK which is less than 0.012. However, comparing Cases 3 and 3*, we see that even taking into account optimum moderation, inclusion of the package materials of construction into the model results in a significant decrease ($\Delta K \approx .14$) in reactivity for a solid pellet model.

It has been demonstrated that while introduction of annular pellets, and flooding the annulus, resulted in a small increase in reactivity, and introduction of optimum moderation resulted in a slightly larger increase in reactivity, it is also shown that taking package materials of construction into consideration results in a decrease in reactivity which is an order of magnitude less than the previously discussed increases. From this, we infer that inclusion of the package materials of construction in the model, at optimum moderation, would result in K_{eff} significantly less than 0.95, and therefore, that the acceptance criteria for criticality are satisfied.

Gd_2O_3 NEUTRON ABSORBER PLATES SPECIFICATIONS

INTRODUCTION

Gadolinium oxide (Gd_2O_3), a strong neutron absorber, has been incorporated into an existing industrial cermet (coating similar to porcelain) for use as a neutron absorber plate. This cermet coating, when applied to a carbon steel base, possesses the required nuclear and mechanical characteristics to permit it to be used in the RCC fuel shipping containers.

These cermets are mainly used in applications requiring heat resistant or chemical resistant coatings such as jet exhausts or heat exchangers. Coating a steel base that provides shape and strength is a relatively simple spraying and fusing process which can be performed in a matter of minutes using existing industrial equipment and techniques.

NUCLEONICS

The most effective absorber plate possible is one which is essentially "black" and absorbs all neutrons directed at it. The amount of Gd_2O_3 necessary to analytically achieve this characteristic is 0.020 gm/cm^2. This value is elevated by 25% such that a minimum of 0.027 gm/cm^2 is set as a design requirement. The number densities used in the criticality calculations for the Gadolinia in the plate coating are based on a coating density of 0.020 grams Gd_2O_3/cm^2. The effects of minor through-holes, to allow for handling and assembly clearance, and welding burn of the coating, have been evaluated and determined to have an insignificant effect on the absorber function of the plates. Although the minimum required concentration of gadolinium oxide is shown to be 0.027 gm/cm^2, the original KENO modelling was based on two layers of coating at 75% of this density; hence the design specifications for all vertical plates require a minimum of 0.054 gm/cm^2.

DESIGN

The Hypothetical Accident Condition (HAC) as defined in 10CFR71 requires that subcriticality of fuel assemblies in the shipping containers be demonstrated after, in sequence, a 30-foot free drop of the loaded container, puncture of the shell, exposure to 1475°F for 30 minutes and water immersion for 8 hours.

Since gadolinium oxide (Gd_2O_3) is a refractory ceramic which is similar to aluminum oxide (Al_2O_3) or zirconium oxide (ZrO_2), substitution of Gd_2O_3 for some or all of the Al_2O_3 or ZrO_2 in the finished coating seemed reasonable. Through trial, a coating composition was arrived at which maximized the Gd_2O_3 content while maintaining physical properties comparable to the base cermet industrial coating. Sample absorber plate sections have demonstrated the coating's damage resistance to normal abrasion, high temperature (1475°F), thermal shock (water splash and quench), impact (30-foot free fall), and flexing. Gd_2O_3 absorber plates were also used in three 30-foot drop tests.

The vertical Gd_2O_3 absorber plate used in all RCC containers has approximate dimensions of 0.075" x 7.25" x 160". The thickness is composed of 20 gauge (0.035") steel with a combined Gadolinia and Alumina coating. The coating is on both sides of the plate, such that the total coating contains at least 0.054 gm Gd_2O_3/cm^2. The assembly is fabricated by overlapping two sections of absorber plate and fusion welding the edges to produce a 160" long assembly. The 160" assembly will weigh approximately 15 pounds.

