CONSOLIDATED LICENSE APPLICATION
FOR
EXXON NUCLEAR COMPANY, INC.
MODEL 51032-1 AND -1a SHIPPING CONTAINERS

Certificate of Compliance 6581
Docket 71-6581

1631 137

November, 1979

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FOR

EXXON NUCLEAR COMPANY, INC.

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Certificate of Compliance 6581

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1631 138

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF APPENDICES

1631 143

LIST OF TABLES

LIST OF TABLES (Continued)

1631 145

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

2.0 PACKAGE DESCRIPTION

As specified in 10 CFR 71.22, the the Model 51032-1 and -1a packages and their respective contents are described herein.

2.1 Model 51032-1 Container

The gross weight of the Model 51032-1 packaging is 4000 ± 100 pounds. Specific materials of construction, weights, dimensions, and fabrication methods of the packaging components are as described below:

2.1.1 Container Description

The containment vessel is a 43 inch diameter (nominal dimension) right cylinder 216 inches long, fabricated of 11-gauge (0.1196 inch) steel (see Figures 2.1 and 2.2). The containment vessel is fabricated in two sections--base and cover assemblies (see Figures 2.3 and 2.4). Continuous 2 x 2 x 1/4-inch closure flanges are welded to the base and cover assemblies and a 1/2-inch rubber "O" ring gasket is fitted between the mating flanges. Using ten 1/2-inch steel alignment pins permanently fixed in the closure flange of the base assembly, the two halves of the containment vessel are mated and sealed together with 58, 1/2-inch 13UNC-2A steel closure bolts; steel washers (9/32 inch thick) are inserted between the mating flanges to prevent excessive distortion of the "O" ring gasket; 1/2-inch 13UNC-2B steel nuts tightly seated complete the closure.

Seven steel stiffening rings (five rollover angles and two end rings) are welded to each of the base and cover assemblies to strengthen the containment vessel shell. Rollover rings are fabricated 2 1/2 x 2 1/2 x 5/16-inch angles and end rings are fabricated of 3 1/2 x 2 1/2 x 3/8-inch angles.

Four 7-gauge (0.1793 inch) steel skids are welded to the base assembly. These skids support the package and are designed to permit bolting the stacking brackets when packages are stacked for storage or transport. Stacked packages, however, are not normally bolted together during transport.

Four sets (two per set) of stacking brackets fabricated of 7-gauge (0.1793-inch) steel are welded to the cover assembly.

Welded to each set of stacking brackets is a steel lifting lug. These lugs are fabricated of 3/8 inch steel and may be used to support the loaded package. Use has been shown not to generate stress in any material of the packaging in excess of its yield strength with a minimum safety factor of 3.4.

Two fork lift pickup channels are welded to the base assembly to facilitate package handling. These channels are fabricated of 1/4 inch steel.

Fourteen (seven per side) shock-mount support brackets fabricated of 1/4 inch steel are welded to the interior side of the base assembly shell. The weight of the fuel elements and the related support mechanism is transferred to these brackets through up to 14 shock mounts. (The actual number of shock mounts included in each package is dependent upon the weight of the fuel elements being transported.)

The shock-mounted strongback supports and protects the fuel elements. The standard strongback (see Figure 2.5) is designed to securely hold two long (or four short, see Figure 2.6) fuel elements in place with a minimum spacing of 6 inches between the two fuel element cavities formed by the strongback components. The main strongback member is a single "U" shaped channel formed of 1/4 inch steel. The standard strongback channel is about 196 inches long, 25-3/8 inches wide, and 12-1/2 inches high. Alternate strongback channels that are shorter or have other minor design variations are used interchangeably with the standard strongback. Alternate strongback channels are structurally the same as the standard ones except for the dimensional differences. All are fabricated of 1/4 inch thick steel. See Figures 2.7, 2.8, 2.9 and 2.10).

Side and bottom steel angle (2 x 2 x 1/4-inch) supports are welded to the exterior of the strongback channel in seven locations on the standard strongbacks and five on the short strongbacks to provide rigidity and additional strength.

Separator blocks (3/8 inch thick channels, 6" wide x 8" high x 9" long) are bolted (two 5/8-11UNC-2 bolts each) to the strongback channel such that the centerline of the spacer blocks corresponds to the centerline of the strongback channel. The number of blocks used in each package is dependent upon the weight of the fuel element to be transported. The minimum number required as a function of fuel element weight in pounds is specified in Section 2.1.2.

Fourteen 4 x 3 x 3/8 inch steel angles are welded to the exterior sides (seven per side) of the strongback channel (five for the short strongback). During shipping, these angles secure the strongback to 2 x 4 x 1/4-inch support tubes by a 5/8-11UNC steel bolt, nut, and lock washer system (one each per lock-down angle).

Seven strongback support tubes (five for the short strongbacks) provide support and hold the strongback assembly in place during shipping and storage. These support tubes are fabricated of 2 x 4-inch steel channels (1/4 inch wall thickness) and are 29-5/8 inches long. The support tubes are attached to the interior of the containment vessel through shock mounts (two per support tube), to the shock mount support brackets. The shock mounts minimize vibrational effects on the fuel elements during transport and handling. In the event of a fire severe enough to destroy the natural rubber portion of the shock mounts, the fuel elements remain in essentially the same position within the package as the result of the steel bolts, washers, and nuts incorporated into the shock mount assemblies (see Figure 2.11).

The effectiveness of the shock mount system is not fully realized unless the trunnion assembly is disengaged prior to sealing the containment vessel. Consequently, the trunnion assembly contains a blocking feature that will not allow the cover and base assemblies of the containment vessel to be mated while it is engaged. The trunnion assembly has no other transport significance; it is merely a device to aid in the loading and unloading of fuel elements.

Steel end thrust brackets (see Figure 2.12) are bolted to the strongback at both ends of the fuel elements to prevent longitudinal movement. When shipping four (4) fuel elements, the two short steel center thrust brackets (see Figure 2.6) are bolted into the strongback between fuel elements in each cavity. A handle is attached to the center thrust bracket to facilitate bracket removal from the strongback during unpacking operations.

There are no materials specifically used as nonfissile neutron absorbers or moderators in this packaging.

2.1.2 Fuel Element Clamps, Shock Mounts and Separator Blocks

Fuel elements are clamped in place within the strongback and restrained from lateral or vertical movement (see Figures 2.1 and 2.6). These clamping devices hold the fuel elements against the bottom and sides of the strongback channel such that the maximum fuel element separation distance is achieved. The adjustable clamps are mounted on 2 x 1-1/2 x 1/8-inch steel angle brackets that extend laterally across the top of the strongback channel. These brackets are clamped (using two 5/3-inch steel bolts per bracket) to the top of the strongback channel. There are two types of clamps, one designed to clamp on the spacers of PWR fuel elements and the other designed to clamp between the spacers of BWR fuel elements. PWR fuel element clamps (see Figure 2.11) are steel and the surfaces of the clamps that contact the fuel element are lined with 1/4 inch thick Buna-N rubber pads. The BWR fuel element clamps (see Figure 2.13) are fabricated of aluminum with ethafoam (low density expanded polyethylene at approximately 6 pounds per cubic foot density) pads, ~ 3/4 and ~ 1/2 inch thick, added between the fuel element and the strongback and clamps, respectively. Fuel elements supported in this manner may contain tight-fitting corrugated polyethylene shims interlaced between adjacent rows of fuel rods within the fuel elements. A typical corrugated polyethylene shipping shim, and a schematic diagram showing the clamping method with associated shims and ethaf am pads in place, are shown in Figure 2.13.

XN Types I, II, III, IV, V, VI, and some of the generically characterized fuel elements will be packaged with molded corrugated polyethylene shims between adjacent rows of fuel rods within the fuel elements. When such shims are used in the packaging, ethafoam (low density expanded polytheylene at 6 pounds per cubic foot density) pads .75 and .50 inch thick will be added between the fuel elenent and the strongback and clamps, respectively. These pads, used in conjunction with the clamping procedure described above, provides support for the fuel elements while retaining the structural integrity of the shipping package. The generically characterized UO_2 fuel elements with which such shims and pads are included, are identified in Section 12.5.

A comparison of the energy absorption capabilities of the alternative support methods indicates that the method using ethafoam pads will absorb at least 1.2 times the energy of the originally designed and tested support system.

As a result of comparisons between the two support methods, it has been concluded that under maximum credible accident loading conditions either support system meets all structural requirements (i.e., either the basic system tested, or the system using ethafoam pads, polyethylene shims, and clamps over the fuel rod spans between spacers).

When transporting fuel elements weighing in excess of 800 pounds, restraint bars are included in the package. Restraint bars consist of 2 x 1 1/2 x 1/8-inch steel angle brackets that extend across the top of the strongback channel and are clamped to the strongback flanges in the same manner as are the full clamps. The restraint bars are provided for additional restraint in the event of an accident.

Strongback components required for each package vary with the size and weight of the fuel elements shipped. The limiting criterion is that the components used to hold the fuel element in place in the strongback (i.e., the full clamps) do not fail at a lower force than the shock mount system. (The fuel elements must be retained within the strongback). The specific criteria applied is that the number of full clamps and separator blocks per unit weight shall be equal to or greater than the number of clamps and separator blocks employed in the Model 51032-1 30 feet drop tests. The number of full clamps, shock mounts, and separator blocks to be included in the package shall satisfy the following equations:

$$N_b \geq W/187.5$$

$$N_c \geq W/183; \text{ and}$$

$$\frac{14}{9} N_c - 2 \leq N_s \leq \frac{14}{9} N_c$$

Where: N_b = number of separator blocks required;
N_c = number of full clamps required;
W = weight of the fuel element (pounds); and
N_s = number of shock mounts.

The number of restraining bars employed for transporting fuel elements weighing in excess of 800 pounds shall be one fewer than the number of full clamps, (i.e., N_c-1). In addition, half clamps are normally applied at the end of each fuel element but are not taken into account in this calculation. These half clamps provide some degree of conservatism. When four short fuel elements are transported in one container W shall be the combined weight of the two fuel elements.

2.2 Model 51032-1a Container

The gross weight of the Model 51032-1a packaging is 4600 ± 100 pounds. Specific materials of construction, weights, dimensions, and fabrication methods of the packaging components are as described below.

2.2.1 Container Description

The outer container vessel of the Model 51032-1a container is identical (interchangeable) to that used for

Model 51032-1 packages and described in Section 2.1. The overall arrangement of the Model 51032-1a container is shown in Figure 2.14. The strongback (see Figure 2.15) is also basically the same as the Model 51032-1 standard strongback except that the interior width is increased by one (1) inch and the thrust plate locations are changed to accommodate slightly larger fuel elements while maintaining at least a six inch separation between adjacent fuel elements. Separator blocks used to assure a minimum separation between fuel elements within each container were modified by additic of a gusset plate for increased strength (see Figure 2.16).

Significant differences between the two models occur in the shock mounts (see Figure 2.14), full clamps (see Figures 2.17 and 2.18), separator blocks (see Figure 2.16), and some of the associated bolts. In addition to these differences which characterize the packaging model, additional components are employed when Type AA fuel elements are transported in the Model 51032-1a containers. These are 1) special strongback thrust brackets (see Figure 2.19) at each end, and 2) aluminum honeycomb impact limiters (see Figure 2.20) at each end between the thrust brackets and the end of the outer containment vessel. (The special thrust bracket and honeycomb material are retained at the lower end (near the trunnion) of the package for all fuel element shipments but the upper thrust bracket and honeycomb may be replaced with the bracket shown in Figure 2.12.)

2.2.2 Fuel Element Clamps, Shock Mounts and Separator Blocks

The fuel element full clamps for Model 51032-1a packages have been strengthened relative to those for Model 51032-1 package as explained in Section 10. The full clamp angle bar has been replaced by a 2-1/2 x 2-1/2 x 1/2 inch angle bar and the clamp that fastens the angle bar to the strongback has been revised for greater strength. The design is shown in Figure 2.17. The steel clamp used to fasten PWR fuel elements in the strongback is shown in Figure 2.17 and the aluminum clamp for use with BWR fuel elements is shown in Figure 2.18. This packaging also requires half clamps, one at each end of each fuel element and not less than one fewer restraining bars than full-clamps. The number of full clamp assemblies (N_c) required shall be sufficient to provide strength greater than that of the net strength of N_s shock-mount bolts, calculated at 13,000 lb force per bolt. The strength of the clamp assemblies has been determined by experiment to exceed 23,000 lb force per assembly. The specific criteria for determining the required number of full clamp assemblies, shock mounts and separator blocks within each package are:

$$N_b \geq \frac{W}{231};$$

$$N_c \geq \frac{W}{210}; \text{ and}$$

$$\frac{23}{13} N_c - 2 \leq N_s \leq N_c \frac{23}{13}.$$

Where: N_b = number of separator blocks required;
N_c = number of full clamps required;
N_s = number of shock mounts required; and
W = weight of the fuel element (pounds).

2.3 Both Models 51032-1 and 51032-1a Containers

There are no sampling ports or tie-down devices.

There are two valves on the containment vessels; one is used for pressurizing (with dry air or nitrogen) the containment vessel prior to shipping (or storage), and one for relieving the containment vessel pressure prior to unsealing the vessel. As such, both valves are located in one end of the containment vessel. These valves are not of safety significance and, indeed, are not normally used (i.e., the containment vessel is not normally pressurized except for leak testing prior to shipment).

There are no structural or mechanical means provided or required for the transfer or dissipation of heat and there are no coolants utilized in the packages. (Decay heat for the unirradiated fuels to be transported is negligible, < 20 watts).

2.4 Package Contents

2.4.1 Model 51032-1 Container

Each fuel element is enclosed in an unsealed polyethylene sheath. The ends of which are neither taped nor folded in any manner that would prevent the flow of liquids into or out of the ends of sheathed fuel elements.

The maximum content weight for the Model 51032-1 package is 3400 pounds.

Currently licensed mixed PuO_2-UO_2 fuel element identification numbers and the corresponding numbers used in this document are tabulated in Table 2-I. Design characteristics for these six specific mixed PuO_2-UO_2 nuclear fuel elements and for generically described low-enriched UO_2 fuel elements are summarized herein. Identification of these fuel elements, along with the maximum number of elements and the maximum radioactivity of the radioactive constituents contained in a single package, are tabulated in Table 2-II for specific mixed-oxide (PuO_2-UO_2) fuel elements and in Table 2-III for generically characterized UO_2 fuel elements.

The identification and maximum quantities of the fissile constituents contained in a single package are tabulated in Table 2-IV for specific mixed-oxide (PUO_2-UO_2) fuel elements and in Table 2-V for generically characterized UO_2 fuel elements.

All fuel elements contain pelletized and sintered UO_2 or PuO_2-UO_2 encapsulated within stainless steel or zircaloy tubing. The physical characteristics of the various fuel elements are tabulated in Table 2-XII. In all cases, individual rods are held in the respective arrays by upper and lower tie plates and intermediate spacers. The contained UO_2 or PuO_2 material is uniformly distributed throughout the active length of the individual fuel rods.

Note that for the generically characterized fuel elements (XN Types A through F) the following conditions were assumed:

1) The fuel is uranium-dioxide (UO_2) at 95 percent of theoretical density.

2) The clad is zircaloy 2 or 4, conservatively modelled as pure zirconium.

3) The clad thickness assumed was 0.020 inch, a value which is conservatively less than any present Exxon Nuclear Zr clad thickness.

4) The gas gap was assumed to be 0.005 inch.

As previously noted, some Exxon Nuclear fuel elements contain gadolinium, cobalt, or other neutron poison rods. In all cases, these poisons are conservatively neglected in performing the criticality safety calculations.

2.4.2 Model 51032-1a Container

In addition to the contents described in Section 2.4.1, the Model 51032-1a container may be used to transport larger fuel elements. The maximum content weight for the Model 51032-1a container is 3700 pounds. One such fuel element design (XN-Type AA) is currently licensed for transport in the Model 51032-1a container. Details relative to that fuel element are also given in Table 2-XII and Section 12.

TABLE 2-I

REVISED FUEL ELEMENT IDENTIFICATION NUMBERS

Licensed Fuel Element Identification Number	Revised Fuel Element Identification Number
I	I
III	II
VII	III
VIII	IV
XIV	V
XVII	VI

TABLE 2-II

RADIOACTIVE MATERIAL LIMITS (MIXED OXIDE FUELS)

XN I.D. (Type)	Radioactive Materials	Maximum Number of Elements per Package	Maximum Curies per Package
I	PuO_2-UO_2	2	20,500
II	PuO_2-UO_2	4	20,000
III	PuO_2-UO_2	2	13,400
IV	PuO_2-UO_2	4	49,200
V	PuO_2-UO_2	4	51,300
VI	PuO_2-UO_2	2	13,500

1631 163

TABLE 2-III

RADIOACTIVE MATERIAL LIMITS (UO_2 FUELS)

XN Fuel Type	Fissile Class	V_w/V_f	Maximum Enrichment	Radioactive Material	Number of Elements per Package	Maximum Curies per Package
A	I	$\leq$ 2.1	3.5	UO_2	2 or 4*	1.5
B	I	$\leq$ 2.1	3.5	UO_2	2 or 4	2.0
C	III	$\leq$ 1.8	4.0	UO_2	2 or 4	2.3
D	III	$\leq$ 2.1	4.0	UO_2	2 or 4	2.3
E	III	$\leq$ 2.3	4.0	UO_2	2 or 4	2.3
F	III	$\leq$ 2.1	5.0	UO_2	2 or 4	2.7

* Two fuel elements of standard length or 4 short fuel elements of equivalent weight.

TABLE 2-IV

FISSILE MATERIAL LIMITS (MIXED OXIDE FUELS)

XN I.D. (Type)	I.D.	Maximum Total Quantity (kg/Package)	Fissile Constituents* I.D.	Maximum Quantity (kg/Package)
I	U	247	U-235	6.1
	Pu	3.0	Pu_f	2.46
II	U	236	U-235	5.3
	Pu	1.70	Pu_f	1.35
III	U	362	U-235	7.6
	Pu	2.42	Pu_f	2.00
IV	U	510	U-235	16.0
	Pu	6.00	Pu_f	4.80
V	U	510	U-235	23.0
	Pu	6.25	Pu_f	5.0
VI	U	240	U-235	5.0
	Pu	1.8	Pu_f	1.4

* A summary of the fuel rods contained in each specific mixed-oxide fuel element is presented in Tables 2-VI through 2-XI.

