GNF-A's NEW POWDER CONTAINER (NPC)

NRC CERTIFICATE OF COMPLIANCE USA/9294/AF

DOCKET NO. 71-9294

To Facilitate Review of the September 2002 Submittal

ATTACHMENTS 5 & 6 TO THE 9/30/2002 APPLICATION

Attachment 5 - Drawings with changes highlighted in yellow

and

Attachment 6 - Chapter 6.0, Revision 2 with new data in red and deleted text shown with blue strikethrough lines

Copies of the Drawing (8 Sheets Each)

Changes are highlighted in yellow.

BOOK 3 OF 3

177D4970	SH 1

NOTES, UNLESS OTHERWISE SPECIFIED:

1. INTERPRET DRAWING PER ANSI Y14.5. INTERPRET WELDS PER ANSI/AWS A2.4.

2. THREADS PER ANSI B1.1.

3> IDENTIFICATION: PACKAGE SHALL BE IDENTIFIED IN ACCORDANCE WITH THE REQUIREMENTS OF 10 CFR 71.85(c) ON THE OUTER SHELL OF THE PACKAGE BODY WITH A STAINLESS STEEL NAMEPLATE.

4> MATERIAL: ASTM A240, TYPE 304L STAINLESS STEEL PLATE AND SHEET OR ASTM A276 FLATS AND BAR.

5. PRIOR TO ASSEMBLY, ALL COMPONENTS SHALL BE CLEANED OF CUTTING OIL, MARKING DYES, WELD FLUX, SPATTER, SCALE, GRIME AND ALL OTHER FOREIGN MATERIAL. FINISHED ASSEMBLY AND ALL INTERIOR SURFACES SHALL BE CLEANED, AND VISUALLY OR WIPE TEST INSPECTED IN ACCORDANCE WITH ASTM-A380.

6. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH ASME CODE, SECTION IX OR ALTERNATE DESIGN ENGINEERING QUALIFICATION. WELD PROCEDURE AND WELDER QUALIFICATIONS SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

7. ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH AWS D1.6.

8> INNER CONTAINMENT CANISTER ASSEMBLY SHALL BE SUBJECTED TO AN INTERNAL PRESSURE TEST AS SPECFIED IN SECTION 8.1.2.2 OF THE NPC SAFETY ANALYSIS REPORT.

9> COAT THREADS WITH A LUBRICANT PRIOR TO ASSEMBLY.

10> TAMPER INDICATING SEALS SHALL BE INSTALLED AT TWO (2) OPPOSITE SIDES.

11> TORQUE TO 50 ±5 LB-FT.

12> TORQUE TO 40 ±5 LB-FT.

13> STENCIL 1" WIDE X 4" LONG STRIPE AND 1/2" HIGH LETTERS AS SHOWN USING BLACK ENAMEL PAINT (ONE SIDE ONLY).

14> FIT CADMIUM SHEET TIGHTLY AROUND INNER SHELL OF CANISTER. BUTT ENDS TOGETHER WITH .000-.100" CLEARANCE. SECURE TO INNER SHELL OF CANISTER WITH DOUBLE SIDED TAPE.

15> WRAP HDPE SHEET CONTINUOUSLY AROUND THE CADMIUM SHEET TO OBTAIN A MINIMUM HYDROGEN AREAL DENSITY OF .199 GRAMS/CM^2. THIS DENSITY WILL BE BASED UPON THE MINIMUM POLYETHYLENE THICKNESS OF .57" AND WIDTH OF 30.3", THE MEASURED POLYETHYLENE ID, A POLYETHYLENE DENSITY OF .92 GRAMS/CC, AND A MINIMUM POLYETHYLENE HYDROGEN CONTENT OF 14.0%. SECURE ENDS WITH DOUBLE-SIDED TAPE.

16> FILL CAVITY WITH HOT GLUE, HYSOL 7804 OR EQUIVALENT, AT EACH END.

17> OPTION: SEAL CREVICE WITH BELZONA 1111 SERIES OR EQUIVALENT SEALANT.

18> COAT EXPOSED SURFACES OF FOAM SLAB WITH ONE THIN COAT OF POLYURETHANE COATING. AFTER INSTALLING SEAL CHANNEL, APPLY A SECOND COAT TO EXPOSED SURFACES OF FOAM SLAB.

19> FILL 1/8 DEEP SPACE OVER EDGES OF CERAMIC FIBER BOARD WITH 3M DP-605 OR EQUIVALENT URETHANE SEALANT.

