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**Westinghouse
Electric Corporation**

**Commercial Nuclear
Fuel Division**

RE-EKR-89-061

Drawer R
Columbia SC 29250
(803) 776 2610

November 30, 1989

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U. S. Nuclear Regulatory Commission
ATTN: Mr. C. E. MacDonald, Chief
Transportation Branch
Division of Fuel Cycle and Material Safety
Office of Nuclear Material Safety and Safeguards
Division of Safeguards
Washington, DC 20555

Gentlemen:

Subject: Application for Amendment for Certificate of Compliance No. 5450 (Docket 71-5450)

Reference: Letter (RE-EKR-89-055) from E. K. Reitler to C. E. MacDonald, "Application for Amendment", dated 10/5/89.

The Westinghouse Electric Corporation hereby submits this revised application for an amendment to Certificate of Compliance No. 5450 (Docket No. 71-5450) for the RCC fuel shipping container. This revised application supersedes the previous submittal and addresses the NRC questions and issues presented to Westinghouse representatives during a meeting held on November 16, 1989. The only changes requested as part of this application are to increase the authorized maximum U-235 enrichment for Westinghouse 17x17 12-foot OFA fuel designs from 4.3 wt % to 4.85 wt % for two separate conditions. Either each assembly contains a minimum of 48 Integrated Fuel Burnable Absorber (IFBA) rods per specification and loading pattern described in Westinghouse drawing SKA-89044, or there is only one assembly shipped per container. These fuel shipments will be limited to the RCC type containers with Gadolinium Oxide poison plates.

Attachment 1A has been provided to demonstrate the integrity of the fuel rod and ZrB_2 (ceramic) pellet coating as a result of the Hypothetical Accident Condition (HAC) testing of IFBA rods in accordance with 10CFR71 criteria. These tests consisted of dropping fuel rods from a height of 30 feet on to a flat, unyielding surface, heating the rods to a temperature of 1475°F followed by water quenching and immersion in water for eight hours. Test results conclusively indicated that the ZrB_2 coating remained on the pellets. Therefore, the ZrB_2 integrity is assured for the HAC test conditions.

1/1

FEE NOT REQUIRED

add. info.

NT01

The Westinghouse Commercial Nuclear Fuel Division — Winner of the 1988 Malcolm Baldrige National Quality Award.

26136

Attachment 19 has been revised to justify this U-235 enrichment increase from 4.30 wt % to 4.85 wt % with one assembly per container or with a minimum of 48 IFBA rods per assembly located in accordance with Westinghouse drawing SKA-89044. The calculated K-effective with the inclusion of a 95/95 confidence level (bias and uncertainties in the calculation and benchmark) are below 0.950.

Pages 18-4, 18-5 and 18-6, provided as an attachment, have been revised to reflect these enrichment increases.

Your timely review of this application would be appreciated as Westinghouse has need to make a shipment of this fuel design on January 4, 1990.

A check in the amount of $150 in payment of the application fee specified in 10CFR170.31 for this revised application was submitted with the previous application.

If you have any questions concerning this application, please contact me by telephone at (803) 776-2610, Extension 3247 or R. D. Montgomery at Extension 3550.

Sincerely,

WESTINGHOUSE ELECTRIC CORPORATION

R. D. Montgomery/for

E. K. Reitler, Manager
Regulatory Engineering

ATTACHMENT 1A

INTEGRITY JUSTIFICATION FOR ZrB_2 INTEGRATED FUEL BURNABLE ABSORBER (IFBA) CERAMIC PELLET COATINGS UNDER HAC TEST CONDITIONS

INTEGRITY TESTING OF IFBA RODS UNDER HYPOTHETICAL ACCIDENT CONDITIONS (HAC)

Introduction

In the HAC test of IFBA rods, a conclusion was drawn that indicated the ZrB_2 maintained its relative design configuration. Therefore, two (2) undamaged fuel assemblies were modeled in the Nuclear Safety Analysis with UO_2 pellets (ZrB_2 coated) within the zircaloy clad, intact, the assembly relative design configuration in a RCC container.

IFBA Design

A zirconium diboride (ZrB_2) coating is deposited onto the cylindrical portion of a uranium dioxide (UO_2) pellet by a sputtering system. This coating process is conducted in a cryogenicly pumped vacuum chamber housing a rotating drum. The coating process is conducted at a temperature range of 1300-1470°F for twelve (12) hours. Planar Magnetron cathodes mounted both within and outside of the rotating drum permit coating of the cylindrical surface of the UO_2 pellets nearly all around, simultaneously.

Each batch of pellets produced is identified as a specific coater lot. Extensive testing of each coater lot is necessary from a quality standpoint to ensure that the ZrB_2 has adhered to the pellet.

IFBA Integrity

In order to demonstrate that the effectiveness of the ZrB_2 coating will not be reduced under the Hypothetical Accident Conditions (HAC) prescribed in 10CFR71, a drop test, thermal test and water immersion test were conducted using two simulated fuel rods.

The test consisted of dropping the fuel rods from a height of 30 feet onto a flat, horizontial, essentially unyielding surface; heating rods to a temperature of 1475°F followed by water quenching; and immersion in water for at least 8 hours.

The test specimens consisted of 18.5 inch long fuel rods containing a nominally six (6) inch long stack of ZrB_2 coated fuel pellets and a 4.2 inch long uncoated fuel pellet stack in a nominally 0.360 inch diameter tube. A nominal plenum length of 7.525 inches with a standard 4G helical spring was used to simulate the hold down. The test rods were pressurized with helium to 200 psig, the standard pressure for IFBA rods.

Coated fuel stacks were weighed prior to rod fabrication. After welding, the rods were helium leak tested and the girth and seal welds were ultrasonically inspected to assure the integrity of the welds. The condition of the pellet stacks was x-rayed and the coated zone location was determined by active gamma scanning. Figure 1 illustrates the test rod configuration. Average boron loading on pellets was analytically determined using coated pellets from the same lot as those used in the test rods.

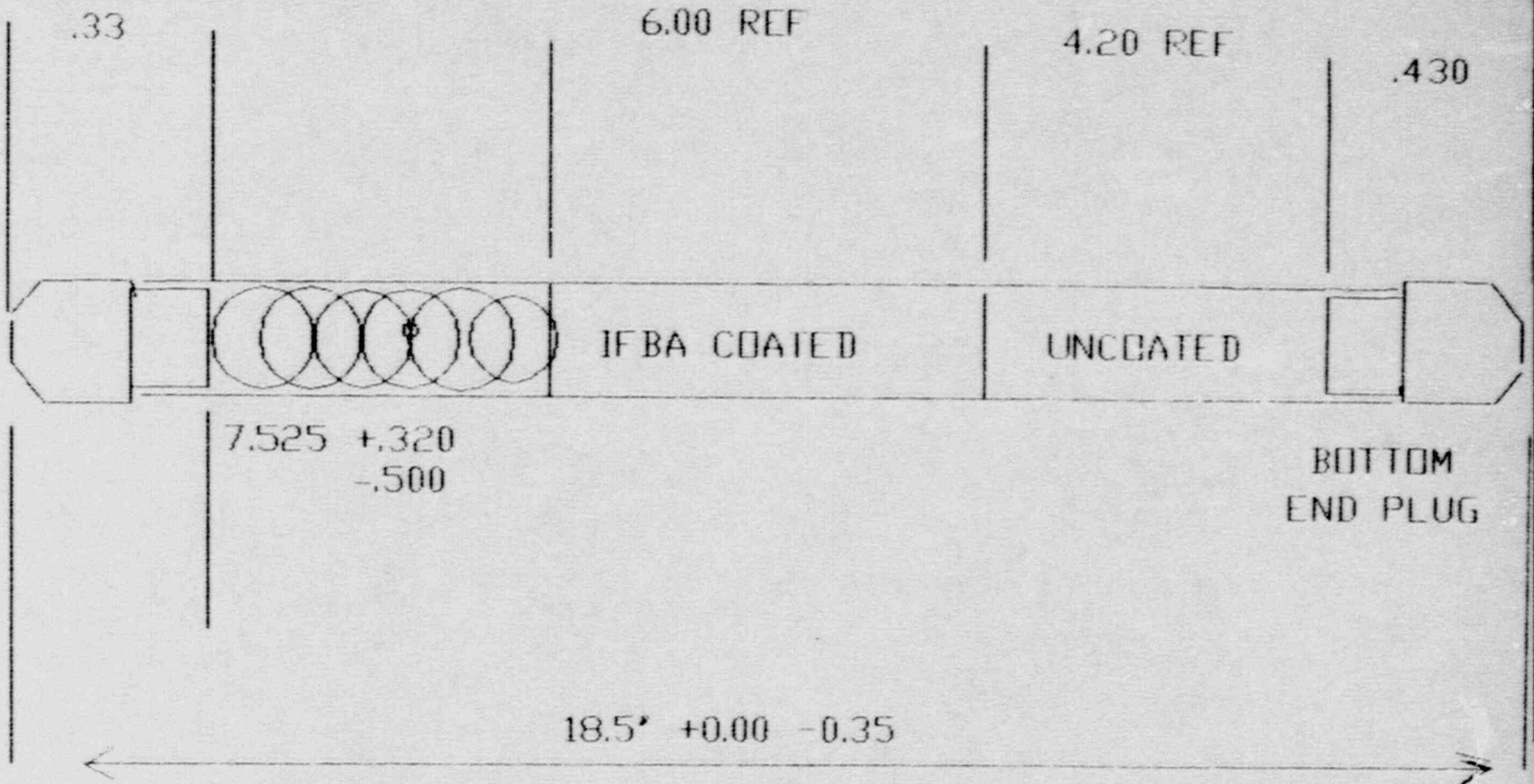
The drop test consisted of dropping one test rod on the bottom (pellet) end and the second rod on the holddown spring end from a height of 30 feet onto a half (1/2) inch thick steel plate that rested on a concrete floor. After the drop test, both rods were helium leak tested to confirm that the rod integrity was not lost. Subsequently, the test rods were placed in a muffle furnace preheated to 1475°F for 30 minutes. Although the average temperature at the center of the furnace was as specified (based on thermocouple indications), the back end of the furnace was 150°F higher. This higher temperature caused the cladding to balloon which resulted in a creep rupture type failure of the cladding in a 2" section. Subsequent water (68°F) immersion for a period of no less than 8 hours resulted in water ingress into the rods. The condition made the test more severe than that specified in 10CFR71 and, therefore, the results are considered to be conservative.

