B&W FUEL COMPANY

An American Company with Worldwide Resources

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March 9, 1993

Charles E. MacDonald, Chief
Transportation Branch
Division of Safeguards
and Transportation, NMSS
United States Nuclear Regulatory
Commission
Washington D.C., 20555

Dear Mr. MacDonald:

REFERENCE: Certificate of Compliance for Model No. 51032-2, Docket 71-9252

B&W Fuel Company (BWFC) submitted an application on October 27, 1992 to become an independent certificate holder of the presently licensed Siemens' 51032-1 fresh fuel shipping container, Docket 71-6581. Your staff requested further information regarding the application on January 21, 1993. This letter with attachments provides the response to your questions.

In response to the structural question number 3, restraining bars, separator block stiffener gussets, and fuel assembly spacers (for shipping control component assemblies) were added. The 5/8" diameter bolts were also changed to 1" diameter bolts. These modifications require that the 51032-2 container maximum empty weight be increased from 4100 lbs to 4200 lbs, and the 51032-2 container maximum loaded weight be increased from 7400 lbs to 7500 lbs. The weight increase is primarily due to necessary structural reinforcements and affects only the container weight. The maximum fuel assembly weight shall remain constant.

The changes made within the text of the document are identified by a side bar. Siemens' test report has been included as Appendix A. This reference change is noted throughout the document by a side bar. Chapter 6 was reformatted and side bars indicate this change. Please note that corrected grammatical errors were not side-barred. Due to the significant amount of changes, the entire SAR has been provided with 3-9-93 date and revision 1. As required, six copies of the SAR are being submitted.

230079

NF01 1/3

delete: Ziegler, E.

It is essential to support upcoming BWFC contracts to have these containers fabricated and approved for use in May of 1993. Should you have any questions regarding this application, please feel free to contact me at (804) 522-6202. Thank you for your attention and cooperation to this matter.

Sincerely,

B&W FUEL COMPANY
COMMERCIAL NUCLEAR FUEL PLANT

Kathryn S. Knapp

Kathryn S. Knapp
Manager, Safety & Licensing

cc: C. W. Carr

ATTACHMENT I

STRUCTURAL

1. Revise the packaging drawings to include the following:
   a. Specify the gross weight of the package.
   b. Specify that each spacer grid and end fitting of a fuel assembly is restrained by a clamp.
   c. Specify the number and maximum spacing of the clamps for each fuel assembly design.

RESPONSE: Eight (8) of the nine (9) licensing drawings were revised to:

a) display the changes specified above;
b) correct errors found in the original licensing drawings; and
c) more clearly show the container details.

All the drawings were reduced to 11x17 dimensions. The revision number of the drawings was removed from throughout the text of the document and is only illustrated in Table 1.1 of the SAR. The removal of the drawing revision number was not indicated by a side bar. A revision was not required for drawing 1216010 D.

2. Specify the maximum weight supported by any clamp for the various fuel assemblies to be shipped, and show how this value was obtained. Show that the weights supported by the clamps in the tests are at least as great as the weight that will be supported by the clamps during shipment.

RESPONSE: The following clamp analysis addresses the NRC's concerns and goes a step beyond by addressing strength improvements BWFC has made to the packaging as a result to your question.

Clamp Load Evaluation

As stated elsewhere, BWFC prefers to ship Control Component Assemblies (CCA's) within their mating Fuel Assemblies (FA's), depending on contract requirements. The following analysis addresses the maximum weight supported by any clamp for the various fuel assembly designs listed.

The weights supported by the 51032-1 clamps in the drop tests were at least as great as the weights that will be supported by the 51032-2 clamps during fuel shipments. The two drop tested (simulated) fuel assemblies weighed 1653 ± 2 lbs each (3306 total) and were loaded into the 51032 container in the same manner as actual fuel assemblies.

As a conservative measure, BWFC will use full clamp assemblies at all fuel assembly spacer grid and end fitting locations when shipping fuel in the 51032-2 container. Half clamp assemblies will be shipped apart from 51032-2 containers and will be used during fuel assembly loading and unloading operations only. The

quantities and maximum spacing of the clamps for each BWFC fuel assembly type are shown on drawing 1215929D.

In the cover drop test of the Model 51032-1 package, the shock mount bolts failed in tension. Tests of the 5/8-inch, Grade 2 shock mount bolts indicate an ultimate strength in the range of 11,000 to 12,000 pounds. Hence, clamp loading/deformation is limited by tensile failure of the shock mount bolts. The maximum restraining force exerted by the shock mount bolts in the drop tested package was 168,000 pounds (14 x 12,000 pounds). Since the nine (9) full clamp assemblies which retained the 3306 pound contents in the package did not fail in the cover drop test (the most severe test of the clamps and shock mounts), it can be stated that each clamp assembly is capable of restraining a load of at least 15,360 pounds.

3306 / (3306 + 710) = 82.32%

82.32% = Percentage of the loaded strongback weight made up by the simulated fuel assemblies
710 = Weight of the strongback channel without attachments†
9 = Number of full clamp assemblies used for cover drop test

(168,000 / 9) (82.32%) ≈ 15,360 lbs

† It is conservative to assume a fixed minimum weight for the strongback when calculating the required number of full clamp assemblies for various fuel assembly weights. However, since the 51032-2 container full clamp quantities are fixed for the various fuel types, calculations for the numbers of full clamp assemblies required are not necessary.

The following table displays the quantities of full clamps to be used for the various fuel assembly types and correlates the weight of each fuel assembly type to the amount of weight which each full clamp assembly would support in hypothetical accident conditions (cover drop).