20> BOLT HOLE PATTERN OF LID SHALL BE COORDINATED WITH THAT OF BODY LOCATING PINS TO ENSURE ALIGNMENT OF BOLTS AND NON-BINDING ASSEMBLY OF LID TO BODY.

21> INSTALL CERAMIC FIBER BOARD PANELS WITH MINIMUM JOINTS. ALL JOINTS, INCLUDING CORNERS, SHALL BE COVERED BY ADJACENT LAYER (STAGGERED). ADHERE PANELS TO BODY AND TO EACH OTHER WITH 3M SUPER 74 SPRAY ADHESIVE, OR EQUIVALENT ADHESIVE.

22> INSTALL PINS BY PIERCING THRU CERAMIC FIBER BOARD AND WELDING TO LID USING COMMERCIAL STUD WELD GUN.

23> INSTALL CERAMIC FIBER BOARD PANELS WITH MINIMUM JOINTS. ALL JOINTS, INCLUDING CORNERS, SHALL BE COVERED BY ADJACENT LAYER (STAGGERED). ADHERE PANELS TO INNER SURFACE OF LID AND TO EACH OTHER WITH 3M SUPER 74 SPRAY ADHESIVE, OR EQUIVALENT ADHESIVE. AT THE CORNERS, ADHERE PANELS TO ITEM 28 ONLY.

24> STENCIL CANISTER BAND CLAMP ORIENTATION ZONES (9 PLACES) USING BLACK ENAMEL PAINT.

25> POLYURETHANE FOAM INSTALLATION TECHNIQUES, ACCEPTANCE TESTS, AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.1 OF THE NPC SAFETY ANALYSIS REPORT.

26> AN ADDITIONAL STRIP OF 24 GA. (.024") X 2" WIDE X 30.6" LONG STAINLESS STEEL MAY BE ADDED UNDER THE WELD JOINT NEAR THE OVERLAP TO FACILITATE SPOT WELDING.

27> THE CADMIUM SHEET MAY BE INSTALLED IN UP TO THREE SECTIONS WITH A MAXIMUM 0.1" GAP BETWEEN ANY MATING SURFACES.

28> EXTERNAL SURFACES OF NPC MAY BE LOCALLY DENTED OR BULGED UP TO A MAXIMUM DEPTH OF 1/2 INCH.

29> EXTERNAL SURFACES OF ICCA MAY BY LOCALLY DENTED UP TO A MAXIMUM DEPTH OF 1/4 INCH.

30> STENCIL "LID LIFT ONLY" APPROX AS SHOWN (4 PLACES) USING BLACK ENAMEL PAINT.

31> TORQUE TO 35-50 LB-IN.

32> CERAMIC FIBER BOARD AND BRAIDED ROPE ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.2 OF THE NPC SAFETY ANALYSIS REPORT.

33. MAXIMUM/MINIMUM WEIGHT OF PACKAGING: 1,680/1,580 LBS. MAXIMUM ALLOWABLE WEIGHT OF CONTENTS: 1,190 LBS. MAXIMUM ALLOWABLE WEIGHT OF CONTENTS IN ANY ICCA: 132.2 LBS. MAXIMUM WEIGHT OF PACKAGE 2,870 LBS.

34> FOAM SLABS MAY BE BONDED TOGETHER WITH EPOXY ADHESIVE.

35> MARKING IS PER 49 CFR 172.310(C).

36> CADMIUM SHEET ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.3 OF NPC SAFETY ANALYSIS REPORT.

37> HDPE POLYETHYLENE ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.4 OF NPC SAFETY ANALYSIS REPORT.

38> WELDS MAY BE MADE ON EITHER SIDE OF THE SURFACE.

