OBJECT

THE OBJECT OF THIS CALCULATION IS TO DETERMINE IF THE REQUIRED SEPARATION BETWEEN FUEL ASSEMBLIES IN THE SHIPPING CONTAINER IS MAINTAINED FOLLOWING A 30 FOOT DROP OF THE CONTAINER ON ITS SIDE.

RESULTS AND CONCLUSIONS

THIS CONSERVATIVE AND APPROXIMATE CALCULATION INDICATES THAT FOR A 30' DROP OF THE SHIPPING CONTAINER ON ITS SIDE, THE TOP FUEL ASSEMBLY WILL FRACTURE THE POSITIONING BRACKETS AND IMPACT ON THE SEPARATIVE BLOCKS WITH A RESULTING MAXIMUM PLASTIC DEFLECTION OF 5.15 IN. THIS DEFLECTION WILL RESULT IN A MINIMUM LOCAL SEPARATION BETWEEN FUEL ASSEM. OF ~2 IN. THE CLEAR DISTANCE BETWEEN SEPARATOR BLOCK REQUIRED TO MAINTAIN A 6 IN. MIN. SEPARATION BETWEEN ASSEMBLIES IS 14 IN.

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COMBUSTION ENGINEERING, INC.
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SUBJECT ______

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I. IMPACT VELOCITY & ENERGY

FOR A 30' DROP THE IMPACT VELOCITY IS

$$V = \sqrt{2gh} = \sqrt{2 \times 386 \times 30 \times 12} = 527 \text{ in/sec.}$$

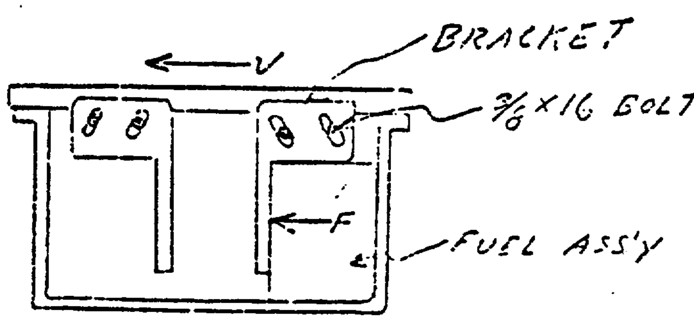
FUEL ASSEMBLY WT. ≈ 1200 lbs

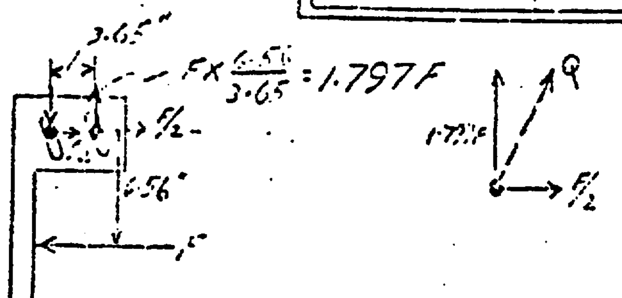
FUEL ASSEMBLY WT./IN = 1200/136.7 = 8.78 lb/in

$$\text{IMPACT ENERGY} = \tfrac{1}{2}mv^2 = \tfrac{1}{2}\left(\tfrac{1200}{386}\right)(527)^2 = 431,700 \text{ in-lbs}$$

II. ENERGY ABSORBED BY BRACKET & FUEL

UPON INITIAL IMPACT THE INERTIA LOAD FROM THE TOP FUEL ASSEMBLY IS REACTED BY THE POSITIONING BRACKETS LOCATED AT EACH SPACER GRID (16 IN. SPACING





BOLT SHEAR LOAD $Q = \sqrt{(\tfrac{F}{2})^2 + (1.797F)^2} = 1.87F$

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MANUFACTURING WAS UNABLE TO PROVIDE ANY INFORMATION ON THE 3/8 X 16 BRACKET BOLT MATERIAL OTHER THAN THAT THEY ARE COMMON CARBON STEEL STOCK BOLTS. THIS TYPE OF OFF-THE-SHELF BOLT HAS A UTS OF ~ 65,000 PSI. ASSUMING AN ULTIMATE SHEAR STRENGTH = .6 X UTS = 39,000 PSI. FROM REF. 1 p. 559 THE INCREASE IN TENSILE STRENGTH DUE TO DYNAMIC LOADING IS ~ 30%. THEREFORE IT WILL BE ASSUMED THAT THE DYNAMIC SHEAR STRENGTH OF THE BOLTS ≈ 1.3 × 39,000 = 50,000 PSI. THUS, THE LOAD Q TO SHEAR THE BOLTS IS

$$Q = 50{,}000A = 1.87F \qquad A = .074\ in^2 \text{ (AREA OF } \tfrac{3}{8} \times 16 \text{ BOLT)}$$

$$\therefore F = \frac{50{,}000A}{1.87} = \frac{50{,}000(.074)}{1.87} \approx 2000\ lbs$$

REF. 1. FAUPEL, J. H.; ENGINEERING DESIGN; JOHN WILEY & SONS, INC. NEW YORK 1964

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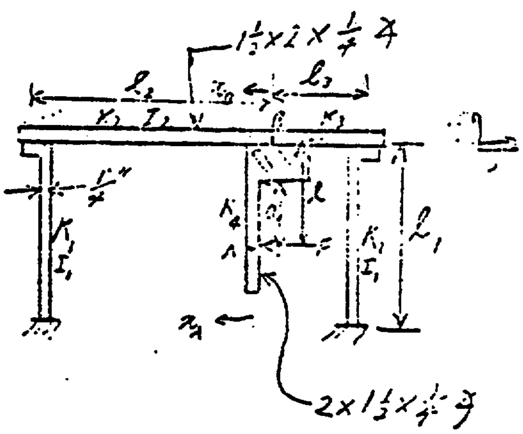
IN DETERMINING THE ENERGY ABSORBED BY THE BRACKET IT IS ASSUMED THAT THE BRACKET ACTS AS A LINEAR SPRING UP TO THE LOAD REQUIRED TO SHEAR THE BOLTS. THE ENERGY ABSORBED BY THE BOLTS IS MINOR AND IS NEGLECTED.



$\ell_1 = 12.25''$
$E = 29\times10^6$ psi
$\nu = .3$
$\ell_2 = 16.75''$
$\ell_3 = 6''$
$\ell = 7.43''$
$a = 4.06$

$$x_B = F_2\left(\frac{1}{K_1}+\frac{1}{K_2}\right) = F_3\left(\frac{1}{K_3}+\frac{1}{K_1}\right)$$

$$F = F_2 + F_3$$

$$\text{Let } \alpha = \left(\frac{1}{K_1}+\frac{1}{K_2}\right),\quad \beta = \left(\frac{1}{K_3}+\frac{1}{K_1}\right)$$

$$\therefore \alpha F_2 = \beta F_3$$

$$F_2 + F_3 = F$$

$$\therefore F_2 = \frac{\beta}{\alpha+\beta}F$$

$$x_B = \alpha F_2 = \frac{\alpha\beta}{\alpha+\beta}F$$

$$x_A = x_B + \ell\theta_B + \frac{F}{K_4} = \frac{\alpha\beta}{[illegible]}F + \frac{\ell^2}{[illegible]}\left(\ell_1 - \frac{\ell_2^{\,2}}{[illegible]} - \frac{\ell_1 \ell_3}{[illegible]}\right)F + \frac{F}{[illegible]}$$

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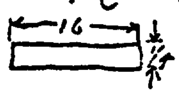
$$\therefore K = \frac{F}{x_A} = \frac{1}{\left[\frac{\alpha\beta}{\alpha+\beta} + \frac{\ell_1^2}{EI_2}\left(\ell_2 - \frac{\ell_2^2}{\ell_2+\ell_3} - \frac{\ell_2+\ell_3}{3}\right) + \frac{1}{K_4}\right]}$$

$$K_1 = \frac{12EI_1}{\ell_1^3(1-\nu^2)}$$



$$I_1 = \frac{16\left(\frac{1}{4}\right)^3}{12} = \frac{1}{48}$$

$$K_1 = \frac{12 \times 29\times10^6 \times \frac{1}{48}}{12.25^3(1-.09)} = 4.32\times10^3 \text{ lbs/in}$$

$$K_2 = \frac{A_2 E}{\ell_2} \qquad A_2 = \text{AREA OF } 2\times1\tfrac{1}{2}\times\tfrac{1}{4}\ \text{[illegible]} = .81\text{ in}^2, \quad I_2 = .15\text{ in}^4$$

$$K_2 = \frac{.81\times29\times10^6}{18.75} = 1.25\times10^6 \text{ lbs/in}$$

$$K_3 = \frac{A_2 E}{\ell_3} = \frac{.81\times29\times10^6}{6} = 3.92\times10^6 \text{ lbs/in}$$

$$\frac{\alpha\beta}{\alpha+\beta} = \frac{\left(\frac{1}{K_1}+\frac{1}{K_2}\right)\left(\frac{1}{K_1}+\frac{1}{K_3}\right)}{\left(\frac{1}{K_1}+\frac{1}{K_2}\right)+\left(\frac{1}{K_1}+\frac{1}{K_3}\right)} = \frac{\left(\frac{1}{4.32\times10^3}+\frac{1}{1.25\times10^6}\right)\left(\frac{1}{4.32\times10^3}+\frac{1}{3.92\times10^6}\right)}{\left(\frac{1}{4.32\times10^3}+\frac{1}{1.25\times10^6}\right)+\left(\frac{1}{4.32}+\frac{1}{3.92\times10^6}\right)}$$

$$= 1.155\times10^{-4}$$

$$\frac{\ell^2}{EI_2}\left(\ell_2 - \frac{\ell_2^2}{\ell_2+\ell_3} - \frac{\ell_2+\ell_3}{3}\right) = \frac{7.43^2}{29\times10^6\times.15}\left(18.75 - \frac{18.75^2}{18.75+6} - \frac{18.75+6}{3}\right) = .4701\times10^{-?}$$

$$\frac{1}{K_4} = \frac{a^3}{3EI_4} = \frac{4.06^3}{3\times29\times10^6\times.32} = .0240\times10^{-4}$$

$$\therefore K = \frac{1\times10^4}{[1.155+.4101+.0240]} = 6.07\times10^3 \text{ lbs/in}$$

