B&W FUEL COMPANY

An American Company with Worldwide Resources

BW

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September 24, 1993

Cass R. Chappell, Section Leader
Cask Certification Section
Storage and Transport Systems Branch
Division of Industrial and Medical
Nuclear Safety, NMSS
United States Nuclear Regulatory
Commission
Washington D.C., 20555

Dear Mr. Chappell:

REFERENCE: Docket 71-6206, USA/6206/AF

B&W Fuel Company's (BWFC) Commercial Nuclear Fuel Plant (CNFP) has revised it's fuel design and the changes require an amendment to condition 5 (b)(1) of the above referenced certificate. Page 2, Section 1.2, Package Contents, of the SAR has been revised to reflect the new design.

The design changes include increasing the pellet diameters, pellet densities, and U235 loading. Worst case accident models used in the KENOIV analyses for previous license amendments were modified for the revised pellet specifications. The results show that the bounding K_{MAX} for a shipment of two 4.6 wt% assemblies is 0.936. For a shipment of one 5.1 wt% assembly the K_{MAX} is 0.917. Thus both shipping configurations with the revised pellet specifications have sufficient margin to the 0.95 criticality safety criterion to meet licensing requirements

Attachment I describes in detail the fuel design changes and the criticality evaluation performed to support the amendment request. If you should have any questions regarding this request, please feel free to contact me at (804)386-5202.

Sincerely,

B&W FUEL COMPANY
COMMERCIAL NUCLEAR FUEL PLANT

Kathryn S Knapp

Kathryn S. Knapp
Manager, Safety & Licensing

060018

9310070160 930924
PDR ADOCK 07106206
C PDR

Change : LP

*The base structure of the container consists primarily of two (2) full length angles welded to the lower half of the container shell

1.1.3.4 Pressure relief and filler valves, lifting and tiedown devices, humidity indicators and accelerometer viewing ports are as shown on the referenced drawings.

1.1.3.5 Heat dissipation not applicable.

1.1.4 Coolants not applicable.

1.2 Package Contents

1.2.1 Radioactive contents are UO_2 sintered pellets .36 inch to .38 inch in diameter, enriched to a maximum of 4.60% in the U-235 isotope.

1.2.1.1 Shipment of UO2 pellets enriched > 4.6% and < 5.1% may be shipped provided that only one fuel assembly be shipped per container.

1.2.2 For contents of 1.2.1, each assembly may contain up to 22.95 kg U-235 fissile constituents, or 45.9 kg U-235 for the container of two assemblies.

1.2.2.1 For contents of 1.2.1.1, each assembly and container may contain up to 25.45 kg U-235 fissile constituents.

1.2.3 UO_2 sintered pellets as described in 1.2.1.

1.2.4 Not applicable in that nuclear safety analysis presumes optimum conditions.

1.2.5 Maximum weight of the contents will be 3360 lbs.

1.2.6 Decay heat not applicable.

ATTACHMENT I

The pellet dimension and density of the MkBW 15x15 fuel assembly have been changed recently to a 0.37" nominal OD and a maximum theoretical density of 0.975 with all tolerances. This is outside the tolerance limits allowed for the Model B shipping container pellet OD and theoretical density on the certificate of conformance (C of C). To preclude future amendments for the remaining types of fuel assemblies that may be shipped in the container, estimates of the maximum pellet specifications were obtained for these assemblies. Analyses were done to determine the reactivity effects of these changes on the K_{MAX} of the container. Table 1 lists the current nominal values in the C of C and the revised maximum values for the pellet OD (nominal + 0.0007") and percent theoretical density. The change in the U-235 loadings related to these changes is also included. It is noted that no dish/chamfer factor has been applied which increases the loadings by about 2%.

The CASMO3[1] computer program was used to determine the most reactive assembly type for a configuration approximating that of the shipping container. Both the revised pellet and the original pellet were modelled. The Δk results of these cases are shown in Table 2. The first column shows the difference between the current pellet and the revised pellet. The second shows the Δk between the MkBW 15x15 assembly and the other assembly types, all with revised pellets. The MkBW 15x15 was chosen as the basis since it was the base assembly for the previous licensing calculation and is the most reactive assembly with the revised pellet specifications.