After completion of water immersion, both test rods were x-rayed to determine the condition of the pellet stacks. X-ray inspection showed that the pellet stacks were intact in both the test rods. In the first rod, dropped on the bottom (pellet) end, considerable pellet fragmentation was observed. In the second rod, dropped on the holddown spring end the coated and uncoated stacks were intact with only a small amount of fragmentation in the uncoated section.

Next, the first rod was gamma scanned to locate the ZrB_2 coated pellet zone. Gamma scan results illustrated in Figure 2 showed that the drop, thermal and water immersion tests did not affect the ZrB_2 coating adherence to the pellets. The coating effectively stayed in position. The differences in the delayed gamma counts before and after the test in Figure 2 are due to normal equipment and test uncertainties. The second rod could not be properly gamma scanned because of problems encountered in transporting it through the gamma scanner due to its bowed condition.

The test rods were subsequently sectioned to remove the pellet

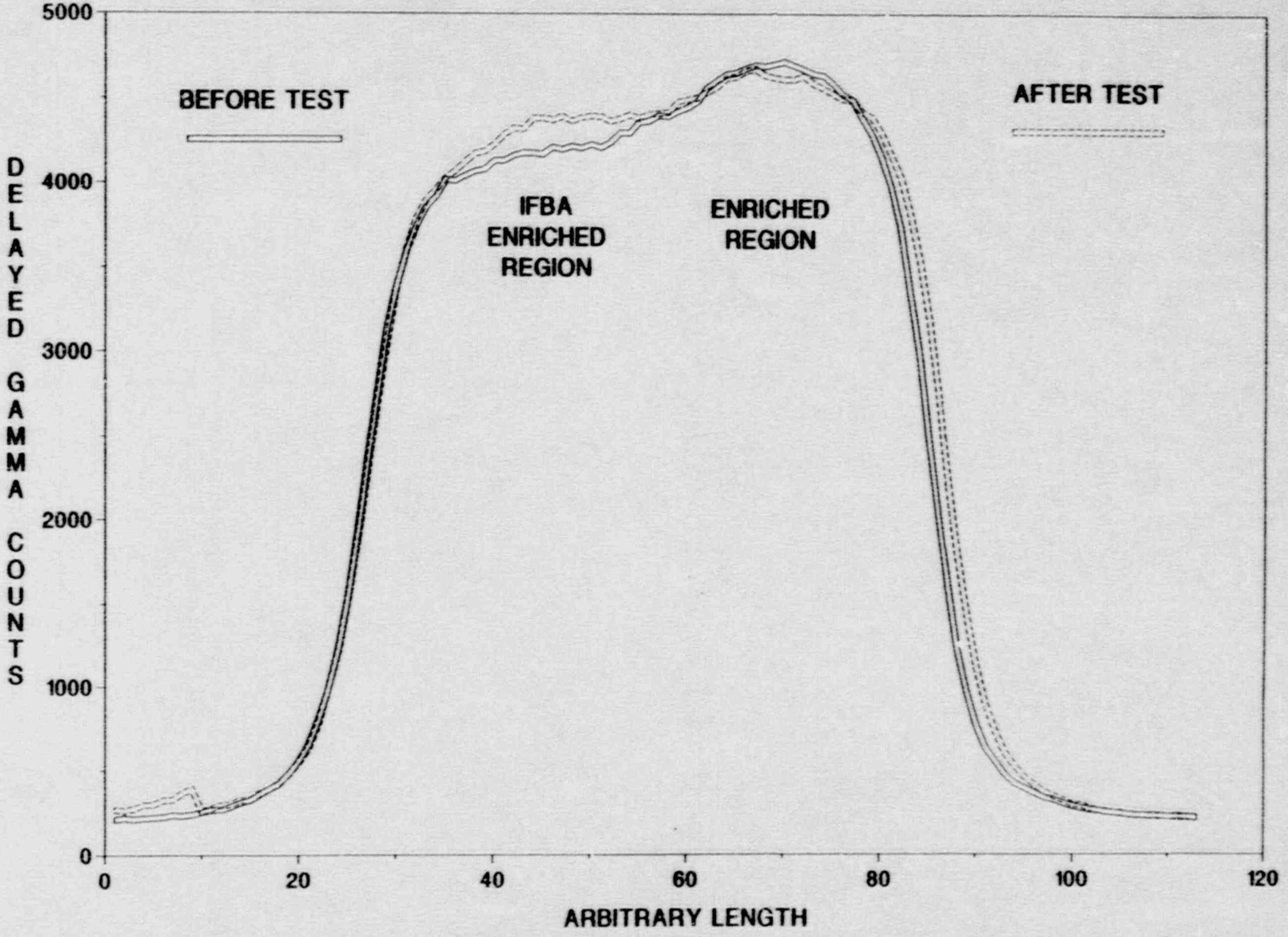
INTEGRITY TEST ROD CONFIGURATION



GAMMA SCAN OF IFBA DROP TEST ROD #1

DELAYED GAMMA COUNTS vs ARBITRARY LENGTH

FIGURE 1.



stacks and perform ceramographic examination of the coated pellets. Since the pellet stack in the second rod could be removed intact, the pellets were dried and weighed and the weight was compared to the pre-test weight. Results are tabulated in Table 1. Adherence of the ZrB_2 coating to the pellet was determined from ceramography and analytical measurement of boron from tested and control pellets from the same coater lot. Table 2 shows a comparison of the measured boron loading on coated pellets from the test rods with that on pellets which had not undergone testing. The test results are within the normal process variability as defined in Table 4. A similar ceramographic comparison is illustrated in Figure 3.

The test results conclusively proved that the ZrB_2 coating stayed on the pellets and the pellet stacks, although fragmented, did not move within the rod, thus demonstrating the effectiveness under the hypothetical accident conditions.

TABLE 1

Stack Length and Weight Measurements

ROD No.	STACK TYPE	STACK LENGTH inches	STACK WEIGHT, g BEFORE	STACK WEIGHT, g AFTER
1	coated	6.203	78.8938	N/A
	uncoated	4.140	N/A	N/A
2	coated	6.179	78.5416	78.5413
	uncoated	4.110	N/A	N/A

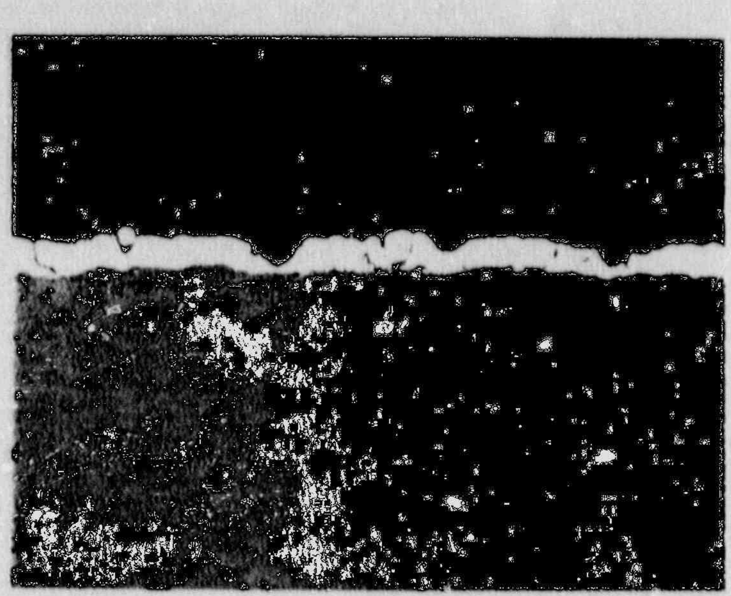
N/A - Not Measured

TABLE 2

BORON LOADING MEASUREMENTS[1]

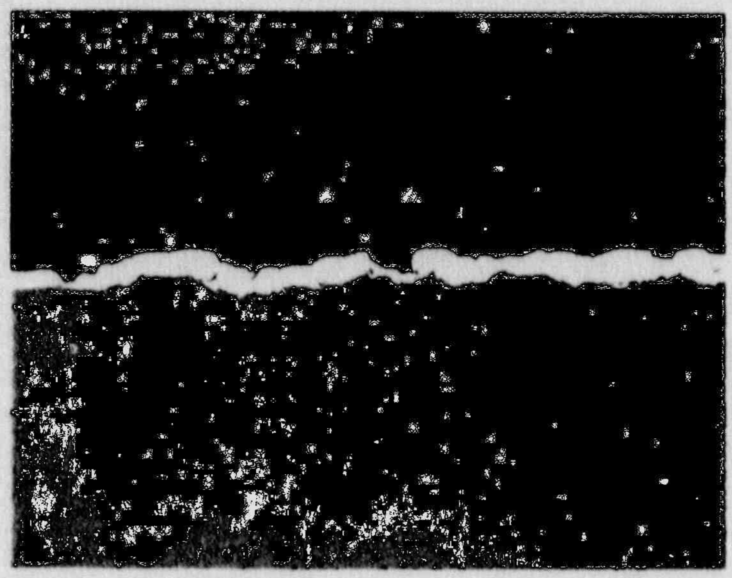
TEST No.	CONTROL PELLETS B, mg/inch	TESTED PELLETS B, mg/inch
1	7.39 +/- 0.11	----
2	7.49 +/- 0.11	----
3	----	7.04 +/- 0.11
4	----	7.43 +/- 0.11

1. These values are within the normal process variability defined in Table 4.



3967 Before 440× #1

CONTROL PELLET



3968 After 440× #1

TEST PELLET

FIGURE 3. CERAMOGRAPHS ILLUSTRATING COATING ADHERENCE TO PELLET SURFACE

QUALITY ASSURANCE

IFBA Pellet ZrB_2 Adherence

IFBA pellets are coated with zirconium diboride, ZrB_2, using a Westinghouse patented and qualified sputtering process. This high temperature, high vacuum process applies a dense, mechanically adherent ZrB_2 coating to 17000 to 20000 pellets at a time during one coating cycle. The coating is applied to a nominal thickness of 0.0004 inch as the pellets are rotated while held in a coating fixture bounded with wire.