TABLE 2-V

FISSILE MATERIAL LIMITS (UO_2 FUELS)

XN Fuel Type	Fissile Class	V_w/V_f	Maximum Enrichment	I.D.	Maximum Total Quantity (kg/Package)	Fissile Constituents I.D.	Fissile Constituents Maximum Quantity (kg/Package)
A	I	≤ 2.1	3.5	U	700	U-235	24.5
B	I	≤ 2.1	3.5	U	1500	U-235	52.5
C	III	≤ 1.8	4.0	U	1500	U-235	60.0
D	III	≤ 2.1	4.0	U	1500	U-235	60.0
E	III	≤ 2.3	4.0	U	1500	U-235	60.0
F	III	≤ 2.1	5.0	U	1500	U-235	75.0

TABLE 2-VI

XN-Type I

Number of Rods	Fuel Rod Description
4	Cobalt Targets
16	2.55 ± 0.05 w/o U-235
12	3.30 ± 0.05 w/o U-235
21	4.20 ± 0.05 w/o U-235
4	3.30 ± 0.05 w/o U-235 - 1.0 ± 0.05 w/o Gd_2O_3
24	3.65 ± 0.05 w/o Pu in Nat. U

TABLE 2-VII

XN-Type II

Number of Rods	Fuel Rod Description
21	2.95 ± 0.05 w/o U-235
6	2.00 ± 0.05 w/o U-235
9	2.84 ± 0.05 w/o Pu in natural uranium

TABLE 2-VIII

XN-Type III

Number of Rods	Fuel Rod Description
5	1.59 ± 0.05 w/o U-235
12	2.42 ± 0.05 w/o U-235
15	2.87 ± 0.05 2/o U-235
4	2.87 ± 0.05 w/o U-235--1.0 ± 0.05 w/o Gd_2O_3
7	2.19 ± 0.05 w/o Pu in Natural U
5	3.05 ± 0.05 w/o Pu in Natural U
1	Solid Zircaloy-2 (No SNM)

TABLE 2-IX

XN-Type IV

Number of Rods	Fuel Rod Description
16	2.30 ± 0.05 w/o U-235
32	3.20 ± 0.05 w/o U-235
40	4.60 ± 0.05 w/o U-235
4	4.60 ± 0.05 U-235--1.2 ± 0.05 w/o Gd_2O_3
24	5.45 ± 0.05 w/o Pu in Natural U
4	Cobalt targets (no SNM)
1	Solid Zircaloy-2 (no SNM)

TABLE 2-X

XN-Type V

Number of Rods	Fuel Rod Description
16	2.30 ± 0.05 w/o U-235
32	3.20 ± 0.05 w/o U-235
36	4.60 ± 0.05 w/o U-235
4	4.60 ± 0.05 U-235 - 1.2 ± 0.05 w/o Gd_2O_3
25	5.45 ± 0.05 w/o Pu in Natural U
4	Cobalt targets (no SNM)
4	Solid Zircaloy-2 (no SNM)

TABLE 2-XI

XN-Type VI

Number of Rods	Fuel Rod Description
20	2.64 ± 0.05 w/o U-235
6	1.79 ± 0.05 w/o U-235
8	2.74 ± 0.05 w/o Fissile; Pu in Natural U
2	2.24 ± 0.05 w/o Fissile; Pu in Natural U

TABLE 2-XII

LIMITING FUEL ELEMENT PHYSICAL CHARACTERISTICS

XN Fuel Type	No. of Fuel Rods	Fuel Rod Array (Square)	Nominal Array Dimensions (inches)	Nominal Rod Pitch (inches)	Clad Material	Nominal Clad Thickness (inches)	Nominal Fuel Rod O.D. (inches)	Nominal Fuel Pellet Diameter (inches)	Nominal Active Fuel Length (inches)
I	81	9 x 9	6.22 x 6.22	0.707	Zircaloy	.0375	0.563	0.478	68.
II	36	6 x 6	4.72 x 4.72	0.770	Zircaloy	.0345	0.570	0.489	60.
III	49	7 x 7	5.35 x 5.35	0.738	Zircaloy	.034	0.570	0.478	144.
IV	121	11 x 11	6.52 x 6.52	0.577	Zircaloy	.034	0.449	0.371	70.
V	121	11 x 11	6.52 x 6.52	0.577	Zircaloy	.034	0.449	0.371	70.
VI	36	6 x 6	4.50 x 4.50	0.700	Zircaloy	.0302	0.563	0.481	116.
A	≤ 100	≤ 10 x 10	≤ 5.2 x 5.2	< 0.806	Zircaloy or SS*	.020 or .015	< 0.550	< 0.500	< 192.
B	≤ 289	≤ 17 x 17	≤ 8.55 x 8.55	< 0.806	Zircaloy or SS	.020 or .015	< 0.550	< 0.500	< 192.
C	≤ 289	≤ 17 x 17	≤ 8.60 x 8.60	< 0.769	Zircaloy or SS	.020 or .015	< 0.550	< 0.500	< 192.
D	≤ 289	≤ 17 x 17	≤ 8.48 x 8.48	< 0.806	Zircaloy or SS	.020 or .015	< 0.550	< 0.500	< 192.
E	≤ 289	≤ 17 x 17	≤ 8.40 x 8.40	< 0.830	Zircaloy or SS	.020 or .015	< 0.450	< 0.400	< 192.
F	≤ 289	≤ 17 x 17	≤ 8.00 x 8.00	< 0.806	Zircaloy or SS	.020 or .015	< 0.550	< 0.500	< 192.
AA**	≤ 256	16 x 16	9.01 x 9.01	0.563	Zircaloy	.030	0.424	0.3565	154.

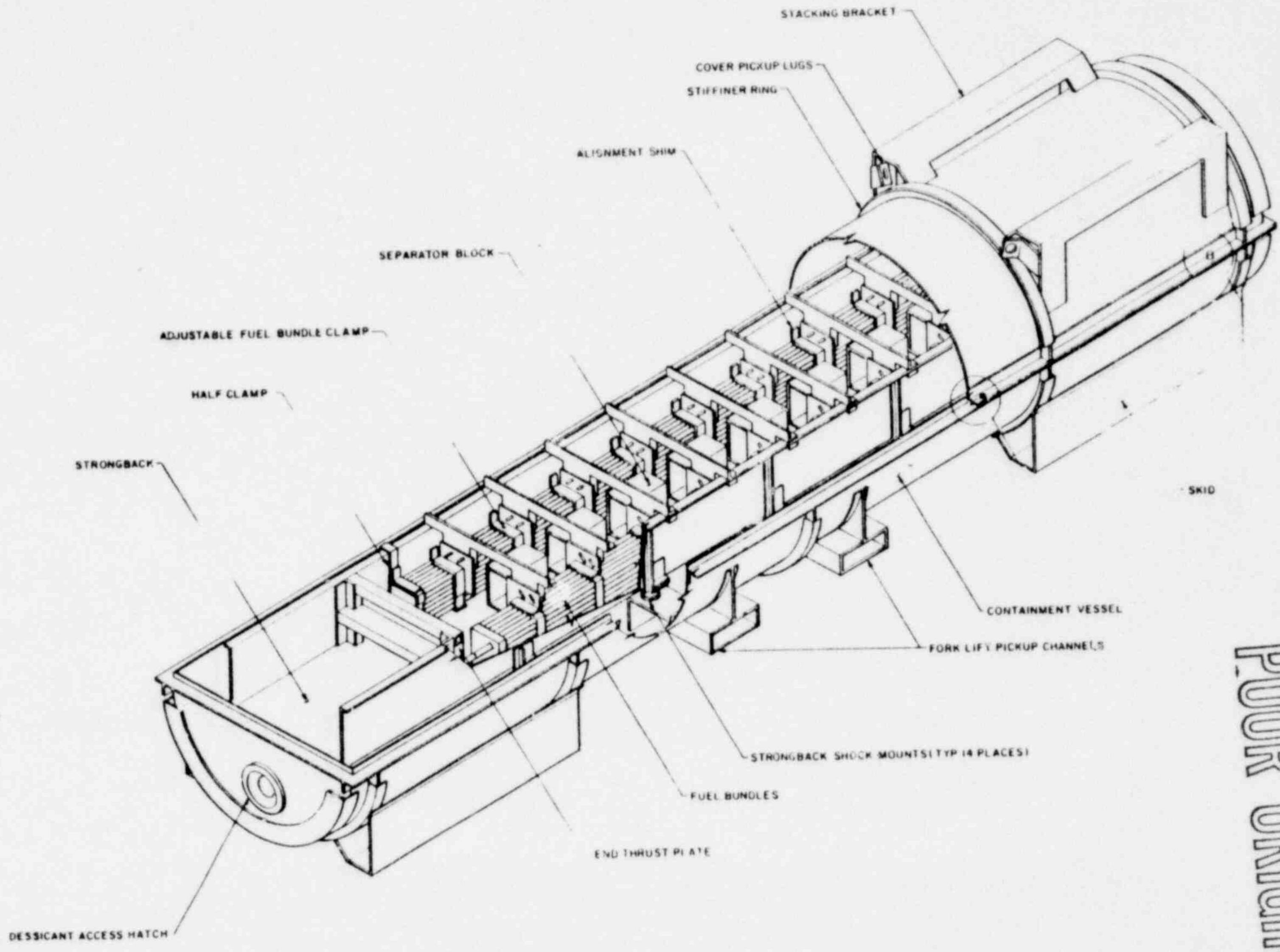
* May be Zircaloy-2, Zircaloy-4 or stainless steel. For criticality safety calculations a 0.20 inch zirconium clad was assumed.

** Type AA fuel elements may be transported only in Model 51032-1a containers.

1631 169

FIGURE 2.1

Model 51032-1 and 1-a Containment Vessel (Isometric View)



1631 170

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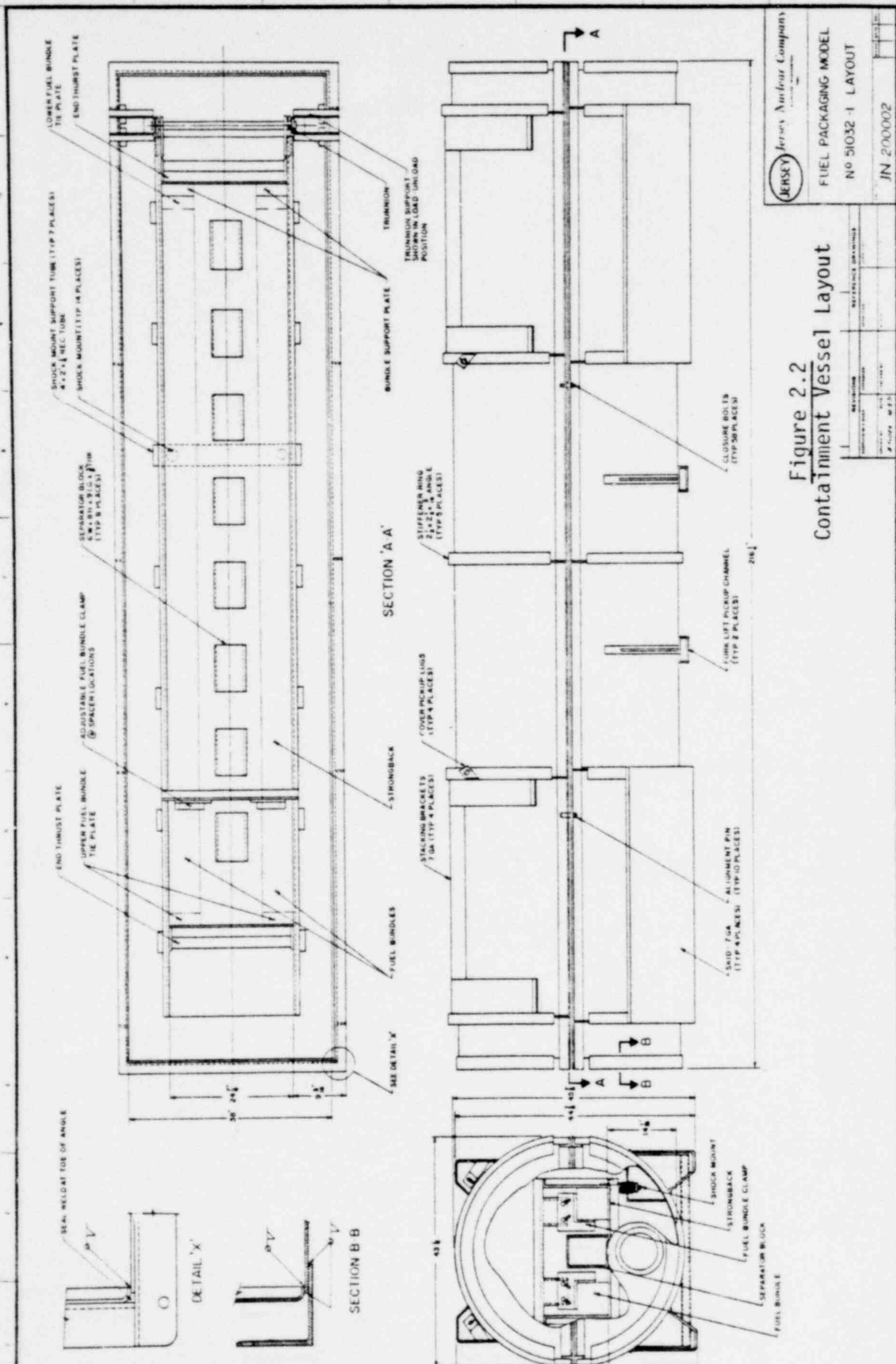