Two KENOIV[2] models, used in the previous analyses, were modified to assess the reactivity effect of the pellet specification change. The first considered two MkBW 15x15 4.6 wt% assemblies in the maximum hypothetical accident configuration (Figure 1). The second examined one 5.1 wt% assembly in this configuration (Figure 2). Table 3 lists the fuel parameters used for this analysis, as well as those used in the previous analyses for comparison. A listing of the input decks for the two KENOIV cases is provided in Attachment A.

The results of the calculations are as follows.

Configuration	$k_{eff} \pm \sigma$	K_{MAX}
Two 4.6 Wt% Assemblies	0.91538 ± 0.00101	0.936
One 5.1 Wt% Assembly	0.90739 ± 0.00107	0.917

K_{MAX} is obtained from the following equation:

$$K_{MAX} = k_{eff} + 0.01529 + \sqrt{(1.763\sigma)^2 + 0.00529^2} \quad \textit{for 2 assemblies}$$
$$= k_{eff} + 0.00500 + \sqrt{(1.763\sigma)^2 + 0.00376^2} \quad \textit{for 1 assembly}$$

where 0.01529 ± 0.00529 (1.736σ) is the KENO bias associated with the spacing between the two fuel assemblies in the container and 0.005 ± 0.00376 is the bias associated with a single assembly. The source of these biases is discussed in Attachment B. Note that this is not the same formulation used in the original calculations which assumed a 0.02 total bias and applied a 2σ uncertainty. The table illustrates that there is ample margin to the 0.95 criticality safety limit. The previous K_{MAX} values for the MkBW 15x15 used for the initial applications were 0.934 for two 4.6 wt% assemblies and 0.929 for a single 5.1 wt% assembly. Thus the combination of the revised pellet diameter/density specification and the modified KENO bias formulation introduces an increase in K_{MAX} of about 0.2% Δk for a shipment with two assemblies. The K_{MAX} is seen to decrease for the one assembly shipment by about 1.2%. This is primarily due to the revised KENO bias that is applied.

Based upon the analysis described above, the pellet specification has only a minimal effect on the reactivity of the Model B container in either shipping configuration and there is ample margin to the 0.95 criticality safety criterion.

References:

1. "CASMO3, User's Manual, A Fuel Assembly Burnup Program(B&W Version of STUDSVIK Code CASMO3)," BWNT-TM-58, Rev. 1, March 1992.

2. "KENO4, An Improved Monte Carlo Criticality Program(B&W Version of ORNL Code - KENO-IV)," NPGD-TM-503, Rev H, January 1992 with 123 Group XSDRN Cross Sections of Cable processed by NITAWL.

Table 1. Pellet Specifications

Fuel Type	Current Specification Pellet OD inches (nom)	Current Specification %TD (max)	Revised Specification Pellet OD inches (max)	Revised Specification %TD (max)
MkB 15x15	0.3686	0.963	0.3707	0.975
MkC 17x17	0.324	0.963	0.3252	0.975
MkBW 15x15	0.3625	0.963	0.3671	0.975
MkBW 17x17	0.3195	0.963	0.3232	0.975
CY 15x15	0.361	0.963	0.3672	0.975

Fuel Type	Current Specification U-235 Loading, kg 4.6 Wt%	Current Specification U-235 Loading, kg 5.1 Wt%	Revised Specification U-235 Loading, kg 4.6 Wt%	Revised Specification U-235 Loading, kg 5.1 Wt%
MkB 15x15	22.41	24.9	22.95	25.45
MkC 17x17	22.98	24.4	22.42	24.86
MkBW 15x15	21.26	23.6	22.08	24.48
MkBW 17x17	21.38	23.7	22.15	24.55
CY 15x15	14.40	19.3	18.24	20.22

Table 2. CASMO Results For Shipping Container, 5 Wt% Fuel

Assy Type	Δk Revised-Current	Δk Revised vs Mk BW 15x15
MkB 15x15	0.00207	-0.00206
MkC 17x17	0.00140	-0.00037
MkBW 15x15	0.00349	0.0
MkBW 17x17	0.00311	-0.00283
CY 15x15	0.00434	-0.00211