When the timed coating cycle is complete, all coated pellets are unloaded and placed on trays for visual inspection and sampling. A trained and qualified inspector performs a 100 % visual inspection, discarding all pellets with chips, cracks, discoloration, and other questionable surface anomalies. Sample pellets are randomly selected for boron chemical analysis (mg B^{10} / inch), coating adherence tests (thermal cycle/peel test), metallographic ZrB_2 / UO_2 interface evaluation, and chemical impurities.

The amount of boron present on the coated pellets is determined by a qualified analytical procedure involving removal of the ZrB_2 coating by pyrohydrolysis and boron measurement by titration. Residual boron is determined by emission spectrometry to assure that all boron is removed from the pellets. A NIST No. SRM 951 boric acid standard is used to standardize the titrant. Control standards are analyzed to verify boron recovery through the pyrohydrolysis system. This procedure is performed on 12 groups of eight pellets each for every coating lot of pellets. The average milligrams of boron measured on the 12 groups is multiplied by the percent B^{10} in Boron as determined by ZrB_2 powder mass spectrographic analyses of supplier and Westinghouse overcheck samples. The result is milligrams B^{10} which is divided by the total length of the 96 pellet sample to achieve milligrams B^{10} per inch.

Adherence testing is performed on a sample of 10 pellets per coating lot. This test takes the form of 10 thermal cycles followed by a Scotch tape peel test. This test is performed to assure that the coating adheres to the UO_2. The sample of 10 pellets is cycled from room temperature to 600 °C ten times to simulate start-up and shut down of reactor operation. The cycled pellets are then weighed and peel tested by applying and removing tape to the pellet circumference. The tape itself must pass an adherence test for stickiness or gripping ability before it is used. After the peel test, pellets are reweighed and disposition is made by determining the amount of coating removed. Less than 0.0008 grams at a 95% confidence limit is the specification. No coating lot has ever failed an adherence test.

A pellet sample from each coating lot is analyzed by emission spectroscopy for metallic impurities. Carbon, nitrogen, and fluorine are also analyzed by other analytical techniques. These analyses are performed to assure that the ZrB_2 coating contains no detrimental impurities. The same analyses were performed on the UO_2 pellets prior to coating as a condition of their release.

IFBA Pellet Location In Fuel Rod

The next precaution taken to assure that ZrB_2 coated pellets are present in the fuel is computerized, robotic stack collation. For each rod design, (three zone - natural / coated / natural, or five zone - natural / enriched / coated / enriched / natural) a software program is loaded into a process control computer at the pellet collation station. This program instructs a pair of robots. The robots are located inside a ring of pellet tray carts which contain the necessary pellet types to fabricate the desired rod design. At the computer's command one robot picks up the appropriate tray of pellets (25 rows) and positions it so that the other robot may measure and remove the correct lengths of pellets. The tray handling robot then puts the tray back and proceeds to place another tray in position for pellet length measurements and removal. This process is repeated until 25 measured and correctly zoned pellet stacks are located on special capture row trays for continued processing. It is important to note that there is no way for pellets to escape from the capture row trays once they are loaded.

After IFBA pellets are loaded into tubes, the resultant rods are pressurized, seal welded, and inspected by passive gamma scanning. The purpose of this inspection is to verify that correct uranium enrichment is present, and that no deviant uranium enrichment pellets are mixed in with the stack.

The final inspection to assure that ZrB_2 pellets are present as desired is a neutron activated gamma scan of the finished rods. This calibrated procedure is performed on 100 % of all rods fabricated at Columbia. This inspection has the capability of discriminating a single coated pellet which may be mixed into an uncoated pellet zone. Each rod containing coated pellets is inspected for correct zone lengths (natural, enriched, or coated) and plenum length. The active gamma scanner inspection is done by activating the uranium with neutrons as the rod passes by a Californium source. The resultant gamma activity is measured for each zone and compared with standard rod activity levels recorded in a process control computer.

IFBA Rod Location In Fuel Assembly

Boron bearing rods are known as Integral Fuel Burnable Absorber (IFBA) rods. There are four separate actions which assure that IFBA rods are in their correct positions within a fuel assembly.

The first step in assuring correct IFBA rod position in the assembly is in loading the magazine. The magazine is a fixture used to stage rods prior to assembly loading. Templates are placed over the end of the magazine which will only permit rods to be loaded into certain positions within the magazine. Templates have been prepared and are selected according to the drawing number of the particular assembly being loaded. The assembly drawing number specifies the particular pattern of IFBA type rods to be used in the assembly. After loading IFBA type rods into the magazine, the template is removed and the standard rods are inserted into the remaining positions in the magazine.

The second step in assuring correct IFBA rod position in the assembly is in the inspection of the loaded magazine. The IFBA rods each have an identifying mark on the top end plug. Quality control (QC) Inspection verifies that the IFBA rods and the standard rods are in their correct positions based on a visual inspection of the top end plugs in the magazine.

The third step in assuring correct rod position in the assembly is the entry of assembly-rod data into the Rod Accountability and Monitoring (RAMS) real-time computer system. The system is preloaded with a list of the correct assembly id's for that region, and the correct rod loading pattern for the assemblies. Unique rod id's are scanned into the RAMS real-time system using barcode reader devices. The computer system records the correct pattern of standard and IFBA rods for each assembly. It recognizes the rod type scanned and compares the location for that rod with acceptable locations for rods of that type. If the rod is in an acceptable location, the transaction accepts; if not, the transaction is rejected and the operator is instructed to check the pattern and make corrections if necessary. If any alterations to the rods loaded in the magazine are required, the corrected magazine is reinspected.

The fourth step in assuring correct rod position in the fuel assembly occurs when the data collected by the real-time computer system is transmitted to the batch database and updated. As in the real-time system, rod patterns for each assembly are preloaded into the computer's memory. The rod location which comes in with each rod transaction is compared to the location table to determine if the rod type is correct for that particular location. If the rod's position is correct, the transaction updates; if not, the transaction suspends and a warning message is generated to alert the area engineers to investigate and resolve the problem.

IFBA Modeling For Shipping Container

Westinghouse models IFBA with the B^{10} uniformly smeared in the clad region of the fuel rod in all its nuclear models. This is done for consistency and because the difference in reactivity is slight. However, for those applications where this could lead to non-conservative results, a bias is included to account for any difference in reactivity.

The modeling effect of boron is slight because, as used with IFBA, it is not a strong absorber. The main reason for this is that little is used per rod, about 10% of the poison density in WABA, Pyrex, or a gadolinium rod. For the comparison to gadolinium, the absorption cross section is also smaller by at least another factor of ten.

Consequently, B^{10} does not self-shield itself significantly as used in IFBA. The flux is reduced across its surface by only about 4%. Thus, it is a volume absorber and the configuration of its surface is relatively unimportant. The amount of absorption does not depend on the amount of surface area.

This compares with Gadolinium which self-shields itself strongly. It, therefore, absorbs neutrons primarily at its surface, so its configuration is vitally important. Any change in effective surface area as would be introduced by nonuniformity would reduce its strength. For IFBA, nonuniformities have no effect as long as the total amount present is not changed.

Several studies in HAMMER, XSDRNPM, KENO, and PACER have shown that the worth of IFBA is about 3% (relative) higher when modeled in the clad instead of as a coating on the pellet. This is attributed to the flux reduction and hardening in approaching the surface of the pellet. The effect of modeling in the clad can be accounted for by taking a bias of 1% in reactivity. For an assembly containing 48 IFBA rods in a 17X17 lattice, the assembly wide effect is 0.18% in reactivity (0.0018 delta K). The reactivity calculated by KENO is thus increased by 0.18% for cases where IFBA is modeled in the clad and which contain 48 IFBA rods.

IFBA Loading Uncertainty

The pellet coating process produces pellets that vary in the amount of ZrB_2 coating deposited. Pellets on the outside of the coating fixture receive less material than the ones on the inside because of shadowing by the fixture supports. Consequently, since we do not attempt to keep track of where the pellets end up, the result is a pseudo pellet variability. The specification calls for the standard deviation of the pellet loading to be less than 25%. Actually, the coaters produce material with a standard deviation of 12%. These values are based on several years worth of measurements of individual pellets by a weight gain technique, and by continuing analyses of each coater run by chemical analysis.

While this pellet variability seems large, it does not result in large variability in either the IFBA rods or in the assemblies containing IFBA. The reason is that there are large numbers of IFBA pellets in each rod (about 300) and still larger numbers in an assembly (greater than 10000). Thus, because of random mixing effects, the variability of rods or assemblies is slight.

Actually, mixing of pellets is not completely random and, consequently, the results of the mixing that does occur is not quite as good as might be expected from the above. For one, the pellets from an individual coater run are not thoroughly mixed so the effective mixing in a rod is decreased. Second, the pellets in a region (coater run to coater run) are not thoroughly mixed so that the assemblies will tend to vary because the coater runs vary.

Table 3 gives a description of the actual mixing process and conservatively estimates the IFBA rod variability. The result is a standard deviation of 4.8%. Gamma scan measurements of the rods show a standard deviation of 5%. For instance, the gamma scanner estimates the U-235 rod variability to be 2.5% where as from more accurate sources we know it is less than 1%. The scanner precision is statistical in nature and is therefore driven by the low count rate produced in the activation process.