Figure 2.2
Containment Vessel Layout

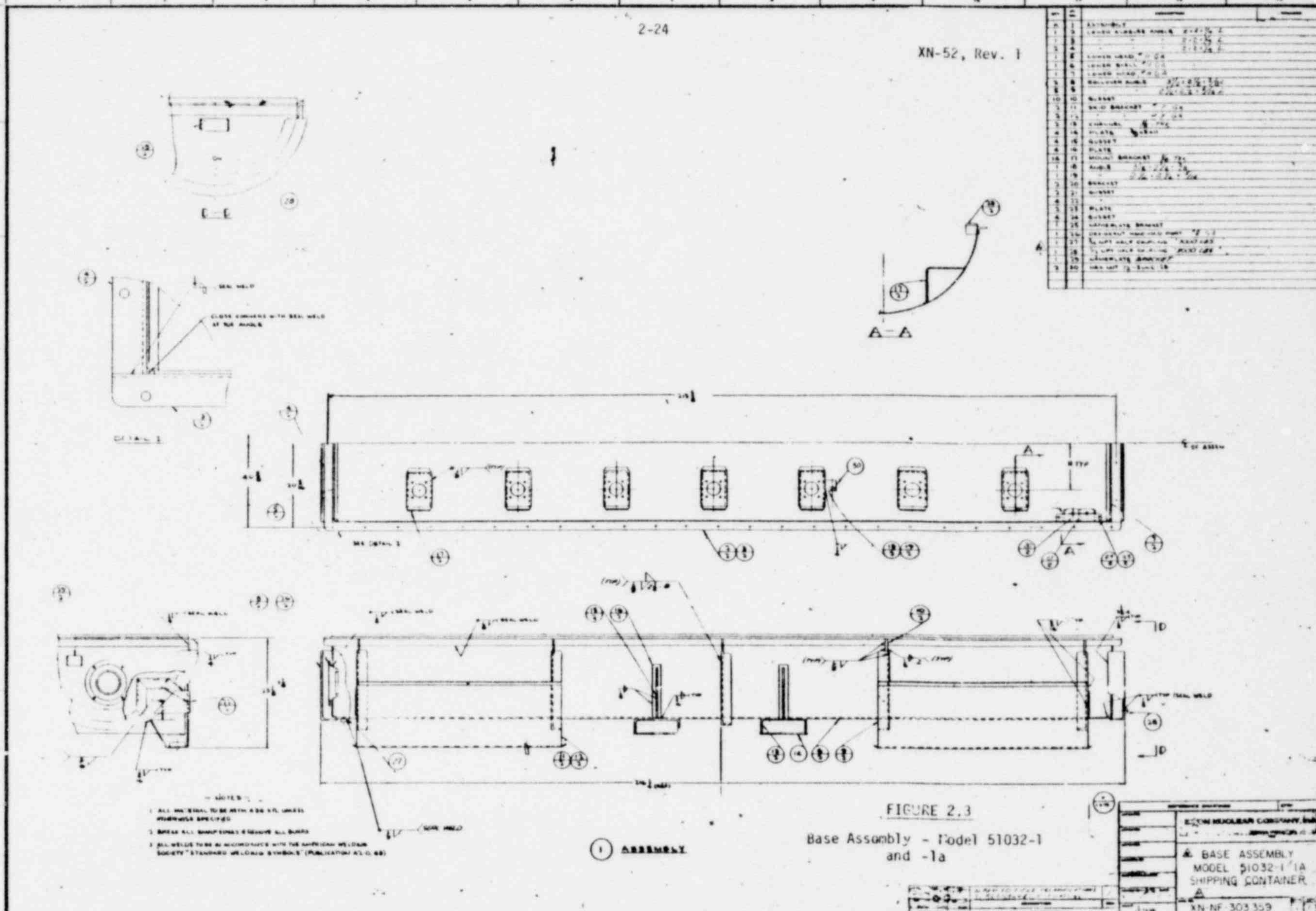

FIGURE 2.3

Base Assembly - Model 51032-1 and -1a

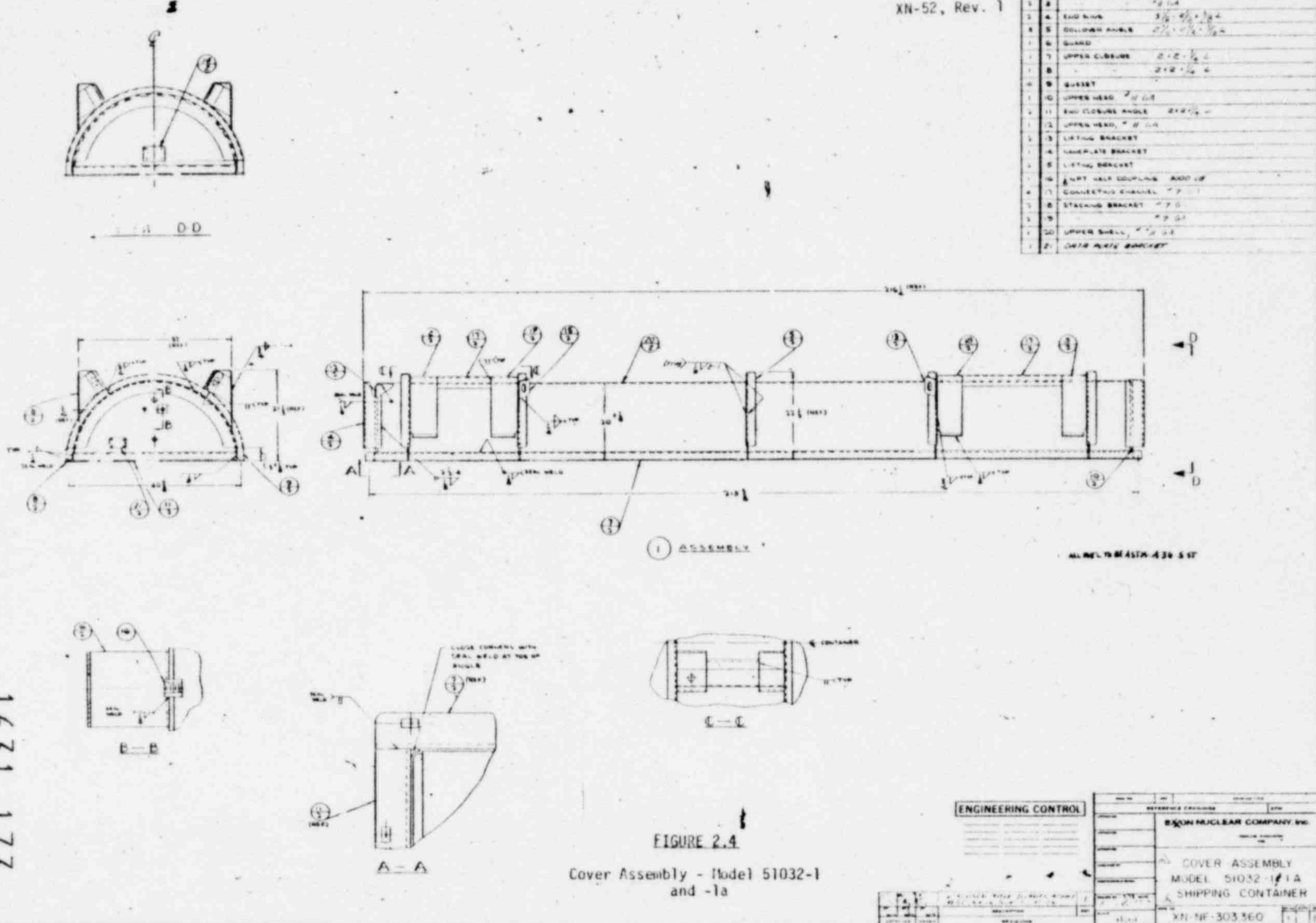

FIGURE 2.4

Cover Assembly - Model 51032-1 and -1a

POOR ORIGINAL

XN-52, Rev. 1

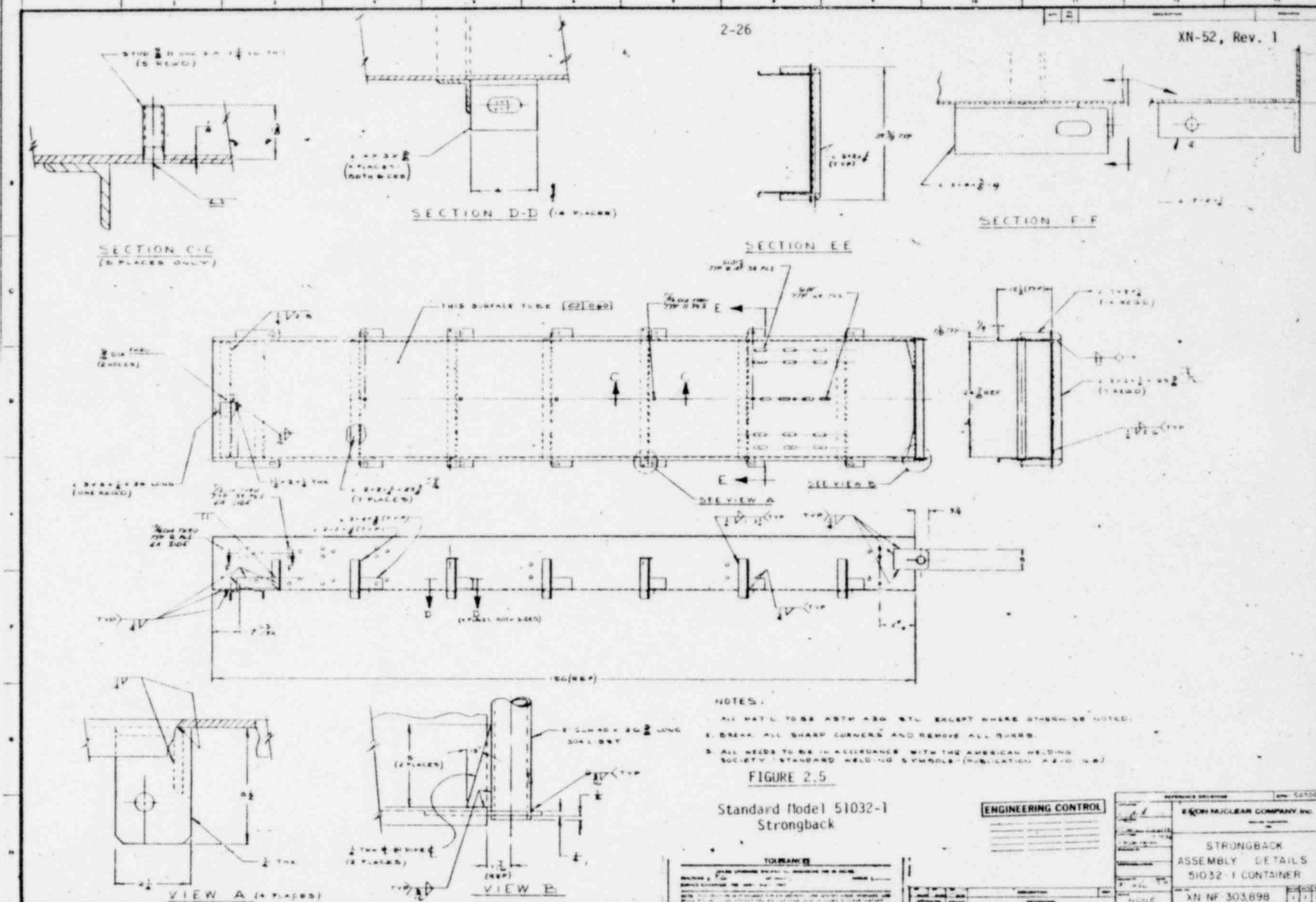

FIGURE 2.5

Standard Model 51032-1
Strongback

1631 174

POOR ORIGINAL

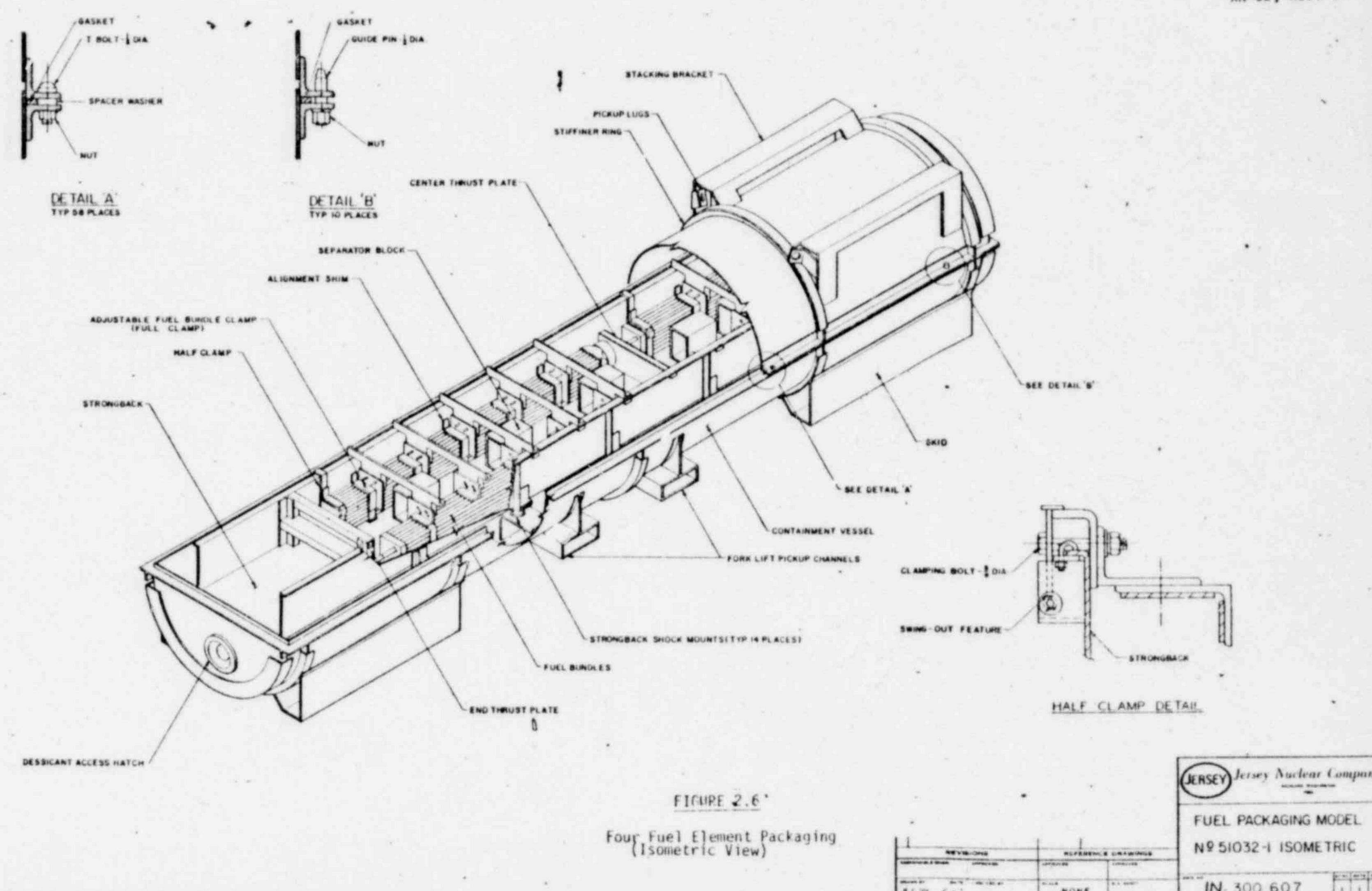

FIGURE 2.6

Four Fuel Element Packaging
(Isometric View)