Table 3. MkBW 15x15 KENOIV Model Fuel Parameters

Parameter	Current Pellet	Revised Pellet
Pellet OR, cm	0.460375	0.466217
Density, %TD	0.963	0.975
Fuel Number Density		
	(5.1 Wt% no dish factor)	
U235	0.00121458	0.00122972
U238	0.02231500	0.02259343
O	0.04705900	0.04764630
	(4.6 Wt% no dish factor)	
U235	0.00109557	0.00110923
U238	0.02243400	0.02271392
O	0.04705900	0.04764630

Figure 1. MkBW 15x15 2 Assembly KENOIV Accident Array Model

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 2. MkBW 15x15 1 Assembly KENOIV Accident Array Model

FIGURE WITHHELD UNDER 10 CFR 2.390

Attachment A
Listing of KENO Input Decks for Model B Container

A.1 Two 4.8 Wt% Mk B 15x15 Fuel Assemblies

```
MODB fat pellet 0.975 den, 4.6 WT% 2 Assys
   4000  603 1001 3  123  75  12 13 31  36 8  16  16  1  -12
    1  0  2000  00  1  0  0  0  0 00  00  0  0
 -1.0 -1.0 -1.0 -1.0  0.0 0.0
  1     -922351  0.00110923111
  1      4692238  0.02271391889
  1       80004  0.04764632
  2      400000  0.037498
  3       10001  0.06685386
  3       80004  0.03342693
  4      400000  0.0425
  5       10001  0.06685386
  5       80004  0.03342693
  6      400000  0.0425
  7       10001  0.06685386
  7       80004  0.03342693
  8       10001  0.06685386
  8       80004  0.03342693
  9       50000  4.9068-3
  9       60002  1.1777-4
  9      250005  1.4763-3
  9      140005  1.0913-3
  9      240003  1.6822-2
  9      280003  1.0991-2
  9      260001  5.3927-2
 10       60002  3.9259-4
 10      250005  3.4332-4
 10      260001  8.4011-2
 11       50000  0.081741
 11       60002  0.027247
 12       10001  0.04182
 12       50000  3.6192-4
 12       60002  0.03346
 13       10001  0.079134
 13       60002  0.039567
BOX TYPE   1
CYLINDER    1  0.465328                                365.76  0.0  123Z
CYLINDER    2  0.535940                                365.76  0.0  123Z
CUBOID      3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   2
CYLINDER    5  0.638175                                365.76  0.0  123Z
CYLINDER    4  0.681355                                365.76  0.0  123Z
CUBOID      5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   3
CYLINDER    7  0.650240                                365.76  0.0  123Z
CYLINDER    6  0.693420                                365.76  0.0  123Z
CUBOID      7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE   4
CUBOID      8  2.936875     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID      9  3.413125     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID     12  3.571875     0.0    1.430020    0.0    365.76  0.0  123Z
CUBOID     13  3.592195     0.0    1.430020    0.0    365.76  0.0  123Z
BOX TYPE   5
CUBOID     11  0.793750     0.0    1.430020    0.0    365.76  0.0  123Z
```

```
CUBOID       8  2.936875      0.0     1.430020     0.0     365.76  0.0  123Z
CUBOID       9  3.413125      0.0     1.430020     0.0     365.76  0.0  123Z
BOX TYPE    6
CUBOID       8  3.592195      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  3.592195      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.699002     0.0     365.76  0.0  123Z
BOX TYPE    7
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  123Z
BOX TYPE    8
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  123Z
CORE BDY     0 25.042495      0.0    25.149300     0.0     365.76  0.0  123Z
CUBOID      13 25.062815      0.0    25.169622     0.0     365.76  0.0  123Z
CUBOID       8 34.794825      0.0    33.81070  -18.93240   365.76  0.0  123Z
CUBOID      10 35.023425      0.0    34.03930  -19.16100   365.76  0.0  123Z
CUBOID       8 35.023425      0.0    34.03930  -19.16100   386.08 -20.32 123Z
 1  2 16 1  2 16  1  1 1 1  0
 2  4  4 1  4  7  3  1 1 1  0
 2  4  4 1 11 14  3  1 1 1  0
 2  5  5 1  9  9  1  1 1 1  0
 2  6  6 1  6 12  6  1 1 1  0
 2  7  7 1  4 14 10  1 1 1  0
 2  9  9 1  5 13  8  1 1 1  0
 2 11 11 1  4 14 10  1 1 1  0
 2 12 12 1  6 12  6  1 1 1  0
 2 13 13 1  9  9  1  1 1 1  0
 2 14 14 1  4  7  3  1 1 1  0
 2 14 14 1 11 14  3  1 1 1  0
 3  9  9 1  9  9  1  1 1 1  0
 4  1  1 1  2 16  1  1 1 1  0
 6  1  1 1  1  1  1  1 1 1  0
 7  2 16 1  1  1  1  1 1 1  0
 8  5 13 1  1  1  1  1 1 1  1
END KENO
/EOR
```