SINCE $F = 2000$ lbs (see p. 3)

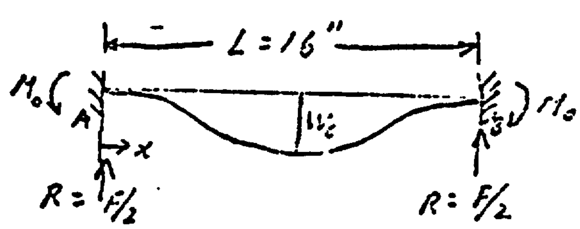
$$x_A = \frac{F}{K}$$

ENERGY ABSORBED BY BRACKET, $E_b = \frac{1}{2} K x_A^2 = \frac{1}{2} K \left(\frac{F}{K}\right)^2$

$$= \frac{1}{2}\frac{F^2}{K} = \frac{1}{2} \times \frac{2000^2}{6.07 \times 10^3} = 330 \text{ in-lbs}$$

FOR 8 BRACKETS $E_{bT} = 8 \times 330 = 2640$ in-lbs

TO APPROXIMATE THE BENDING ENERGY ABSORBED BY THE FUEL ON IMPACTING THE BRACKETS A SINGLE SPAN BETWEEN BRACKETS WITH A SINUSOIDAL INERTIA LOADING IS ASSUMED



$w_x = w_c \sin \frac{\pi x}{L}$ where $w_c = \frac{F\pi}{2L}$

$$\Delta_A = \frac{\partial U}{\partial R} = \int_0^L M \frac{\partial M}{\partial R} \frac{dx}{EI} = 0$$

$$\theta_A = \frac{\partial U}{\partial M_o} = \int_0^L M \frac{\partial M}{\partial M_o} \frac{dx}{EI} = 0$$

$$M_{(x)} = M_o - Rx + \frac{w_c L x}{\pi} - \frac{w_c L^2}{\pi^2} \sin \frac{\pi x}{L}$$

$$\frac{\partial M}{\partial R} = -x, \quad \frac{\partial M}{\partial M_o} = 1$$

$$\int_0^L M \frac{\partial M}{\partial R} \frac{dx}{EI} = \frac{1}{EI}\int_0^L \left(M_0 - Rx + w_0 \frac{L}{\pi} x - \frac{w_0 L^2}{\pi^2} \sin\frac{\pi x}{L}\right)(-x)\,dx$$

$$= \frac{1}{EI}\left[-\frac{M_0 L^2}{2} + R\frac{L^3}{3} - w_0 \frac{L^4}{3\pi} + \frac{w_0 L^4}{\pi^3}\right] = 0$$

$$\therefore \quad R\frac{L}{3} - \frac{M_0}{2} = w_0 L^2\left(\frac{1}{3\pi} - \frac{1}{\pi^3}\right)$$

$$\int_0^L M \frac{\partial M}{\partial M_0} \frac{dx}{EI} = \frac{1}{EI}\int_0^L \left(M_0 - Rx + w_0 \frac{L}{\pi} x - \frac{w_0 L^2}{\pi^2} \sin\frac{\pi x}{L}\right)dx$$

$$= \frac{1}{EI}\left[M_0 L - R\frac{L^2}{2} + w_0 \frac{L^3}{2\pi} - 2 w_0 \frac{L^3}{\pi^3}\right] = 0$$

$$\therefore \quad R\frac{L}{2} - M_0 = w_0 L^2\left(\frac{1}{2\pi} - \frac{2}{\pi^3}\right)$$

THUS $R = \frac{w_0 L}{\pi}$

$M_0 = \frac{2 w_0 L^2}{\pi^3}$

AND $M_{(x)} = \frac{2 w_0 L^2}{\pi^3} - \frac{w_0 L^2}{\pi^2} \sin\frac{\pi x}{L}$

$M_{(x)\,MAX}$ @ $x = 0$ $= M_0$

$$M_0 = \frac{2 w_0 L^2}{\pi^3} = \frac{2\left(\frac{F\pi}{2L}\right)L^2}{\pi^3} = \frac{FL}{\pi^2}$$

FROM REF 2 - CALC. # 23666-16-10-36 by G. DEGRASSI 6/9/70

EI FOR OMAHA FUEL ASS'Y = 20×10^6 PSI FOR LARGE DEFLECTI[ON]
$E = 15.3 \times 10^6$ FOR ZIRC-4 @ 1600°F

$\therefore I = \frac{20 \times 10^6}{15.3 \times 10^6} = 1.3$

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$$\sigma_{max} = \frac{M_0 c}{I} \approx \frac{\frac{FL}{\pi^2} c}{I} = \frac{2000 \times \frac{16}{\pi^2} \times 4}{1.3} \approx 10{,}000 psi < Y.S \text{ FOR ZIRC-4}$$

$\therefore$ FUEL ASSEMBLY IS ELASTIC

ENERGY ABSORBED BY FUEL ASSY = E_f

$$E_f = \int_0^L \frac{M_x^2 dx}{2EI} = \frac{1}{2EI}\int_0^L \left(\frac{2W_0 L^2}{\pi^3} - \frac{W_0 L^2}{\pi^2} \sin\frac{\pi x}{L}\right)^2 dx$$

$$= \frac{1}{2EI}\left(\frac{F^2 L^3}{\pi^2}\right)\left(\frac{1}{8} - \frac{1}{\pi^2}\right) = \frac{1}{2 \times 20 \times 10^3}\left(\frac{2000^2 \cdot 16^3}{\pi^2}\right)\left(\frac{1}{8} - \frac{1}{\pi^2}\right) = 1 \text{ in-lb}$$

FOR 8 SPANS

$E_{fT} = 8 \times 1 = 8$ in lbs

$\therefore$ ENERGY REMAINING AFTER BRACKET BOLT FRACTURE

$= 431{,}700 - 330 - 8 = 431{,}360$ in-lbs

$\therefore$ BRACKETS & FUEL ABSORB VERY LITTLE ENERGY

III. IMPACT OF FUEL ASSEMBLY ON SEPARATOR BLOCK

IN THE PREVIOUS SECTION IT WAS SHOWN THAT THE BRACKETS & FUEL ABSORB A NEGLIGIBLE AMOUNT OF THE AVAILABLE ENERGY DURING FRACTURE OF THE BRACKET BOLTS. THUS THE FUEL ASSEMBLY WILL IMPACT

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THE 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 IS

$$v = \sqrt{\frac{2(W)L}{m}} = \sqrt{\frac{2(431,360)}{1200/386}} = 526.7 \text{ in/sec}$$

FOR IMPACT AT THIS VELOCITY IT IS UNLIKELY THAT THE SPACER GRIDS WILL PROVIDE SIGNIFICANT LATERAL SHEAR RESISTANCE. THUS IT WILL BE ASSUMED THAT THE FUEL RODS ACT INDIVIDUALLY INSTEAD OF AS A COMPOSITE STRUCTURE.