1631 175

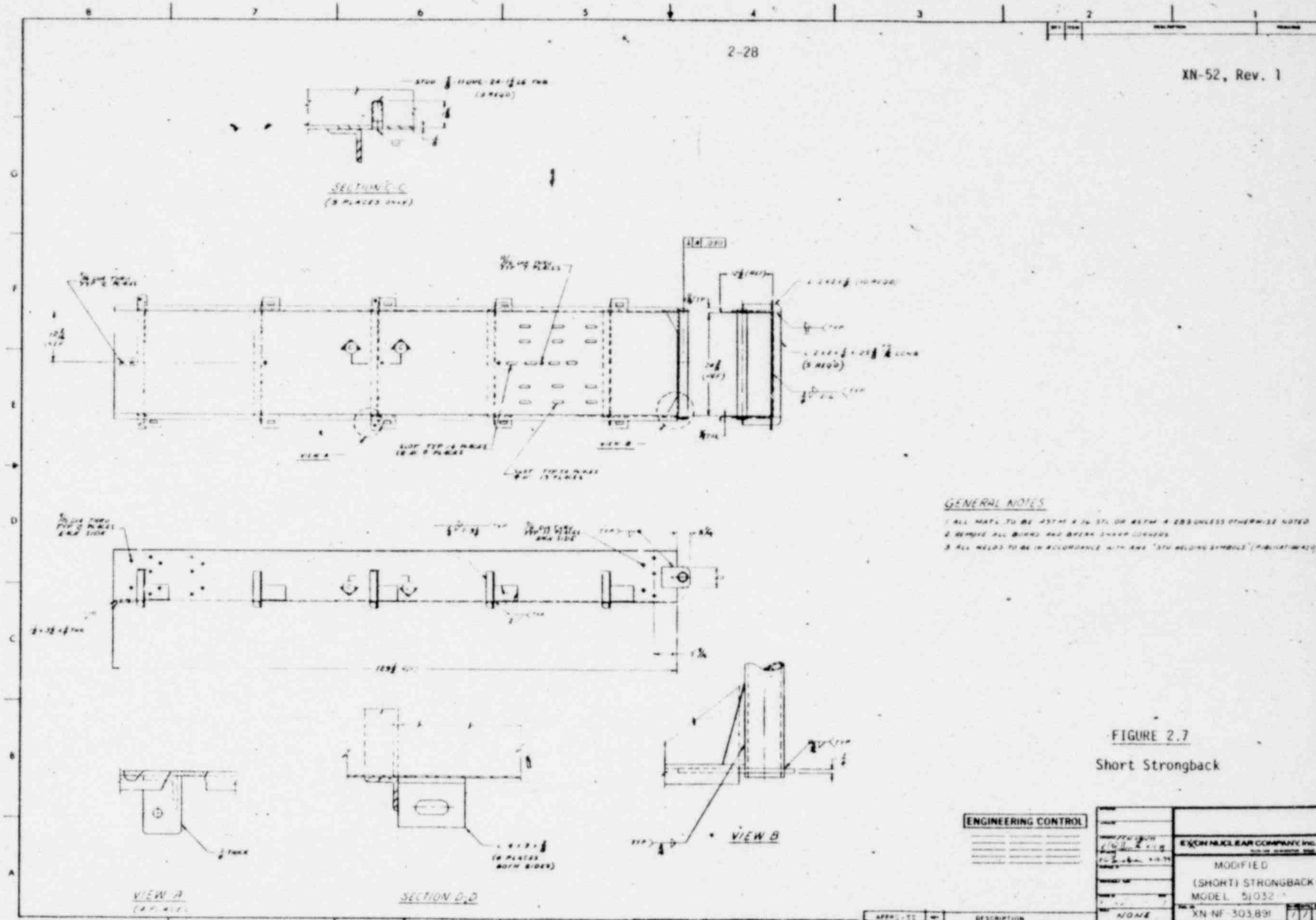

FIGURE 2.7

Short Strongback

POOR ORIGINAL

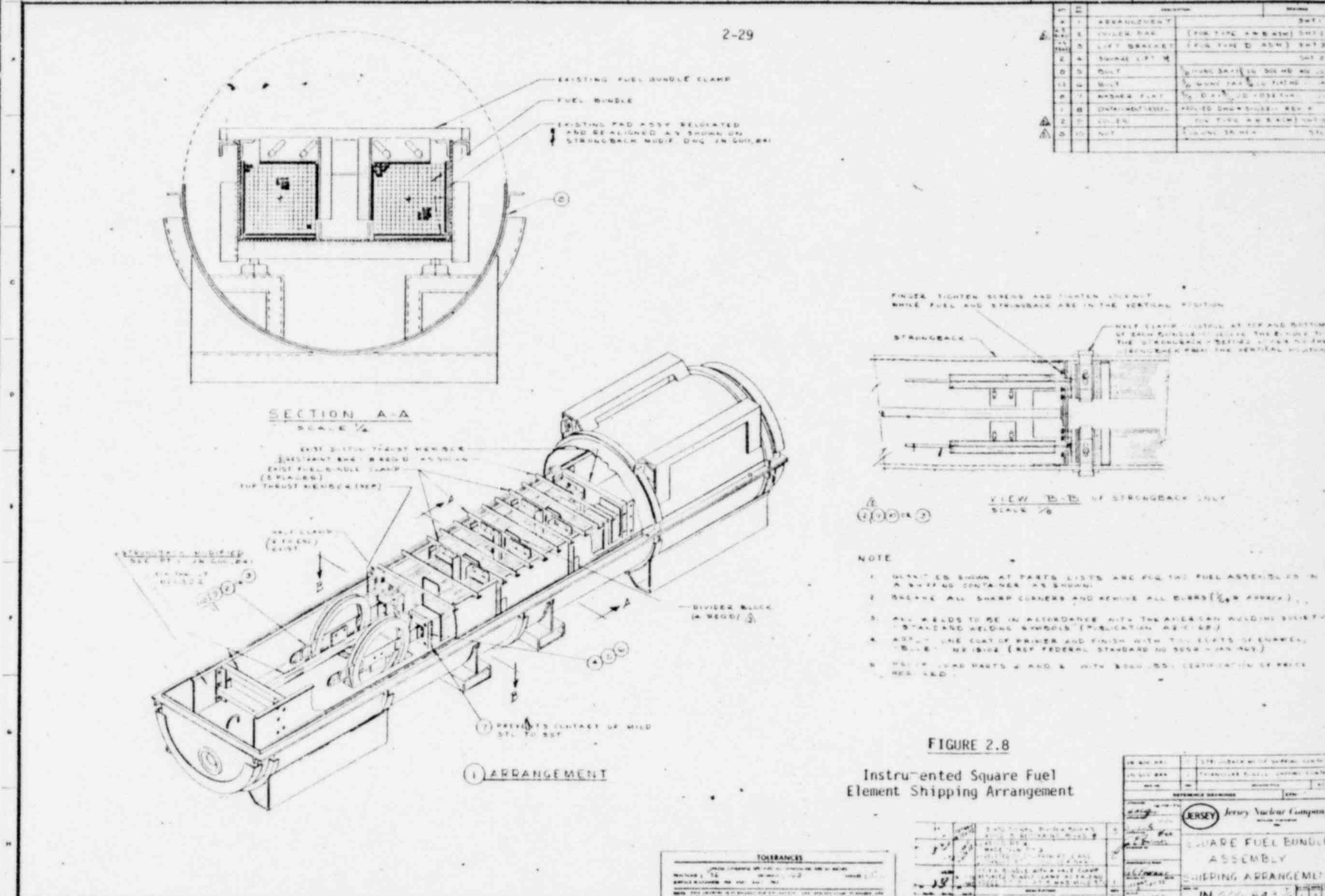

FIGURE 2.8

Instru-ented Square Fuel
Element Shipping Arrangement

1631 177

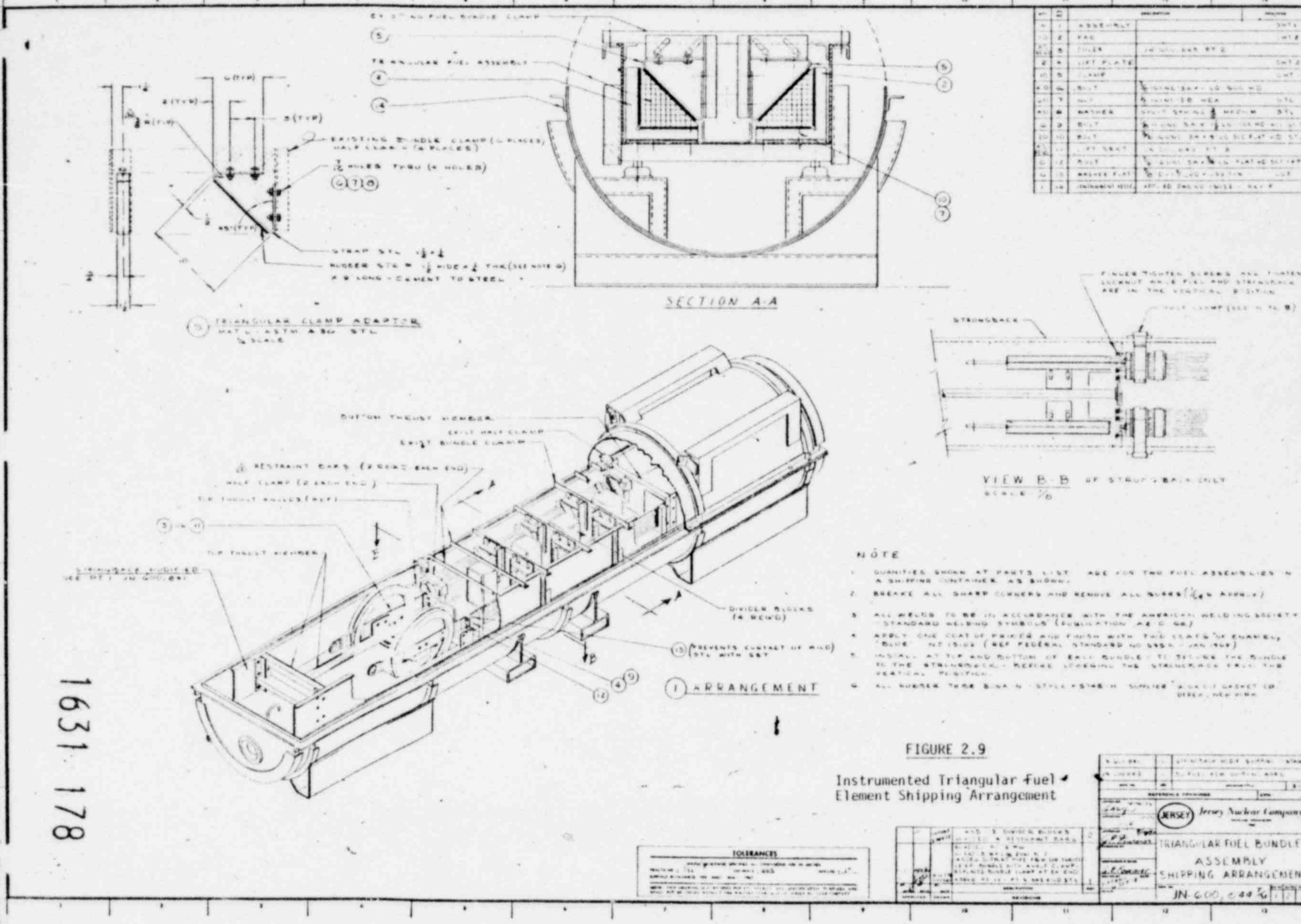

FIGURE 2.9

Instrumented Triangular Fuel Element Shipping Arrangement

POOR ORIGINAL

1631 178

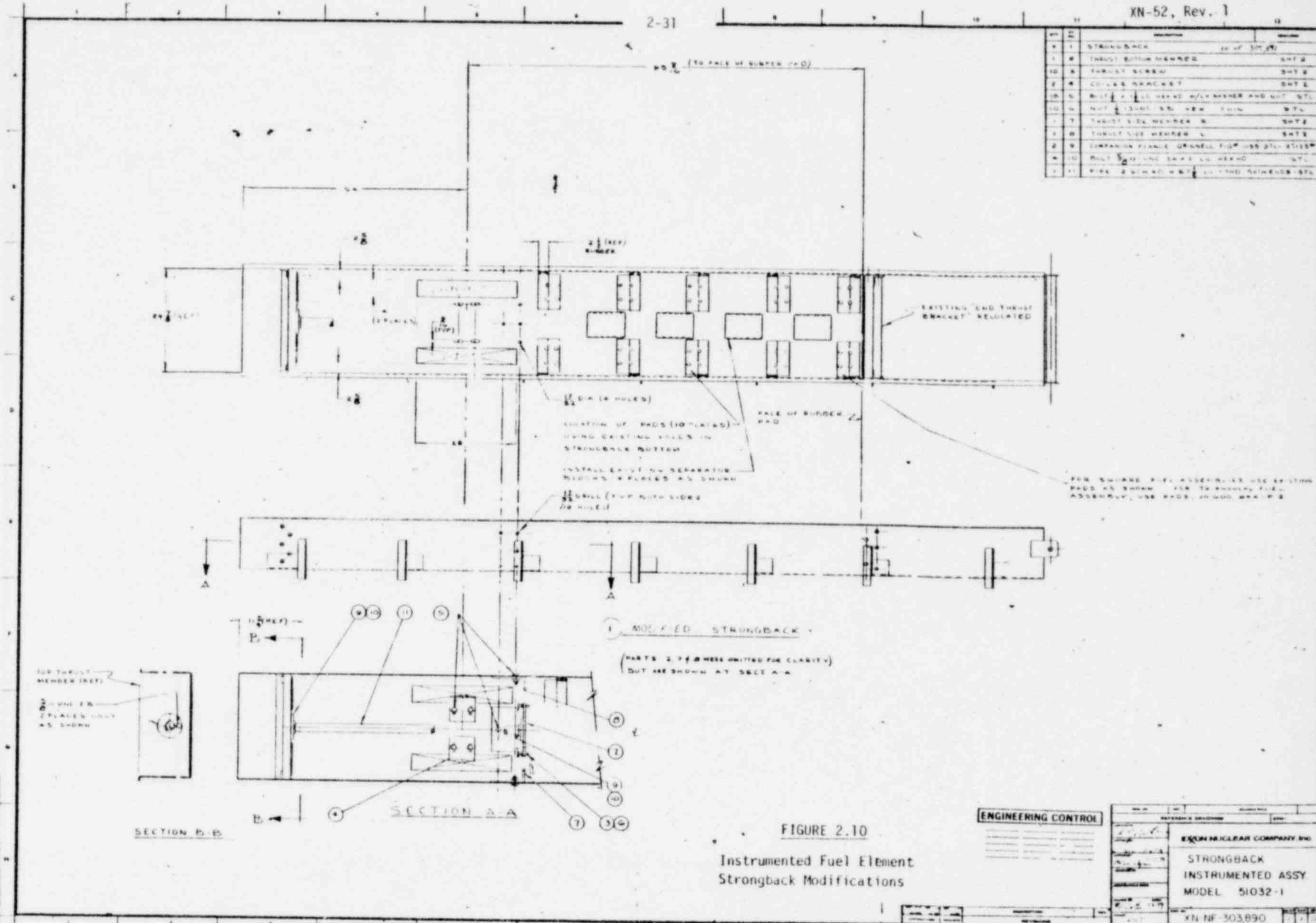

FIGURE 2.10

Instrumented Fuel Element
Strongback Modifications

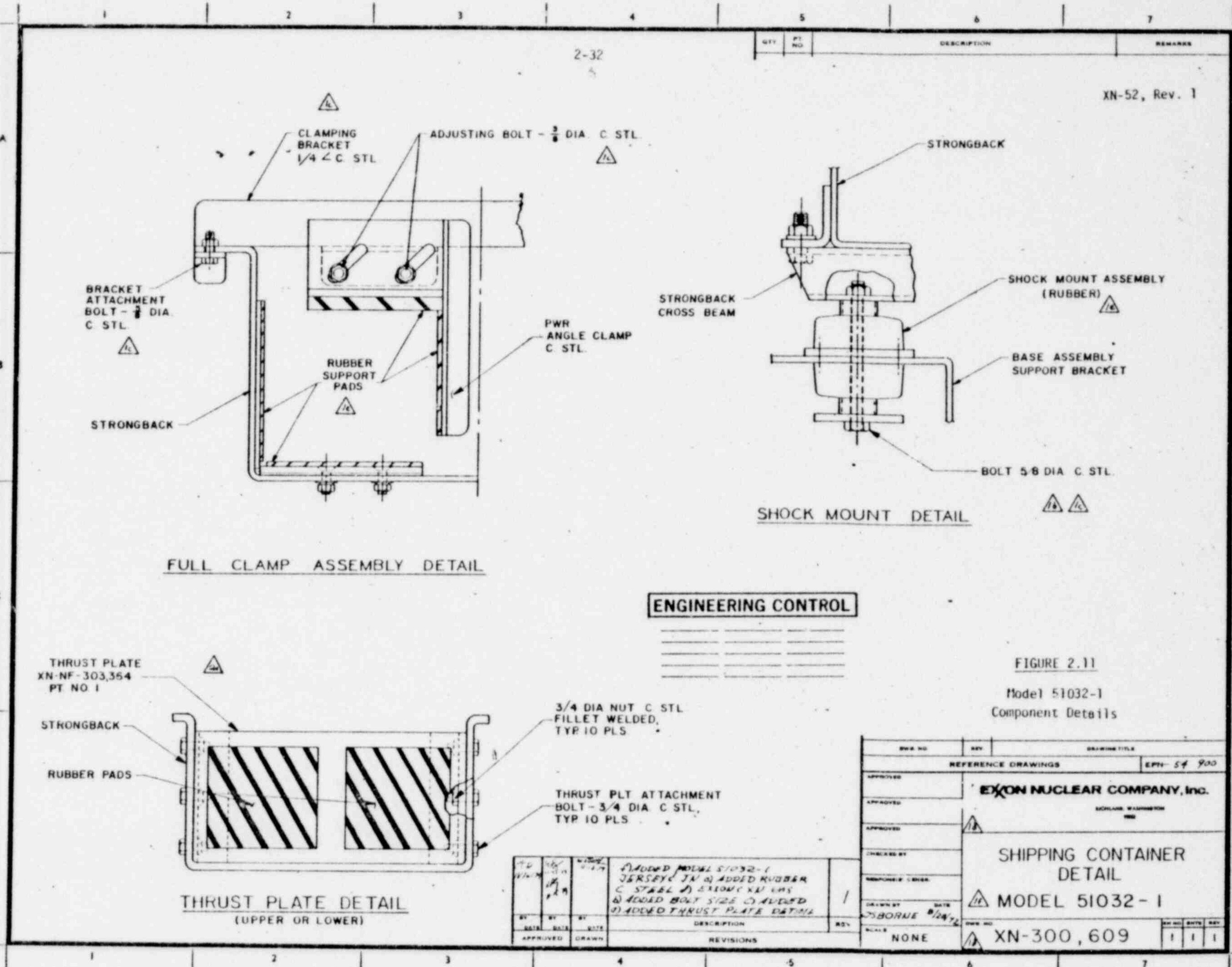

FIGURE 2.11

Model 51032-1

Component Details

1631. 180

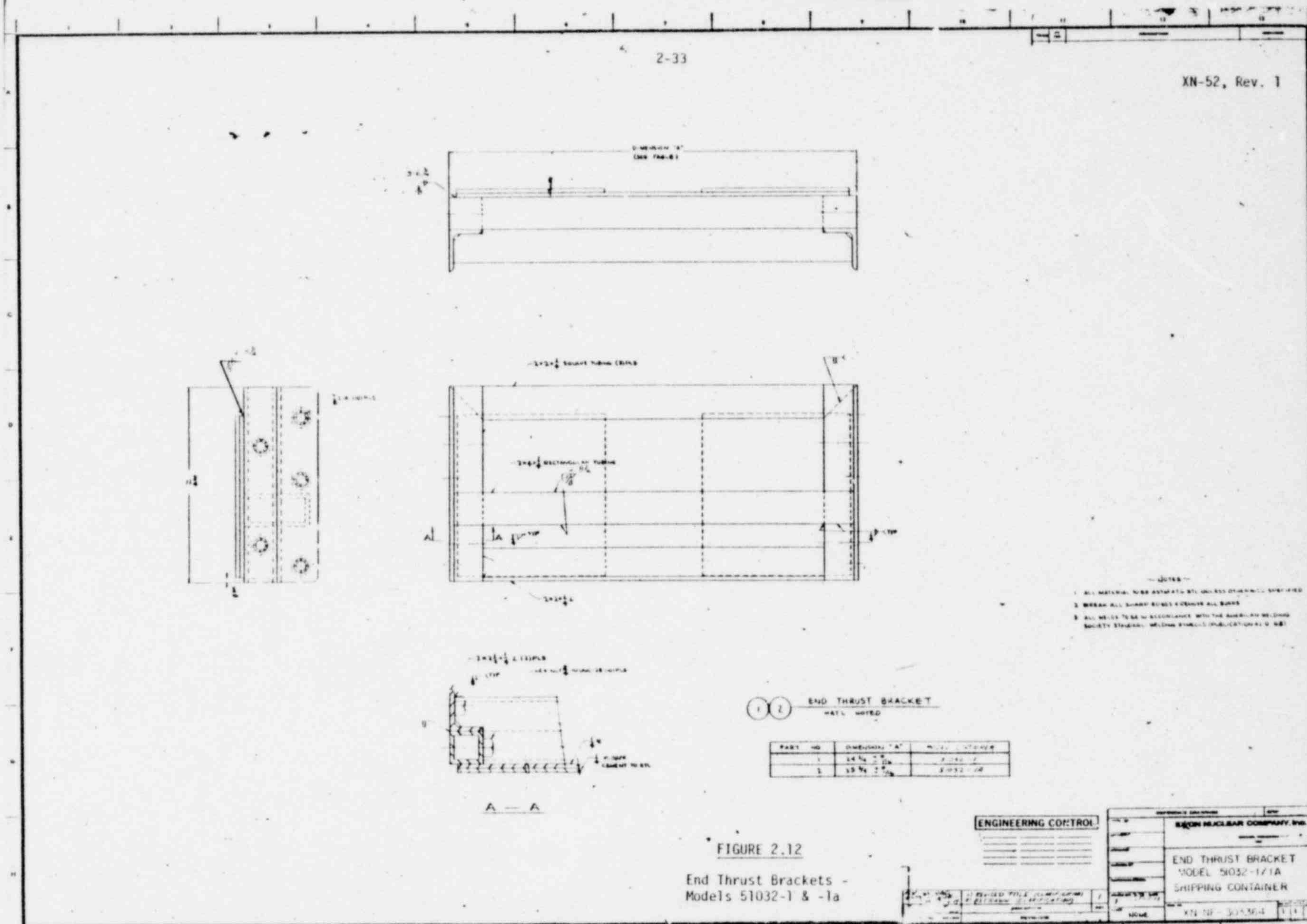

FIGURE 2.12

End Thrust Brackets - Models 51032-1 & -1a

POOR ORIGINAL

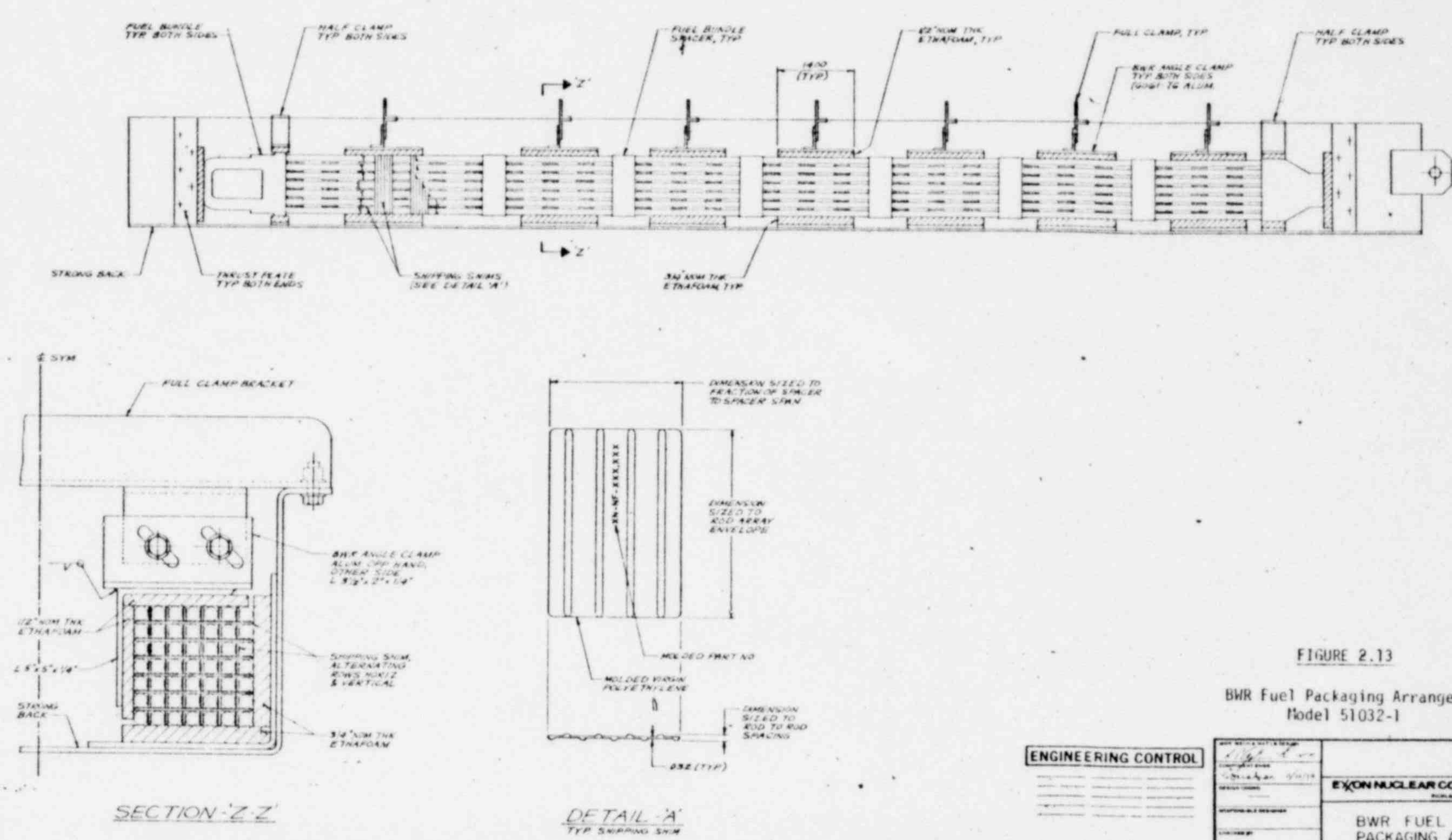

FIGURE 2.13

BWR Fuel Packaging Arrangement
Model 51032-1

ENGINEERING CONTROL

EXXON NUCLEAR COMPANY, Inc.