MODEL 51032-2 PACKAGE
FUEL ASSEMBLY CLAMP REQUIREMENTS

FA Type	FA + CCA Max. Wt. (2 each)	No. Full Clamps Reqd.	Maximum Weight Supported by Each Full Clamp Assy. (lbs)
MK-B	3300 lbs	10	3300 / (3300 + 710) = 82.29% (168,000 / 10) (82.29%) = 13,825
MK-BW	3016 lbs	10	3016 / (3016 + 710) = 80.94% (168,000 / 10) (82.29%) = 13,599
C-Y	2510 lbs	9	2510 / (2510 + 710) = 77.95% (168,000 / 9) (77.95%) = 14,551

All values listed are less than the 15,360 lb load which each clamp supported in the 51032-1 drop testing. Therefore, the weights supported by the 51032-2 full clamps during fuel assembly shipments are conservative and acceptable.

As an additional conservative measure, the bolts which secure the clamps to the strongback, the bolts which secure the strongback to the shock mounts and the shock mount bolts will all be Grade 5 bolts, having an ultimate strength of 120,000 psi. This is a tremendous increase in strength from the bolts present in the drop tested 51032-1 containers which used shock mount bolts having an ultimate strength of 11,000 to 12,000 psi.

The table has been added to section 1.2.1.2 of the SAR.

3. Evaluate the separation distance between fuel assemblies during the 30-foot side drop test. Note that criticality calculations should be based on the minimum separation between fuel assemblies.

RESPONSE: Combustion Engineering performed a 30 foot drop test in which a cask experienced a horizontal side impact. However, the early Combustion Engineering cask design (Model 927A) contained a single stainless steel separator plate that spanned the length of the cask. Combustion Engineering later modified this design (Models 927C and 51032-1) to contain separator blocks that were designed to maintain a minimum 6 inch separation between assemblies. The BWFC Model 51032-2 shipping container contains nine 6 inch wide - 9 inch long separator blocks. Therefore, the direct application of Model 927A drop test results to the BWFC cask design is questionable since the design of the cask internals is significantly different.

Combustion Engineering later gave consideration to the potential for rod bow in the open spaces between the separator blocks after a horizontal side drop. BWFC also evaluated the amount of rod bow that could occur for the BWFC Model 51032-2 cask as a function of separator block spacing. The BWFC Model 51032-2 shipping cask will maintain a separator block spacing that will not exceed 11.4 inches in order that rod bow will be maintained less than 0.648 inches during a horizontal drop accident.

With fuel assemblies assuming a normal configuration within the shipping cask, a 0.648 inch gap is maintained between the separator block and the edge of the fuel assembly to facilitate loading and unloading of the assemblies. This spacing is maintained for the bottom fuel assembly during a horizontal side drop as long as the two 5/8 inch grade 8 carbon steel bolts holding the separator blocks to the strongback or the blocks themselves do not shear or deform during an accident. BWFC performed a structural analysis, provided as Attachment 1A, on the separator blocks assuming the top assembly came loose from the clamps and impacted the separator blocks. The results of this analysis demonstrated that the separator blocks would remain in their original positions during a horizontal side drop accident if two 1 inch diameter bolts were used to secure the separator blocks. Additionally, a gusset plate was added to the separator blocks to prevent deformation. The rod bow in the top fuel assembly caused by the horizontal side drop accident is offset by the gap between the separator blocks and the bottom fuel assembly as long as the longitudinal distance between separator blocks does not exceed 11.4 inches. Therefore, the minimum 6 inch separation between assemblies in a cask, which was assumed for both normal and accident calculations is conservative for criticality calculations.

The analysis results have been added as Section 2.10.

4. The application should address the requirement of 10 CFR §71.73 (c)(2) for puncture.

RESPONSE: The puncture test was not performed on the 51032-1 container. However, puncture tests, as specified in 10 CFR §71.73 (c)(2), were performed on two similar packages:

A. Models 927A, 927B and 927C; USNRC Certificate of Compliance No. 6078.

B. Model UNC-2800; USNRC Certificate of Compliance No. 5419.

The Model 51032-2 container design is based on the Model 51032-1 container design which is based on the Model 927C packaging. In all structural and containment respects, however, the Model 51032-2 package equals or exceeds the capabilities of the packages upon which the design is based.

A. The 927A container was subjected to the puncture test in accordance with 10 CFR §71.73 (c)(2). The container was loaded with dummy fuel assemblies and allowed to drop freely onto a steel cylinder, 6 inches in diameter by 8 inches high, from a height of 42 inches. This distance is measured from the bottom of the shell to the top of the steel cylinder. The point of impact was approximately midway between the edge of the aft fork lift guide and the edge of the aft container skid.

Following impact, the external birdcage structure of the container sustained no damage as a result of this test. Examination of the inside of the container indicated no damage to the simulated fuel assemblies, no relative movement of the simulated fuel assemblies and no damage to the suspension frame. It is , therefore, concluded that the container satisfactorily passed the puncture test.

B. **The UNC-2800 container was also subjected to the puncture test, in which a container was loaded with dummy fuel assemblies to simulate the weight of actual fuel assemblies. The inner container and the outer container were then sealed in the same manner as for fuel shipments. The loaded package was then dropped 40 inches upon a 6-in. diameter by 8-in. high steel cylinder.**

As a result of the puncture test, the package experienced a three inch deflection in the impact area, deforming uniformly up to the central rollover rings. There was no evidence of any damage to the welded joint.

Section 2.7.2 has been changed to reflect these tests.

5. Compare the fabrication standards specified in the application to the corresponding ASME Code standards. Show that the packaging will have quality equivalent to packaging using the ASME Code.

RESPONSE: The fabrication standards of MIL-STD-278F require the welding procedure and performance qualifications to be in accordance with MIL-STD-248D. So, in comparing the welding standards of ASME Section IX to MIL-STD-278F, MIL-STD-248D is required in the welding procedure and performance qualification.