A.2 One 5.1 Wt% Mk B 15x15 Fuel Assembly Case

```
ONE FA XY (1.5% .75C BS PLATE,CS STRONGBAK)3.98C100MD 97.5TD 5.1E,fat pel
   4000  603 1001 3  123  75  13 14 34  57 13 31  16  1  -13
    1  0  2000  00  1  0  0  0  0 00  00  0  0
 -1.0 -1.0 -1.0 -1.0  0.0 0.0
  1     -922351  0.00122972109
  1      5092238  0.02259342891
  1       80004  0.0476463
  2      400000  0.037498
  3       10001  0.06685386
  3       80004  0.03342693
  4      400000  0.0425
  5       10001  0.06685386
  5       80004  0.03342693
  6      400000  0.0425
  7       10001  0.06685386
  7       80004  0.03342693
  8       10001  0.06685386
  8       80004  0.03342693
  9       50000  4.9068-3
  9       60002  1.1777-4
  9      250005  1.4763-3
  9      140005  1.0913-3
  9      240003  1.6822-2
  9      280003  1.0991-2
  9      260001  5.3927-2
 10       60002  3.9259-4
 10      250005  3.4332-4
 10      260001  8.4011-2
 11       50000  0.081741
 11       60002  0.027247
 12       10001  0.04182
 12       50000  3.6192-4
 12       60002  0.03346
 13       10001  0.079134
 13       60002  0.039567
 14     -922351  0.00101226
 14      922381  0.022517
 14       80004  0.047059
BOX TYPE    1
CYLINDER     1  0.466217                                365.76  0.0  123Z
CYLINDER     2  0.535940                                365.76  0.0  123Z
CUBOID       3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    2
CYLINDER     5  0.638175                                365.76  0.0  123Z
CYLINDER     4  0.681355                                365.76  0.0  123Z
CUBOID       5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    3
CYLINDER     7  0.650240                                365.76  0.0  123Z
CYLINDER     6  0.693420                                365.76  0.0  123Z
CUBOID       7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  123Z
BOX TYPE    4
CUBOID       8  2.936875     0.0    1.430020     0.0   365.76  0.0  123Z
CUBOID      10  3.413125     0.0    1.430020     0.0   365.76  0.0  123Z
CUBOID      12  3.571875     0.0    1.430020     0.0   365.76  0.0  123Z
CUBOID      13  3.592195     0.0    1.430020     0.0   365.76  0.0  123Z
BOX TYPE    5
CUBOID      11  0.793750     0.0    1.430020     0.0   365.76  0.0  123Z
CUBOID       8  2.936875     0.0    1.430020     0.0   365.76  0.0  123Z
```

```
CUBOID      10  3.413125      0.0     1.430020     0.0     365.76  0.0  123Z
BOX TYPE    6
CUBOID       8  3.592195      0.0     1.611376     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.043682     0.0     365.76  0.0  123Z
CUBOID      10  3.592195      0.0     3.519932     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.678682     0.0     365.76  0.0  123Z
CUBOID       8  3.592195      0.0     3.699002     0.0     365.76  0.0  Z
BOX TYPE    7
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  Z
BOX TYPE    8
CUBOID       8  1.430020      0.0     1.611376     0.0     365.76  0.0  Z
CUBOID       8  1.430020      0.0     3.043682     0.0     365.76  0.0  Z
CUBOID      10  1.430020      0.0     3.519932     0.0     365.76  0.0  Z