LIST OF MATERIAL

A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
					40		BAND, .06 X 1" SILICONE RUBBER, DURO 45 ±5	
	AR				39		WRAPPER, 24 GA (.024)	ASTM A240, TYPE 304L
	AR				38		SHEET, HDPE POLYETHYLENE, .015" NOM. THK X 30.3" MIN.	
	AR				37		SHEET, CADMIUM, .020" MIN. THK. X 30.3" MIN.	
	AR				36		RING, 7 GA (.187)	ASTM A240, TYPE 304L
	1				35		LID CANISTER, 18 GA (.059)	ASTM A240, TYPE 304L
	1				34		BASE CANISTER, 7 GA (.187)	ASTM A240, TYPE 304L
	1				33		BODY CANISTER, 18 GA (.048)	ASTM A240, TYPE 304L
			4		32		SCREW, MACHINE, 5/16-18 TRUSS HEAD	
		4			31		THREADED INSERT, 5/16-18, INTERNAL THD	
		1			30		ROPE, BRAIDED, CERAMIC FIBER, 1" X 1" X AR	
		AR			29		FOAM, 15 LBS/FT^3	POLYURETHANE
		8			28		LINER, 16 GA (.059) X 3.7 X 5.6	ASTM A240, TYPE 304L
		16			27		BOLT SUPPORT, 1.5 X 1.5 X 6	ASTM A276, TYPE 304L
		4			26		LIFT PAD, 3/8" THK X ø1.5	ASTM A276 OR A240, TYPE 304L
		4			25		CORNER REINFORCEMENT, 10 GA (.135)	ASTM A240, TYPE 304L
		4			24		ANGLE, 1 X 1 X 1/8	ASTM A276, TYPE 304L
		4			23		LID CORNER REINFORCEMENT, 10 GA (.135)	ASTM A240, TYPE 304L
		1			22		LID, 10 GA (.135)	ASTM A240, TYPE 304L
			9		21		PAD, ICCA, 1/16 THK X ø9.0	SILICONE RUBBER
			5		20		PIPE PLUG, 1/2 NPT, PLASTIC	
		12	16		19		CUPPED PIN, INSULATION	
		AR	AR		18		SEAL TROUGH, 24 GA (.0235)	ASTM A240, TYPE 304L
			AR		17		FOAM, 11 LBS/FT^3	
			5		16		HALF COUPLING, 1/2-14NPT	
		1	1		15		FOAM SLAB, 1 3/8" THK, 40 LBS/FT^3	POLYURETHANE
			9		14		FOAM SLAB, 3 1/4" THK, 7 LBS/FT^3	POLYURETHANE
			1		13		FOAM SLAB, 3" THK, 11 LBS/FT^3	POLYURETHANE
		AR	AR		12		CERAMIC FIBER BOARD, 1/2" THK	
1					11		LINER BASE, 22 GA (.029)	ASTM A240, TYPE 304L
1					10		LINER, 22 GA (.029)	ASTM A240, TYPE 304L
			8		9		GUARD, 7 GA (.187) X 6.3 X 9.0	ASTM A240, TYPE 304L
			16		8		LOCATING PIN, 1.3 X 1.5 X 3.5	ASTM A276, TYPE 304L
			4		7		BAR, 5/8 X 1	ASTM A276, TYPE 304L
			4		6		LIFT CHANNEL, 7 GA (.187) X 6.0 X 1.5 X 19.6	ASTM A240, TYPE 304L
			8		5		LIFT TUBE, 6 X 3 X 7 GA. (3/16 WALL NOMINAL)	ASTM A554, TYPE 304
			4		4		BODY CORNER GUSSET, 14 GA (.075)	ASTM A240, TYPE 304L
			1		3		DOUBLER, 16 GA (.060) X 18 3/8 SQ	ASTM A240, TYPE 304L
			1		2		BOTTOM PLATE, 10 GA (.135) X 27 13/16 SQ	ASTM A240, TYPE 304L
			2		1		BODY, 10 GA (.135)	ASTM A240, TYPE 304L
X				9	A5		SILO WELDMENT	
	X			9	A4		INNER CONTAINMENT CANISTER ASSEMBLY (ICCA)	
					A3		OCA LID ASSEMBLY	
					A2		OCA BODY ASSEMBLY	
				X	A1		OUTER CONFINEMENT ASSEMBLY (OCA)	
A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
					ASSEMBLY & QUANTITY		LIST OF MATERIAL	

A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
				8	52		WASHER, FLAT, 1/4-20 NOM	
				8	51		SCREW, MACHINE, 1/4-20UNC PAN HEAD	
				8	50		COVER, 16 GA (.060) X 3.7 X 6.3	18-8 SS
				1	49		NAMEPLATE, COMPLIES WITH 10CFR71.85	
				16	48		PLUG, WEATHER, ø1"	RUBBER & PLASTIC
				24	47		BOLT, HEX HD, 7/16-14UNC X 3/4	CAD OR ZINC PLATED GR 5
				16	46		SOC HD, CAP SCREW, 1/2-13UNC X 2	18-8 SS
				16	45		THREADED INSERT, 1/2-13UNC INTERNAL THD	
				24	44		THREADED INSERT, 7/16-14UNC INTERNAL THD	
				4	43		STRIP, CLOSURE, 10 GA (.135)	ASTM A240, TYPE 304L
	1				42		BAND CLAMP ASSY #NH1009394-10	AEROQUIP OR EQUIVALENT
	1				41		GASKET, 1/8" THK SILICONE RUBBER, DURO 60-70	
A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
					ASSEMBLY & QUANTITY		LIST OF MATERIAL	