A more important variability than the rods, is the variability of the assembly loading. This is more important because it affects the overall reactivity of the assembly. The variability of the rods only slightly affect the reactivity of the assembly because the statistical combination of rods with variable loading tends to cancel the effect of high and low rods. (Note this is not true for strong poisons which can only have reduced worth as a result of variability.)

Because assembly worth is important in reactor core design, the amount of boron in each assembly is monitored. Each rod is assumed to have an amount of boron in it based on the coater run or runs it came from. The boron from each of the rods in the assembly is added and compared to the amount the assembly should contain. The standard deviation of the percentage differences between nominal and measured values is calculated to assure it is less than 1.5% as defined in the product specification.

Because of coater run variability, this is a difficult value to meet and we would expect to exceed it occasionally if steps were not taken to reduce the assembly variability. One step taken is to monitor rods in channels before loading into assemblies. If the variability of the rods between channels is too great, the rods in the channels are mixed to form a more uniform population. Since monitoring channels was begun, no contract has exceeded the 1.5% limit on assembly variability.

Another step taken to reduce assembly variability is coater mixing. At the present time coater runs are mixed if they are more than 3% from the contract nominal. They are mixed with another run so that the combined run is within +/- 3%. Credit for this is not taken because the specification does not require it. This is an in house method of ensuring that we meet the 1.5% assembly variability specification.

All of these factors which go into making up the assembly boron loading variability are given in Table 4. This table shows the specification requirements on IFBA variability, a conservative estimate of these variabilities, and a best estimate value for the variabilities. The bases for the estimates is also given.

The assembly variability is the pertinent result for criticality work. This variability is a specification quantity and is measured on each contract to be below 1.5%. We have reduced the boron content in the IFBA rods by 5% in our analysis of the shipping container. This is conservative for two reasons. First, the 5% value is much larger than the 1.5% limit times the one sided 95/95 uncertainty factor. Second, we are including this as a bias by reducing the number of B^{10} atoms in the assembly. If we were to include it as a variability (which is what it is) instead of as a bias, its resulting effect would be smaller because of statistical convolution with other variable factors of equal or larger magnitude.

TABLE 3 (1/3)
MIXING MECHANISMS

1. When the pellet fixtures from the coater are unloaded, the first operation is to get them onto a receiving tray. This tray is placed upside down on the fixture and the fixture overturned. There is some mixing of rows in this operation since frequently pellets end up on top of each other or roll to locations different than the one they were in while in the coater.

2. Chipped or other reject pellets are removed at this stage by manufacturing. Filling the vacancies left introduces a slight amount of mixing.

3. Since the fixtures are 17 to 18 rows wide and the trays they are to be placed on in the pellet cart are 25 rows wide, there has to be considerable rearranging of rows of pellets in this process to get the number of rows to match. This operation is done by hand and in a happenstance manner which is dictated by the state that the person doing the mixing finds the receiving tray after overturning. This state will be different from overturning to overturning.

4. Once the pellets get on the 25 row trays about 150 pellets are removed by Quality Assurance (QA) for sampling. The largest portion (96) of these pellets are used to determine the average coater loading. Others are used to check for hydrogen, coating adherence, etc. QA also removes any pellets that do not meet the visual specification. Again, the vacancies introduced increase mixing slightly.

5. At this stage the pellets are in 20 inch strings on the pellet trays. For ease of analysis, these strings are assumed to have been together in the coater as a continuous string. This is a conservative assumption since the required handling as described in the steps above produces considerable mixing. This is the second conservative assumption in the mixing analysis.

   In addition, since these strings are about 20 inches long, they must contain at least one section of pellets from an end of the fixture or a section of pellets from next to one of the vertical support bars. This means that no string can contain only pellets from the middle of the fixture. No string can contain just high loading pellets.

6. The strings of pellets on these trays are then measured for length and loaded onto separate trays by the collator for

later loading into rods. Since a typical IFBA stack length is 120 inches and since the trays hold stacks of about 20 inches, it takes about 6 lengths of pellets from 6 different trays to make up one IFBA stack. Since the stacks on the trays are in no particular order with respect to their position in the coater they will be loaded into rods in a pseudo random manner.

7. Assuming the mixing as described above (but excluding the important additional mixing during the fixture overturn and tray loading operations), randomly loaded pellet strings that have a standard deviation of about 10% taken from coater runs that are varying by about 2.5% produce a rod population that is varying by about 5% in boron content [(10/sqrt(6))**2+2.5**2=4.8**2]. This sum of squares is permissible since the variability of the rods due to the variability of the pellet strings [10%/sqrt(6)] is independent of the variability of the rods due to the coater variability of 2.5%.

   This estimate that the rod variability is less than 5% is conservative for several reasons.

   a. The pellet string variability will be less than 10%. This number assumes no mixing of the pellets during the overturn operation. Since much of the variability of the strings is the result of the low outside rows in the fixtures, any mixing of these pellets will reduce the variability of the strings. Since the pellet variability is about 12%, the 10% pellet string variability assumption is conservative (there are about 50 pellets in a string).

   b. The effective number of strings in a rod will be greater than 6. Since the tray and fixture length and width are different, the strings of pellets on a tray are not likely to be composed of a continuous string of pellets from a fixture. Thus, most pellet strings on the trays will themselves be composed of two or more pellet strings from the fixtures.

   c. The effective coater variability will be less than 2.5%. A coater mixing process was introduced in March of 1989 where any coater run outside +/- 3% of nominal is mixed with another coater run so that the

TABLE 3 (3/3)
MIXING MECHANISMS

average of the two is within +/-3%. The mixing process guarantees that approximately half of the pellets in each rod come from each of the two coater runs. Thus, on a rod basis, the coater runs will effectively vary less than the 2.5% assumed.

8. Assembly variability is measured for each contract. The rod channels are checked before rod loading and, if necessary, rod mixing is used to ensure all assemblies meet the specification limit of 1.5%.

TABLE 4

IFBA VARIABILITY (Percent)

Item	$\sigma_{\underline{SPEC}}$[1]	$\sigma_{\underline{CE}}$[2]	$\sigma_{\underline{BE}}$[3]	BASIS
Pellets	25	12	12	These values are on individual pellet weight gain data collected over 3 years and on group pellet chemistry data required as part of the product specification.
Strings	--	10	7.0	Inferred from the pellet distribution. These are conservative values since they assume no mixing during overturn operation or due to the dimension differences between the fixtures and the receiving trays.
Coater	2.5	2.5	2.0	Each run is measured with a 96 pellet sample. The expected error of this estimate is 1.2% so the true values will be less than estimated. The best estimate value accounts for mixing to +/- 3%.
Rods[4]	--	4.8	3.5	The standard deviations are estimated from the statistical convolution of the variability of the strings and the variability of the coater. Gamma scanner results show that the standard deviation of the rods is less than 5% which includes the large uncertainty of the scanner.
Assembly[5]	1.5	1.9	1.5	Assembly variability is measured for each contract. The rod channels are checked before rod loading and, if necessary, rod mixing is used to ensure assemblies meet this criterion.

1. Product specification of the standard deviation.
2. Conservative estimate of the standard deviation.
3. Best estimate of the standard deviation.

4. $(\sigma^2_{\underline{string}}/6 + \sigma^2_{\underline{coater}})$**0.5

5. $(\sigma^2_{\underline{coater}}/2 + \sigma^2_{\underline{rod}}/48)$**0.5

Axial Reflector Modeling

Westinghouse models shipping containers as infinite in length because this is convenient and slightly conservative since credit for axial leakage is ignored. However, since part-length poisons are to be used, a full 3D model is needed rather than constructing a more conservative infinite model.

Table 5 shows the composition of the material between the fuel stacks. The values in this table assume that two assembly bottoms are lined up even though assemblies always ride front to back on the truck. This is a considerable conservatism because it excludes the 7 inch plenum region (3 inch if spring compression is assumed) from separating the two fuel stacks.

TABLE 5

Structure Between Axial Fuel Stacks

Region	Length	Approx Comp.
Fuel Stack	0.0 in.	
End Plug	0.43 in.	30% Zr 70% H_2O
Bottom Nozzle	2.4 in.	20% SS 80% H_2O
Container End Plate	0.75 in.	100% SS
Container Structure	1.5 in.	10% SS 90% H_2O
Center Line	5.08 in	

Table 5 defines a 5.08 inch distance from the fuel stack to the center line between two fuel stacks or a 10.16 inch axial spacing between fuel stacks. This is essentially an infinite distance between fuel stacks. This is conservative since the plenum space is excluded.

The composition in this region does not alter this conclusion. It is neither a good reflector nor does it remove a large portion of the water between the assemblies. While stainless steel is a relatively good reflector material by itself (compared to water), when it is mixed with water, as it is here, it becomes worse than just water alone. The reflector region has been modeled as a 5.08 inch region of water to the center line which is a reflection boundary.

Conclusions

The ZrB_2 pellet coating for the IFBA fuel rod is applied and tested at temperatures beyond the HAC thermal test of 1475·F for 30 minutes. Previous HAC drop and thermal tests have demonstrated the integrity of the ZrB_2 coated UO_2 pellets. As a result, it is expected that the ZrB_2 coating will perform its intended function as a neutron poison under shipping container transport conditions,as well as, reactor operating conditions.

Therefore, the ZrB_2 is an effective and reliable neutron poison that can be modeled in the Westinghouse Shipping Container Criticality Analyses provided in Attachment 19.

WESTINGHOUSE SHIPPING CONTAINER ANALYSIS

Introduction

Criticality calculations are performed using the AMPX modules NITAWL and XSDRNPM for cross-section generation and KENO-IV for eigenvalue calculations. These methods have been benchmarked to various critical experiments and are now used exclusively for fuel assembly criticality calculations.

In addition to the standard RCC container (copper absorber plates), an upgraded RCC container with Gd_2O_3 coated carbon steel absorber plates is also analyzed.