In comparing the (2) two welding standards, ASME Section IX to MIL-STD-248D, they are similar in the qualification requirements for welding procedure qualification, welder/operator performance qualification, testing and examination requirements.

Both require a welding procedure qualification. This is done to determine that the weldment proposed for construction is capable of having the required properties for its intended application. The welder/operator performing the welding procedure qualification test must be a skilled workman. The welding procedure qualification report shall include the essential and nonessential variables of the welding procedure along with the destructive and nondestructive test results. The approved procedure qualification report shall be retained as long as the procedure is applicable. If a change is made in any essential variable, requalification of the procedure is required. If a change is made in a nonessential variable, the procedure need only be revised to address the changes. A comparison of the procedure qualification requirements of both standards for range limits and testing are shown in Tables 1 and 2.

Table 1. Welding Procedure Qualification Thickness Range.

Welding Procedure Qualification Material Thickness Limits

ASME Section IX

Thickness (T) of Test Material	Range of Thickness (T) Qualified Min.	Max.
Less than 1/16	T	2T
1/16 to 3/8	1/16	2T
Over 3/8, less than 3/4	3/16	2T
3/4 to less than 1 1/2	3/16	2T
1 1/2 and over	3/16	8

MIL-STD-248D

Thickness (T) of Test Material	Range of Thickness (T) Qualified Min.	Max.
Less than 3/4	T or 1/8 (whichever is less)	2T
3/4 to less than 3	3/16	2T
3 and over	3/16	unlimited

Table 2. Welding Procedure Qualification Test Requirements.

Welding Procedure Qualification Assembly Test Requirements

ASME Section IX

Thickness (T) of Test Material	Type and Number of Tests: Tensile	Side	Face	Root
Less than 1/16	2	...	2	2
1/16 to 3/8	2	Note (1)	2	2
over 3/8, less than 3/4	2	Note (1)	2	2
3/4 to less than 1 1/2	2	4	...	...
1 1/2 and over	2	4	...	...

MIL-STD-248D

Thickness (T) of Test Material	Type and Number of Tests: Tensile	Side	Face	Root
Less than 3/4	2	...	2	2
3/4 to less than 3	2	3	...	...
3 and over	2	3	...	...

Note (1): Four side-bend tests may be substituted for the required face and root-bend tests thickness (T) is 3/8 in. and over.

Acceptance criteria for the bend test are the same for both standards. The requirements state that after bending, the specimen shall have no cracks or open defects in the weld or heat affected zone that exceed 1/8 in..

MIL-STD-248D also requires visual, radiographic, and magnetic particle inspection to be performed. Visual inspection of all test assemblies shall be performed prior to other nondestructive testing. Radiographic examination shall be performed on 100 percent of the weld. Magnetic particle inspection is required and is intended for the detection of surface or near surface discontinuities. These requirements are not stated in the ASME Section IX procedure for procedure qualification.

Both standards require a welding performance qualification. In performance qualification, the basic criterion is to determine the welder's ability to deposit sound weld metal. Each welder/operator shall know the workmanship and the visual inspection requirements of all fabrication documents with which the welder will be working. Both standards ensure that each welder/operator has satisfactorily welded the applicable performance qualification test assemblies and that inspection of each qualification assembly is in accordance with requirements. The Performance qualification tests shall include the essential variables, the type of test and test results, and the range qualified for each welder/operator. As with the procedure qualification, both standards require requalification of the welder/operator if a change is made to any essential variables. A comparison of the performance qualification requirements of both standards for range and testing are shown in Tables 3 and 4.

Table 3. Welder Performance Qualification Thickness Range.

Welder Performance Qualification Material Thickness Limits

ASME Section IX

Thickness (T) of Test Material	Thickness (t) of Deposited Weld Metal Qualified (Max)
Up to 3/8	2t
Over 3/8, less than 3/4	2t
3/4 and over	Max. to be welded

MIL-STD-248D

Thickness (T) of Test Material	Range of Thickness (T) Qualified	
	Min.	Max.
Less than 3/4	T	2T
3/4 to less than 3	T	2T
3 and over	T	2T

Table 4. Welder Performance Qualification Test Requirements.

Welder Performance Qualification Assembly Test Requirements

ASME Section IX

Thickness (T) of Test Material	Type and Number of Tests Side	 Face	 Root
Up to 3/8	Note (2)	1	1
Over 3/8, less than 3/4	Note (3)	1	1
3/4 and over	2	...	...

MIL-STD-248D

Thickness (T) of Test Material	Type and Number of Tests Side	 Face	 Root
Less than 3/4	...	1	1
3/4 to less than 3	2	...	...
3 and over	2	...	...

Note (2): For a 3/8 in. thick coupon, a side-bend test may be substituted for each of the required face and root-bend tests.

Note (3): A side-bend test may be substituted for each of the required face and root-bend tests.

Radiographic examination may be substituted for mechanical testing for performance qualification to prove the ability of the welder/operator to make sound welds. This is stated in both standards.

Comparing maintenance and renewal of qualification, the standards differ slightly, the more stringent requirement being that of MIL-STD-248D. Maintenance of qualification for ASME Section IX, consists of at least one verification of process use during a (6) month period. MIL-STD-248D requires at least one verification of process use during each (3) month period or calendar quarter. Requalification is required when a (6) month period (ASME) or a (3) month period (MIL-STD-248D) is not maintained. Both standards require requalification when there is a specific reason to question the ability of the welder/operator to make welds that meet requirements. With MIL-STD-248D, each welder/operator must be re-tested every (3) years to maintain qualification of that process. ASME Section IX has no automatic requalification requirements based on time.