THE LARGEST CLEAR DISTANCE BETWEEN SEPARATOR BLOCKS FOR THE OMAHA CONTAINER IS ~ 29 IN. AND THE FUEL ROD WEIGHS ~ .051 LBS/IN. THUS FOR THE 29 IN. SPAN THE IMPACT ENERGY THAT MUST BE ABSORBED IN A SINGLE FUEL ROD IS

$$E_1 = \frac{1}{2} m v^2 = \frac{1}{2} \times \frac{.051 \times 29}{386} \times 526.7^2 = 531.5 \text{ in-lbs}$$

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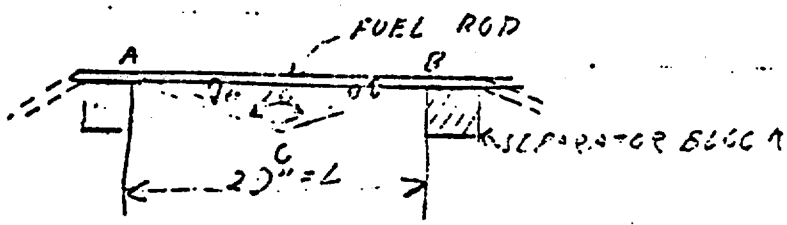
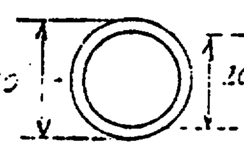


ASSUMING PLASTIC HINGES FORM AT LOCATIONS, A, B & C ON THE IMPACTING FUEL ROD THE INTERNAL WORK IS $4M_p\theta$ WHERE M_p IS THE FULLY PLASTIC MOMENT AT EACH HINGE. FOR THE FUEL ROD CROSS SECTION

$$M_p = \sigma_y \frac{4(b^3 - a^3)}{3} \quad \text{-- Ref. 1 p. 395}$$

WHERE σ_y = YIELD STRESS



ALTHOUGH THIS EXPRESSION IS ACTUALLY ONLY APPLICABLE FOR PERFECTLY PLASTIC MATERIALS AND ZIRC-4 EXHIBITS STRAIN HARDENING IT IS CONSIDERED VALID IN THIS CASE IN VIEW OF THE APPROXIMATE NATURE OF THE WHOLE CALCULATION. TO SOMEWHAT COMPENSATE FOR THE STRAIN HARDENING EFFECT σ_y WILL BE TAKEN AS THE AVG. VALUE BETWEEN THE YIELD & ULTIMATE STRENGTHS [illegible]

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ZIRC-4 FUEL ROD.

FROM REF 3 - MEMO - NLM-70-255, July 7, 1970 FOR ZIRC-4 TUBING 15% COLD WORKED THE AVG. VALUES FOR Y.S @ OTS ARE 72,000 & 96,000 PSI RESPECTIVELY

$$\therefore \sigma_y = \frac{72{,}000 + 96{,}000}{2} = 84{,}000 \text{ psi}$$

$$\therefore M_p = 84{,}000(4)\frac{\left[\left(\frac{.440}{2}\right)^3 - \left(\frac{[illegible]}{2}\right)^3\right]}{3} = 375 \text{ in-lbs}$$

THIS NEGLECTS THE POSSIBLE INCREASE IN STRENGTH UNDER DYNAMIC LOADING SINCE THIS INFORMATION IS NOT AVAILABLE.

EQUATING INTERNAL WORK TO IMPACT ENERGY GIVES

$$4M_p\,\theta = \tfrac{1}{2}mv^2$$

$$\therefore \theta = \frac{\frac{1}{2}mv^2}{4M_p} = \frac{531.5}{4 \times 375} = .355 \text{ rad}$$

THE MAX. STRAIN IS $\epsilon = 2b\theta = 2 \times \frac{.440}{2} \times .355 = .156 \text{ in/in} = 15.6\%$

FROM REF 3 THE AVG. ELONGATION FOR ZIRC-4 IS 23%

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∴ THE MAXIMUM PLASTIC DEFLECTION OF THE FUEL ROD IS

$$\delta = \theta \cdot \frac{L}{2} = .355 \times \frac{29}{2} = 5.15 \text{ in.}$$

THUS THE MIN SPACING BETWEEN ASSEMBLIES IS

$$6 + 1.19 - 5.15 \approx 2 \text{ IN.}$$

BY THIS ANALYSIS THE CLEAR DISTANCE BETWEEN SEPARATOR BLOCKS REQUIRED TO MAINTAIN A 6 IN. MIN. SEPARATION BETWEEN ASSEMBLIES IS 14 IN.

$$\delta_{max} = 6 + 1.19 - 6 = 1.19 \text{ IN} = \frac{\theta L}{2} = .355 \frac{L}{29} \times \frac{L}{2}$$

$$\therefore L = \sqrt{\frac{1.19 \times 2 \times 29}{.355}} \approx \underline{14 \text{ IN.}}$$

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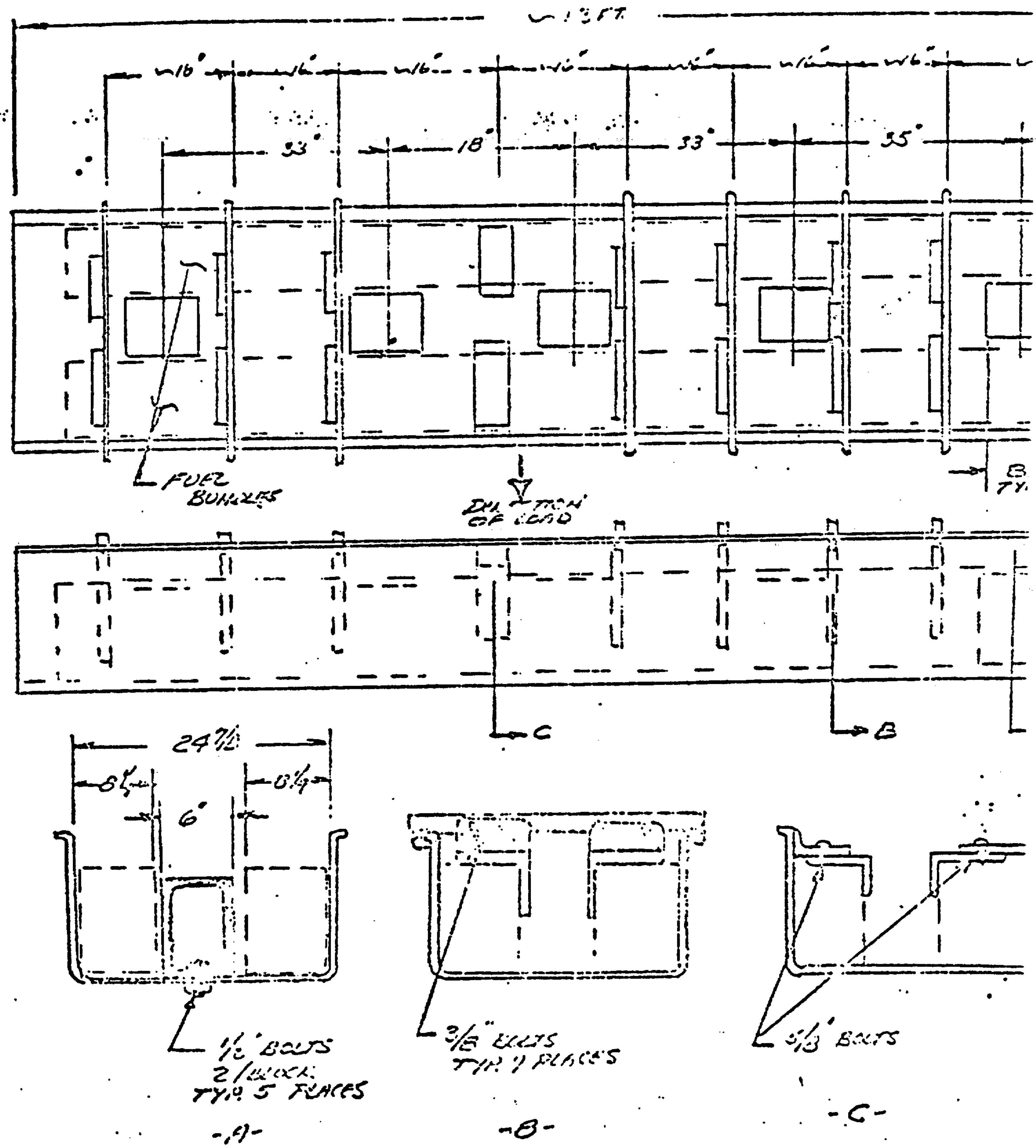


3.71.22 Package Description

A. Package

(1) Gross Weight of Loaded Shipping Container is 7000 lbs.

(2) Model Number - 92/C

(3) The shipping container is made of carbon steel and is described in the documents listed in 71.22 A (3), except that the two assemblies are separated by 1/4 inch thick 6 inch wide carbon steel spacer blocks and the overall length is increased to 216 1/2 inches, as shown in sketches #P-11 and P-12.