PATENT #6,166,391

TOLERANCES, UNLESS OTHERWISE SPECIFIED:

LINEAL DIMENSION RANGE	DECIMAL 3 PLACE	DECIMAL 2 PLACE	DECIMAL 1 PLACE	FRACTIONAL	ANGULAR
0-6"	±0.020	±0.06	±0.2	±3/16	±2°
6"-24"	±0.030	±0.10	±0.3	±5/16	
> 24"	±0.050	±0.20	±0.5	±1/2	

ESSENTIAL TO SAFETY

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

SAFETY-RELATED CLASSIFICATION CODE Q

	SIGNATURES	DATE
DRAWN	J W MOODY	23-SEP-02
CHECKED	R P GONZALES	23-SEP-02
PROD ENG	J F. SCHARDT	25-SEP-02
ENGRG	D BROWN	25-SEP-02

APPLIED PRACTICES N/A

ALL SURF. 125√

UNLESS OTHERWISE SPECIFIED TOLERANCES ON
2 PLACE DECIMALS ± --- FRACTIONS ± ---
3 PLACE DECIMALS ± --- ANGLES ± ---

GNF Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

ISSUE DATE	DWG NO.	REV.
26-SEP-02	177D4970	0
RMCN01146	COMPL. C	SH NO. 1 / CONT ON 2

F-IV-AC

FIGURE WITHHELD UNDER 10 CFR 2.390

0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02
REV	DESCRIPTION	BY	APPROVAL	DATE
REVISIONS				

GNF Global Nuclear Fuel	DATE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	2	3

FIGURE WITHHELD UNDER 10 CFR 2.390

0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02
REV	DESCRIPTION	BY	APPROVAL	DATE
REVISIONS				

GNF Global Nuclear Fuel		DATE	177D4970	0
J.W. MOODY		23-SEP-02		
R.P. GONZALES		23-SEP-02	3	4

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	DATE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	4	5

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	DATE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	5	6

3 2 F-IV-AC 1

FIGURE WITHHELD UNDER 10 CFR 2.390

0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02
REV	DESCRIPTION	BY	APPROVAL	DATE
	REVISIONS			

GNF	Global Nuclear Fuel	DATE	177D4970	0
DRAWN	J.W. MOODY	23-SEP-02		
CHECKED	R.P. GONZALES	23-SEP-02	SH NO. 6	CONT ON 7

3 2 F-IV-AD 1

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	DATE	177D4970		0
J.W. MOODY	23-SEP-02			
R.P. GONZALES	23-SEP-02		7	8

3 2 F-IV-AC 1

MODEL NO.: NPC

TYPE A

OWNER: GLOBAL NUCLEAR FUEL–AMERICAS

MANUFACTURE DATE:

SERIAL NO.:

PACKAGE IDENTIFICATION NUMBER: USA/9294/A(F)–85

GROSS WEIGHT: 2870 LBS (1302 KG)

DETAIL ITEM (49) SAMPLE NAMEPLATE

MATERIAL: STAINLESS STEEL (ANY GRADE)
LETTERING: 1/2" HIGH MINIMUM, ENGRAVED, BLACK PAINT FILLED

PATENT #6,166,391

TOLERANCES, UNLESS OTHERWISE SPECIFIED:

LINEAL DIMENSION RANGE	DECIMAL			FRACTIONAL	ANGULAR
	3 PLACE	2 PLACE	1 PLACE		
0–6"	±0.020	±0.06	±0.2	±3/16	±2°
6"–24"	±0.030	±0.10	±0.3	±5/16	
> 24"	±0.050	±0.20	±0.5	±1/2	

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel

J.W. MOODY	23–SEP–02	177D4970 — REV 0
R.P. GONZALES	23–SEP–02	SH 8 F

F–N–AC

177D4970 8

Copies of Chapter 6.0 that Show
the Deleted Text with Blue Strikethrough Lines
and the New Text/Data in Red