BWR FUEL ASS'Y
PACKAGING ARRG'T
51032-1 CONTAINER

NONE

XN-NF-303,897

POOR ORIGINAL

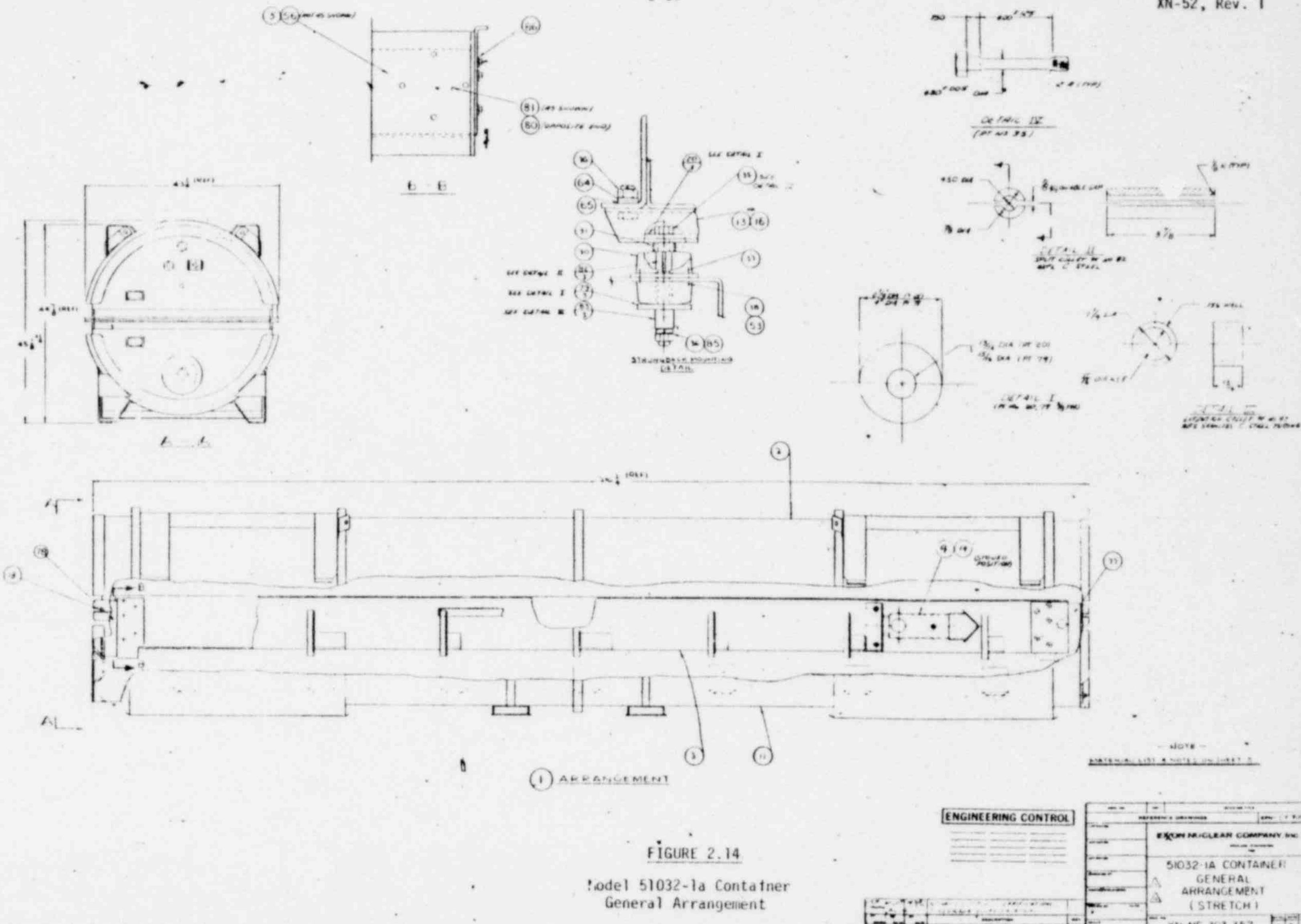

FIGURE 2.14

Model 51032-1a Container
General Arrangement

1631 183

POOR ORIGINAL

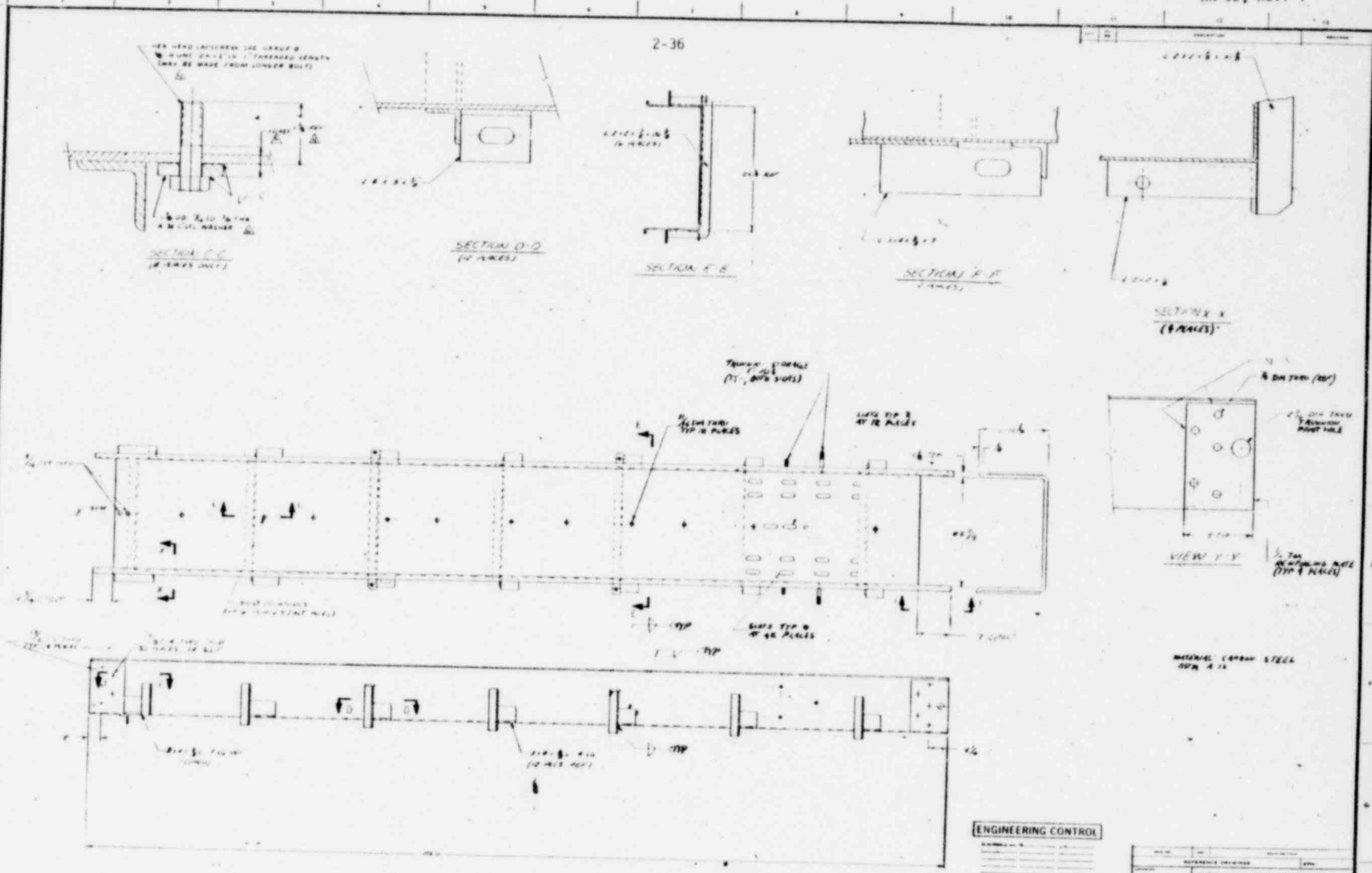

FIGURE 2.15

Model 51032-1a Container Strongback

1631 184

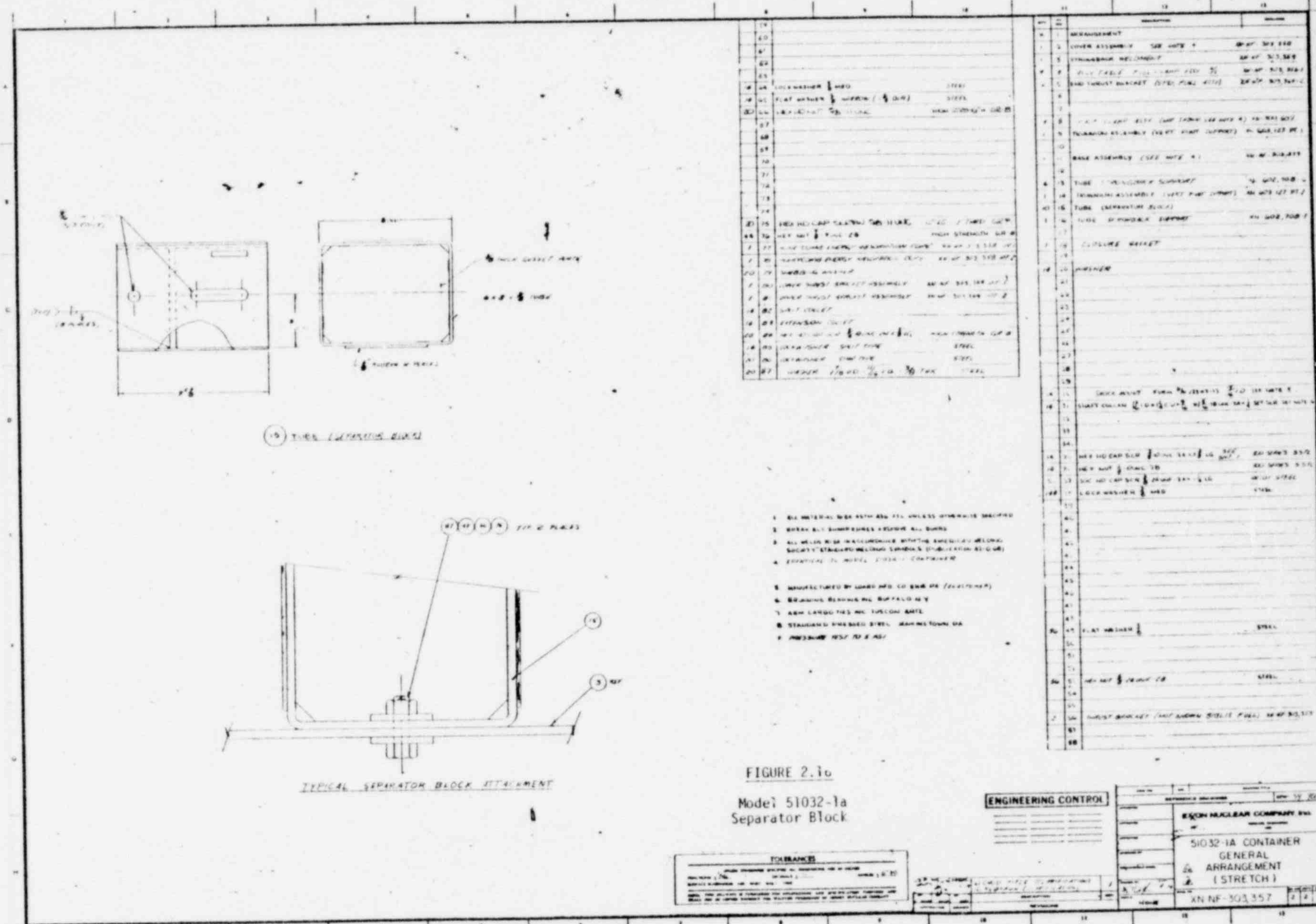

FIGURE 2.1o

Model 51032-1a
Separator Block

POOR ORIGINAL

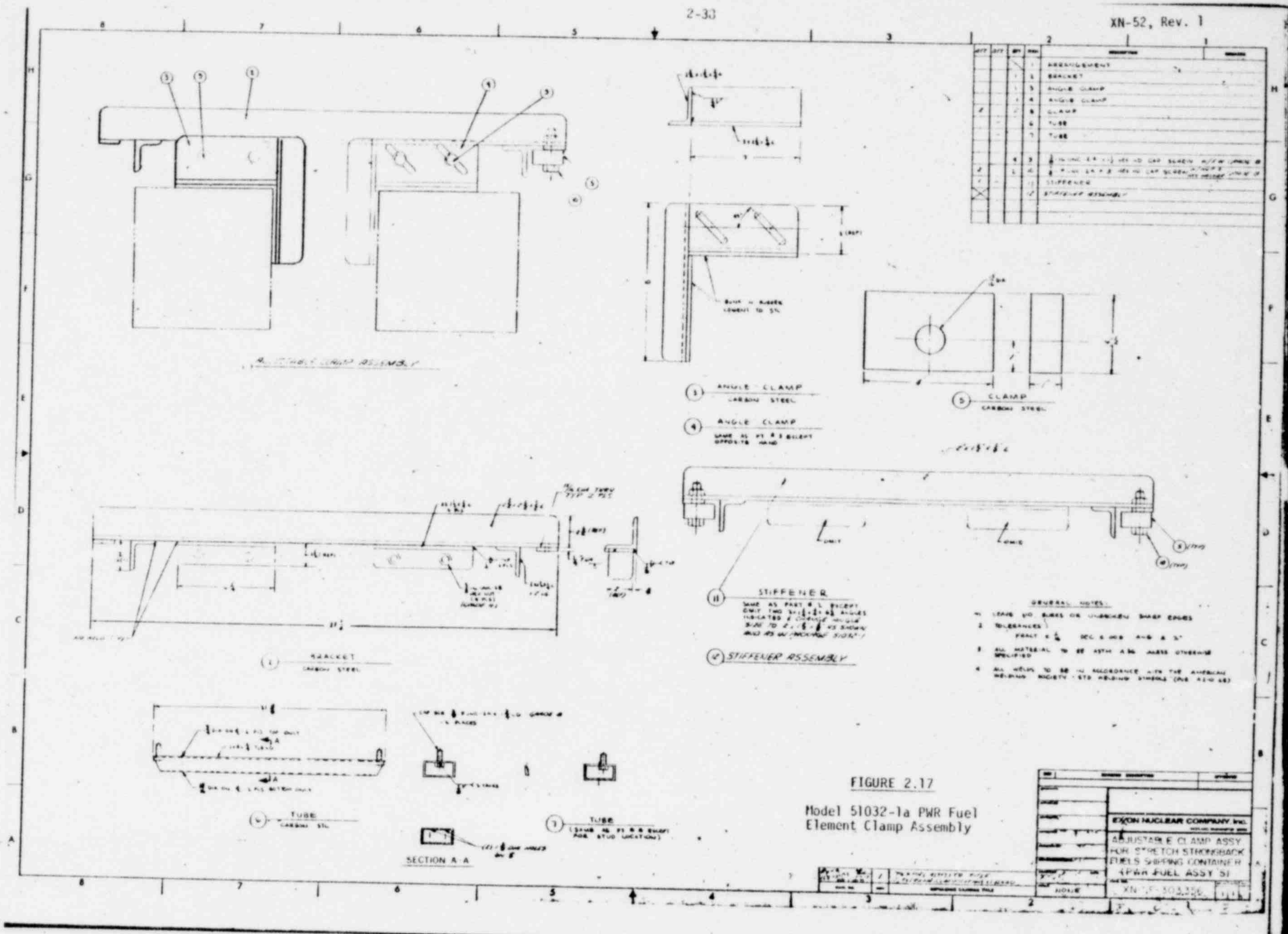

FIGURE 2.17

Model 51032-1a PWR Fuel Element Clamp Assembly

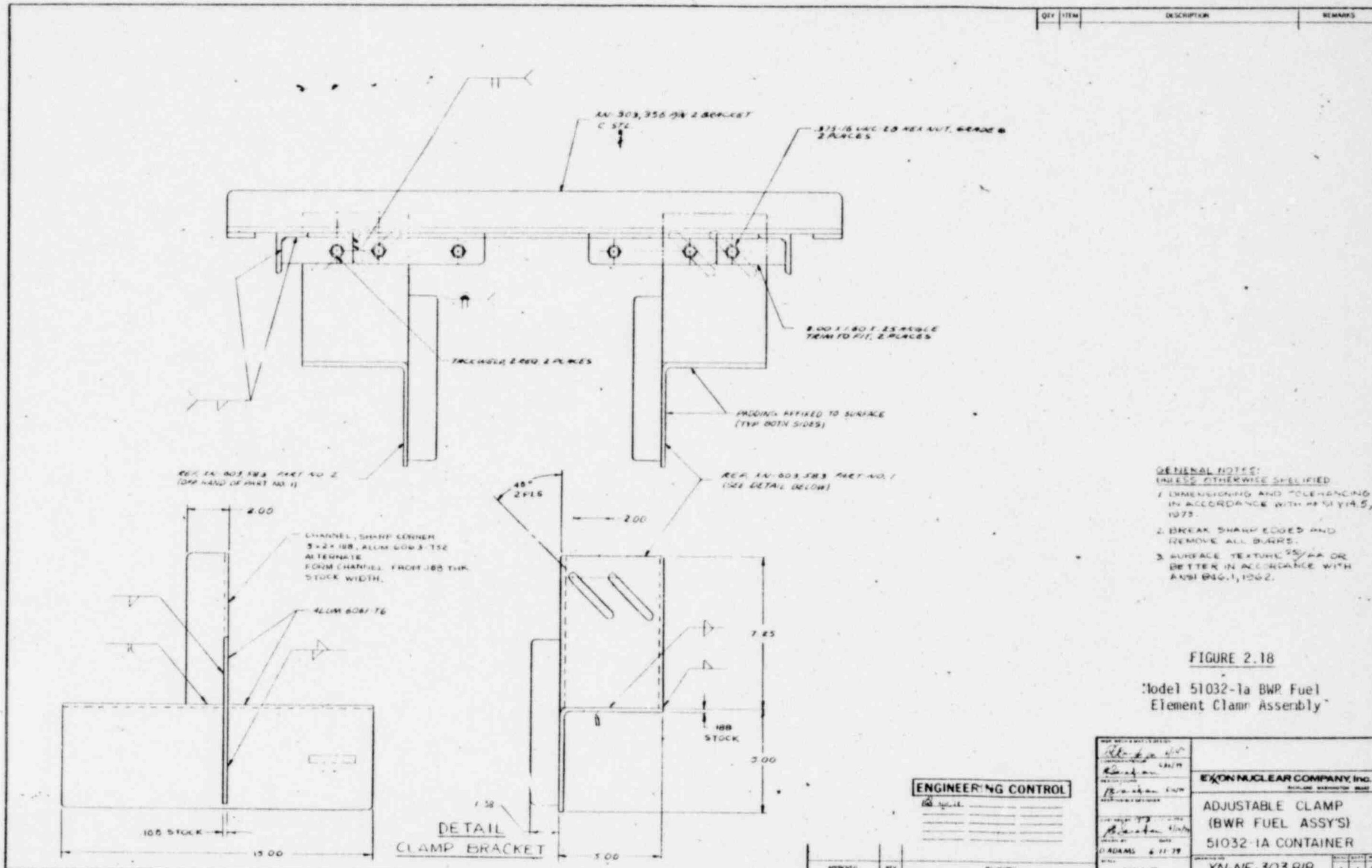

FIGURE 2.18

Model 51032-1a BWR Fuel Element Clamp Assembly

1631 187

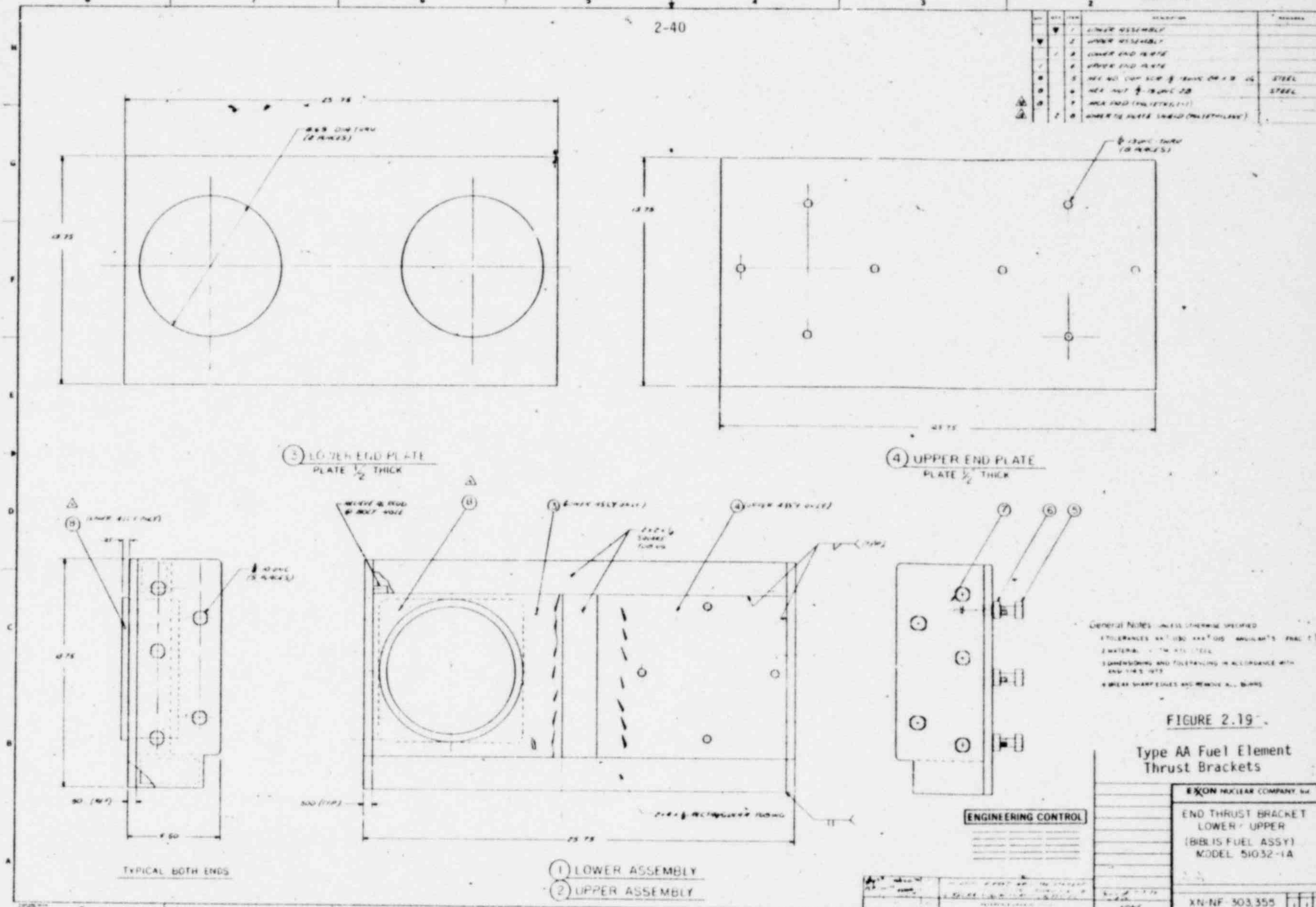

FIGURE 2.19. Type AA Fuel Element Thrust Brackets

1631 188

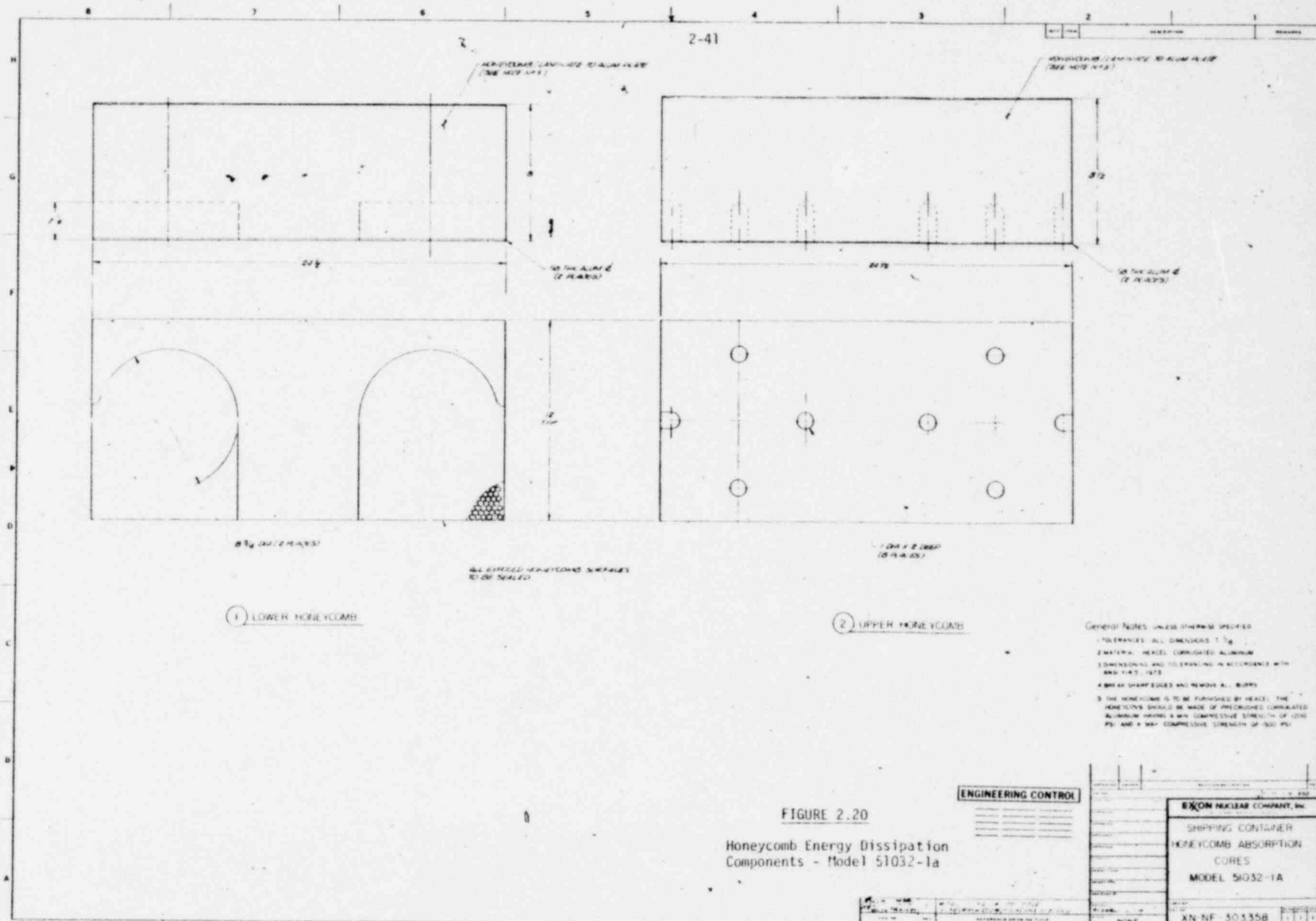

FIGURE 2.20

Honeycomb Energy Dissipation Components - Model 51032-1a

1631 189

5.0 GENERAL STANDARDS FOR PACKAGING

The materials from which the packaging is fabricated (steel, rubber padding, and gaskets), along with the contents of the package (zircaloy or stainless steel clad fuel rods, stainless steel and inconel fuel element hardware, polyethylene wrapping, and desiccant material), will not cause significant chemical, galvanic, or other reactions in air, nitrogen, or water atmospheres.

The positive closure system has been previously described in Section 2. In addition, each package will be sealed with Type E, tamper indicating seals. These features prevent inadvertent and undetected opening.

The lifting system (four steel lugs welded to the cover assembly stacking brackets) was analyzed to be capable of lifting an 8300-pound package without generating stress in any material of the packaging in excess of its yield strength with a minimum safety factor of 3.4 (see Appendix I). Alternatively, two forklift pickup channels (1/4 inch steel), are welded to the bottom of the containment vessel base assembly to facilitate forklift handling. Administrative controls are used to prevent the lifting of stacked packages.

If the lifting system were to be subjected to an excessive load and fail, continued containment of the contents would not be jeopardized since the containment of the radioactive materials is not dependent upon the packaging. There are no shielding considerations involved.

Administrative controls prevent the use of any structural part of the package as a lifting device.

There is no identified system of tie-down devices on the packages. However, a combination of shoring, positioning studs, axial, and transverse chokers (chain or cables) is employed to secure packages to the transport vehicles. The "tie-down" system used to satisfy the criteria set forth in 10 CFR 71.31(d) is as shown in Figure 3.1. The only structural part of the packaging which could be employed to tie the packages down are the stacking brackets and stiffening rings. There are eight stacking brackets per package and the analyses in Appendix II show that a minimum of two of these (per package) could be used in a "tie-down" arrangement (along with shoring and cross chokers). The stiffening rings are normally used as tie-down points. These are heavy members that can easily support the tie down loads.

If the stacking brackets were to be subjected to an excessive load and fail, continued containment of the package contents would not be jeopardized since the containment of the radioactive materials is not dependent upon the packaging.

Where W is the weight of one fuel element expressed in pounds or, if four fuel elements are contained, the combined weight of two fuel elements.

10.1.2.2 Integrity of the Aluminum Clamps

Due to the excessive weight of steel fuel clamps for packaging BWR fuel elements, Exxon Nuclear has designed the aluminum clamps shown in Figure 2.13. These clamps would be loaded most severely in a hypothetical drop on the container cover. As described in Appendix V, the clamp loading and deformation is limited by the early tensile failure of the shock mount bolts and contact of the clamp angle bars with the container cover. Tests on the aluminum clamps have shown that the aluminum clamps will behave as well as the steel ones used in the drop tests and will retain the fuel elements within the strongback. (See Figure 10.1 for the comparison of the force deflection curves for the steel and aluminum clamp assemblies.)

10.1.2.3 Short Strongbacks Used in Some Shipments

Some fuel elements are significantly shorter than the standard strongback for Model 51032-1 containers. A shorter strongback (see Figure 2.7) has been designed which will be used interchangeably with the standard strongback for those fuel elements which can be accomodated. Except for length, it is structurally the same and would be equally effective in retaining the fuel elements in the hypothetical accident. In addition, the shorter fuel elements have a corresponding decrease in weight which results in reduced loads under hypothetical accident conditions.

When used for shipping fuel elements which result in a package gross weight of 7400 pounds or less, the upper thrust plate and honeycomb material shown in Figures 2.19 and 2.20 may be replaced with the thrust plate shown in Figure 2.12. In this configuration energy dissipation at the upper end of the strongback is quite similar to that of the Model 51032-1 package except that the increased energy dissipation capability of shock mount and other bolts within the package is preserved.

10.2.1 Model 51032-1a Container-End Drop Evaluation