As noted, both standards are similar in the qualification requirements for procedure, performance, and testing and evaluation. In the certification of qualification testing, MIL-STD-248D states that procedure qualifications previously prepared for other Government agencies, American Bureau of Shipping (ABS), American Society of Mechanical Engineers (ASME), or other established regulatory codes may be submitted for approval. The qualification limitations for welding procedure qualifications performed for other agencies shall be as specified in this standard. As an example, a flat position ASME procedure qualification may only qualify flat position welding in accordance with this standard.

ASME Section IX does not make such a statement as listed above, but as stated prior, standards require a welding procedure qualification be performed to comply with the required properties for its intended application. Both standards require a welding performance qualification be performed to determine the ability of the welder/operator to produce sound weldments. Both standards require that the procedure and performance qualifications be tested and examined using nondestructive testing, destructive testing, or both.

Therefore, containers welded in accordance with MIL-STD-278 will be equivalent in quality to packagings welded to ASME Section IX.

CRITICALITY

1. Section 2.7.1.2 of the application states that after the horizontal 30 foot drop test, the distance between the deformed stiffener rings and the top of the fuel elements is 5 inches. Show that an array of damaged packages placed cover- to-cover, i.e., with a 10-inch fuel separation between adjacent containers, remains subcritical under accident conditions. Also verify that the criticality model for the accident conditions adequately represents the damaged package (see Item 3 under STRUCTURAL).

RESPONSE: It is the conclusion of BWFC that the accident model used in the original ANF licensing analysis, which is the same one used by the BWFC in it's license application, models the fuel in the most reactive configuration possible. This model is very conservative and additional accident calculations are not required.

ANF performed a 30 foot horizontal drop test on the Model 51032-1 shipping cask. The cask was positioned upside down with the top of the cask facing the test pad and dropped. The cask impacted the ground directly on the cask top. Appendix IV of the ANF license (see reference 1) indicated that "as well as could be detected visually, the container struck the test pad on a perfectly horizontal plane. The container was then turned over and its bottom pads and cover removed. Interior examination revealed that the strong back remained totally inside the container and that the fuel elements remained totally inside the strong back. Almost all of the fuel bundle clamps showed pronounced bowing; however, only one clamp came completely loose. Most of the bolts attaching the strong back cross beam to the strong back failed allowing the strong back to contact the top cover." Following the horizontal drop test numerous bolts and clamps were strengthened and the number of separator blocks were increased. The reader is referred to Appendix V of Reference 1 for a complete discussion of bolt modifications and static tests performed to assure that the shock mounts would dissipate energy without failure of the bolts connecting the strong back to the strong back cross beam. A drawing of the shock mount detail and strong back - cross beam bolts is shown in Figure 2.7 of Reference 1. It should be noted that it was the failure of the strong back bolts that allowed the fuel assembly pair to move as a unit within the cask and assume a more critical configuration. Should the drop test be repeated, only minor movement of the strongback would occur as the shock mount bolts are designed to bend (yield) to dissipate energy.

The contact point of the strong back and the top cover is shown in Figure 6.3 in reference 2 where the top cover is hemispherical. On page 49, section 10.1.1 of the ANF-52 Revision 5 licensing document (see reference 1), the statement is made "In its damaged condition, and as the package lay immediately following impact, the minimum distance between the top of the fuel elements and the outer edge of the deformed stiffener rings was 5 inches (3 inches between top of the fuel elements and the inner edge of the stiffener rings)." This statement in the ANF license document is not clear. From review of Appendix IV and the ANF calculation file it appears that the minimum distance between the top (edge) of the fuel elements and the outer edge of the deformed stiffener rings was 5 inches. The distance to the fuel assembly edge is being measured in the horizontal or x-axis plane. In the accident model using KENOIV, a minimum distance of 4.716 inches was modeled to the <u>top</u> of the stiffener rings (in the x-axis plane from the top edge of the fuel) because the closest proximity of fuel assemblies between casks is possible in this plane. Only larger separation distances are possible in the direction of the drop as will be shown later. With assumed movement of fuel assemblies within the strong back saddle, movement of the strong back itself, and flattening of the cask top (which was conservatively represented as a pitch reduction in both x and y-directions, compare Figures 6.2 and 6.3), the assemblies in two casks are moved towards each other in the x-direction by [(42.240 -39.240)/2 + 15.29248 - 11.5200] * 2 = 10.545 inches for the MkB 15X15 fuel assembly design. This results in a total separation distance between assemblies of (39.240/2 - 15.29248) * 2 = 8.655 inches.

The accident model also conservatively modeled the strong back shifting in the y-direction (toward the center of the cask top) by 1.6725 inches. Additionally, the cask deformation data and photographs (see Appendix IV of Reference 1) indicate some flattening of the cask top and stiffener rings due to impact. Therefore, the accident model had the pitch between casks reduced from 42.240 inches to 39.240 inches for a total of 3 inches in both x and y-directions. Since reflective boundary conditions are used in the infinite array problem, the casks are modeled with the top of one cask facing the top of another cask in groups of two. Therefore, fuel assembly distances between two casks were reduced by [(42.240-39.240)/2 + 1.6725] * 2 = 6.345 inches in the y-direction. For the MkB 15X15 fuel assembly design the total separation distance between assemblies in the y-direction in the accident configuration is (39.240/2 - (8.52 -2.55)) * 2 = 27.30 inches. The cask would need to be severely flattened in the y-direction (which the data and photographs in Reference 1 Appendix IV do not indicate) for the cover-to-cover separation distance between fuel assemblies in the y-direction to be reduced from a nominal value of 33.645 inches to only 10 inches. Even if it were assumed that the strong back broke loose and moved the maximum distance possible in only the y-direction and including the reduced pitch which represents cask flattening, there would still remain a minimum of 18.413 inches separating assemblies (cover-to-cover) using the MkB 15X15 assembly design. Finally, fuel-to-fuel distances of 10 inches or more are large enough that for fully flooded casks the neutron spectrums are decoupled (see Figure 6.16 and compare 10 and 12 inch separations). Therefore, movement of the fuel in the strong back in the x-direction was the most reactive configuration possible.