BOOK 3 OF 3

6.0 CRITICALITY SAFETY EVALUATION

6.1 GENERAL DESCRIPTION

This criticality safety analysis is performed to demonstrate safety of the New Powder Container (NPC). This ~~new~~ transport package meets applicable IAEA and 10 CFR 71 requirements for a Type A fissile material-shipping container for homogeneous and heterogeneous uranium ~~powder in oxide form~~compounds enriched to a maximum of 5.00 wt. percent ~~%~~ U-235. ~~Uranium compounds may be in the form of solids, or solidified or dewatered materials. The uranium compounds must have a ratio of non-fissile atoms to uranium atoms greater than or equal to two (2) and the maximum density of these compounds must be no greater than 10.96 gm/cm^3 (the maximum theoretical density of UO_2). This specifically includes uranium oxides (UO_2, U_3O_8, or $UO_{x, x>2}$). Materials such as uranium metal, uranium metal alloys, or uranium hydrites (e.g. UH) are not covered by this analysis. Other uranium compounds specifically authorized include oxides, carbides, nitrates (e.g., UNH, whose chemical formula is $UO_2(NO_3)_2 \bullet 6H_2O$, with a theoretical density of ~2.81 gm/cm^3) and silicates. Uranium-bearing contents may be moderated by graphite to any degree and may be mixed with other non-fissile materials with the exception of deuterium, tritium and beryllium. This specifically includes uranium oxide bearing ash from combustible waste incineration. Moderating materials containing hydrogen with a hydrogen density greater than that in water are not covered by this analysis.~~

The NPC transport package design features include an internal 3x3 array of stainless steel Inner Containment Canister Assemblies (ICCAs) enclosed in a near cubic stainless steel reinforced Outer Confinement Assembly (OCA) as described in Section 1.2, *Package Description.*

The uranium ~~powder~~ contents are~~is~~ contained within 8.515" (21.63-cm) maximum ID stainless steel canisters internally spaced on nominal 12.0" (30.48-cm) center-to-center positions within the OCA. Manufacturing tolerance effects on package models~~reactivity~~ are addressed in Section 6.3.1~~later~~, *General Model.*

Water exclusion from the ICCAs ~~under accident conditions~~ is not required for this package design. Each cylindrical inner container within the package is analyzed in both ~~the~~ undamaged and damaged container arrays under optimal moderation conditions and is demonstrated to be a favorable geometry.

This analysis is performed at a maximum enrichment of 5.00 wt. percent U-235 for both homogeneous UO_2 powder and heterogeneous UO_2 in the form of ~~pellets~~pellets, and cylindrical~~/rod~~ elements to represent unrestricted particle size (e.g., outer diameter, OD, is varied through optimum)s. The most reactive condition is therefore modeled for each authorized payload to demonstrate safety.~~,~~ The following Table 6.1 summarizes the uranium mass limits per ICCA and ~~,~~ ~~and~~ per package for the NPC ~~, demonstrated by this analysis for the NPC~~ container.~~This analysis demonstrates safety up to a maximum of 60 kgs UO_2 per ICCA, for a total maximum package payload of 540 kgs UO_2 per NPC package.~~ Other uranium compounds complying with the requirements stated in Table 6.1 ~~in the above~~ are acceptable for shipment ~~also equally valid~~ provided that the equivalent uranium payloads are not exceeded.

Table 6.1 -

Table 6.1—UO_2 and Uranium Equivalent Mass Limits* per NPC Package

Material Fuel Form (≤5.00 wt.% U-235)	Particle Size Restriction: Minimum Pellet OD Diameter (Inches)	Maximum Loading per ICCA (kgs)		Maximum Loading per NPC (kgs)	
		UO_2	Uranium	UO_2	Uranium
Homogeneous UO_2 Homogeneous Uranium Oxides/Compounds Powder	N/AA	60.0	52.898	540.0	476.15.2
Heterogeneous UO_2 Pellets (10X10 Pellets)(BWR)	0.34243	55.0	48.48	495.0	4356.36
Heterogeneous UO_2 Pellets (PWR) UO_2 Pellets (17X17 Pellets)	0.3008	53.0	46.716	477.0	42019.4
Heterogeneous Uranium Compounds O_2 Materials	Unrestricted particle size Unlimited	46.0	40.54	414.0	364.85