(4) Receptacles

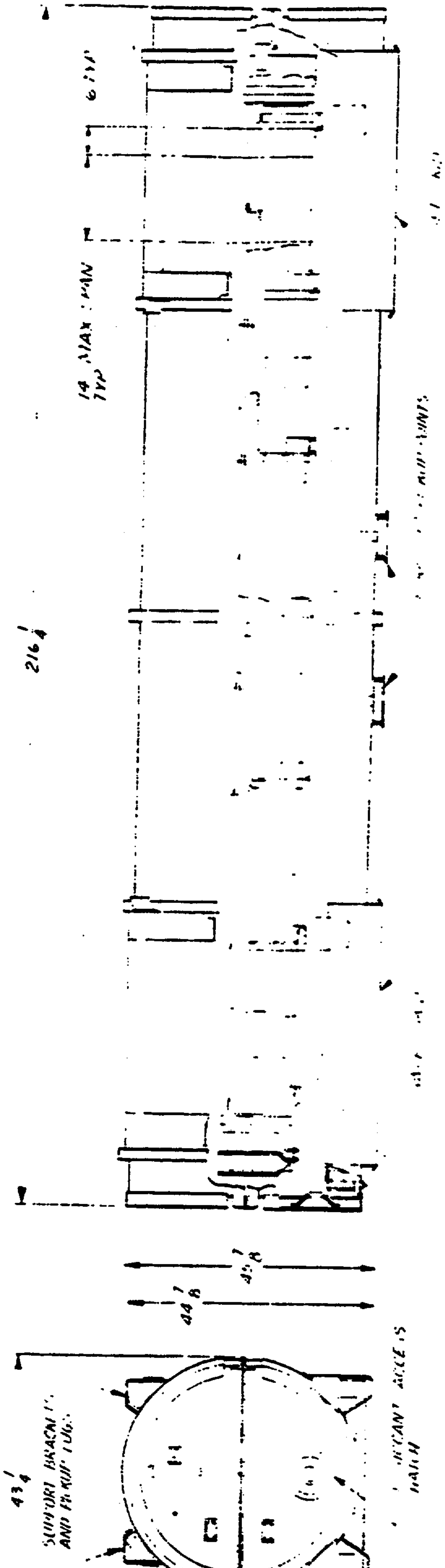
The containment vessel for the two (2) fuel bundles is the 43 in. diameter outer shell of the shipping container.

(5) The pressure release valves and lifting devices are also shown in the referenced drawings. There are no sampling ports.

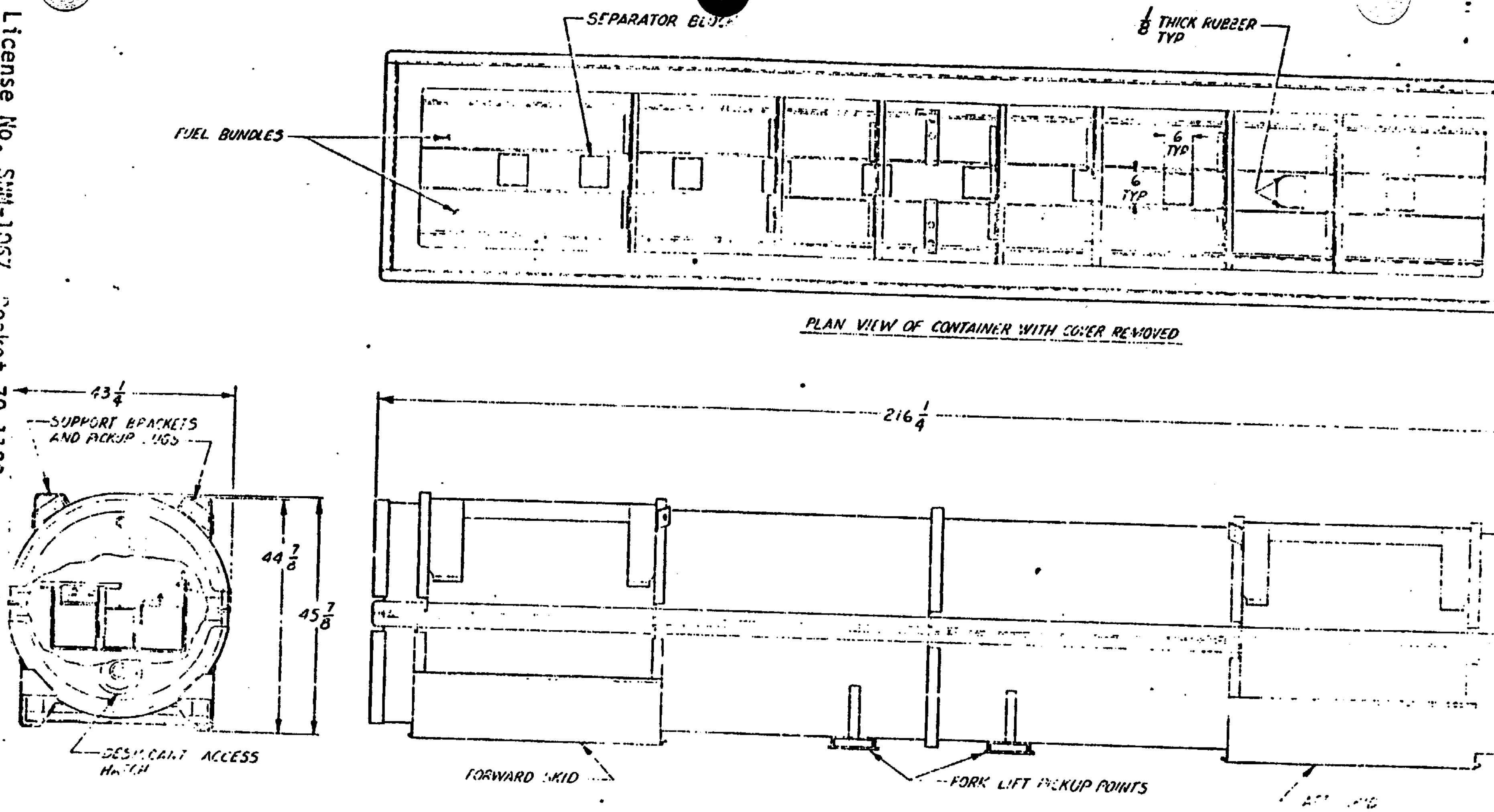
B. Contents of the Package

Each shipping container shall house two fuel bundles. The most reactive of these bundles have enrichments of 3.5 w/o U^{235}. Each fuel bundle shall be encased in a plastic bag.

The radioactive constituents are unirradiated uranium dioxide fuel pellets, enriched to a maximum of 3.5 w/o U^{235}. The maximum radioactivity for each fuel bundle is 0.7 curies. The maximum for each loaded fuel container is 1.4 curies, with the maximum radioactivity for a shipment of eight (8)



FUEL BUNDLE SHIPPING CONTAINER MODEL NO. 927C



FUEL BUNDLE SHIPPING CONTAINER MODEL NO. 927C containers or sixteen (16) fuel bundles being eleven (11) curies.

The maximum amount of uranium dioxide ceramic pellets in each shipping container is 2100 lbs., i.e., 1050 lbs., per fuel bundle.

Paragraphs a (3) and a (4) are not applicable. Paragraph b (6) is not applicable.

3.71.23 Package Evaluation

(a) The package satisfies the standards specified in the applicable paragraphs in Sub-part C, as discussed below:

71.31 - General Standards for All Packaging

a. There will be no significant chemical, galvanic or other reaction among the packaging components or between the packaging components and the package contents. The shipping container is made of carbon steel and the contents are zircaloy clad fuel bundles wrapped in polyethylene bags.

b. The shipping container is equipped with a positive closure which will prevent inadvertent opening.

c. Lifting Devices:

(1) Same as 71.23 of this section.

3.71.24 Procedural Controls

Prior to each shipment, the container shall be inspected to assure that:

(a) The container has not been significantly damaged.

(b) The closure of the package and any sealing gaskets are present and are free from defects.

(c) The internal gauge pressure of the container will not exceed, during the anticipated period of transport, the maximum normal operating pressure.

3.71.33 Criticality Standards for Fissile Material Packages

The package is so designed and constructed, and its contents are so limited that it would be sub-critical if it is assumed that water leaks into the containment vessel, and

(1) Water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents, and

(2) The containment vessel is fully reflected on all sides by water.

Nuclear safety calculations were performed and show a k_{eff} of 0.91 for the above conditions. Physics constants for the various regions of the assembly were obtained from the same codes as were used in previous safety calculations. Please refer to Amendment No. 8, as amended, to the subject License.

3.71.34 Evaluation of a Single Package

(a) The effect of the transport environment of the safety of any single package as described in 71.34 of this section, applies for normal conditions of transport.

The effect on the loaded container of conditions likely to occur in an accident is as described in 71.34 (2) of this section, except that an additional study was undertaken to demonstrate that the six inch separation between assemblies will be retained. This study enclosed as Appendix P-1 confirms that the separation is not reduced by the 30 foot drop.

3.71.37 Evaluation of an Array of Packages of Fissile Material

(a) The effect of the transport environment on the nuclear safety of an array of packages was evaluated by assuming:

(1) That two (2) damaged shipping containers became abutted top-to-top under water, thus involving four (4) fuel assemblies in close proximity. It was further assumed that separation between pairs of assemblies would be provided only by the collapsed steel walls and the top restraining structure of the strongbacks of the two (2) shipping containers. It was postulated that this separation between pairs of bundles could never be less than 12 inches, because in the undamaged condition the separation is more than twice that, and the 30 foot drop tests have shown that the containment shell does not collapse, the bundles remain in the same relative position with respect to the top of the container, and the 6 inch separation remains intact between the two (2) bundles in each container. Any other alignment of the shipping containers, or abutment, other than top-to-top should result in a less reactive situation, because of the steel structure within the lower sections of the shipping container and the runners that provide a base for each container. Nuclear safety calculations were performed and showed k_{eff} to be $\leq$ 0.91.