2. Show how the maximum bundle average enrichment was determined. Show that using the bundle average enrichment in the criticality calculations is appropriate and does not underestimate reactivity. Also, specify the maximum enrichment of any individual pellet and the maximum U-235 mass per assembly (the U-235 masses given in Table 6.1 appear to be based on the bundle average enrichment).

RESPONSE: The criticality analysis for the ANF shipping cask was performed assuming every rod and pellet in the assembly was at the maximum enrichment of 5.05 wt% U^{235} which includes an enrichment tolerance of 0.05 wt% U^{235}. The use of the term "average" enrichment was misleading. BWFC may at times load fuel rods of different enrichments in a fuel assembly but none of the as-built loadings for any rod will exceed the 5.05 wt% U^{235} maximum. The SAR was revised to eliminate the word "average" with regard to enrichment.

3. Specify the calculational bias, and show that the bias was determined with appropriate benchmarking procedures. Show that K_{eff} for the package and array of packages is less than 0.95 when adjusted for bias and uncertainty.

RESPONSE: Typically, a discussion of bias (or lack of one) is contained in section 6.5 in a Safety Analysis Report (SAR). The information concerning the bias for the ANF shipping cask was contained in section 6.3.1. The SAR was revised to have section 6.3 reflect a discussion of the calculational model, 6.4 to consider potential rod bow, and 6.5 reflect a discussion of the KENOIV bias.

APPENDIX 1A

MODEL 51032-2 SHIPPING CONTAINER
SIDE DROP ANALYSIS

1.0 PURPOSE

The purpose of this analysis is to determine if the required separation between fuel assemblies in the Shipping Container Model No. 51032-2(Ref. 1) is maintained following a 30 foot drop of the container on its side. The analysis method found in Appendix P-1 of References 2 and 3 will be followed.

2.0 SUMMARY

This conservative analysis indicates that for a 30 foot drop of the shipping container on its side, the top fuel assembly will fracture the positioning brackets and impact onto the separating blocks with a resulting maximum plastic deformation of 4.18 inches for lengthwise spacing of separator blocks of 29 inches. This deflection will result in a minimum local separation between fuel assemblies of about 2.5 inches. The clear distance between separation blocks required to maintain a 6 inch minimum separation between fuel assemblies is 11.4 inches.

3.0 IMPACT VELOCITY AND ENERGY

For a 30 foot drop, the Impact Velocity is,

$$v = (2gh)^{1/2} = ((2)(386\ in/sec^2)(30\ ft)(12\ in/ft))^{1/2}$$

$$v = 527\ in/sec$$

Fuel Assembly Weight(maximum for licensing) ≈ 1650 lbs. (Ref.2)

Impact Energy = $\frac{1}{2}\ mv^2 = \frac{1}{2}(1650/386)(527)^2$ = 593,592 in-lbs.

4.0 ENERGY ABSORBED BY BRACKET AND FUEL

It was found, in the corresponding section of the analysis in Appendix P-1 of Reference 2, that the amount of available energy absorbed by the brackets and the fuel assembly during the fracture of the bracket bolts is **negligible**. Therefore, for conservatism, it will be assumed in the present analysis that the energy absorbed by the bracket and fuel is **zero**.

5.0 IMPACT OF FUEL ASSEMBLY ON SEPARATOR BLOCKS

5.1 Separator Block Spacing

The fuel assembly will thus impact the 6"x8"x9"long separator blocks with a large amount of kinetic energy. Since the separator blocks are relatively rigid, this energy will be absorbed in the fuel assembly primarily by "plastic strain." The impact velocity would be the maximum velocity calculated in Section I(i.e. 527 in/sec).

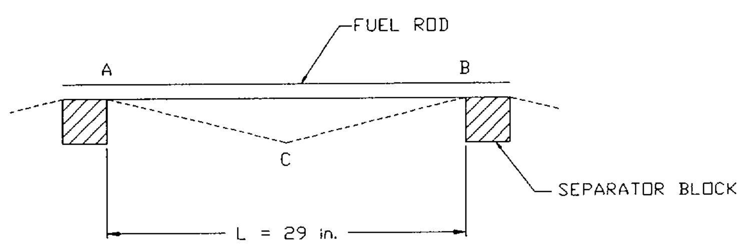
For impact at this velocity, it is unlikely that the spacer grids will provide significant lateral shear resistance. Therefore, it will be assumed that the fuel rods act individually, instead of as a composite structure. It will also be assumed in this section that the separator blocks are rigid and do not deflect upon impact.

The "clear" distance between separator blocks for the shipping container used as a basis for analysis is 29 inches. The MK-B9 Fuel Rod weight-per-inch(Ref. 4) is approximately 6.94/151 ≈ 0.046 lbs/in. Thus, for a 29 inch span, the impact energy that must be absorbed by a single fuel rod is,

$$E_f = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}(0.046 \text{ lbs/in})(29 \text{ in.})(527 \text{ in/sec})^2/(386 \text{ in/sec}^2)$$

$$E_f \approx 480 \text{ in-lbs.}$$

Assuming plastic hinges form at locations A, B, and C on the impacting fuel rod, the internal work is derived by the following,



Work = $\tfrac{1}{2}P\delta$ (Ref. 5) where $P = 16M_p/L$ (case 2d, p.225, Ref. 6)
M_p = the fully plastic moment at each hinge of the deformed fuel rod.
$\delta = (L/2)(\theta)$

Substitution gives,

Work = $4M_p\theta$

For the fuel rod cross section (Ref. 7),

$M_p = \sigma_y \cdot 4/3 \cdot (R^3 - R_i^3)$ where σ_y = yield stress
$2R$ = O.D. of cladding = 0.430"
$2R_i$ = I.D. of cladding = 0.377"

Although the previous expression is actually only applicable for perfectly plastic materials, and Zircaloy-4 exhibits strain hardening, it is considered valid in this case due to the "approximate" nature of the calculation. To somewhat compensate for the strain hardening effect, σ_y will be taken as the average of the yield and ultimate strength of the Zirc-4 fuel rod. The yield strength and ultimate strength of cold-worked Zirc-4 cladding at 70°F are 81,000 psi and 112,000 psi, respectively (Ref. 8).