Westinghouse has used two separate design criterion for the criticality of the shipping containers. The first criterion is that K_{eff} is less than or equal to 0.95 on a best estimate basis with minimal additional uncertainties for the Hypothetical Accident Condition (HAC). The second criterion is that k_{eff} is less than or equal to 0.98 for "optimum moderation" conditions on a best estimate basis with minimal additional uncertainties for the HAC.

The HAC model for the RCC container analysis was either two flooded containers crushed together such that the assemblies are separated by four inches of moderator or an infinite number of containers crushed together such that the assemblies are separated by four inches of moderator on one side, sixteen inches on two sides, and 30 inches of moderator on the fourth side. The container shell is assumed to be in place, with adjacent container shells in contact with each other.

Design Methods

As mentioned previously, the current Westinghouse criticality design methods employ the two AMPX(1) modules NITAWL and XSDRNPM along with the Monte Carol code KENO-IV.(2) The NITAWL code is used to add resolved resonance parameters to the master library.(3,7) The XSDRNPM code then takes the revised group library and performs a cell calculation. An additional cell calculation is performed if ZrB_2 Integral Fuel Burnable Absorbers (IFBA) are modeled. Cross sections for the IFBA cell are obtained by placing the B10 material from the absorber in the cladding region of the cell. The solution for this cell calculation is then used to collapse the cross-sections into a working library. This library is then used as input to KENO-IV.

Cross-sections for a shipping container are obtained from a cell calculation. The cross-sections for the structural material and the absorber are obtained by introducing trace amounts into the moderator in the cell. This procedure does not produce any bias in the results due to the fineness of the group structure.

The geometric capabilities of KENO-IV are used to provide an essentially exact two-dimensional representation of the problem. The problem is considered to extend infinitely along the length of the fuel assemblies, conservatively ignoring the benefits of axial leakage. The three dimensional problem models the 144 inch stack with 5.08 inches of water at each end, conservatively ignoring the additional spacing between the fuel rod plenum and the absorption of the top and bottom assembly structure. Each cell (or box type) is modeled explicitly as a fuel pellet, cladding, and associated moderator. Fuel rods containing ZrB_2 IFBA are modeled by placing the B_{10} absorber material in the fuel rod cladding and centering the 108" coating over the axial length of each coated fuel rod. Thimble cells are also modeled explicitly. No credit is taken for the presence of U-234 or U-236; neither is credit taken for any structural material (grids, clamping frames, etc.) that does not extend the full length of the assembly.

A representation of the HAC problem with two crushed containers is given in Figure 1. The boundary conditions on the top and left are zero current, while those on the bottom and right are zero flux. A representation of the HAC problem with an infinite number of crushed containers is given in Figure 1A. The boundary conditions are zero current on all sides.

The Westinghouse criticality method has been benchmarked to a set of critical experiments from several sources. Two sets of the experiments were performed at Battelle's Pacific Northwest Laboratories (4,5); the third was performed at ORNL.(6) The PNL experiments were performed with LWR-type fuel in LWR-type geometries; the ORNL experiments were performed with dry highly enriched uranium metal cylinders. Table 1 provides general information about the critical experiments. Table 2 provides statistical information about the PNL analyses, the ORNL analyses, and the combined set. As is evident, there is very little difference between the PNL analyses and the combined set, indicating the wide range of applicability of the method. The results of the benchmark calculations show that there is essentially no bias to the experiments, with a 95/95 uncertainty of 0.013. No critical experiment was eliminated on the basis of an anomalous result.

Container Analyses

The RCC container (copper absorber plates) was analyzed for three different Westinghouse Optimized Fuel Assemblies (OFA) - the 14x14 OFA, the 15x15 OFA, and the 17x17 OFA. These assemblies were designed to maximize reactivity by optimizing the H/U ratio. Each of these assemblies uses Zircaloy-4 cladding. Figure 2 shows LEOPARD calculations of K_{eff} versus H/U for the 14x14 and 17x17 lattices (the 15x15 assemblies are already optimized, and no changes have been made to the H/U ratio between standard 15x15 and 15x15 OFA). In both cases, the OFA is more reactive than the standard assembly, indicating that the OFA is limiting from a criticality standpoint. An analysis has also been performed for a 17x17 standard fuel assembly in a container in which the copper absorber plate has been replaced by a carbon steel plate of the same dimensions.

The Westinghouse 16x16 assembly was designed to fit the same envelope as the 14x14 assembly. In the shipping container analyses, therefore, the more reactive of the two assemblies is limiting. Unit assembly calculations have been performed for both 14x14 standard and 16x16 assemblies under cold conditions. The 16x16 assembly is 0.007 delta-k less reactive than the standard 14x14 assembly which is 0.007 delta-k less reactive than the 14x14 OFA. The 14x14 OFA is limiting, therefore, both for 14x14 and 16x16 fuel types. Table 3 indicates the fuel types that are covered by each of the OFA types that will be analyzed.

Each of the three limiting fuel types (14x14 OFA, 15x15 OFA, 17x17 OFA) was analyzed in the RCC container with copper absorber plates in KENO. The HAC problem used in this analysis consists of two crushed containers as given in Figure 1. A summary of the results is given in Table 4, the KENO input listings are in Tables 5, 6 and 7 and the nuclide/nuclide number correspondence is given in Table 13. In each case, the best estimate K_{eff} is less than or equal to 0.95 while the final K_{eff} with uncertainties is less than 0.96. The 14x14 and 16x16 assemblies, therefore, exhibit no criticality safety problems at enrichments less than or equal to 4 w/o while the 15x15 and 17x17 assemblies behave similarly at enrichments less than or equal to 3.65 w/o.

The 17x17 standard fuel assembly with the carbon steel absorber plates is limited to an enrichment of 3.55 w/o. A summary of the KENO calculation results for this case is given in Table 4. The KENO input listing is given in Table 14, and the nuclide/nuclide number correspondence is given in Table 13. The best estimate K_{eff} is less than 0.95 while the final K_{eff} with uncertainties is less than 0.965.

The analysis for the CE-type fuel is given in Appendix 19B. The same benchmarks and methods apply. The HAC problem used in this analysis consists of the two crushed containers as given in Figure 1.

The limiting fuel types were also analyzed in the RCC container under optimum moderation conditions using the representation of the HAC problem with an infinite number of crushed containers (Figure 1A). In the worst case, the best estimate K_{eff} was found to be less than 0.865. As a result, the fuel shipping containers with carbon steel or copper absorber plates under optimum moderation conditions, are bounded by the full moderator density cases and exhibit no criticality safety problems.

The Westinghouse 14x14, 16x16, 15x15 and 17x17 fuel types with U-235 enrichments of up to 4.0, 4.0, 3.65 and 3.65 w/o respectively can be shipped with copper absorber plates under finite and infinite array HAC conditions and not exceed the criticality criterion of K_{eff} less than or equal to 0.95 for full density water and K_{eff} less than or equal to 0.98 for optimum moderation conditions. The Westinghouse 17x17 standard fuel assembly with the carbon steel absorber plates and U-235 enrichment up to 3.55 w/o can also be shipped under the same conditions.

Figure 3 shows the relationship (calculated by LEOPARD) between K_{eff} and rod pitch for all three rod types. In each case it is obvious that the drier the lattice, the less reactive it is. A square tight-packed lattice of individual fuel rods is, therefore, less reactive than those same fuel rods in a fuel assembly. The fuel assembly is, therefore, the limiting case for fuel rod shipments.

The upgraded RCC shipping container has two absorber plates made of carbon steel, 0.035 inches in thickness, with 0.02 g - Gd_2O_3/cm^2 affixed to each side of the plate. The HAC problem used in this analysis consists of an infinite number of crushed containers as given in Figure 1A. Five Westinghouse fuel assembly types were analyzed in this RCC shipping container. These were the 14x14 OFA, 15x15 OFA, 16x16 C-80 and 17x17 OFA/STD. An additional analysis was performed for 17x17 OFA, loading only one assembly per shipping container. The 17x17 OFA fuel assembly has also been analyzed with 48 ZrB_2 Integral Fuel Burnable Absorber (IFBA) rods contained in the fuel assembly. The applicable fuel types for the OFA fuel assemblies are shown in Table 8.

Table 8 summarizes the KENO calculated nominal K_{eff} for each of the five problems analyzed. The KENO input listings are in Tables 9 through 12C and the nuclide/nuclide number correspondence is given in Table 13. The Westinghouse 17x17 OFA, STD and Westinghouse 15x15 OFA fuel assemblies with U-235 enrichments of up to 4.3, 4.7

and 4.3 w/o can be shipped under HAC conditions and not exceed the criticality criterion of K_{eff} less than or equal to 0.95. The 17x17 OFA fuel assembly with U-235 enrichments up to 4.85% can be shipped under HAC conditions by loading only one assembly per shipping container. The 17x17 OFA fuel with enrichments from 4.30 up to 4.85 w/o U-235 and containing a minimum of 48 ZrB_2 IFBA rods can be shipped under HAC conditions and not exceed the criticality criterion of K_{eff} less than or equal to 0.95. Furthermore, Westinghouse 14x14 OFA, 16x16 and 16x16 C-80 fuel assemblies with U-235 enrichments of up to 5 w/o can also be shipped under HAC conditions. Enrichments greater than 5 w/o were not considered in this study for those three fuel assembly types.

The upgraded RCC shipping container with the two Gd_2O_3 coated absorber plates was also analyzed using the representation of the HAC problem with an infinite number of crushed containers (Figure 1a) under optimum moderation conditions. It was again found that the optimum moderation cases are bounded by the full moderator density cases, with the worst case best estimate K_{eff} under optimum moderation conditions less than 0.92. As a result, the shipping containers with two Gd_2O_3 coated absorber plates exhibit no criticality safety problems under optimum moderation conditions.