CUBOID      12  1.430020      0.0     3.678682     0.0     365.76  0.0  Z
CUBOID      13  1.430020      0.0     3.699002     0.0     365.76  0.0  Z
BOX TYPE    9
CYLINDER     3  0.460375                                     365.76  0.0  Z
CYLINDER     3  0.535940                                     365.76  0.0  Z
CUBOID       3  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  Z
BOX TYPE   10
CYLINDER     5  0.638175                                     365.76  0.0  Z
CYLINDER     4  0.681355                                     365.76  0.0  Z
CUBOID       5  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  Z
BOX TYPE   11
CYLINDER     7  0.650240                                     365.76  0.0  Z
CYLINDER     6  0.693420                                     365.76  0.0  Z
CUBOID       7  0.715010 -0.715010  0.715010 -0.715010 365.76  0.0  Z
BOX TYPE   12
CUBOID      13  0.020320      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID      12  0.179070      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID       9  0.655320      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID       8  6.529070      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID       9  7.005320      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID      12  7.164070      0.0     1.430020     0.0     365.76  0.0  Z
CUBOID      13  7.184390      0.0     1.430020     0.0     365.76  0.0  Z
BOX TYPE   13
CUBOID       8  7.184390      0.0     1.611376     0.0     365.76  0.0  Z
CUBOID       8  7.184390      0.0     3.043682     0.0     365.76  0.0  Z
CUBOID      10  7.184390      0.0     3.519932     0.0     365.76  0.0  Z
CUBOID       8  7.184390      0.0     3.678682     0.0     365.76  0.0  Z
CUBOID       8  7.184390      0.0     3.699002     0.0     365.76  0.0  Z
CORE BDY     0 50.084990      0.0    25.149300     0.0     365.76  0.0  123Z
CUBOID      13 50.105310 -.020320    25.169622     0.0     365.76  0.0  123Z
CUBOID       8 59.837320 -9.75233    33.81070  -18.93240   365.76  0.0  123Z
CUBOID      10 60.065920 -9.98093    34.03930  -19.16100   365.76  0.0  123Z
CUBOID       8 60.065920 -9.98093    34.03930  -19.16100   386.08 -20.32 123Z
  1 17 31 1  2 16  1  1 1 1  0
  2 19 19 1  4  7  3  1 1 1  0
  2 19 19 1 11 14  3  1 1 1  0
  2 20 20 1  9  9  1  1 1 1  0
  2 21 21 1  6 12  6  1 1 1  0
  2 22 22 1  4 14 10  1 1 1  0
  2 24 24 1  5 13  8  1 1 1  0
  2 26 26 1  4 14 10  1 1 1  0
  2 27 27 1  6 12  6  1 1 1  0
  2 28 28 1  9  9  1  1 1 1  0
  2 29 29 1  4  7  3  1 1 1  0
  2 29 29 1 11 14  3  1 1 1  0
```

```
  3 24 24 1  9  9  1  1 1 1  0
 12 16 16 1  2 16  1  1 1 1  0
 13 16 16 1  1  1  1  1 1 1  0
  7 17 31 1  1  1  1  1 1 1  0
  9  1 15 1  2 16  1  1 1 1  0
  7  1 15 1  1  1  1  1 1 1  0
  9  3  3 1  4  7  3  1 1 1  0
  9  3  3 1 11 14  3  1 1 1  0
  9  4  4 1  9  9  1  1 1 1  0
  9  5  5 1  6 12  6  1 1 1  0
  9  6  6 1  4 14 10  1 1 1  0
  9  8  8 1  5 13  8  1 1 1  0
  9 10 10 1  4 14 10  1 1 1  0
  9 11 11 1  6 12  6  1 1 1  0
  9 12 12 1  9  9  1  1 1 1  0
  9 13 13 1  4  7  3  1 1 1  0
  9 13 13 1 11 14  3  1 1 1  0
  9  8  8 1  9  9  1  1 1 1  1
END KENO
/EOR
```