(2) That two (2) damaged shipping containers become abutted side-to-side under water, and the strongbacks shifted sideways so that the outermost bundles are 6 inches apart and separated by the two (2) steel shells, (each is 1/8 inch thick), and the two (2) steel strongback edges (each is 1/4 inch thick). Nuclear safety calculations were performed and shown k_{eff} to be $\leq$ 0.92.

The nuclear safety calculations for the accident conditions are presented in Reference C.

3.71.40 Specific Standards for a Fissile Class III Shipment

This container shall be used as a Fissile Class III Shipment and Meets the criteria of 71.40 (a). Nuclear safety analyses performed previously, for Amendment No. 8 as amended to the subject License, showed that the loaded containers are sub-critical when stored three (3) high in an array that is infinitely long and infinitely wide. This assures that the undamaged shipment of two high, two wide and two long would be subcritical with an identical shipment in contact with it, and the two shipments closely reflected on all sides by water. The analysis presented as part of the requirements of paragraph 71.37 shows that the shipment would be sub-critical, if subjected to the hypothetical accident conditions specified in 71.40 (b).

APPENDIX D

BWFC BUCKLING LOAD ANALYSIS
BWFC SIDE DROP ANALYSIS

BWFC BUCKLING LOAD ANALYSIS

The following analysis was conducted to verify that the failure load of the shipping container spacer assemblies exceeds the fuel assembly critical buckling load. The analysis is also documented in BWNT document ID 32-1224342-00, "51032-2 Container Spacer."

1.0 PURPOSE

The purpose of this analysis is to verify that the failure load of MK-B and MK-BW shipping container spacer assemblies exceeds fuel assembly critical buckling load.

2.0 SUMMARY

An extremely conservative buckling and compression failure analysis was performed on the MK-B spacer. This represents a worst case analysis for both spacers since the MK-B spacer is taller and the MK-B fuel assembly has a higher critical buckling load.

The critical buckling load for the MK-B fuel assembly is 3584 pounds (Ref. Doc. B&W 32-1176304-00). To determine the buckling load of the MK-B spacer, each support was modeled as a column with pinned ends. Each support is actually a composite member. To provide a more conservative analysis, the smallest member of the composite was considered to carry the full load. The critical buckling load for each support is 32,800 pounds. With four supports, this translates to a buckling load in excess of 131,200 pounds.

The compressive failure load was calculated to be 15,000 pounds for each support. This translates to a spacer compressive failure load in excess of 60,000 pounds.

3.0 CALCULATIONS

The MK-B spacer was modeled as four (4) supports made of 1/2 schedule 40 stainless steel round tubing. The following support properties were used:

Modulus of Elasticity	(E) = 28,000 ksi [1]
Tensile Strength	(S_{ut}) = 60,000 psi [2]
Wall Thickness	(t) = 0.109 inches
Inside Diameter	(d) = 0.622 inches
Outside Diameter	(D) = 0.840 inches
Support Length	(L) = 12 inches (conservatively long)
Area	(A) = 0.250 in^2

Moment of Inertia (I) $= \pi \cdot D^4/64 - \pi \cdot d^4/64$
$= \pi \cdot 0.840^4/64 - \pi \cdot 0.622^4/64$
$= 0.0244 - 0.0073$
$= 0.0171\ in^4$

Each support was modeled as a column with pinned ends. The following equation was used for the critical buckling load:

Critical Buckling Load: P_{cr} $= \pi^2 \cdot E \cdot I/L^2$ [3]
$= 9.870 \cdot 28e6 \cdot 0.0171/144$
$= 32{,}800$ pounds per support

For the entire spacer the buckling load is in excess of 131,200 pounds.

The compressive failure load was calculated using the same member as analyzed for buckling. The following equation was used:

Critical Compressive Load: P_{cr} $= A \cdot S_{ut}$
$= 0.250 \cdot 60{,}000$
$= 15{,}000$ pounds per support

For the entire spacer the critical compressive load is in excess of 60,000 pounds.

4.0 CONCLUSION

It is impossible for the spacer to fail before the fuel assembly buckles. This conclusion can be drawn by visually comparing the fuel assembly to the spacer. The minimum load to cause failure of the MK-B shipping container spacer assembly is in excess of 60,000 pounds. This is well over the 3584 pound critical buckling load of the fuel assembly.

These calculations shall also serve to verify the performance of the MK-BW spacer. This spacer is more heavily constructed than the MK-B spacer and is required to carry less load.

5.0 REFERENCES

(1) Gere & Timoshenko, Mechanics of Materials, PWS, Boston, 1984, page 744.

(2) Gere, p746.

(3) Gere, p557.

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 could fracture the positioning brackets and impact onto the separating blocks, assuming no impact energy is absorbed by the brackets or the fuel assembly itself. The maximum "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 calculation of the maximum separator block spacing, 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

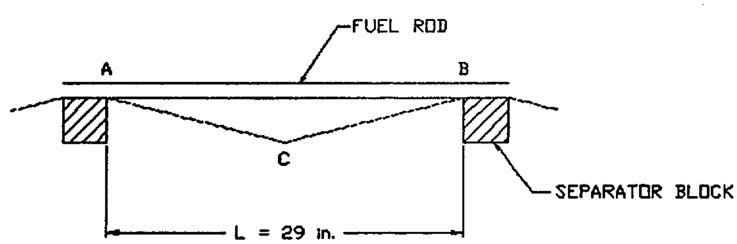
In accordance with the assumption in section 4.0, the fuel assembly would impact the 6"x8"x9"long separator blocks with a large amount of kinetic energy. Since the separator blocks are relatively rigid, this energy will be absorbed in the fuel assembly primarily by "plastic strain." The impact velocity would be the maximum velocity calculated in Section 3(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 MK-B9 Fuel Rod weight-per-inch (Ref. 4) is approximately 6.94/151 ≈ 0.046 lbs/in. Thus, for a span of length "L", the impact energy that must be absorbed by a single fuel rod is,

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

$E_f \approx (16.55)(L)$ 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 = $\frac{1}{2}P\delta$ where $P = 16M_P/L$ (case 2d, p.225, Ref. 6)

(Ref. 5) 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,

$4M_P\theta = \frac{1}{2}mv^2$
$\therefore \theta = (E_f)/4M_P) = ((16.55\ (L)\ )/(\ (4)\ (417)\ ) = (0.0099)(L)$ rad

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

$\delta = \theta \cdot L/2 = (\ (0.0099)\ (L)\ )\ (L/2) = (0.00496)\ (L^2) = \delta_{max}$

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.

Therefore, $\delta_{max} \approx 0.648$ in., to maintain a 6 inch minimum fuel assembly spacing.

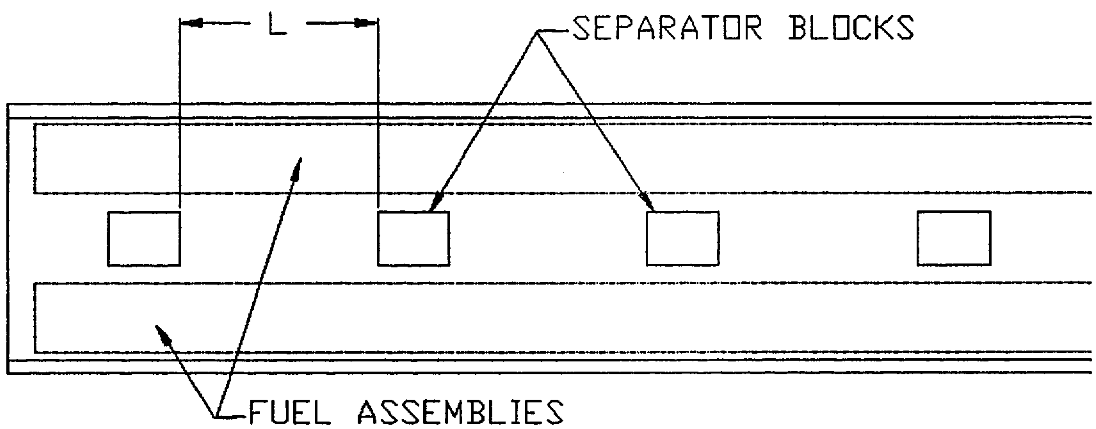
Substitution gives the following expression,

$$(\ (0.00496)\ (L^2)\ ) = 0.648$$

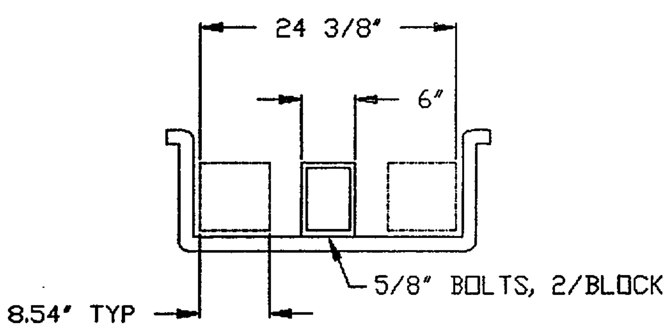
It is concluded that the maximum "clear" distance between separator blocks required to maintain a 6 inch minimum separation between fuel assemblies is,