In the Model 51032-1 drop test, the shock mount bolts sheared with little energy dissipation when the container impacted with the ground. The container crumpled only two inches at impact with the only evident damage being to the container end where the ring was torn loose at the weldments and the end pushed in slightly at the flange which was crumpled over. Those distortions represented the conversion of the container kinetic energy to strain energy. Then, following shearing of the shock mount bolts, the moving strongback impacted the end and caused both further container end damage and crumpling of the end of the strongback. Except for localized damage, the package was not significantly damaged and the result demonstrated compliance with the Part 71 packaging standards.

With respect to the vertical drop model, the main differences with the new package design are the shorter strongback extensions beyond the thrust plates, the increased weight of strongback and fuel elements, the added aluminum honeycomb, and the change in bolts as outlined above. Damage to the end of the container in the initial impact

Due to the increased energy dissipation of bolts and clamps in the Model 51032-1a package, the impact energy would be significantly reduced. Otherwise, the nature of the impact of the strongback against the cover would be very similar to that observed in the drop test. The approximate energy balance is presented in Table 10-I.

10.2.4 Model 51032-1a Separator Block Integrity

The integrity of the separator blocks in the Model 51032-1 package was not tested in the Exxon Nuclear drop tests. In a hypothetical drop on a closure flange, the separator blocks would be loaded by deceleration of one of the fuel elements. It is assumed that the fuel element clamps would not be effective in supporting this load and would fail if the separator blocks were crushable. To assure that the blocks will withstand the required force, a gusset plate is welded within the blocks as shown in Figure 2.16.

The blocks were tested as described in Appendix V and assure a minimum spacing of six inches between fuel elements within the container. The number of blocks required for 1850 pound fuel elements is eight (8).

10.3 Fuel Rod Drop Tests

To supplement information obtained from the package drop tests and assess the capability of fuel rods to withstand dynamic loads similar to those experienced under hypothetical accident conditions, drop tests were also performed with individual fuel rods. Details relative to those tests

12.0 SPECIFIC STANDARDS FOR FISSILE CLASS I AND III PACKAGES

Model 51032-1 packages containing XN Type III, IV, and VI fuel elements are transported as Fissile Class I shipments on, or in, multiple use vehicles. Model 51032-1 packages containing XN Type I, II, and V fuel elements are transported as Fissile Class III shipments on, or in, exclusive use vehicles.

Model 51032-1 or 51032-1a packages containing generically characterized (UO_2) fuel are transported either as Fissile Class I shipments on, or in, multiple-use vehicles; or as Fissile Class III shipments on, or in, exclusive use vehicles, as identified herein. Model 51032-1a packages containing Type AA fuel elements are transported as Fissile Class I.

To demonstrate that shipments of these packages remain subcritical under all credible conditions, nuclear criticality safety evaluations have been made for each of the specific mixed-oxide (PuO_2-UO_2) XN-type fuel elements described in Section 2, and for Type AA fuel elements. Furthermore, conservative limits on the physical dimensions, enrichment, fuel pellet diameter, and water-to-fuel volume ratio of generically characterized UO_2 fuel elements, from the viewpoint of nuclear criticality safety, have been established for both Fissile Class I and Fissile Class III shipments. The results of these evaluations are presented herein and a summary of the derived limits is given in Section 12.5. The criterion used to derive limits on fuel element parameters was that for both normal conditions of transport and accident conditions (damaged package arrays), $k_{eff} + 3\sigma \leq 0.970$. Fuel element parameter limits were established by applying the criterion to both conditions with subsequent selection of the more conservative limitations.

12.1 Method, Discussion, and Verification

12.1.1 XN Type I Fuel Elements

The methods and nuclear data utilized to calculate k_∞ of XN Type I fuel elements are consistent with the methods and data used throughout the nuclear industry for water moderated systems. The analysis utilizes the HRG code to obtain multi-group epithermal cross sections and the THERMOS code to obtain cell-averaged thermal group parameters for each rod. The two-dimensional diffusion theory code 2DB is used to compute the k_∞ of the fuel elements. To verify the accuracy of this method, it was used to compute the k_{eff} of a series of experimental arrays of mixed oxide (Type I) fuel rods surrounded by water reflectors. Comparisons of calculated and experimental k_{eff} values are shown in Table 12-I and are discussed in more detail in Reference 4.

As can be seen in Table 12-I, the calculational method predicts k_{eff} well within 1 percent $\Delta k/k$ in each case.

The calculated k_∞ for a fuel element is applied to the criticality evaluations by use of the one-group buckling calculation:

$$k_{eff} = \frac{k_\infty}{1 + B_g^2 M^2}$$

The value of the migration area (M^2) is also obtained from the HRG/THERMOS model, and is internally consistent with the calculated k_∞.

The geometrical buckling ($B_g{}^2$) is obtained from:

$$B_g = \left(\frac{\pi}{x + 2\lambda}\right)^2 + \left(\frac{\pi}{y + 2\lambda}\right)^2 \quad ,$$

Where x and y are the lateral dimensions of the fuel element and the fuel element is assumed to be infinitely long. The augmentation distance (λ) for light water moderated and reflected fuel rods normally falls in the range of 6 to 7 cm; a value of 7 cm is used in these criticality calculations.