Attachment B
KENOIV Bias

B.1 Bias For Two Assemblies in Container

For the Model B container with two assemblies, an extrapolated bias based upon the 2.6875" spacing between assemblies is obtained from Table B-1. This table provides a comparison of KENOIV benchmark results for 21 B&W critical experiments[1] for fuel assemblies in typical storage rack configurations. Linear extrapolation between the following values, having the largest measured-to-calculated differences from this table, are used:

Separation Distance, in	Bias, keff ± σ
2.576	0.01453 ± 0.00206
1.932	0.01016 ± 0.00219

The extrapolated bias is 0.01529 ± 0.00300, where the sigma is obtained from the sum of the squares of the biases for the given spacings. A 1.763 one side uncertainty factor is applied to give a bias for the Model B container with two assemblies of 0.01529 ± 0.00529.

Table B-1. KENOIV Bias Versus Separation Distance (in.)

Spacing Between Arrays inches	Core Configuration	KENOIV Calculated Keffective On IBM R/C 6000	Measured Critical Keffective	Calculated Minus Measured
None	I	1.00447 (0.00181)[a]	1.0002 (0.0005)	+0.00427
	II	1.00892 (0.00168)	1.0001 (0.0005)	+0.00882
0.644	III	0.99937 (0.00149)	1.0000 (0.0006)	-0.00063
	IV	1.00669 (0.00192)	0.9999 (0.0006)	+0.00679
	XI	1.00242 (0.00168)	1.0000 (0.0006)	+0.00242
	XIII	1.01025 (0.00188)	1.0000 (0.0010)	+0.01025
	XIV	1.00405 (0.00181)	1.0001 (0.0010)	+0.00395
	XV	0.99596 (0.00171)	0.9998 (0.0016)	-0.00384
	XVII	1.00015 (0.00188)	1.0000 (0.0010)	+0.00015
	XIX	1.00150 (0.00176)	1.0002 (0.0010)	+0.00130
1.288	V	1.00189 (0.00186)	1.0000 (0.0007)	+0.00189
	VI	1.00929 (0.00187)	1.0097 (0.0012)	-0.00041
	XII	0.99691 (0.00173)	1.0000 (0.0007)	-0.00309
	XVI	0.99193 (0.00200)	1.0001 (0.0019)	-0.00817
	XVIII	0.99139 (0.00179)	1.0002 (0.0011)	-0.00881
	XX	0.99193 (0.00186)	1.0003 (0.0011)	-0.00837
1.932	VII	0.99190 (0.00192)	0.9998 (0.0009)	-0.00790
	VIII	1.01708 (0.00181)	1.0083 (0.0012)	+0.00878
	X	0.99182 (0.00179)	1.0001 (0.0009)	-0.00828
	XXI	0.98954 (0.00159)	0.9997 (0.0015)	-0.01016
2.576	IX	0.98847 (0.00185)	1.0030 (0.0009)	-0.01453

[a] Read as $k_{eff} \pm \sigma$

B.2 Bias For One Assembly in Container

The following discussion of bias was included in the SAR for the Model No. 51032-2 shipping container[2]. It determined a bias of 0.005 ± 0.00376(2σ) for a 6 inch spacing between fuel assemblies in containers. For one assembly in the Model B container, the results of KENOIV benchmarks against Cores I and II in Table B-1 are applicable. However, for conservatism, the 0.005 ± 0.00376 bias will be applied to the one assembly case.