$\therefore L = (0.648/0.00496)^{1/2} \approx$ <u>11.4 in.</u>

Figure 1 - Strongback Channel



- TOP VIEW -



- END VIEW -

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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 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

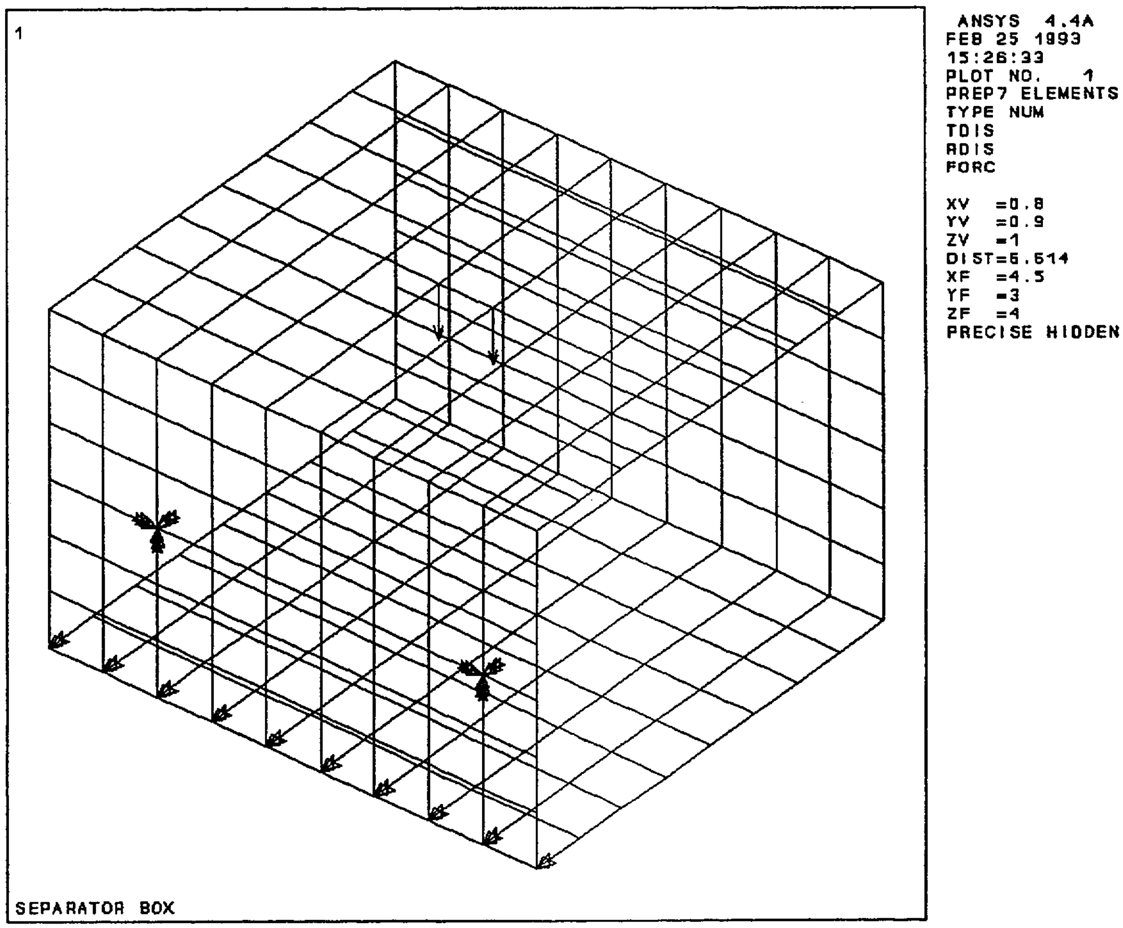
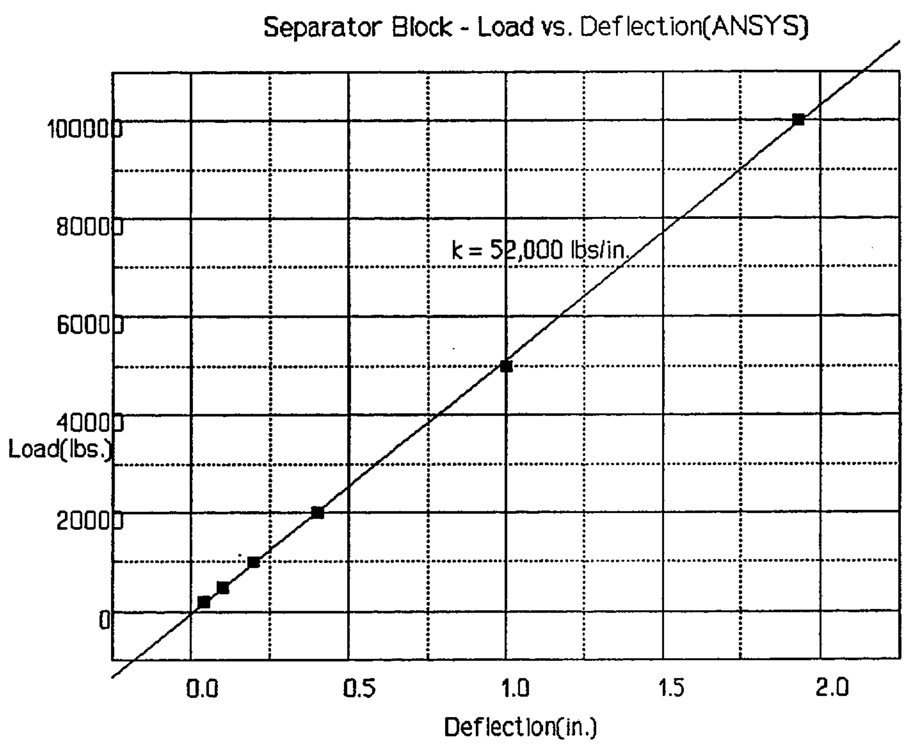


Figure 3 -
Separator Block - Load vs. Deflection(ANSYS)



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,

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

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

5.3 Realistic Separator Block Loading

In the previous section, a conservative impact load was estimated for purposes of examining the strength of the separator bolts only. A more realistic maximum impact load can be estimated from the drop testing results of references 12 and 13. Since the drop height, container material, geometry, and strongback supporting structure of the 51032 container and the 927 container are essentially the same, the dynamic loading applications upon impact would be approximately the same.

The 30 foot side drop test results showed that the fuel assemblies remained in the hold-down brackets and the brackets remained in place across the strongback. This shows that a significant amount of energy was absorbed prior to loading the brackets. It is therefore concluded that the loading required to shear the 3/8 inch SAE J429 Grade 5 bolts of the 51032-2 ("limiting"), would not be reached in the bracket assemblies during impact. This loading, however, will be calculated and used as an estimate of the maximum loading that the separator block could see if the bolts were to break in a 30 foot side drop.

From Reference 9, the yield strength of Grade 5 bolts is 92,000 psi. Therefore, the shear strength of the bolts is,

$$\tau_y = (0.6)\ (92{,}000 \text{ psi}) = 55{,}200 \text{ psi}$$

The cross-sectional area of the bolts (per bracket assy) is,

A_{bolts} = (2 bolts) (π) (0.375 in.)^2/4 = 0.221 in^2

The maximum impact load would then be,

F_{max} = (55,200 psi) (0.221 in^2) (10 bracket assy's) = 121,933 lbs.

The corresponding maximum "g" factor is then,

"g" factor = 121,933 lbs./1,650 lbs. = 74 g's

Assuming, conservatively, that the "dynamic" yield strength of the 1/4 inch strongback equals the "static" yield strength, or 36,000 psi., and that the one inch separator block bolts are used, the maximum bearing load that the strongback can take is calculated as follows,

$P_{max} = 2td\sigma_y$ (Ref. 14) where t = 1/4 inch
d = 1 inch

P_{max} = (2) (0.25 in.) (1 in.) (36,000 psi.) (9 separator Blocks)
= 162,000 lbs.

"g" factor = 162,000 lbs./1,650 lbs. = 98 g's

$$M.S. = \frac{98 - 74}{74} \times 100\% = 32\%$$

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. 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.

It should be noted that the 121,933 pound impact force calculated corresponds in section 5.3 corresponds to about 13,548 pounds per each of the nine separator blocks. In references 2 and 3 it was stated that the separator block, with gusset plate, could take a compressive load of greater than 30,000 pounds without significantly deflecting; and without a gusset plate at about 16,000 pounds.

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.

12. TEST REPORT NO. 2312A, QUALIFICATION TEST PROCEDURE FOR THE APPLIED DESIGN COMPANY MODEL 927A METAL SHIPPING AND STORAGE CONTAINER FOR COMBUSTION ENGINEERING, INC. FUEL BUNDLE ASSEMBLY. TEST REPORT NO. 231B ON THE APPLIED DESIGN COMPANY MODEL 927A METAL SHIPPING AND STORAGE CONTAINER FOR COMBUSTION ENGINEERING, INC. FUEL BUNDLE ASSEMBLY

13. JERSEY NUCLEAR COMPANY, INC. SHIPPING CONTAINER MODEL NUMBER

51032-1, 30 FOOT DROP TEST REPORT.