$\therefore\ \sigma_y \approx (81{,}000 + 112{,}000)/2 = 96{,}500$ psi.
$\therefore\ M_p = (96{,}500)(4)((0.430/2)^3-(0.377/2)^3)/3 = 417$ in-lbs.

It should be noted that this neglects the possible increase in strength under dynamic loading.

Equating internal work to impact energy gives the following,

$4M_p\theta = \frac{1}{2}mv^2$
$\therefore\ \theta = (\frac{1}{2}mv^2)/(4M_p) = (480 \text{ in-lbs})/((4)(417 \text{ in-lbs}) = 0.288$ rad

The maximum strain is then,

$\epsilon = 2R\theta = (2)(0.430/2)(0.288) = 0.124$ in/in = 12.4 %

Therefore, the maximum plastic deflection of the fuel rod is,

$\delta = \theta \cdot L/2 = (0.288)(29/2) = 4.18$ in.

Fuel assembly-to-separator block spacing (See Figure 1), prior to drop, assuming the fuel assembly outer envelope is 8.54 in. for MK-B, can be calculated as follows,

$(24.375 - (2)(8.54) - 6)/2 = 0.648$ in.

The minimum spacing between fuel assemblies is then,

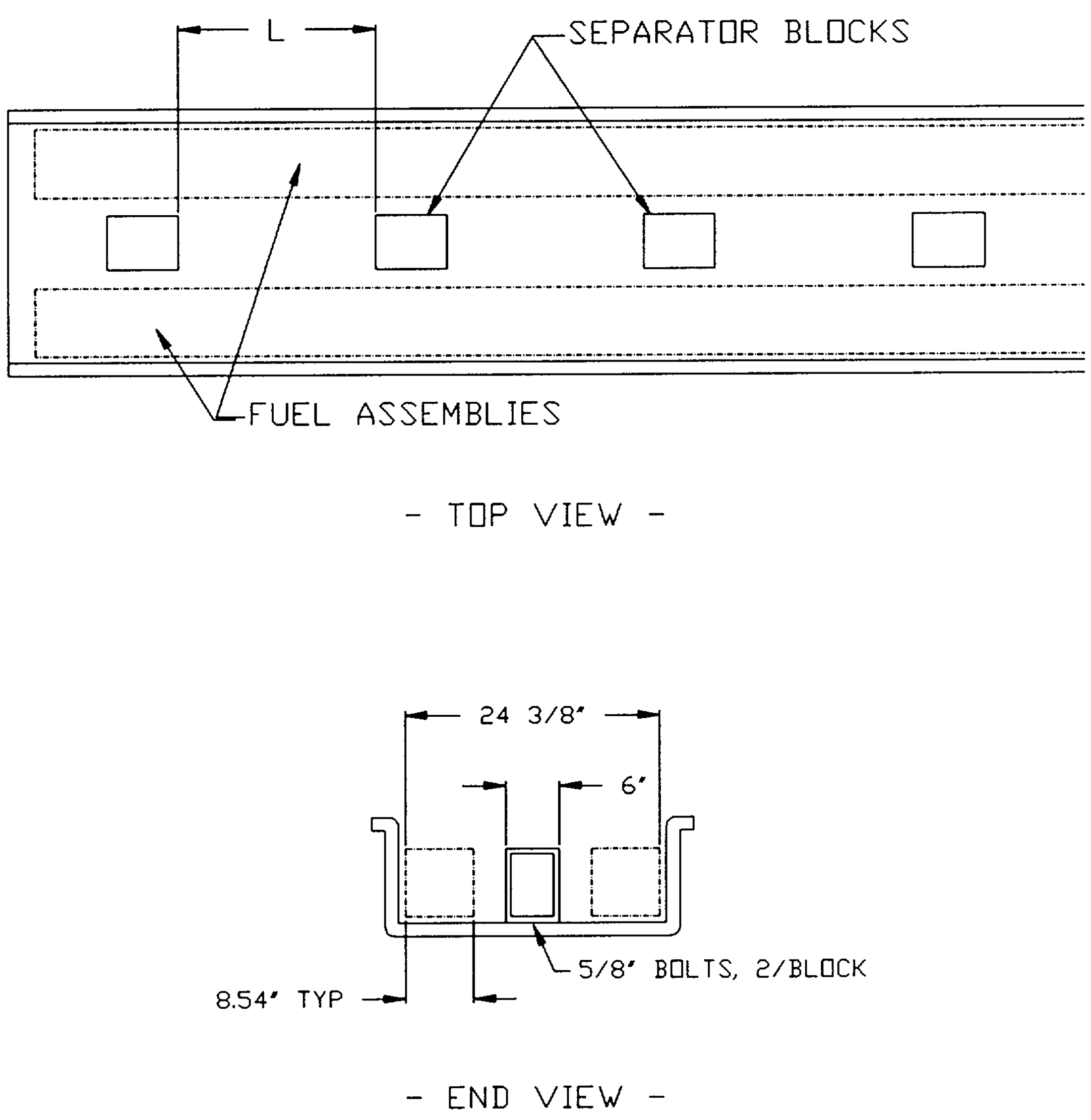
$6 + 0.648 - 4.18 \approx 2.5$ in. $\ll 6$ in. required

It is concluded that the "clear" distance between separator blocks required to maintain a 6 inch minimum separation between fuel assemblies is,

$\delta_{max} = 6 + 0.648 - 6 = 0.648 \text{ in} = \theta L/2 = ((0.288)(L/29))\cdot(L/2)$

$\therefore\ L = ((0.648)(2)(29)/(0.288))^{1/2} \approx$ <u>11.4 in.</u>

Figure 1 - Strongback Channel



5.2 Separator Block Bolts

The impact force of the fuel assembly on the separator block following a 30 foot drop of the container on its side will be estimated. It will be assumed that this force will be transferred to the separator block bolts in the form of a direct shear force through their cross sectional area. The designed bolts are made from 5/8" diameter Grade 8 High Strength Steel(Ref. 9).