INTEGRITY

Coating Flexibility

The absorber plates are restrained by the container internals once the plates are installed. One side of each vertical plate faces a continuous sheet metal skin. The other side of each plate faces a ladder-like frame of 1.5 inch square tubing spaced approximately every 20-24 inches. Consequently the plate may bow approximately 1.5 inches at the most between any pair of square tubes. A simple simulation of these conditions with a section of full-size absorber plate reveals no noticeable effect except for slight permanent set of the steel backing.

Improper handling of fabricated plates could cause coating damage. Small radius bends (approximately 2") will cause the coating on the compression side of the plate to crack locally and flake. Bends of 4" radius have no noticeable effect on the coating surface or adherence to the metal base. Normal handling can easily accommodate this restriction by use of a strongback or manual support to prevent small radius bends of the plate. Detection of possible coating damage by bending is simple. First, the metal backing will take a permanent set long before the coating is affected. Second, when damage occurs, it causes noticeable flaking and/or loss of material. Expected handling and service of the plates will not exceed their capability to flex without functional impairment.

Coating Impact Resistance

As part of the HAC, three MCC containers containing two plates each were subjected to 30-foot drops. It should be noted that the plates used in RCC containers are manufactured to identical specifications as the plates used in MCC containers. Since the internals suspension system cannot absorb all internal energy, mechanical shock of the internals will occur. Sample plates were also subjected to a 30-foot free drop onto ½ inch steel plate. The plates were dropped, using guide wires, in the flat (plate width horizontal) and guillotine (plate width vertical) configurations. The flat configuration only slightly deformed the metal backing with no obvious coating damage. The guillotine configuration, where the plate dropped on edge, caused local deformation of the plate edge and random flaking of the coating edge up to 1/8" away from the plate edge. The bulk of the coating was unaffected by the severe shock.

As part of the process specification, adhesion tests are performed on production plates to industry standards. These tests allow a process check to verify the consistency of the coating process and that production plates are representative of sample performance.

These tests demonstrated that the coating is capable of withstanding impacts far greater than that expected under accident conditions in its protected location inside the MCC shipping container support frame. Gd_2O_3 plates present in the three drop tests described in Chapter 2 yielded no obvious coating damage.

Coating Abrasion Resistance

The absorber plates which are positioned within the support frame are not exposed to conditions where abnormal abrasion forces would occur. The edges of the plate do not need to be coated, and purposely are not coated, although the spraying operation will tend to deposit material there. The bottom edge of the vertical absorber plate interfaces with the internals and bears the weight of the plate. Therefore, the edges of the plates which have been coated and fused will be abraded to base metal to eliminate the generation of gadolinium bearing debris and its possible migration from the container during inspection, cleaning, painting, etc.

The sides of the plates see negligible loads and broad contact areas. The coating is not easily affected by distributed loads; a hard, sharp edge tool is necessary to visibly scar the coating surface.

The gadolinium absorber plates installed in containers which were subjected to a 30-ft. drop test were visually examined after a one year period to verify that their condition was comparable to that of original installation. There was no visible evidence of loss of coating. The coating is adequately abrasion resistant to withstand its service environment and maintain its functional capabilities.

High Temperature Integrity

The HAC essentially requires the container and its contents to withstand 1475°F for 30 minutes and subsequent cooldown. Commercially available materials were either inadequate as neutron absorbers or deteriorate upon exposure to 1475°F. The components of the coating are fused at approximately 1530°F during processing. The sides of the plates are oriented vertically during processing; fusing of the coating at these temperatures does not cause the material to flow from its applied configuration. The fusing is more of a limited wetting condition where materials in intimate contact join as compared to brazing, for example, where the braze wets the base material and flows under the effects of gravity and capillary action.

Sample plates were arranged in a muffle furnace to simulate their interface with the shipping container internals and each other. The purpose of the test was to verify that the plate's coating would not be altered by contact with interfacing surfaces such that its functional characteristics were affected. Once arranged, the furnace was turned on, stabilized at 1475° for three-and-one-half hours and then turned off. The furnace door was opened and the plates removed when the indicated temperature had dropped to approximately 200°F. The plates were not noticeably altered in either case from their pre-test condition.