14. MECHANICAL ENGINEERING DESIGN, 2ND EDITION, SHIGLEY, MCGRAW-HILL BOOK CO., NY, 1972, PP. 327-328.

APPENDIX D

BWFC BUCKLING LOAD ANALYSIS
BWFC SIDE DROP ANALYSIS

BWFC BUCKLING LOAD ANALYSIS

The following analysis was conducted to verify that the failure load of the shipping container spacer assemblies exceeds the fuel assembly critical buckling load. The analysis is also documented in BWNT document ID 32-1224342-00, "51032-2 Container Spacer."

1.0 PURPOSE

The purpose of this analysis is to verify that the failure load of MK-B and MK-BW shipping container spacer assemblies exceeds fuel assembly critical buckling load.

2.0 SUMMARY

An extremely conservative buckling and compression failure analysis was performed on the MK-B spacer. This represents a worst case analysis for both spacers since the MK-B spacer is taller and the MK-B fuel assembly has a higher critical buckling load.

The critical buckling load for the MK-B fuel assembly is 3584 pounds (Ref. Doc. B&W 32-1176304-00). To determine the buckling load of the MK-B spacer, each support was modeled as a column with pinned ends. Each support is actually a composite member. To provide a more conservative analysis, the smallest member of the composite was considered to carry the full load. The critical buckling load for each support is 32,800 pounds. With four supports, this translates to a buckling load in excess of 131,200 pounds.

The compressive failure load was calculated to be 15,000 pounds for each support. This translates to a spacer compressive failure load in excess of 60,000 pounds.

3.0 CALCULATIONS

The MK-B spacer was modeled as four (4) supports made of 1/2 schedule 40 stainless steel round tubing. The following support properties were used:

Modulus of Elasticity	(E) = 28,000 ksi [1]
Tensile Strength	(S_{ut}) = 60,000 psi [2]
Wall Thickness	(t) = 0.109 inches
Inside Diameter	(d) = 0.622 inches
Outside Diameter	(D) = 0.840 inches
Support Length	(L) = 12 inches (conservatively long)
Area	(A) = 0.250 in^2

Moment of Inertia (I) $= \pi \cdot D^4/64 - \pi \cdot d^4/64$
$= \pi \cdot 0.840^4/64 - \pi \cdot 0.622^4/64$
$= 0.0244 - 0.0073$
$= 0.0171 \text{ in}^4$

Each support was modeled as a column with pinned ends. The following equation was used for the critical buckling load:

Critical Buckling Load: $P_{cr} = \pi^2 \cdot E \cdot I/L^2$ (3)
$= 9.870 \cdot 28e6 \cdot 0.0171/144$
= 32,800 pounds per support

For the entire spacer the buckling load is in excess of 131,200 pounds.

The compressive failure load was calculated using the same member as analyzed for buckling. The following equation was used:

Critical Compressive Load: $P_{cr} = A \cdot S_{ut}$
$= 0.250 \cdot 60,000$
= 15,000 pounds per support

For the entire spacer the critical compressive load is in excess of 60,000 pounds.

4.0 CONCLUSION

It is impossible for the spacer to fail before the fuel assembly buckles. This conclusion can be drawn by visually comparing the fuel assembly to the spacer. The minimum load to cause failure of the MK-B shipping container spacer assembly is in excess of 60,000 pounds. This is well over the 3584 pound critical buckling load of the fuel assembly.

These calculations shall also serve to verify the performance of the MK-BW spacer. This spacer is more heavily constructed than the MK-B spacer and is required to carry less load.

5.0 REFERENCES

(1) Gere & Timoshenko, Mechanics of Materials, PWS, Boston, 1984, page 744.

(2) Gere, p746.

(3) Gere, p557.

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 could fracture the positioning brackets and impact onto the separating blocks, assuming no impact energy is absorbed by the brackets or the fuel assembly itself. The maximum "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 calculation of the maximum separator block spacing, 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

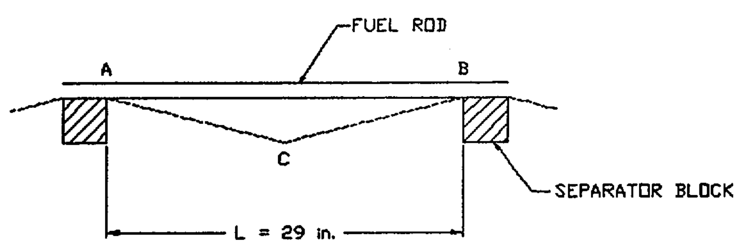
In accordance with the assumption in section 4.0, the fuel assembly would impact the 6"x8"x9"long separator blocks with a large amount of kinetic energy. Since the separator blocks are relatively rigid, this energy will be absorbed in the fuel assembly primarily by "plastic strain." The impact velocity would be the maximum velocity calculated in Section 3(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 MK-B9 Fuel Rod weight-per-inch (Ref. 4) is approximately 6.94/151 ≈ 0.046 lbs/in. Thus, for a span of length "L", the impact energy that must be absorbed by a single fuel rod is,

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

$$E_f \approx (16.55)(L) \text{ in-lbs.}$$



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

Work = $\tfrac{1}{2}P\delta$ where $P = 16M_p/L$ (case 2d, p.225, Ref. 6)

(Ref. 5) 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),

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$\therefore \sigma_y \approx (81{,}000 + 112{,}000)/2 = 96{,}500$ 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,

$4M_p\theta = \frac{1}{2}mv^2$
$\therefore \theta = (E_f)/4M_p) = ((16.55\ (L)\ )/(\ (4)\ (417)\ ) = (0.0099)(L)$ rad

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

$\delta = \theta \cdot L/2 = (\ (0.0099)\ (L)\ )\ (L/2) = (0.00496)\ (L^2) = \delta_{max}$

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.

Therefore, $\delta_{max} \approx 0.648$ in., to maintain a 6 inch minimum fuel assembly spacing.

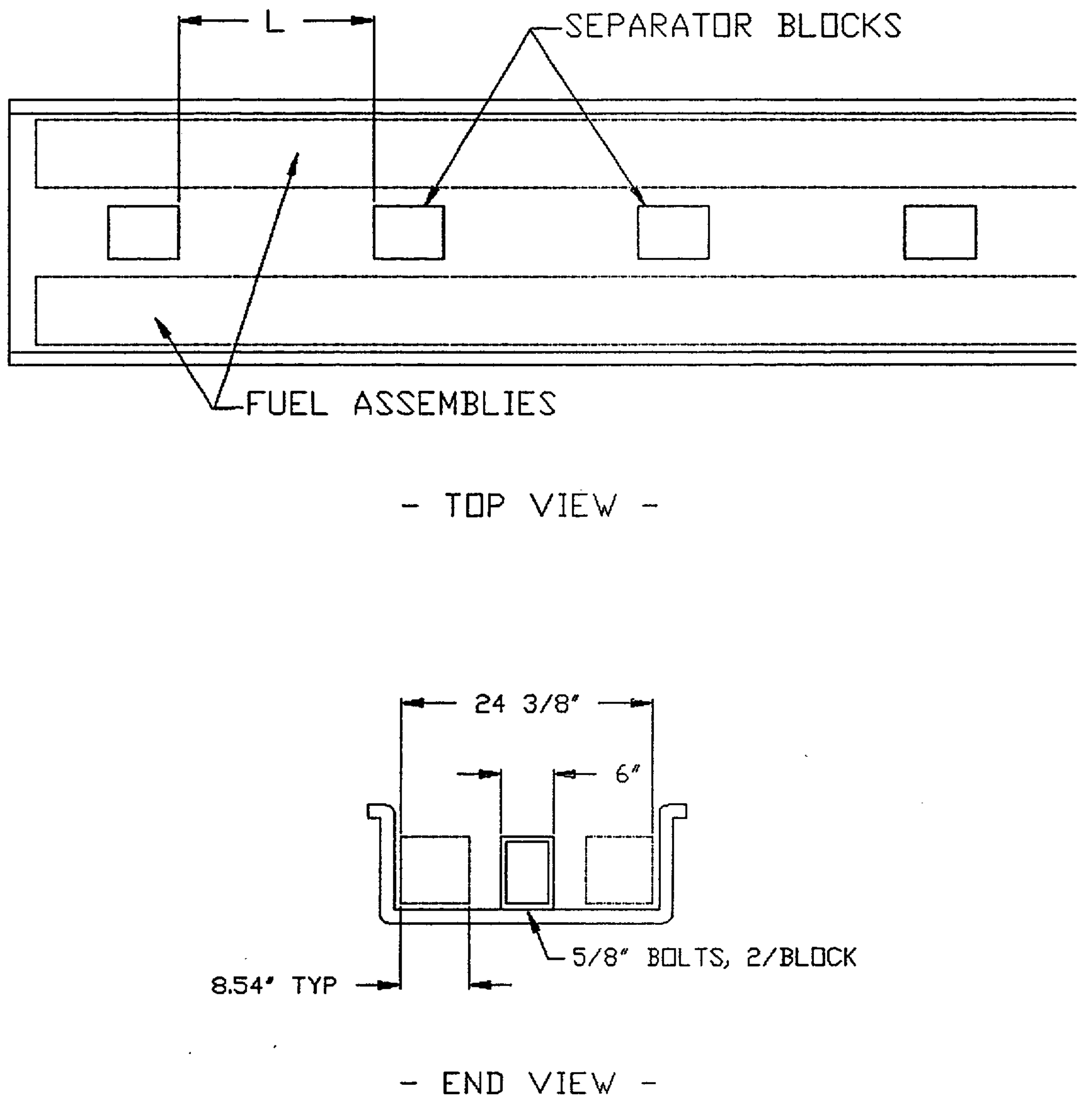
Substitution gives the following expression,

$(\ (0.00496)\ (L^2)\ ) = 0.648$

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

$\therefore L = (0.648/0.00496)^{1/2} \approx$ 11.4 in.