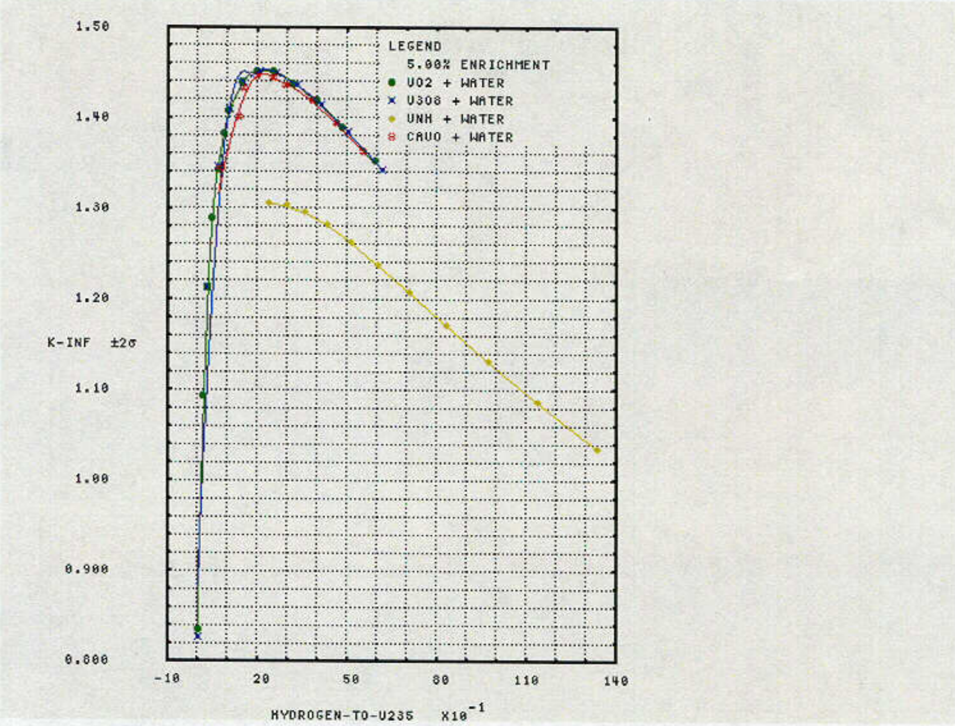
*For U-235 enrichments ≤ 5.00 wt. %.
%.

The "Material Form" column in Table 6.1 includes both homogeneous and heterogeneous uranium compounds in the form of solids, or solidified or dried materials. All homogeneous and heterogeneous compounds are restricted to material forms having a bulk density ≤10.96 g/cc (theoretical UO2), with a percent uranium content ≤0.88144.

This specifically includes homogneous uranium oxides (UO_2, U_3O_8, or $UO_{x,\,x>2}$). Other homogeneos uranium compounds specifically authorized include dried (calcium containing) sludges, nitrates, uranyl nitrate hexahydrate (UNH, chemical formula $UO_2(NO_3)_2 \bullet 6H_2O$, with a theoretical density of 2.807 gm/cm^3), and uranium oxide bearing ash from combustible waste incineration.

A reactivity comparison between 5% enriched theoretical UO_2, U_3O_8, UNH, and $CaU_6O_{19} \bullet 11H_2O$ compounds with water is provided in Figure 6.0 demonstrating that the theoretical mixture of UO2 and water is conservative relative to other homogeneous uranium compounds. For k-infinite reactivity comparisons, refer Appendix 6.11 for a more complete material specification listing of uranium compounds evaluated.

Figure 6.0 K-infinite Comparison of U-compounds



This also specifically includes heterogeneous uranium oxides (UO_2, U_3O_8, or $UO_{x,\ x>2}$) and UO2 pellets present in standard BWR and PWR reactor fuel assembly lattices designs (e.g., PWR: 17X17; BWR: 10X10, 9X9, 8X8 nuclear fuel assemblies). This analysis demonstrates safety for uranium compounds through optimal heterogeneity (unrestricted or unlimited particle size). As such, the specified pellets having diameters greater than or equal to the "Minimum" value specified in the table may be safely transported in the NPC package provided the tabulated UO_2 (or equivalent uranium) material contents per ICCA and package are met.