The Westinghouse 17x17 OFA, 17x17 OFA with 48 ZrB_2 IFBA, 17x17 STD and 15x15 OFA fuel assemblies with U-235 enrichments of up to 4.30, 4.85, 4.70 and 4.3 w/o can be shipped under the infinite array HAC conditions and not exceed the criticality criterion of K_{eff} less than or equal to 0.95 for full density water and K_{eff} less than or equal to 0.98 for optimum moderation conditions. The 17x17 OFA fuel assembly with U-235 enrichments up to 4.85 w/o can be safely shipped under HAC conditions by loading only one assembly per shipping container. Furthermore, Westinghouse 14x14 OFA, 16x16 and

C-80 16x16 fuel assemblies with U-235 enrichments of up to 5.0 w/o can also be shipped under the same HAC conditions.

Conclusion

A Monte Carlo criticality analysis of the RCC shipping container under finite array and infinite array conditions, with copper absorber plates has demonstrated that, at enrichments of 4.0, 3.65, 4.0, and 3.65, the Westinghouse 14x14 OFA, 15x15 OFA, 16x16, and 17x17 OFA fuel assemblies, respectively, can be safety shipped without risk of criticality. The analysis has also shown that, since loose fuel rods in a tight lattice are less reactive than fuel assemblies, loose fuel rods of the above enrichments can also be safely shipped in the RCC container. With the carbon steel absorber plates, the Monte Carlo criticality analysis of the RCC shipping container has demonstrated that, at an enrichment of 3.55 w/o, the 17x17 fuel assemblies can be safely shipped without risk of criticality.

The Monte Carlo criticality analysis of the upgraded RCC shipping container under infinite array conditions, using Gd_2O_3 absorber plates has demonstrated that, at enrichments of 5.0, 4.3, 5.0, 5.0, 4.3 and 4.7 w/o, the 14x14 OFA, 15x15 OFA, 16x16, C-80 16x16 and the 17x17 OFA and STD fuel assemblies, respectively, can be safely shipped without risk of criticality. 17x17 OFA fuel assemblies containing a minimum of 48 ZrB_2 IFBA rods per assembly with U-235 enrichments up to 4.85 w/o can also be shipped safely without risk of criticality. Furthermore, the 17x17 OFA fuel assembly with enrichments up to 4.85 w/o can be safely shipped by loading only one assembly per container.

TABLE 8

KENO CALCULATED RESULTS FOR THE HYPOTHETICAL ACCIDENT CONDITION

(RCC Container with Gd203 Absorber Plates)

FUEL TYPE	U-235 WT % ENRICHMENT	KENO NOMINAL K_{eff}	1 SIGMA
W 15X15 OFA	4.3	0.93906	0.00335
W 17x17 STD	4.7	0.95479	0.00309
W 17x17 OFA	4.3	0.93974	0.00317
W 14x14 OFA	5.0	0.92391	0.00311
W 16x16	5.0	0.92391	0.00311
C-80 16x16	5.0	0.92935	0.00307
W 17x17 OFA[1]	4.85	0.94570[2]	0.00341
W 17x17 48 IFBA	4.85	0.93684[2]	0.00304

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1. This analysis performed with one assembly per shipping container

2. Reported KENO k_{eff} results include biases and 95/95 uncertainties

(iii) Uranium dioxide as clad unirradiated fuel elements. Two (2) neutron absorber plates consisting of carbon steel, 0.035 inches in thickness, with 0.02 gm-Gd_2O_3/cm^2 affixed to each side of the plate are required between fuel elements of the following specifications:

Type	14x14 Zr Clad	15x15 Zr Clad	14x14 SST Clad	15x15 SST Clad	17x17 Zr Clad	17x17 Zr Clad	16x16 Zr Clad	16x16 Zr Clad
Pellet diameter (nom), in	0.344-0.367	0.367	0.384	0.384	0.322	0.308	0.322	0.325
Rod diameter (nom), in	0.400-0.422	0.422	0.422	0.422	0.374	0.360	0.374	0.382
Maximum fuel length, in	144	144	120	120	168	168	144	150
Maximum rods/ element	180	204	180	204	264	264	235	236
Maximum cross section, (nom), in^2	7.8	8.4	7.8	8.4	8.4	8.4	7.8	7.8
Maximum U-235/ element, kg	26.3	21.5	27.5	22.0 (144"L) 25.5 (168"L)	21.75 (144"L) 23.3 (168"L)	19.9	24.7	25.1
Maximum U-235/ enrichment, w/o	5.0	4.3	5.0	4.3	4.7	4.3	5.0	5.0

(iv) Uranium dioxide as clad unirradiated fuel elements. Two (2) neutron absorber plates consisting of carbon steel, 0.035 inches in thickness, with 0.02 gm-Gd_2O_3/cm^2 affixed to each side of the plate are required between fuel elements of the following specifications:

Type	17x17 Zr Clad
Pellet diameter (nom), in	0.308
Rod diameter (nom), in	0.360
Maximum fuel length, in	168
Maximum rods/ element	264
Maximum cross section, (nom), in^2	8.4
Maximum U-235/ element, kg	22.5 (144"L)
Maximum U-235/ enrichment, w/o	4.85

(v) Uranium dioxide as clad unirradiated fuel elements. Two (2) neutron absorber plates consisting of carbon steel, 0.035 inches in thickness, with 0.02 gm-Gd_2O_3/cm^2 affixed to each side of the plate are required between fuel elements of the following specifications:

Type	17x17 Zr Clad
Pellet diameter (nom), in	0.308
Rod diameter (nom), in	0.360
Maximum fuel length, in	168
Maximum rods/ element	264
Maximum cross section, (nom), in^2	8.4
Maximum U-235/ element, kg	22.5 (144"L)
Minimum ZrB_2 IFBA rods/element	48(1)
Minimum ZrB_2 IFBA length, in	108
Maximum U-235/ enrichment, w/o	4.85

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1. Load pattern per Westinghouse Drawing SKA-89044.

(vi) Uranium dioxide as zircaloy or stainless steel clad unirradiated fuel rods of the following specification:

Type	SST Clad	ZR Clad	ZR Clad	ZR Clad	ZR Clad	ZR Clad
Pellet diameter (nom), inches	0.384	0.344-0.367	0.308 0.322	0.322	0.3805	0.325
Rod diameter (nom), inches	0.422	0.400-0.422	0.360-0.374	0.374	0.44	0.382
Fuel length (max), inches	120	144	168	144	144	150
U-235 enrichment (max), w/o	4.0[1] 4.2[2] ---	4.0[1] 4.2[2] ---	3.65[1] 4.3[2] 3.55[3]	4.0[1] 4.3[2] ---	3.85[1] --- ---	--- 4.2[2] ---

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1. Two neutron absorber plates consisting of 0.19 inch thick, full length stainless steel containing 1.3% (minimum) Boron or 0.19 inch thick OFHC copper are required between the rod boxes.

2. Two neutron absorber plates consisting of carbon steel, 0.035 inches in thickness, with minimum 0.02 gm-Gd_2O_3/cm^2 affixed to each side of the plate are required between the rod boxes.

3. Two neutron absorber plates consisting of 0.19 inch thickness carbon steel are required between the rod boxes.

(2) **Maximum quantity of material per package:**

(i) For the contents described in (1)(i), (1)(ii), (1)(iii), and (1)(v):

Two fuel elements.

(ii) For the contents described in (1)(iv):

One fuel element.

(iii) For the contents described in (1) (vi):

Two inner containers containing not more than 80 kilograms U-235.

TABLE 12B (1/3)