10CFR71 regulations specify exposure to an environment of 1475°F with an emissivity coefficient of 0.9 and package absorption coefficient of 0.8. Consequently, the package is heated up to its maximum temperature during the 30 minute period. Also, cooling of the package realistically begins as soon as the radiation environment is removed. The test performed is conservative since the plates were held at 1475°F for the entire 30 minute period, as well as the subsequent three-hour period where natural cooling is permitted.

The plates were then individually heated to 1475°F, removed at that temperature and subjected to poured (room temperature) water on one side. The plates were again heated, removed and then quenched in a bucket of room temperature water. The plates did not exhibit any noticeable cracks, flaking or separations. The plates' demonstrated resistance to thermal shock is similar to the industrial cermets and is adequate for any thermal shock the plates could possibly experience in a shipping container.

These tests demonstrated that absorber plates are capable of meeting the required high temperature accident conditions as well as unlikely, severe thermal shock.

Water Exposure

The absorber plate coating, by its characteristic cermet nature, is essentially impervious to water exposure for an eight-hour period. No formal tests are conducted.

QUALITY ASSURANCE

The basic requirement is that at least the design amount of absorber material ($0.027 g/cm^2$) is present in any given area. This requires verification first that the absorber material is present and second that the minimum quantities have been deposited.

For all types of plates, the cermet is composed of 32.5 wt% Gd_2O_3. The distribution of absorber material in a unit thickness of the coating is assumed to be uniform because the extremely fine (1-10 microns) Gd_2O_3 powder and other powder coating components are combined in a water slurry and sprayed onto the metal backing. An analysis by X-ray fluorescence at Westinghouse ARD laboratories, as expected, did not discover any areas in sample absorber plates significantly deficient in Gd_2O_3 compared to other areas (the equipment examined areas the diameter of a dime). This test is not performed on production samples or plates because the nature of the materials and process are unlikely to cause any segregation of materials and, as explained, there will be absorber material in excess of actual design minimum loadings.

Final verification that the neutron absorber Gd_2O_3 is actually in the coating (not Al_2O_3 or ZrO_2 for example), and present in acceptable concentrations, is made using verified standards and a portable elemental analyzer. The analyzer, using the X-ray fluorescence method, verifies that gadolinium is present by measuring the energy of the fluorescing X-rays that are uniquely characteristic of that element. By comparing the intensity of those X-rays to that of verified standards, it can be determined that the minimum density of 0.054 gm Gd_2O_3/cm^2 is indeed present.

Process control of the coating composition and minimum thickness will insure that the minimum design loading of Gd_2O_3 is applied to each plate. Use o the analyzer verifies the Gd_2O_3 loading in the end product composition. The analyzer reading will be documented according to the bright yellow identification number stenciled and fused into the coating of each plate.

The standards used to calibrate the elemental analyzer will have a master in Columbia archives for quality control standards. Preservation of the master standard will enable the plates' Gd_2O_3 content to be checked anytime in the future.

The vendor who will fabricate the absorber plates has a quality assurance plan approved by Operations Product Assurance. Vendors will be qualified in accordance to WCAP 8370.

CONTROL OF CONTAINER USAGE

For RCC containers, once an absorber plate is installed it remains permanently in that container. As each container receives plates, the documentation associated with that container is updated to show its current configuration, and the container is marked. Container selection for each contract's shipments is made based on the information contained in the permanent records, and is approved by the Manager of Nuclear Materials Management. The process specification, operating procedures, and quality control instructions contain explicit guidance on requirements for the required plate verification and documentation at the time of plate installation. Additional controls exist in the Fuel Assembly Packing area to assure that the correct containers are used. "Correct" means that the container has at least the minimum allowable absorbers for the enrichment of the assemblies to be shipped; any container having more absorbers than required by the assembly enrichment may be used.