Figure 1 - Strongback Channel



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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 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

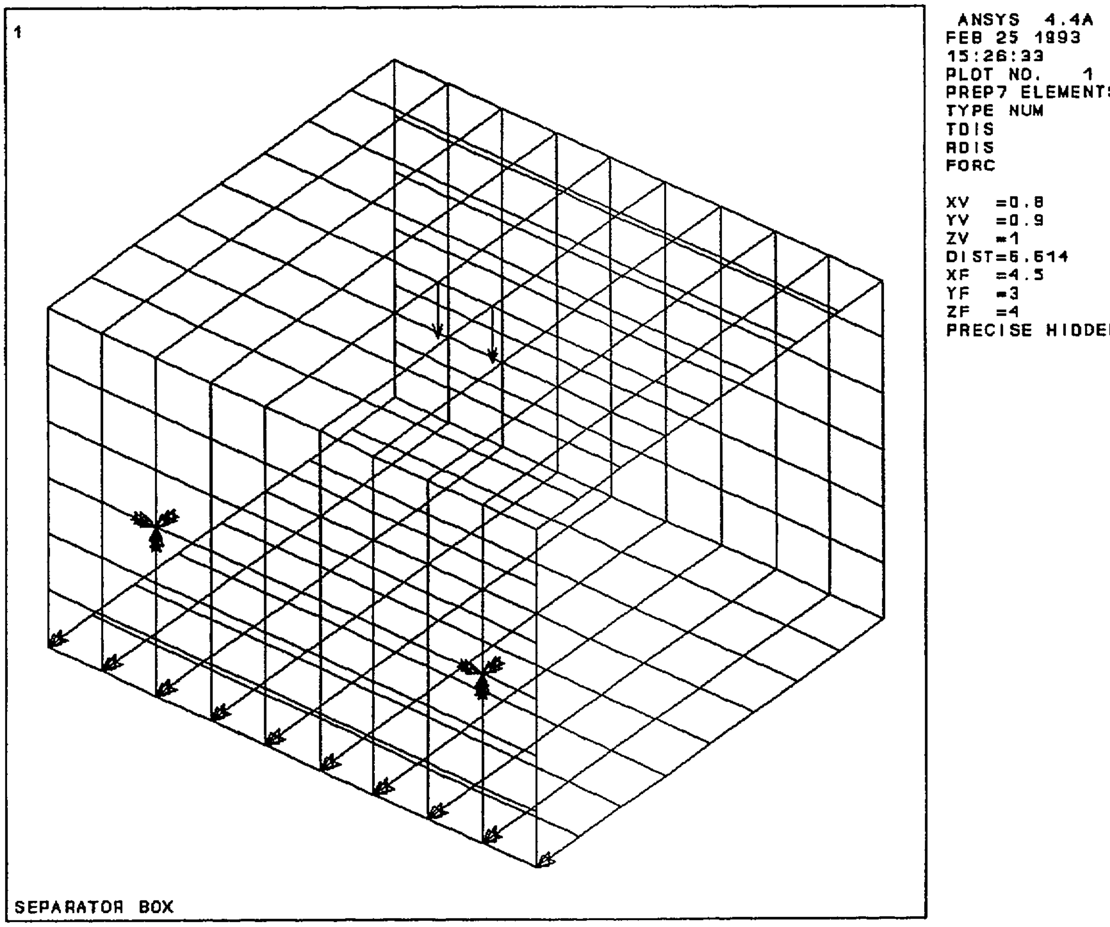
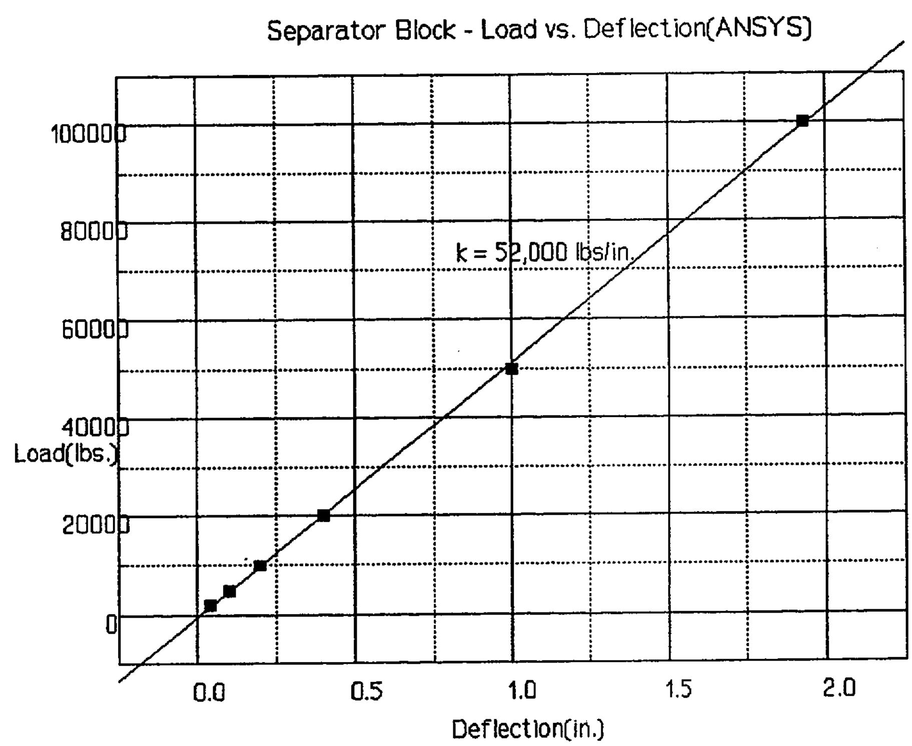


Figure 3 -
Separator Block - Load vs. Deflection(ANSYS)



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,

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

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

5.3 Realistic Separator Block Loading

In the previous section, a conservative impact load was estimated for purposes of examining the strength of the separator bolts only. A more realistic maximum impact load can be estimated from the drop testing results of references 12 and 13. Since the drop height, container material, geometry, and strongback supporting structure of the 51032 container and the 927 container are essentially the same, the dynamic loading applications upon impact would be approximately the same.

The 30 foot side drop test results showed that the fuel assemblies remained in the hold-down brackets and the brackets remained in place across the strongback. This shows that a significant amount of energy was absorbed prior to loading the brackets. It is therefore concluded that the loading required to shear the 3/8 inch SAE J429 Grade 5 bolts of the 51032-2 ("limiting"), would not be reached in the bracket assemblies during impact. This loading, however, will be calculated and used as an estimate of the maximum loading that the separator block could see if the bolts were to break in a 30 foot side drop.

From Reference 9, the yield strength of Grade 5 bolts is 92,000 psi. Therefore, the shear strength of the bolts is,

$$\tau_y = (0.6)\ (92{,}000 \text{ psi}) = 55{,}200 \text{ psi}$$

The cross-sectional area of the bolts (per bracket assy) is,

A_{bolts} = (2 bolts) (π) (0.375 in.)^2/4 = 0.221 in^2

The maximum impact load would then be,

F_{max} = (55,200 psi) (0.221 in^2) (10 bracket assy's) = 121,933 lbs.

The corresponding maximum "g" factor is then,

"g" factor = 121,933 lbs./1,650 lbs. = 74 g's

Assuming, conservatively, that the "dynamic" yield strength of the 1/4 inch strongback equals the "static" yield strength, or 36,000 psi., and that the one inch separator block bolts are used, the maximum bearing load that the strongback can take is calculated as follows,

$P_{max} = 2td\sigma_y$ (Ref. 14) where t = 1/4 inch
d = 1 inch

P_{max} = (2) (0.25 in.) (1 in.) (36,000 psi.) (9 separator Blocks)
= 162,000 lbs.

"g" factor = 162,000 lbs./1,650 lbs. = 98 g's

$$M.S. = \frac{98 - 74}{74} \times 100\% = 32\%$$

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. 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.

It should be noted that the 121,933 pound impact force calculated corresponds in section 5.3 corresponds to about 13,548 pounds per each of the nine separator blocks. In references 2 and 3 it was stated that the separator block, with gusset plate, could take a compressive load of greater than 30,000 pounds without significantly deflecting; and without a gusset plate at about 16,000 pounds.

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