Use of the one-group buckling calculation rather than the two-group model,

$$k_{eff} = \frac{k_\infty \text{ EXP } (-B_g^2 \tau)}{1 + B_g{}^2 L^2},$$

results in a calculated k_{eff} for these fuel elements which is approximately 10 to 20 percent $\Delta k/k$ conservative (high).

12.1.2 XN Type II Fuel Elements

The methods and nuclear data utilized to calculate the k_∞ of the XN Type II fuel elements are consistent with the methods and data used throughout the nuclear industry. The analysis utilizes the JERBEL code (an improved version of LEOPARD) to obtain multigroup cross sections and k_∞ for fuel rod cells, and the PDQ-7 code for two-dimensional rod array calculations. Confirmatory rod array calculations and reactivity calculations for the fuel element arrays (described in Section 12.4) were performed with the Monte Carlo code KENO, using cross sections derived from the CCELL (HRG/THERMOS) code.

The JERBEL code has also been used by Exxon Nuclear to compute k_{eff} of a series of experimental critical arrays of fuel rods which represent wide variations in fissile isotope type and content, wide variations in moderator-to-fuel ratio, both zircaloy and stainless steel cladding, and various concentrations of soluble poison in the water moderator. The results of these calculations are tabulated in Table 12-II. The average difference between the computed k_{eff} and 1.000 is less than 0.2 percent.

12.1.3 XN Type III, IV, V, VI, AA and Generically Characterized Fuel Elements

12.1.3.1 KENO II (18 Energy Groups) Calculational Method

The KENO-II Monte Carlo code was used to calculate reactivities of interacting arrays of well moderated packages. Multi-group cross section data (18 energy groups) used in the Monte Carlo calculations were averaged by the GAMTEC-II and CCELL codes, respectively.

Extensive theory-experiment correlations have been performed using cross section data averaged by the GAMTEC-II code.

These evaluations, although primarily for plutonium fueled systems, demonstrate the self consistency of the GAMTEC-II code.

To demonstrate the adequacy of the GAMTEC-II code for undermoderated slightly enriched uranium systems, the infinite media multiplication factor was computed for 5 w/o U-235 UO_2 powder using cross section data obtained from the ENDF/B-III library. The resulting value of k_∞, as well as the values obtained using the JERBEL and HAMMER codes, are given in Table 12-III.

The computed value for k_∞ for unmoderated 5 w/o enriched UO_2 shows that the GAMTEC-II code, utilizing cross section data obtained from ENDF/B-III library, is conservative with respect to the other calculational methods by at least 2 percent.

Theory-experiment comparisons have been made for small water-moderated critical arrays of fuel rods. Such critical experiments have been evaluated using the KENO Monte Carlo code with 18 energy group cross section data averaged using the CCELL code.

The upper boundaries of the 18 energy groups used to average cross sections for these calculations were as follows:

> 10 Mev, 7.79 Mev, 6.07 Mev, 4.72 Mev, 3.68 Mev, 2.87 Mev, 1.74 Mev, 1.35 Mev, 183 Kev, 24.8 Kev, 3.36 Kev, 454 ev, 101 ev, 37.3 ev, 13.7 ev, 5.04 ev, 1.86 ev, 0.683 ev.

The results of these calculations are shown in Table 12-IV and are presented with the results of other theory-experiment correlations in Reference 7. Inspection of the results indicate that the calculational method yields conservative results relative to the experimental data. In addition, the KENO calculated reactivities given in Table 12-IV agree with the previously performed DTF-IV transport theory calculations within the statistical uncertainty of the Monte Carlo calculations.

12.1.3.2 KENO IV (123 Energy Group) Calculational Method

In addition to the method described above, the KENO IV Monte Carlo code was utilized to calculate the reactivity of various undermoderated and moderated package arrays. Multigroup cross section data from the XSDRN 123 group data library were produced for input into KENO IV using the NITAWL and XSDRNPM codes. Specifically, the NITAWL code was used to obtain cross section data adjusted to account for resonance self-shielding by the Nordheim Integral Method. The XSDRNPM code, a discrete ordinates, one-dimensional, transport theory code, was then used to prepare cell-weighted cross section data representative of the fuel region for input into KENO IV.

Theory-experiment correlations have been performed for UO_2 rod-water lattices using the 123 energy group XSDRN cross section library data in KENO IV. Results of these calculations are summarized in Table 12-IV and are presented with the results of other theory-experiment correlations in Reference 7.

12.2 Results of k_∞ Calculations

12.2.1 XN Types I and II Fuel Elements

The fully moderated k_∞ of the nominal Type I fuel elements is 1.148 (cobalt and gadolinia included), and 1.34 (neither cobalt nor gadolinia included). The fuel elements will be shipped with both types of poison rods installed. For nuclear safety evaluations, it is assumed that the poisons are omitted, and a k_∞ of 1.34 is used in related calculations. The uncertainties in the fissile isotope content of the fuel elements introduce an uncertainty in k_∞ of less than 1 percent.

For fully moderated XN Type II fuel elements k_∞ is calculated to be 1.32 using the JERBEL/PDQ-7 method, and 1.34 using the HRG/THERMOS method. Since the calculations performed using the JERBEL/PDQ-7 method explicitly recognize the actual distribution of PuO_2 within the fuel element while the HRG/THERMOS method assumes a uniform distribution of PuO_2, the difference between the two calculated values of k_∞ is to be expected. The uncertainties in the fissile isotope content of the fuel elements introduce an uncertainty in k_∞ of less than 1 percent.

12.2.2 XN Types III, IV, V, and VI Fuel Elements

For the specific XN-type mixed-oxide fuel elements covered herein, values of k_∞ have been computed, assuming full water moderation, using the CCELL code. The results of those calculations are shown in Table 12-V.

For comparison, Table 12-V also gives values of k_∞ computed using the JERBEL code, or a two-dimensional diffusion theory code JDT. The two-dimensional code used cross-section data averaged either by the CCELL code or by the JERBEL code, indicated as CCELL/JDT or JERBEL/JDT, respectively. The two-dimensional code gives values of k_∞ for the entire fuel element while values of k_∞ computed using the CCELL and JERBEL codes assume a fuel element averaged pin. This assumption has been shown to be conservative by comparisons with detailed design calculations (see Table 12-V for typical comparisons). It is also apparent from data given in Table 12-V that for XN Type IV fuel elements, the CCELL code is approximately 7 percent conservative with respect to the more detailed CCELL/JDT method; and that, for XN Type V fuel elements, it is conservative by about the same amount relative to the JERBEL/JDT method. This conservatism for the XN Types IV and V fuel elements results due to the significant quantities of gadolinium which were neglected in the CCELL calculations. Other calculations indicate that the actual degree of conservatism is approximately 1 percent in reactivity for unpoisoned cases.

It is readily apparent that neutron poisons included in the fuel elements have substantial influence on criticality safety, and that the practice of neglecting them in criticality safety calculations introduces a significant degree of conservatism. Note that XN Types III, IV, and V mixed-oxide fuel elements all contain Gd_2O_3 poisoned fuel rods which were ignored in the CCELL calculations reported in Table 12-V and in subsequent criticality safety calculations.

12.2.3 Generically Characterized Fuel Elements

Infinite media multiplication factors for UO_2 rod-water lattice systems were calculated using the CCELL code for low U-235 enrichments as a function of enrichment (< 5 wt percent U-235), pellet diameter (< 0.5 inches), and fuel rod pitch (square lattice) or, equivalently, water-to-fuel volume ratio (< 2.3).

Results of k_∞ calculations for rod-water lattices with limitations on the U-235 enrichment, pellet diameter, and water-to-fuel volume ratios as noted above, are summarized in Figures 12.1, 2, 3, and 4. Examination of these data indicates that:

1) Figure 12.1--The maximum values of k_∞ for 3, 4, and 5 wt percent U-235 enriched UO_2 rods in water occur at water-to-fuel volume ratios of greater than 2.1.

2) Figures 12.2, 3, and 4--The maximum value of k_∞ for 3, 4, and 5 wt percent U-235 enriched UO_2 rods in water occurs at a pellet diameter of $\geq$ 0.5 inches for water-to-fuel volume ratios of $\leq$ 2.1. At a water-to-fuel volume ratio of 2.3, the maximum value of k_∞ occurs at a pellet diameter of $\geq$ 0.4 inch.

Calculational results summarized in Figures 12.1-12.4 indicate that for fully moderated fuel elements having enrichments of < 5 wt.% 235-U and water-to-fuel volume ratios of $\leq$ 2.1, it is conservative to assume a pellet diameter of 0.5 inches. At a water-to-fuel volume ratio of 2.3 it is conservative to assume a pellet diameter of 0.4 inch.

12.2.4 XN Type AA Fuel Elements

For the XN Type AA fuel element the value of k_∞ was computed assuming full water moderation, using the CCELL code. The calculation assumed a fuel element averaged fuel-rod-cell and resulted in a value of k_∞ of 1.421.

12.3 Single Package Evaluation

12.3.1 XN Type I and II Fuel Elements

The Model 51032-1 package will contain two XN Type I fuel elements. The Model 51032-1 packaging was designed to accommodate four such fuel elements, but current needs require that no more than two be loaded per package. The two Type I (short) fuel elements will be secured at opposite ends of the strongback and on opposite sides of the separator blocks. In order to simplify calculations, the two fuel elements are assumed to be secured at the same end of the strongback with a separation distance equal to the width (6 inches) of the separator blocks (the actual separation distance will be approximately 12 inches). Complete water moderation (k_∞ = 1.34) and full water reflection are also assumed. The isolation provided by the water assumed to be between the fuel elements is ignored.

Based on the above information and assumptions, k_{eff} of a single Model 51032-1 package containing two XN Type I fuel elements was calculated to be less than 0.84.

Model 51032-1 packages may contain four XN Type II fuel elements (two positioned end-to-end on each side of the separator blocks). Complete water moderation and full water reflection are assumed. Based on these assumptions, the k_{eff} of a single package is calculated to be < 0.74 using the JERBEL/PDQ-7 method, and < 0.75 using the CCELL/KENO method.

12.3.2 <u>XN Types III, IV, V, and VI Fuel Elements</u>

For the XN Type III, IV, V and VI fuel elements described in Section 2, the reactivity of a single package is less than those computed for the fully flooded array of damaged packages. The reasons for such a decrease are:

1) No fissile material will be interacting with the single package, and

2) Two sides of each fuel element are separated from the water reflector by the 1/4 inch thick steel strongback rather than one side as assumed in the fully flooded array of damaged packages (see Figure 12.5 for geometrical details). Additionally, for the Type VI fuel elements, it was assumed that the ethafoam pads between the strongback and the fuel elements were totally crushed. This assumption increases the reactivity of the array by approximately 2 percent.

Maximum reactivities for the single packages of fuel elements assuming full water moderation, reflection, and infinite fuel element length, are shown in Table 12-VI.

These values are all based on the 95 percent confidence level (k_{eff} average ± 1.96σ), and were computed using the KENO-II Monte Carlo code with multi-group data averaged by the CCELL code as previously described. These results demonstrate compliance with accepted criticality safety criteria.

12.3.3 Generically Characterized Fuel Elements

To satisfy the requirement of 10 CFR 71.36(b), it must be shown that a single damaged package will be subcritical under conditions of full water reflection and optimum credible moderation. The package was assumed to be fully flooded with water, and where applicable, the ethafoam (expanded polyethylene at approximately 6 pounds per cubic foot density) pads located between the fuel element and the strongback were (conservatively) assumed to be crushed. The resulting geometrical configuration is as shown in Figure 12.5. Note that the results of these calculations are nonconservative when compared with those presented in Section 12.4.3 of this report which assumed an infinite array of damaged packages. This results because of the larger portion of the strongback considered here and the absence of surrounding regions of fissile material with which each package in the infinite array may interact. However, the elimination of significant quantities of steel (i.e., the spacer blocks and other package structures) indicate that these calculations retain a fair degree of conservatism. Since this configuration is not limiting when compared with the requirements for subcriticality of interacting arrays, only a few cases were examined.

In these and all subsequent cases evaluating generically characterized fuel elements, unless otherwise noted, the fuel material was UO_2 at 95 percent of theoretical density; the clad was 0.020 inch thick zirconium; and the diametrical gas gap was 0.010 inch. For all KENO-II calculations, water cross sections and steel epithermal cross sections were averaged by the GAMTEC-II code, and the steel thermal group self-shielded cross sections were calculated using the BRT-1 (Battelle-Revised THERMOS-1) code.

The results of KENO-II Monte Carlo calculations based on the geometrical arrangement shown in Figure 12.5 are summarized in Table 12-VII.

12.3.4 XN Type AA Fuel Elements

For the XN-Type AA fuel element described in Section 2, the reactivity of a single package is less than that computed for the fully flooded infinite array of damaged packages. The reasons for such a decrease are two-fold:

1) No fissile material will be interacting with the single package; and

2) Two sides of each fuel element will be separated from the water reflector by the 1/4 inch steel strongback rather than one side as assumed in the fully flooded array of damaged packages (see Figure 12.6 for geometrical details).

As a consequence, the reactivity of a single package when fully flooded and reflected by water is less than 0.886 ± .008 which was computed for the damaged package array.

12.4 Demonstration of Compliance With 10 CFR 71.38 and 71.40

12.4.1 Undamaged Fissile Class I Package Arrays

12.4.1.1 XN Types III, IV, and VI Fuel Elements

Under normal conditions of transport, fuel elements contained within undamaged packages can be considered to be moderated only by the materials used for packaging. (There is no leakage of water into the packaging during the water spray test; reference Section 9). Specifically, some moderation of the fuel elements results from the addition of corrugated polyethylene shims within the fuel elements as previously described. These shims may be included in the packaging of XN fuel element Types I through VI. In addition, ethafoam (low density expanded polyethylene at approximately 6 pounds per cubic foot density) pads may be included around these fuel elements.

A summary description of the Fuel Types to be shipped as Fissile Class I packages (Types III, IV, and VI) is given in Table 12-VIII. Since these fuel types may be shipped with or without the inclusion of polyethylene shipping shims, the analysis examined both the totally unmoderated and slightly moderated configurations. For the unmoderated configurations, each fuel-bearing region was assumed to contain the PuO_2-UO_2 at the pellet density reduced by the volume fraction of the oxide contained within the fuel element (see Table 12-VIII). This volume fraction was computed based on the volume of the fuel element surrounding the outside fuel pellets. Reactivity calculations, however, assumed the oxide to be homogeneously spread throughout the maximum fuel element size. These assumptions result in an excess of fissile material present within the package of between 8 and 27 percent. In addition to the unmoderated configuration, calculations were performed for the alternate configuration which includes the use of plastic shipping shims and ethafoam pads around the fuel elements.

A single cell of an infinite array of such undamaged packages would appear as shown in Figure 12.7. To simplify the Monte Carlo calculations, conservative assumptions were made regarding the geometry of an array of such undamaged packages. The assumed geometric configuration is shown in Figure 12.8.

The ethafoam region shown in Figure 12.8 is 0.75 inch thick between the fuel element and the steel strongback, and 0.50 inch thick elsewhere. When the ethafoam pads are not included in the packaging, the fuel element region is located 0.50 inch from the steel strongback (spacing is preserved by rubber-backed steel pads).

The carbon steel region is nominally 0.125 inch thick on top and 0.375 inch thick on the sides and bottom. The water region was varied in thickness from 0 to 1 inch to determine the optimum thickness.

Results of the infinite array calculations for XN Fuel Types III, IV, and VI are shown in Table 12-IX. As can be seen, an infinite array of undamaged packages of Types III, IV, or VI fuel elements is subcritical and thereby satisfies the requirement of 10 CFR 71.38(a).

12.4.1.2 Generically Characterized Fuel Elements

As previously noted fc, Fissile Class I shipments, an infinite array of undamaged packages, with optimum interspersed moderation, must be subcritical in any arrangement. Under normal conditions of transport, fuel elements will be either unmoderated or slightly moderated by the inclusion of plastic shipping shims. Consequently, both of the alternative packaging methods have been evaluated.

A. Sl'ghtly Moderated Systems

For fuel elements packaged with polyethylene shipping shims, the reactivity of each array was determined assuming a limiting effective water density within each fuel element. The effective water density is determined based on the total hydrogen content of the contained mass of polyethylene shims. Typically, the effective water density is between 0.12 and 0.17 g/cm^3.

To determine the fuel element size which may be transported as a Fissile Class I package, reactivities were computed using the KENO-IV code for the conservative geometrical arrangement shown in Figure 12.8. These calculations were performed for U-235 enrichments of 3.2, 3.5, and 4.0 wt. percent using the limiting fuel pellet diameter and water(void)-to-fuel volume ratios which result in the highest package reactivity. Effective water densities of 0.15 and 0.20 g/cm^3 were examined. The results of those calculations assuming optimum interspersed moderation, are given in Table 12-X. These data were utilized to establish a limiting fuel element size of 5.2 inches, at an enrichment of 3.5 wt.% 235-U, when the packaging includes plastic shipping shims within the fuel element and surrounding ethafoam pads. The limiting conditions for the shipment of fuel elements containing corrugated polyethylene shipping shims as Fissile Class I packages are indicated as XN Type A fuel in Table 12-X while other configurations which have no fuel type identified are for comparison purposes to indicate the effect of variable parameters.

B. Unmoderated Systems

For fuel elements that are not packaged with corrugated polyethylene shipping shims (i.e., no moderating materials internal to the fuel element) analyses were performed with the KENO-IV code using the geometric arrangement shown in Figure 12.7 (ethafoam pads were not included adjacent to the fuel element). For this particular evaluation, however, the fuel element size was fixed at 8.55 inches square.

In the case of unmoderated fuel elements, the maximum reactivity of the array occurs at the maximum UO_2 density within the fuel element. Consequently, the following limitations were assumed:

1) UO_2 pellet density--100 percent of theoretical;
2) Pellet diameter--0.5 inches (maximum); and
3) Water-to-fuel volume ratio of the fuel assembly--1.3 (minimum).

The results of these calculations are given in Table 12-XI. These data show that the maximum reactivity occurs when there is approximately 0.6 inches of water between adjacent packages. (Note that there is no ethafoam included around the fuel elements thereby resulting in optimum conditions occurring when moderation is included external to the packages.)

As for Part A above, applying the criterion that $k_{eff} + 3\sigma \leq 0.97$, it is demonstrated that Type B fuel elements packaged in Model 51032-1 or -1a containers meet the requirements for normal conditions of transport as Fissile Class I packages.