LISTING OF KENO INPUT DATA FOR THE W 17X17 OFA FUEL PROBLEM LOADING ONE 4.85 WT% ASSEMBLY PER SHIPPING CONTAINER

```
4.85 W/O 17OFA IN GD CASK WITH 4" CRSH GAP 3-D 1.0 G/CC H2O 1ASMBLY/CASK
9.7 900 300 5 27 27 20 6 23 52 19 20 19 1 -20 1 0 1011 00 1 1 1 0 00 0 0 112189
-1. -1. -1. -1. -1. -1.
 1   -192235     0.0011524
 1    192238     0.022323
 1    18016      0.046951
 2    240302     0.043326
 3    31001      0.066854
 3    38016      0.033427
 4    324000     0.017386
 4    325055     0.001732
 4    326000     0.058019
 4    328000     0.008142
 5    38016      0.00981210
 5    364152     0.000013083
 5    364154     0.000142603
 5    364155     0.000968129
 5    364156     0.001339027
 5    364157     0.001023731
 5    364158     0.001624886
 5    364160     0.001429952
 6    326000     0.0842012
 6    36012      0.00047290
 6    325055     0.00038871
 6    315031     0.00005807
 6    316032     0.00006642
 BOX TYPE  1
 CYLINDER  1     0.392176                                 365.76 -0.0 27*0.5
 CYLINDER  0     0.40005                                  365.76 -0.0 27*0.5
 CYLINDER  2     0.45720                                  365.76 -0.0 27*0.5
 CUBOID    3     0.62992   -0.62992  0.62992   -0.62992 365.76 -0.0 27*0.5
 BOX TYPE  2
 CYLINDER  3     0.56896                                  365.76 -0.0 27*0.5
 CYLINDER  2     0.60198                                  365.76 -0.0 27*0.5
 CUBOID    3     0.62992   -0.62992  0.62992   -0.62992 365.76 -0.0 27*0.5
 BOX TYPE  3
 CUBOID    6     0.4572     0.0      0.0       -0.45720 365.76 -0.0 27*0.5
 CUBOID    3     2.9972     0.0      0.0       -0.45720 365.76 -0.0 27*0.5
 BOX TYPE  4
 CUBOID    6     0.0       -0.4572   0.0       -0.45720 365.76 -0.0 27*0.5
 CUBOID    3     0.0       -2.9972   0.0       -0.45720 365.76 -0.0 27*0.5
 BOX TYPE  5
 CUBOID    6     0.62992   -0.62992  0.0       -0.45720 365.76 -0.0 27*0.5
 BOX TYPE  6
 CUBOID    6     0.89789    0.80899  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    5     0.90805    0.79883  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    3     2.99720    0.45720  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    6     2.99720    0.0      0.62992   -0.62992 365.76 -0.0 27*0.5
 BOX TYPE  7
 CUBOID    6    -0.80899   -0.89789  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    5    -0.79883   -0.90805  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    3    -0.45720   -2.99720  0.62992   -0.62992 365.76 -0.0 27*0.5
 CUBOID    6     0.0       -2.99720  0.62992   -0.62992 365.76 -0.0 27*0.5
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TABLE 12B (2/3)

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BOX TYPE  8
CUBOID    6    0.45720   0.0       0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    3    2.99720   0.0       0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  9
CUBOID    6    0.0      -0.45720   0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    3    0.0      -2.99720   0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  10
CUBOID    3    0.62992  -0.62992   5.08000   0.0     365.76 -0.0 27*0.5
BOX TYPE  11
CUBOID    6    0.45720   0.0       2.71272   0.0     365.76 -0.0 27*0.5
CUBOID    3    2.99720   0.0       5.08000   0.0     365.76 -0.0 27*0.5
BOX TYPE  12
CUBOID    6    0.0      -0.45720   2.71272   0.0     365.76 -0.0 27*0.5
CUBOID    3    0.0      -2.99720   5.08000   0.0     365.76 -0.0 27*0.5
BOX TYPE  13
CUBOID    6    0.89789   0.80899   0.62992   0.18288 365.76 -0.0 27*0.5
CUBOID    5    0.90805   0.79883   0.62992   0.18288 365.76 -0.0 27*0.5
CUBOID    3    2.99720   0.45720   0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    6    2.99720   0.0       0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  14
CUBOID    6   -0.80899  -0.89789   0.62992   0.18288 365.76 -0.0 27*0.5
CUBOID    5   -0.79883  -0.90805   0.62992   0.18288 365.76 -0.0 27*0.5
CUBOID    3   -0.45720  -2.99720   0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    6    0.0      -2.99720   0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  15
CUBOID    6    0.89789   0.80899  -0.29972  -0.62992 365.76 -0.0 27*0.5
CUBOID    5    0.90805   0.79883  -0.29972  -0.62992 365.76 -0.0 27*0.5
CUBOID    3    2.99720   0.45720   0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    6    2.99720   0.0       0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  16
CUBOID    6   -0.80899  -0.89789  -0.29972  -0.62992 365.76 -0.0 27*0.5
CUBOID    5   -0.79883  -0.90805  -0.29972  -0.62992 365.76 -0.0 27*0.5
CUBOID    3   -0.45720  -2.99720   0.62992  -0.62992 365.76 -0.0 27*0.5
CUBOID    6    0.0      -2.99720   0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  17
CUBOID    6   21.41728   0.0       0.0      -0.45720 365.76 -0.0 27*0.5
BOX TYPE  18
CUBOID    3   21.41728   0.0       0.62992  -0.62992 365.76 -0.0 27*0.5
BOX TYPE  19
CUBOID    3   21.41728   0.0       5.08000   0.0     365.76 -0.0 27*0.5
CORE BDY  0   24.41448 -24.41448 13.47724 -13.47724 365.76 -0.0 27*0.5
CUBOID    3   44.73448 -44.73448 13.47724 -51.12004 365.76 -0.0 27*0.5
CUBOID    6   44.96054 -44.96054 13.70330 -51.34610 365.76 -0.0 27*0.5
CUBOID    3   44.96054 -44.96054 13.70330 -51.34610 378.6632 -12.9032 27*0.5
  1  1 20  1  1  19   1   1   1   1   0
  2  3 15  3  7  13   3   1   1   1   0
  2  4 14 10  5  15  10   1   1   1   0
  2  6 12  3  4  16  12   1   1   1   0
```

TABLE 12B (3/3)

```
  3 18 18  1  1   1   1   1   1   1   0
  4 19 19  1  1   1   1   1   1   1   0
  5  1 17  1  1   1   1   1   1   1   0
  6 18 18  1  3  16   1   1   1   1   0
  7 19 19  1  3  16   1   1   1   1   0
  8 18 18  1 18  18   1   1   1   1   0
  9 19 19  1 18  18   1   1   1   1   0
 10  1 17  1 19  19   1   1   1   1   0
 11 18 18  1 19  19   1   1   1   1   0
 12 19 19  1 19  19   1   1   1   1   0
 13 18 18  1  2   2   1   1   1   1   0
 14 19 19  1  2   2   1   1   1   1   0
 15 18 18  1 17  17   1   1   1   1   0
 16 19 19  1 17  17   1   1   1   1   0
 17 20 20  1  1   1   1   1   1   1   0
 18 20 20  1  2  18   1   1   1   1   0
 19 20 20  1 19  19   1   1   1   1   1
-1
END KENO
```

TABLE 12C (1/4)

LISTING OF KENO INPUT DATA FOR THE W 17X17 OFA FUEL ASSEMBLY CONTAINING 4.85 W/O FUEL AND 48 ZRB2 IFBA

```
4.85 W/O 17OFA 48 IFBA 108 IN  B10*.95  STD SHIPPING CASK H2O=1.0 G/CM3 3D
11.5 500 303 5 27 27 27 9 30 66 22 18 19 3 -27 1 0 1011 00 1 1 1 0 0 0 00 0 0 112289
-1. -1. -1. -1. -1. -1.
1  -192235     .0011524
1   192238     .022323
1   18016      .046951
2  -492235     .0011524
2   492238     .022323
2   48016      .046951
3   240302     .043326
4   540302     .043326
4   55010      .00021926
5   31001      .066854
5   38016      .033427
6   61001      .066854
6   68016      .033427
7   326000     .058019
7   324000     .017386
7   328000     .008142
7   325055     .001732
8   38016      .00981210
8   364152     .000013083
8   364154     .000142603
8   364155     .000968129
8   364156     .001339027
8   364157     .001023731
8   364158     .001624886
8   364160     .001429952
9   326000     .0842012
9   36012      .00047290
9   325055     .00038871
9   315031     .00005807
9   316032     .00006642
BOX TYPE  1
CYLINDER  1    .392176                           45.72 -0.0 27*0.5
CYLINDER  0    .40005                            45.72 -0.0 27*0.5
CYLINDER  3    .45720                            45.72 -0.0 27*0.5
CUBOID    5    .62992 -.62992 .62992 -.62992     45.72 -0.0 27*0.5
BOX TYPE  2
CYLINDER  1    .392176                           45.72 -0.0 27*0.5
CYLINDER  0    .40005                            45.72 -0.0 27*0.5
CYLINDER  3    .45720                            45.72 -0.0 27*0.5
CUBOID    5    .62992 -.62992 .62992 -.62992     45.72 -0.0 27*0.5
BOX TYPE  3
CYLINDER  5    .56896                            45.72 -0.0 27*0.5
CYLINDER  3    .60198                            45.72 -0.0 27*0.5
CUBOID    5    .62992 -.62992 .62992 -.62992     45.72 -0.0 27*0.5
BOX TYPE  4
CUBOID    9    .4572  0.0     0.0    -.4572      45.72 -0.0 27*0.5
CUBOID    5   2.9972  0.0     0.0    -.4572      45.72 -0.0 27*0.5
BOX TYPE  5
CUBOID    9    .62992 -.62992 0.0    -.4572      45.72 -0.0 27*0.5
```

TABLE 12C (2/4)