> "Examination of light water reactor critical experiments[1] for low-enriched U^{235} lattices demonstrated an increasing negative bias with increasing separation distances between assemblies. Twenty-one critical light water moderated, low enriched fuel configurations of reference 1 were evaluated using KENOIV with the 123 group cross section library with 160,000 neutron histories. The bias reached a maximum of -0.0145 $\Delta K \pm 0.00411\ \Delta K$ (2σ Unc) with 2.576 inches separating fuel assemblies as shown in Table B-1. Values in parenthesis in Table B-1 indicate 1σ uncertainty.
>
> "Applicable critical experiments in the industry only address separation distances up to 2.576 inches with and without interspersed absorber materials. The separation distance between fuel assemblies in the shipping cask is at least 14 inches with an undamaged fuel configuration (6 inches was actually used in the "nominal" cases for conservatism) and 6 inches during a limiting accident (the minimum distance between assembly pairs in a single cask). Therefore, application of the full $-0.0145\ \Delta K$ bias is questionable for the fully moderated cask since the neutron spectrums for larger separation distances are decoupled with fully dense water (assemblies appear to be isolated and do not see significant neutron contributions from adjacent assemblies). For critical experiments that represent isolated assemblies the average bias for critical cores I and II is $+0.0065\ \Delta K \pm 0.00376\ \Delta K$ (2σ Unc). The critical k_{eff} for isolated assemblies is therefore conservative by approximately $+0.0065\ \Delta K$. Therefore it is reasoned that the negative bias cannot continue to increase with larger separation distances between assemblies. Although the maximum k-effective calculated by the BWFC analysis may accommodate the $-0.0145\ \Delta K \pm 0.00411\ \Delta K$ bias (2σ), application of a $-0.005\ \Delta K \pm 0.00376\ \Delta K$ bias would be conservative and more reasonable based on fuel assembly separation distances in the range of 6 inches.
>
> "To demonstrate that the $-0.005\ \Delta K$ KENOIV bias is conservative for a 6 inch fuel separation, twelve KENOIV accident cases were performed and each modeled an infinite array of casks. The damaged cask configuration shown in Figure B-1 was modeled, however, the outer steel shell was

removed to allow closer separation distances than are actually possible between casks. A conservative minimum edge-to-edge separation distance of 6 inches (defined by the separator blocks) was maintained between pairs of assemblies in each cask for all of the cases evaluated. The data in Table B-2 and Figure B-2 demonstrates the reactivity behavior as cask packages are moved closer together.

"For cask fuel edge-to-edge separation distances (the distance between the edge of an assembly in one cask to the edge of an assembly in an adjacent cask) greater than 4.5 inches and up to 10 inches of water or more there is a slight decrease in k-effective due to the presence of increasing amounts of water moderator (see Figure B-2). The water moderator increases the effective absorption of neutrons by the steel strong back saddle uprights that are positioned adjacent to each assembly. The strong back saddle uprights act as a mild poison for the thermal flux trap between cask packages. For separation distances less than 4.5 inches, k-effective begins to increase rapidly as fast neutrons are able to "see" adjacent fuel assembly pairs and the worth of the thermal flux trap decreases.

"These results demonstrate that the thermal neutron spectrums of fuel assembly pairs are essentially decoupled with as little as 4.0 inches of fully dense water in a flux trap (4.0 inches of water plus 0.25 inches of steel * 2 equals 4.5 inch total separation). Since a minimum total separation distance of 6 inches is maintained under all fuel configurations, the application of a +0.0065 $\Delta K \pm 0.00376\ \Delta K$ bias credit could be argued based on critical experiments. It is possible that Siemens did not apply a bias to their calculations for this reason. However, for conservatism the BWFC will apply an arbitrary bias and uncertainty of $-0.005\ \Delta K \pm 0.00376\ \Delta K$ to all fully dense water moderated cases.

"To ensure that removal of the outer steel shell did not significantly affect the k-effective trend, two accident cases were performed with the steel shell modeled (see Table B-3). One had a fuel edge-to-edge separation distance of 10 inches while the other was performed with 8.655 inches. The results of both cases indicate that k-effective of the casks is increased by approximately 0.003 ΔK relative to the equivalent non-shell cases. The increase in k-effective is due to reflection of neutrons by the outer steel shell.

Table B-2 Cask K-effective Versus Separation Distance (in.)

(Without Outer Steel Shell)

Spacing	Base Keff	2*Sigma Unc	Max Keff	Min Keff
0.000	1.02223	0.00516	1.02739	1.01707
2.000	0.97178	0.00494	0.97672	0.96684
2.600	0.95554	0.00464	0.96018	0.95090
3.345	0.94514	0.00496	0.95010	0.94018
4.000	0.93562	0.00484	0.94046	0.93078
4.500	0.92631	0.00490	0.93121	0.92141
5.000	0.92566	0.00514	0.93069	0.92041
6.000	0.92856	0.00522	0.93378	0.92334
8.655	0.92450	0.00516	0.92966	0.91934
10.000	0.91962	0.00526	0.92488	0.91436
12.000	0.91929	0.00542	0.92471	0.91387

Table B-3 Cask K-effective Versus Separation Distance (in.)