12.4.1.3 XN Type AA Fuel Elements

Under normal conditions of transport, XN Type AA fuel elements (see Table 12-XII) contained within undamaged Model 51032-1a packaging can be considered to be unmoderated. The packaging method for XN-Type AA fuel elements does not include the use of ethafoam (low density expanded polyethylene) pads around the fuel element or any materials interspersed within the fuel elements. To simplify the Monte Carlo calculations, conservative assumptions were made regarding the geometry of an array of such undamaged packages. The assumed geometric configuration is shown in Figure 12.9.

With optimum interspersed moderation (0.55 inch) between the packages, the reactivity of an infinite array of Model 51032-1a packages containing XN Type AA fuel elements was computed to be < 0.905 at the 95% statistical confidence level. This value was computed using the KENO-IV computer code with 123 group cross section data obtained from the NITAWL/XSDRNPM codes as described in Section 12.1.3.2.

12.4.2 Undamaged Fissile Class III Package Arrays

12.4.2.1 XN Type I Fuel Element

A shipment of XN Type I fuel will consist of a single package containing two Type I fuel elements. For purposes of evaluating a double shipment, it was assumed that two undamaged packages were stacked on top of one another. Thus, the four fuel elements would be in a rectangular array with minimum horizontal and vertical edge-to-edge separation distances of 6 (assumed) and 19 inches, respectively. Since the packages were assumed undamaged, there would be no water inside the containment vessel. Nevertheless, in this evaluation, complete water moderation of the package contents was assumed.

The system was evaluated by the solid angle method (described in Reference 5). The k_{eff} of each fuel element, in this case air reflected to permit interaction, was calculated to be less than 0.59 (augmentation distance = 4 cm). The subtended fractional solid angle of three units, centered on the fourth unit, was calculated to be 0.191. This value falls within the guideline in TID-7016, Revision 1, which assumes a closely fitted reflector around the array. Thus, a double shipment of undamaged packages containing XN Type I fuel has been demonstrated (conservatively) to be subcritical.

12.4.2.2 XN Type II Fuel Element

A shipment of XN Type II fuel consists of a maximum of five packages containing up to four XN Type II fuel elements each. Two shipments would contain 40 fuel elements. Packages are shipped in an array, two packages wide by two packages high. Compliance with 10 CFR 71.40(a) and (b) was evaluated using the KENO code as described below.

To assure a conservative evaluation of the nuclear safety of the shipment, it was assumed that the shipment was disarrayed and crushed so that the separation between fuel elements provided by the outer container was lost. It was further assumed that the separation between adjacent fuel elements in a single strongback was reduced to only that provided by the separator blocks (6 inches), as opposed to the as-loaded separation (15 inches). Under these assumptions, the shipment becomes an array of four-fuel element cells, as shown in Figure 12.10. The steel shown in Figure 12.10 represents the sides and bottoms of the strongbacks plus the steel of the outer shell.

The calculations assumed a horizontal infinite array of such cells, and the cells were assumed to be infinitely long. The multiplication factor of this infinite array was calculated using cross sections (18 energy groups) averaged by the CCELL code in the Monte Carlo code KENO. The resulting k_{eff} for the array is $0.803 \pm .009$. The result conservatively demonstrates compliance with 10 CFR 71.40(a) which requires that subcriticality be maintained for two undamaged shipments placed side-by-side and closely reflected by water. This result also conservatively demonstrates compliance with 10 CFR 71.40(b) with respect to the criticality safety of a single shipment subjected to the hypothetical accident conditions (see Section 12.4.3.1).

12.4.2.3 XN Type V Fuel Element

For undamaged packages containing XN Type V fuel (Fissile Class III shipments), infinitely long and wide arrays of two-high packages were examined. The geometric arrangement of fuel elements within each package was assumed to be as shown in Figure 12.11. For these packages, however, each fuel element was conservatively considered to be fully moderated by water and the two-high array of packages was reflected by an effectively infinite thickness of water (6 inches) on both the top and bottom.

The reactivity for this array, computed using the KENO-II code, was 0.530 $\pm$ .014 for the XN Type V fuel element. These calculations conservatively demonstrate that touching identical shipments of undamaged packages containing XN Type V fuel would be subcritical when fully reflected on all sides by water.

12.4.2.4 Generically Characterized Fuel Elements

For undamaged arrays of Fissile Class III packages of generically characterized UO_2 fuel elements the geometric arrangement and calculational methods summarized in Section 12.4.2.3 were used. Results of the calculations for the various fuel element parameter limitations are given in Table 12-XIII.

These results, when compared to those presented in Section 12.4.3, show that Fissile Class III packaging limitations must be established on the basis of the damaged package arrays (i.e., arrays of damaged packages containing identical fuel elements are more reactive than the two undamaged shipments placed edge-to-edge and reflected by water).

12.4.3 Damaged Package Arrays

12.4.3.1 XN Types I and II Fuel Elements

A shipment of Type I fuel will consist of a single package containing not more than two Type I fuel elements. The calculations and evaluation presented in Section 12.3.1 are applicable to this case. Thus, a shipment subjected to the hypothetical accident conditions has been demonstrated to be subcritical.

As stated above in 12.4.2.2, compliance with 10 CFR 71.40(b) for XN Type II fuel elements is demonstrated by evaluation of the array considered therein.

12.4.3.2 XN Types III, IV, V, and VI Fuel Elements

Packages have been subjected to a series of drop tests (see Sections 10 and 11) and supporting analyses were performed to ascertain the maximum package damage under hypothetical accident conditions. The tests demonstrate that the minimum spacing between fuel elements in adjacent, stacked, damaged packages, is 8 inches. At least 3 inches is provided by the assembly clamps in each of the adjacent packages, and a minimum of 2 inches is provided by the package stiffener rings. (This results in a total minimum separation of 8 inches, and assumes that the stiffener rings overlap and do not meet when stacking damaged packages.) Also, the separator blocks between fuel elements within individual packages have been shown to maintain a 6-inch separation between fuel elements. The most reactive possible arrangement of fuel elements within four adjacent damaged packages is shown in Figure 12.12. The assumed geometric arrangement of fuel elements used in the nuclear safety calculations is shown in Figure 12.6. As can be seen, the effect of the containment vessel walls, and portions of the steel strongback, have been conservatively ignored. Also, the assumed geometric configuration postulates both the minimum vertical and horizontal separations simultaneously, a situation that is impossible to achieve under hypothetical accident conditions.

Reactivities calculated for the XN Types III and IV mixed-oxide fuel elements in this assumed configuration, and for XN Types V and VI fuel elements in a similar configuration in which the one-half-inch spacing between the steel and fuel element regions has been eliminated, are given in Table 12-XIV. These results conservatively demonstrate compliance of XN Fuel Types III, IV, V, and VI with the requirements of 10 CFR 71.40(b).

12.4.3.3 Generically Characterized Fuel Elements

The specific standards for licensing of Fissile Class I packages includes the requirement that (see 10 CFR 71.38(b)) 250 damaged packages remain subcritical in any arrangement with optimum credible interspersed hydrogenous moderation when closely reflected by water. Furthermore, for Fissile Class III packages a single shipment--when subjected to the effects of the hypothetical accident conditions as specified in 10 CFR 71, Appendix B, with optimum credible interspersed hydrogenous moderation and close-water reflection-- must remain subcritical. Both of these requirements are conservatively satisfied by consideration herein of an infinite array of damaged packages.

As discussed in Section 12.4.3.2, the most reactive possible configuration of damaged packages, as determined by drop test results, can be conservatively represented by the configuration shown in Figure 12.6. As previously noted, the geometrical configuration in Figure 12.6 allows both the minimum vertical and horizontal separations simultaneously, a situation which cannot be achieved under hypothetical accident conditions. Also, portions of the steel strongback are conservatively ignored. The packages were assumed to be fully flooded. Homogenized cross sections were generated by the CCELL code (HRG/THERMOS) for the fuel elements while the cross sections for water were generated by GAMTEC-II. GAMTEC-II was also used to generate the epithermal cross section data for steel and the BRT-1 code (Battelle-Revised THERMOS-1) was used to generate the thermal group self-shielded cross sections for steel.

Results of the KENO-II Monte Carlo calculations, for the geometric configuration described are given in Table 12-XV as a function of fuel element size for various combinations of U-235 enrichments and water-to-fuel volume ratios. The criterion utilized to establish packaging limits for damaged package arrays is that k_{eff} of the array be $\leq$ 0.97 at the 99 percent statistical confidence level (i.e., k_{eff}(average) + 3σ < 0.97). Using this criterion, data presented in Table 12-XV were used to derive Fissile Class I and III package limits based on the reactivity of infinite arrays of damaged packages. Limiting fuel element characteristics are summarized in Table 12-XVI.

12.4.3.4 XN Type AA Fuel Elements

The assumed geometric arrangement of damaged fuel elements in the nuclear safety calculations is shown in Figure 12.6. As for the generic fuel elements, the effect of the containment vessel walls and portions of the steel strongback have been conservatively ignored and both the minimum vertical and horizontal separations are assumed to occur simultaneously.

The reactivity calculated for an infinite array of fuel element packages in this assumed configuration is 0.886 ± .008. This value was computed using the KENO-IV computer code with 123 group cross section data obtained as summarized in Section 12.1.3.2.

12.4.3.5 Shipments of Individual Rods

Analyses presented in Section 12 demonstrate compliance of various generic UO_2 fuel types under a variety of limits which are not dependent on the method of confining the fuel rod arrangement. Since optimum interspersed moderation is assumed for all Class I shipments, and full moderation with water is assumed for all Class III shipments, the results of these evaluations are not affected by minor additions of materials between adjacent fuel elements. Consequently, it is requested that generic packaging limitations derived in Section 12 be applied to permit shipment of fuel rods in wooden boxes. Such boxes would be constructed as indicated in Figure 12.13. (Dimensions and packaging methods shown in Figure 12.13 are intended to be typical of those actually used.) Individual packaging limits on U-235 enrichment, rod diameters, assembly size, and water-to-fuel volume ratios and internal moderation would be the same as those established for generic UO_2 fuel elements.

In addition to permitting the shipment of fuel rods in wooden boxes, it is requested that a single fuel rod enriched to < 5 wt percent U-235 and having a UO_2 pellet diameter of $\leq$ 0.5, be permitted within individual packages as shown in Figure 12.14. As can be seen, the rod will be wrapped in a protective material and enclosed within either a steel pipe or an angle iron protective cover. If a pipe cover is used, it will be closed with threaded pipe caps at both ends to prevent rod escapement during normal and accident conditions of transport. If an angle iron is used, end plugs will be welded on each end.

Packaged as described above, the single fuel rod will be positioned on top of the clamps used to clamp fuel elements within the strongback. Four (4) U bolts having a diameter of 1/4 inch will be used along the length of the rod to securely position the rod package on the strongback framework.

The addition of a single fuel rod, located and packaged as described above, is considered to have a negligibly small effect on the reactivity of the package under both normal and accident conditions of transport.

Additionally, the total weight of a loaded package will be limited to the licensed maximum gross weight of 7,400 pounds and 8300 pounds for the Model 51032-1 and -1a packages, respectively. Hence, the addition of this single rod does not alter the previous evaluation of the package performance under hypothetical accident conditions.

12.5 Summary

The results of criticality safety evaluations reported herein demonstrate that the XN Types III, IV, and VI mixed-oxide fuel element packages using Model 51032-1 shipping containers satisfy the requirements for Fissile Class I packages. The results also demonstrate that XN Types I, II, and V mixed-oxide fuel elements contained in Model 51032-1 packaging satisfy the requirements for Fissile Class III packages.

Table 12-XVI contains a summary of the limits on fuel element parameters determined for both Fissile Class I and Fissile Class III shipments of generically characterized low-enriched uranium fuel elements transported in either Model 51032-1 or 51032-1a packages. The criterion which was applied to determine these limits was that $k_{eff} + 3\sigma \leq .970$ for both normal and accident (damaged package) conditions. Fuel element parameter limits were determined by using the criterion which imposed the more conservative limitations. A summary of the reactivities computed or interpolated for the various fuel types under both normal and accident conditions is given in Table 12-XVII.

13.0 REFERENCES

1. CONF-710801 (Volume 2) Health and Safety (TID-4500), "Proceedings, Third International Symposium, Packaging, and Transportation of Radioactive Materials", August 1971, pp 873-885.

2. Exhibit P, "Application for Licensing of Combustion Engineering, Inc., Shipping Container Model 927A", July 3, 1969, License SNM-1067, Docket 70-1100.

3. Exhibit P (including Appendix P-1), "Application for Licensing of Combustion Engineering, Inc., Shipping Containers Models 927B and 927C", February 23, 1971, License SNM-1067, Docket 70-1100.

4. V. O. Uotinen, G. L. Gelhause, U. P. Jenquin and C. R. Gordon, "Calculations of Power Distribution and Reactivities", Reactor Physics Quarterly Report, April, May and June, 1970, BNWL-1381-2, August 1970.

5. Nuclear Safety Guide, TID-7016, Revision 1, 1971.

6. L. E. Hansen, et al., "Critical Parameters of Plutonium Systems. Part I: Analysis of Experiments", Nuclear Applications, Volume 6, 381-390, April, 1969.

7. XN-NF-499, "Criticality Safety Benchmark Calculation for Low-Enriched Uranium Metal and Uranium Oxide Rod-Water Lattices", April 1979.

APPENDIX V

PACKAGE COMPONENT EVALUATIONS

The Model 51032-1a package includes design changes to assure that the main shock mount bolts yield and dissipate energy in any drop configuration, except for a drop in the normal upright configuration which is the least subject to failure potential. Clearances between the assembled strongback and the containment vessel are about two and one-half inches and may limit the combined distortion of bolts, full-clamps and shock mounts. The static tensile tests result in shock mount bolt failure at about 1.7 inches of bolt distortion, which is sufficient for the desired energy dissipation. When the bolts are loaded transverse to the shock mount, the net distortion at failure, including bolt and mount, is about 3.2 inches in static tests.

To assure that the distortion occurs in the shock mount bolts, other bolts which could fail and relieve the stress on the shock mounts have been strengthened. These have also been tested statically to verify that their strength exceeds that of the shock mount bolts.

Full-clamp assemblies consist of 2-1/2 x 2-1/2 x 1/2 inch angle bars which span the strongback, clamping to its lip, and sliding clamps which bolt to the angle bars and hold the fuel elements in the corners of the strongback (see Figure 2.17). These full-clamps were strengthened, by about a factor of three, relative to the drop-tested package to assure that they retain the fuel elements within the strongback during the time required to distort and fail the shock mount bolts. In the drop-tested package, abrupt failure honeycomb is not sensitive to this uncertainty and is described here assuming that the gap is closed only by relative motion between strongback and container.

The two ends of the shipping package differ in honeycomb absorber design because at the fuel element nozzle end the nozzle projects two inches into the honeycomb. The honeycomb is cut back in that area and additionally cut back to facilitate assembly. The design is shown in Figure 2.20. As the strongback and fuel elements move forward, the nozzle impails into the honeycomb and it is assumed that the honeycomb area interior to the nozzle is unavailable for energy dissipation. Crushing of the raised section of honeycomb material begins when the 1/2 inch clearance gap is closed. The area of the raised section is 135 in^2 and begins crushing first. With the exception of the nozzle area, the depressed section begins to compress when the strongback has moved an additional 2.25 inches toward the container end. The depressed area crushed is 77 in^2. The honeycomb thickness is 7.75 inches in the raised area and 5.625 inches in the depressed area.

The manufacturer has provided test data on the production run for the honeycomb which shows that the honeycomb will crush 80% with an average force of 1310 psi. The energy absorption capability is therefore:

$$E = 1310 \times 0.8 \times \{7.75 \times 135 + 5.625 \times 77\} = 1,550,000 \text{ in-lb}$$

$$E = 120,000 \text{ ft-lb}$$

crushes uniformly and has a restraining force of 400,000 lb. Complete compression from 8.25 inch thickness to 1.65 inch thickness could absorb 220,000 ft-lb of energy. Since the shock mounts provide 30,000 ft-lbs and the total needed is only 159,000 ft-lbs, the honeycomb will only crush 4 inches. The strongback will not reach the container end and will not crush.

V.4 Integrity of the Full Clamps

A lower limit for the strength of the full clamps was determined by loading one in a near prototypical manner on the Tinius-Olsen testing machine. Preliminary tests demonstrated that small design changes would greatly improve the performance and, therefore, part no. 5 of Figure 2.17 was replaced by a similar part 3/4 inch thick and 2 1/2 x 4 inches. This provides 4 inches of bearing length on the lip of the strongback. The bolts for the sliding clamp have been replaced by similar but high-strength grade 8 bolts with 150,000 psi ultimate strength. In the final test the 2 1/2 x 2 1/2 x 1/2 inch angle bar began yielding at 17,000 pounds force and was bent 1 inch at 23,000 pounds force. At that point there was some slippage in the test jig linkage and the bolts, part 10 of Figure 2.17 appeared near to failure. The test was run with a weaker SAE grade 2 bolt rather than the specified grade 8. Because the test had demonstrated sufficient strength the test was terminated prior to failure. The total deflection of the beam resulting from combined beam bending, bolt distortion, clamp distortion, and strongback lip distortion was 2.3 inches. The distortion at 23,000 lb would have been less and the strength higher with the high-strength bolt.

The test also determined that the sliding clamp is self-locking under the applied loads and will not slip.

There are nine full clamps in the Model 51032-1a shipping package with the Type AA fuel elements. These provide a total restraining force in excess of 207,000 pounds of force (9 x 23,000). This is sufficiently larger than the 180,000 pound strength of the 14 shock-mount bolts and assures that the shock-mount bolts would elongate to failure and prevent failure of the full clamps in a 30 ft drop on the cover.

Tests conducted on the aluminum clamp assemblies shown in Figure 2.18, result in a deflection of 0.267 inch at 10,000 pounds force. For BWR fuel elements this indicates smaller deflections, at equivalent "g" loadings, than were obtained in the drop tested Model 51032-1 package. The force deflection curve is shown in Figure V.4.

V.5 Integrity of the Separator Blocks

The Model 51032-1a package separator blocks have been tested on the Tinius-Olsen compression machine. The test established that buckling strength of the gusset plate was greater than the 30,000 pound limit of the machine. The plate did not buckle and there was no significant block deformation. Without the gusset plate, significant deformation occurs at 16,000 pounds force. The attachment of the separator blocks to the strongback was also strengthened. Notably, Grade 8 bolts with a shear strength of 90,000 psi are used instead of carbon steel bolts with a shear strength of 38,400 psi and 3/8 inch thick washers are added in place of 1/8 inch thick washers to distribute the load over a larger area of the strongback channel.