A finite element model of the separator block using "shell" elements (STIF 63) was made on ANSYS 4.4A(Ref. 10) to estimate the block stiffness. Loads ranging from 2,000 to 100,000 pounds were applied at the center of one side of the block(nodes 105 & 106), while two points in the approximate location of the bolts were constrained in 6 degrees-of-freedom and the nodes along bottom edge of the block were constrained in the Z-direction to simulate the constraint of the strongback that the block is bolted to(See Figure 2). The actual impact load of the F/A onto the separator block would be more distributed, therefore this is considered conservative.

The results can be seen in Figure 3 in terms of an apparent linear "Load vs. Deflection", from which the approximate stiffness of the separator block, in its actual orientation, is determined. It should be noted that in this section it is assumed that the strongback and F/A are rigid and do not deflect or absorb energy upon impact. All energy is thus absorbed by the separator block and bolts, where the stiffness of the block is the limiting case. This is also conservative. The calculated stiffness of the block is 52,000 lbs/in. An unrestrained deflection, "x", is then determined for the above stiffness by equating kinetic energy and "elastic" potential energy as follows,

$\frac{1}{2}mv^2 = \frac{1}{2}kx^2$ where m = 1650 lbs./9 blocks = 183 lbs.
v = 527 in/sec (Section 3.0)
k = 52,000 lbs./in. (Figure 3)

$x = ((183)(527)^2/(386)(52{,}000))^{1/2} = 1.59$ in.

Figure 2 -
Separator Block ANSYS Model

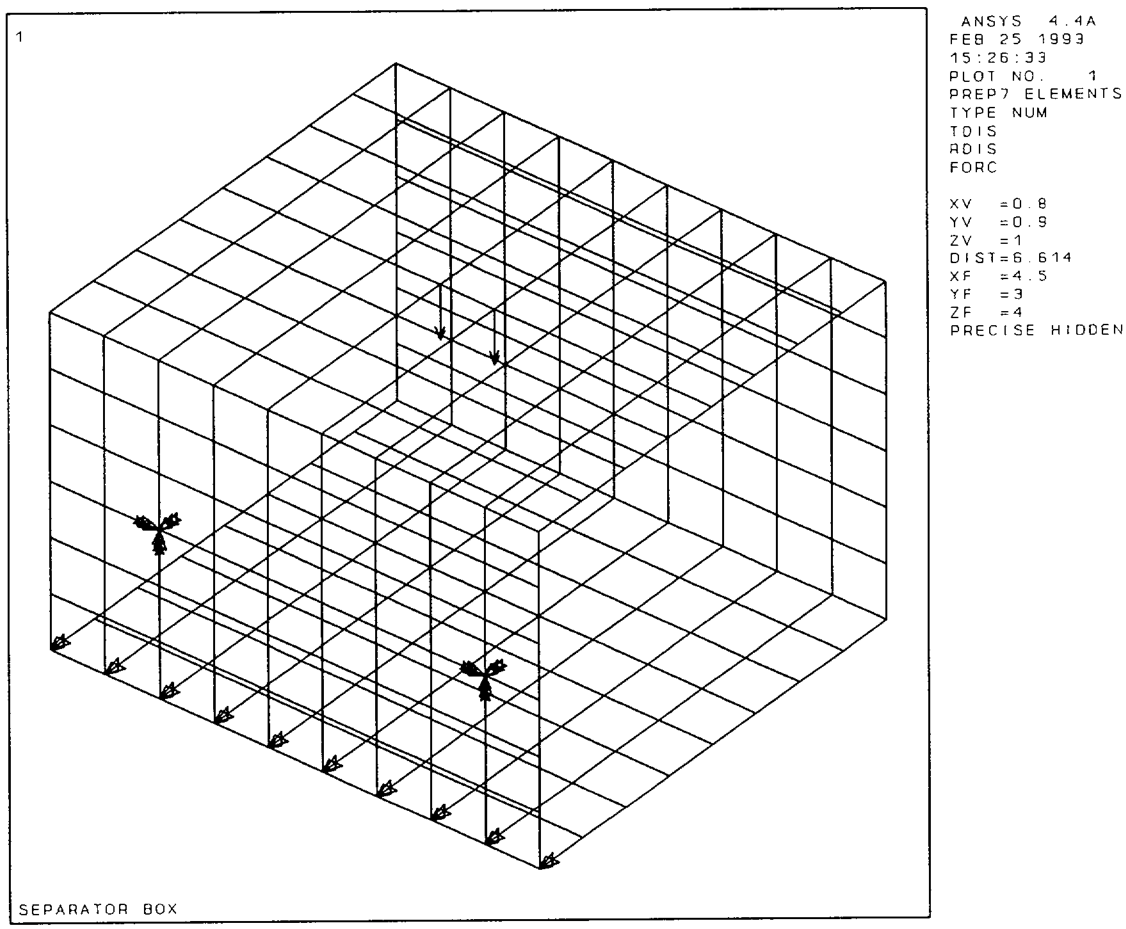
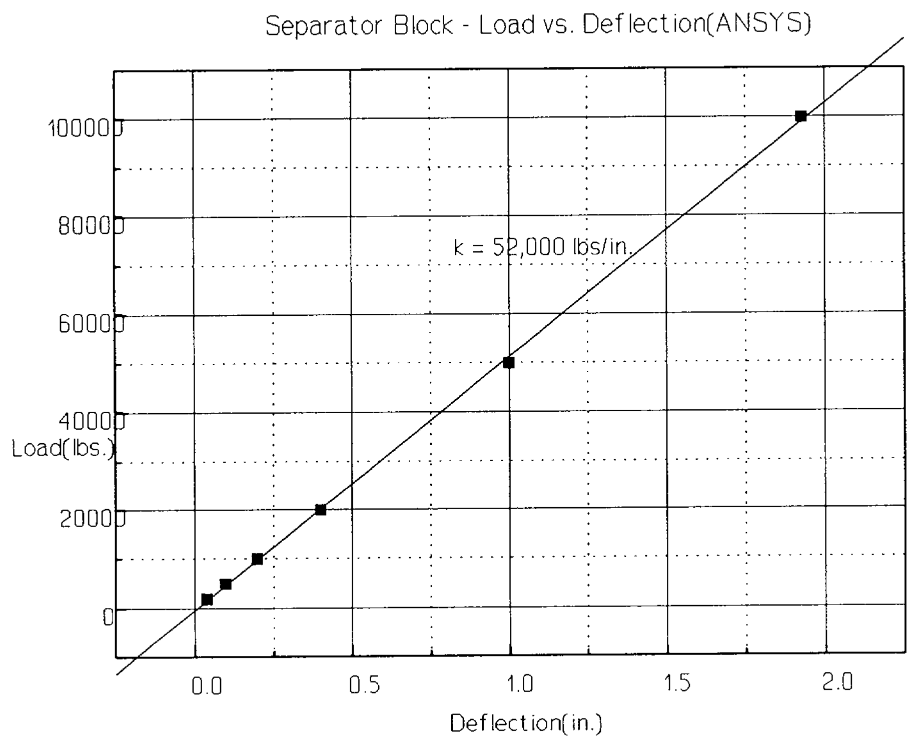