(With Outer Steel Shell)

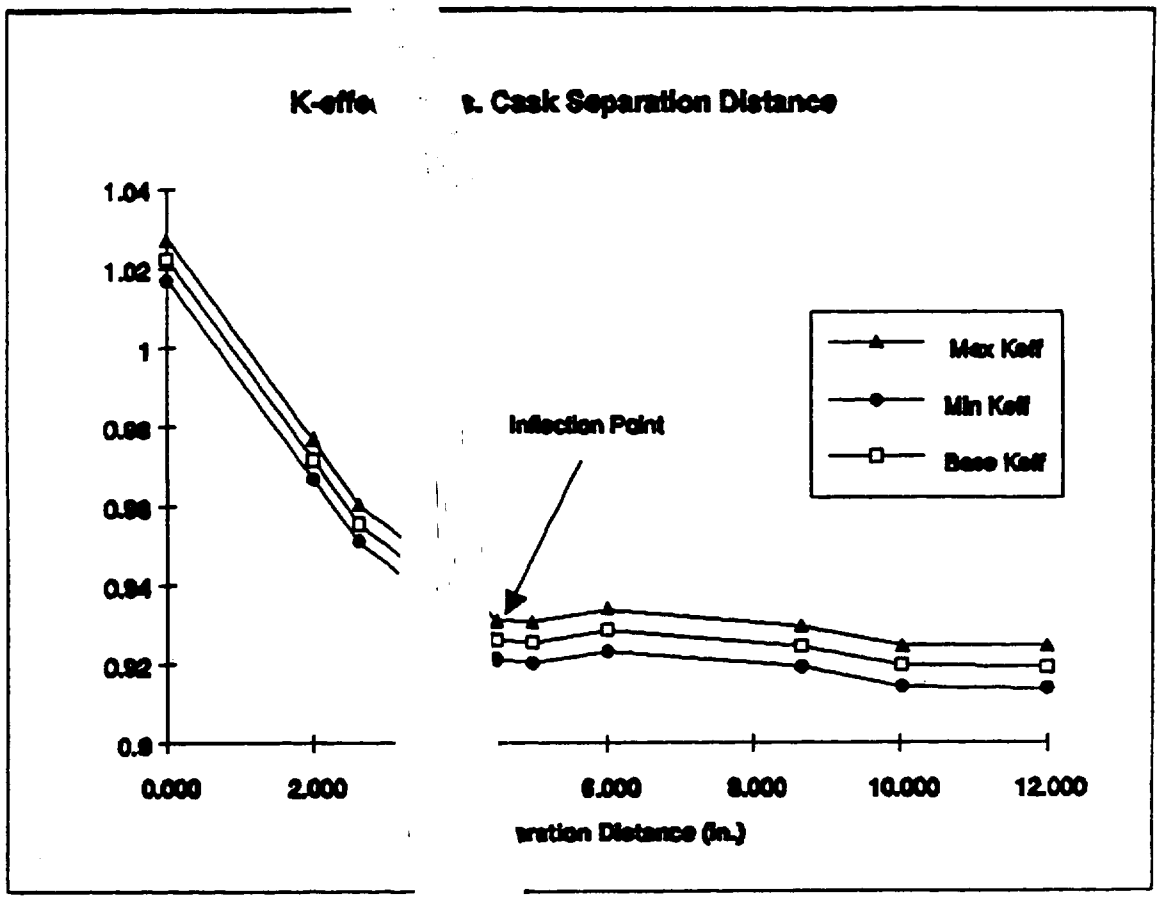
Spacing	Base Keff	2*Sigma Unc	Max Keff	Min Keff
8.655	0.92763	0.00534	0.93297	0.92229
10.000	0.92230	0.00452	0.92682	0.91778

Figure B-1 Model 51032-2 Accident Configuration

FIGURE WITHHELD UNDER 10 CFR 2.390

All Dimensions in Inches

Figure B-2 Keff Versus Separation Distance For Model 51032-2



B.3 References

1. BAW-1484-7, "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel," DOE Contract EY-77-C-09-1001, Babcock & Wilcox Company, July 1979.

2. "Application For Use Of The 51032-02 Shipping Container For Transport Of Radioactive Materials," B&W Fuel Company, March 9, 1993, Docket 71-9252.