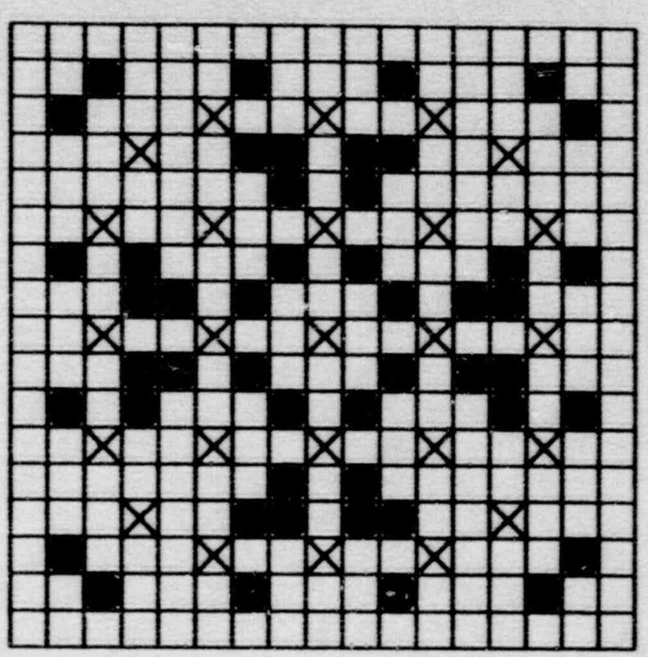
```
BOX TYPE   6
CUBOID     9    .89789  .80899 .62992 -.62992       45.72 -0.0 27*0.5
CUBOID     8    .90805  .79883 .62992 -.62992       45.72 -0.0 27*0.5
CUBOID     5   2.9972   .4572  .62992 -.62992       45.72 -0.0 27*0.5
CUBOID     9   2.9972   0.0    .62992 -.62992       45.72 -0.0 27*0.5
BOX TYPE   7
CUBOID     9    .4572   0.0    .62992 -.62992       45.72 -0.0 27*0.5
CUBOID     5   2.9972   0.0    .62992 -.62992       45.72 -0.0 27*0.5
BOX TYPE   8
CUBOID     5    .62992  -.62992 5.08  0.0           45.72 -0.0 27*0.5
BOX TYPE   9
CUBOID     9    .4572   0.0     2.71272 0.0         45.72 -0.0 27*0.5
CUBOID     5   2.9972   0.0     5.08  0.0           45.72 -0.0 27*0.5
BOX TYPE   10
CUBOID     9    .89789  .80899   .62992 0.18288     45.72 -0.0 27*0.5
CUBOID     8    .90805  .79883   .62992 0.18288     45.72 -0.0 27*0.5
CUBOID     5   2.9972   .4572    .62992 -.62992     45.72 -0.0 27*0.5
CUBOID     9   2.9972   0.0      .62992 -.62992     45.72 -0.0 27*0.5
BOX TYPE   11
CUBOID     9    .89789  .80899  -.29972 -.62992     45.72 -0.0 27*0.5
CUBOID     8    .90805  .79883  -.29972 -.62992     45.72 -0.0 27*0.5
CUBOID     5   2.9972   .4572    .62992 -.62992     45.72 -0.0 27*0.5
CUBOID     9   2.9972   0.0      .62992 -.62992     45.72 -0.0 27*0.5
BOX TYPE   12
CYLINDER   1    .392176                            274.32 -0.0 27*0.5
CYLINDER   0    .40005                             274.32 -0.0 27*0.5
CYLINDER   3    .45720                             274.32 -0.0 27*0.5
CUBOID     5    .62992 -.62992 .62992 -.62992      274.32 -0.0 27*0.5
BOX TYPE   13
CYLINDER   2    .392176                            274.32 -0.0 27*0.5
CYLINDER   0    .40005                             274.32 -0.0 27*0.5
CYLINDER   4    .45720                             274.32 -0.0 27*0.5
CUBOID     6    .62992 -.62992 .62992 -.62992      274.32 -0.0 27*0.5
BOX TYPE   14
CYLINDER   5    .56896                             274.32 -0.0 27*0.5
CYLINDER   3    .60198                             274.32 -0.0 27*0.5
CUBOID     5    .62992 -.62992 .62992 -.62992      274.32 -0.0 27*0.5
BOX TYPE   15
CUBOID     9    .4572  0.0    0.0     -.4572       274.32 -0.0 27*0.5
CUBOID     5   2.9972  0.0    0.0     -.4572       274.32 -0.0 27*0.5
BOX TYPE   16
CUBOID     9    .62992 -.62992 0.0    -.4572       274.32 -0.0 27*0.5
BOX TYPE   17
CUBOID     9    .89789  .80899 .62992 -.62992      274.32 -0.0 27*0.5
CUBOID     8    .90805  .79883 .62992 -.62992      274.32 -0.0 27*0.5
CUBOID     5   2.9972   .4572  .62992 -.62992      274.32 -0.0 27*0.5
CUBOID     9   2.9972   0.0    .62992 -.62992      274.32 -0.0 27*0.5
BOX TYPE   18
CUBOID     9    .4572   0.0    .62992 -.62992      274.32 -0.0 27*0.5
CUBOID     5   2.9972   0.0    .62992 -.62992      274.32 -0.0 27*0.5
BOX TYPE   19
CUBOID     5    .62992  -.62992 5.08  0.0          274.32 -0.0 27*0.5
BOX TYPE   20
CUBOID     9    .4572   0.0     2.71272 0.0        274.32 -0.0 27*0.5
CUBOID     5   2.9972   0.0     5.08  0.0          274.32 -0.0 27*0.5
```

TABLE 12C (3/4)

```
BOX TYPE  21
CUBOID    9     .89789  .80899    .62992 0.18288     274.32 -0.0 27*0.5
CUBOID    8     .90805  .79883    .62992 0.18288     274.32 -0.0 27*0.5
CUBOID    5    2.9972   .4572     .62992 -.62992     274.32 -0.0 27*0.5
CUBOID    9    2.9972   0.0       .62992 -.62992     274.32 -0.0 27*0.5
BOX TYPE  22
CUBOID    9     .89789  .80899   -.29972 -.62992     274.32 -0.0 27*0.5
CUBOID    8     .90805  .79883   -.29972 -.62992     274.32 -0.0 27*0.5
CUBOID    5    2.9972   .4572     .62992 -.62992     274.32 -0.0 27*0.5
CUBOID    9    2.9972   0.0       .62992 -.62992     274.32 -0.0 27*0.5
CORE BDY  0    12.20724 -12.20724 13.47724 -13.47724 365.76 -0.0 27*0.5
CUBOID    5    12.20724 -32.52724 13.47724 -51.12004 365.76 -0.0 27*0.5
CUBOID    9    12.20724 -32.75330 13.70330 -51.34610 365.76 -0.0 27*0.5
CUBOID    5    12.20724 -32.75330 13.70330 -51.34610 378.6632 -12.9032 27*0.5
  1  1 18  1  1  18   1   1   1   1   0
  2  3 15  4  3  17  14   1   1   1   0
  2  2 16 14  4  16   4   1   1   1   0
  2  8 10  2  5  15  10   1   1   1   0
  2  8 10  2  6  14   8   1   1   1   0
  2  8 10  2  8  12   4   1   1   1   0
  2  7 11  4  5  15  10   1   1   1   0
  2  7 11  4  9  11   2   1   1   1   0
  2  4 14 10  8  12   4   1   1   1   0
  2  4 14 10  9  11   2   1   1   1   0
  2  5 13  8  9  11   2   1   1   1   0
  3  3 15  3  7  13   3   1   1   1   0
  3  4 14 10  5  15  10   1   1   1   0
  3  6 12  3  4  16  12   1   1   1   0
  4 18 18  1  1   1   1   1   1   1   0
  5  1 17  1  1   1   1   1   1   1   0
  6 18 18  1  3  16   1   1   1   1   0
  7 18 18  1 18  18   1   1   1   1   0
  8  1 17  1 19  19   1   1   1   1   0
  9 18 18  1 19  19   1   1   1   1   0
 10 18 18  1  2   2   1   1   1   1   0
 11 18 18  1 17  17   1   1   1   1   0
 12  1 18  1  1  18   1   2   2   1   0
 13  3 15  4  3  17  14   2   2   1   0
 13  2 16 14  4  16   4   2   2   1   0
 13  8 10  2  5  15  10   2   2   1   0
 13  8 10  2  6  14   8   2   2   1   0
 13  8 10  2  8  12   4   2   2   1   0
 13  7 11  4  5  15  10   2   2   1   0
 13  7 11  4  9  11   2   2   2   1   0
 13  4 14 10  8  12   4   2   2   1   0
 13  4 14 10  9  11   2   2   2   1   0
 13  5 13  8  9  11   2   2   2   1   0
 14  3 15  3  7  13   3   2   2   1   0
 14  4 14 10  5  15  10   2   2   1   0
 14  6 12  3  4  16  12   2   2   1   0
 15 18 18  1  1   1   1   2   2   1   0
 16  1 17  1  1   1   1   2   2   1   0
 17 18 18  1  3  16   1   2   2   1   0
 18 18 18  1 18  18   1   2   2   1   0
 19  1 17  1 19  19   1   2   2   1   0
 20 18 16  1 19  19   1   2   2   1   0
 21 18 18  1  2   2   1   2   2   1   0
 22 18 18  1 17  17   1   2   2   1   0
```

TABLE 12C (4/4)

```
  1  1 18  1  1  18   1   3   3   1   0
  2  3 15  4  3  17  14   3   3   1   0
  2  2 16 14  4  16   4   3   3   1   0
  2  8 10  2  5  15  10   3   3   1   0
  2  8 10  2  6  14   8   3   3   1   0
  2  8 10  2  8  12   4   3   3   1   0
  2  7 11  4  5  15  10   3   3   1   0
  2  7 11  4  9  11   2   3   3   1   0
  2  4 14 10  8  12   4   3   3   1   0
  2  4 14 10  9  11   2   3   3   1   0
  2  5 13  8  9  11   2   3   3   1   0
  3  3 15  3  7  13   3   3   3   1   0
  3  4 14 10  5  15  10   3   3   1   0
  3  6 12  3  4  16  12   3   3   1   0
  4 18 18  1  1   1   1   3   3   1   0
  5  1 17  1  1   1   1   3   3   1   0
  6 18 18  1  3  16   1   3   3   1   0
  7 18 18  1 18  18   1   3   3   1   0
  8  1 17  1 19  19   1   3   3   1   0
  9 18 18  1 19  19   1   3   3   1   0
 10 18 18  1  2   2   1   3   3   1   0
 11 18 18  1 17  17   1   3   3   1   1
-1
```



ENGINEERING SPECIFICATIONS:

1. NOMINAL B^{10} LOADING: 1.5 MILLIGRAM/INCH
2. TOLERANCE-NOMINAL ON LOADING: ± 5.0 %
3. FUEL LENGTH (ZrB2,ENRICHED,NATURAL): 144 IN.
4. ACTIVE ZrB2 COATED FUEL LENGTH: 120 IN.

KENO MODEL PARAMETERS:

1. MODELED B^{10} LOADING: 1.425 MILLIGRAM/INCH.
2. MODELED ZrB2 COATED FUEL LENGTH: 108 IN.
3. MODELED ENRICHED FUEL LENGTH (EACH END) 18 IN.

LEGEND

● : ZrB2 COATED FUEL RODS (48 ROD/ASSY)

☐ : FUEL RODS (216 ROD/ASSY)

☒ : THIMBLE AND INSTRUMENT LOCATIONS (25 LOC/ASSY)

LOAD PATTERN WAS 32
RODS FOR 4.45 WT%
17X ASSEMBLY
REQ#5715
CGC 12/1/89
12/1/89

DFTM	JPR.	10/05 89
CHKD		
APPD		
APPD		
APPD		
APPD		
APPD		
APPD		
APPD		

Westinghouse Electric Corporation
WATER REACTOR DIVISIONS - COLUMBIA, S.C. U.S.A.

AREA / PROCESS

TITLE IFBA (48) LOAD PATTERN & DETAILS FOR 4.85 WT% 17 OFA FUEL ASSY

SIZE A
REQN NO 5555
DWG NO SKA-89044
REV 02
SCALE 1/2
DWG TYPE
SHEET 01 OF 01 SHEETS

CADAM DRAWING
DO NOT REVISE MANUALLY