Figure 3 -
Separator Block - Load vs. Deflection(ANSYS)



The impact force can then be estimated as follows,

$$F = kx = (52,000)(1.59) = 82,680 \text{ lbs.}$$

The allowable shear stress is as follows (Ref. 11),

$$\tau_{allow} = (0.6)(\sigma_y) = (0.6)(130,000) = 78,000 \text{ psi.}$$

The shear stress in the bolts is then,

$$\tau = F/A_{bolts} \qquad \text{where } A_{bolts} = (2)((\pi)(5/8)^2/4)$$

$$\tau = 82,680/0.614 = 134,747 \text{ psi.} >> 78,000 \text{ psi.}$$

Assuming 2 bolts are used per separator block, the required bolt diameter can be determined as follows,

$$\tau_{allow} = (F)/((2)(\pi)(d)^2/4)$$

$$d_{min} = ((2)(82,680)/(\pi)(78,000))^{1/2} = 0.821 \text{ in.} \rightarrow 7/8"$$

6.0 CONCLUSIONS AND RECOMMENDATIONS

It has been shown by the present analysis that the maximum "clear" spacing between separator blocks, to maintain a 6 inch minimum fuel assembly separation, following a 30 foot drop of the shipping container on its side, is 11.4 inches. It has also been shown conservatively that, as a minimum, 7/8" diameter bolts should be used to withstand the shear of the impact force. It is recommended that 1" bolts be used. Due to the high deflection calculated in Section 5.2, it is also recommended that a 3/8" inch rectangular gusset be fillet welded within each separator block, perpendicular to the length of the square tubing and located lengthwise between bolt holes. This will stiffen the separator block, minimize deformation due to such high impact loads, and most likely eliminate interference of the separator block with the other adjacent fuel assembly.

7.0 REFERENCES

1. A) 02-1215929D-01, MODEL 51032-2 VESSEL(ISOMETRIC VIEW).

   B) 02-1085158D-01, SHIPPING CONTAINER FOR JERSEY NUCLEAR CO. FUEL ASSEMBLIES(51032-1)

   C) 02-1085281A-00, TUBE(SEPARATOR BLOCK).

   D) 02-1085191B-00, SEPARATOR ASSEMBLY.

2. 38-1210302-00, CONSOLIDATED LICENSE APPLICATION FOR ANF FOR MODEL NO. 51032-1 SHIPPING CONTAINER.

3. 43-10188A-00, APPLICATION FOR USE OF MODEL NO. 51032-1 SHIPPING CONTAINER FOR TRANSPORT.

4. 32-1202241-00, MK-B9 FUEL ROD VOLUME & WEIGHT, O. PACHECO.

5. <u>MECHANICS OF MATERIALS</u>, 2ND EDITION, GERE & TIMOSHENKO, PWS, BOSTON, 1984.

6. <u>ROARK'S FORMULAS FOR STRESS AND STRAIN</u>, YOUNG, MCGRAW-HILL, N.Y., 1989.

7. 02-1190498C-03, MK-B FUEL ROD TUBING(AS ORDERED).

8. 32-1173370-00, TENSILE PROPERTIES OF ZIRC-4 F/R CLADDING, S. WILLIAMS.

9. SAE-J429, MECH. AND MATL. REQ. FOR EXTERNALLY THREADED FASTENERS, AUGUST 1983, GLOBAL ENGINEERING DOCUMENTS.

10. BWNT-TM-83, REV. ORIG. 6/92. ANSYS REVISION 4.4A ENGINEERING ANALYSIS SYSTEM USERS MANUAL, VOLUMES 1 & 2.

11. ASME CODE SECTION III, APPENDIX F.