Uranium-bearing contents may be moderated by water or carbon to any degree and may be mixed with other non-fissile materials with the exception of deuterium, tritium and beryllium. Materials such as uranium metal and uranium metal alloys are not covered by this analysis.
~~The "10X10 Pellets" and "17X17 Pellets" descriptions in the Fuel Forms column in the above table refer to the UO_2 pellets present in standard 10X10 and 17X17 nuclear fuel assembly (i.e., bundle) designs. Since the optimum fuel pellet/rod diameter (corresponding to the "Unlimited" Case in Table 6.1) is at or close to 0.100 inches, pellets or unclad rods having diameters greater than the "Minimum" value specified in the table may be transported in the NPC package with the tabulated UO_2 or uranium Maximum Loadings.~~

For this package, undamaged packages have been analyzed in infinite arrays and hence pursuant to 10 CFR §71.59(a)(2) the more restrictive value of "N" is derived from the damaged array calculations ~~pursuant to 10 CFR §71.59(a)(2)~~. The Transport Index for criticality control is then derived from this value of "N" per~~pursuant to~~ 10 CFR §71.59(b).

This analysis demonstrates safety for 2N=150 packages. The corresponding Transport Index (TI) for criticality control of non-exclusive vehicles is given by TI = 50/N. Since 2N = 150, it follows that N =

C01

75, and TI = 50/75 = 0.6667 ≈ 0.7 [rounded to nearest tenth]. Using the rounded Transport Index result, the maximum allowable number of packages per non-exclusive use vehicle is 50/0.7 = 71.

6.2 PACKAGE DESCRIPTION

6.2.1 CONTENTS

The package shall be used to transport homogeneous or heterogeneous uranium compounds conforming to the requirements stated in Section 6.1 and with uranium enrichments of ~~powder in oxide form (UO_2, U_3O_8, or $UO_{x, x>2}$) enriched to a maximum of~~not greater than~~more~~ than 5.0 weight percent U-235. The ~~modeled~~ uranium isotopic distribution considered in the models used in~~for~~ this criticality safety demonstration is shown in Table 6.~~1~~2

Table 6.~~1~~2 - Uranium Isotopic Distribution

Isotope	Modeled wt. %
^{235}U	5.0000
^{238}U	95.0000

This analysis conservatively demonstrates safety for homogeneous UO_2 powder, ~~and~~ pellets, and heterogeneous forms of uranium oxides (unlimited particle size) -over the entire range of UO_2~~2~~ densities and degree of moderation by H_2O. The maximum ~~net~~ UO_2 equivalent payload demonstrated safe in the NPC is specified in Table 6.1.~~-60 kgs UO_2 per ICCA which corresponds to a maximum package payload of 540 kg total UO_2.~~

~~Other homogeneous forms of uranium powder in oxide form (e g , U_3O_8, or $UO_{x, x>2}$) are also equally valid, provided the total uranium mass does not exceed 52 9 kgs U per ICCA (or 476 1 kgs U per NPC package)~~

Any mass distribution including authorized non-uranium packaging materials such as plastic or metal in the form of bags, bottles, cans etc. within the 3 × 3 array of ICCAs is also acceptable, provided the total uranium content~~s including any packaging materials such as bags, bottles, cans used to contain the uranium powder~~ in any one ICCA does not exceed the applicable limit in Table 6.1~~-60 kgs total mass.~~ and provided that the entire contents meets the applicable total package weight limit.

6.2.2 PACKAGING

A general discussion of the NPC packaging design ~~designed for transportation of homogeneous uranium oxides enriched up to 5% U 235~~ is provided in Section 1.2.1, *Packaging*. A detailed set of drawings of the NPC packaging is provided in the Appendix 1.3.1, *Packaging General Arrangement Drawings*. The NPC packaging is comprised of two primary components: 1) an Outer Confinement

Assembly (OCA) consisting of the body and lid sections, and 2) nine Inner Containment Canister Assemblies (ICCAs). These major components are described below.

Product containment occurs inside an 18 gauge (0.048" wall thickness) Type 304L stainless steel Inner Containment Canister Assembly (ICCA). This ICCA is sequentially wrapped in a 0.020" (minimum) thick cadmium sheath, followed by a 0.570- inch thick polyethylene wrap (minimum), followed by a 24-gauge (.024" wall thickness) outer Type 304L stainless steel containment sheath welded closed to effectively contain the cadmium and polyethylene.

The bottom of an ICCA consists of a 9.72" OD, 7-gauge (0.188" thick) Type 304L stainless steel plate. The top of an ICCA includes 7-gauge (0.188" thick) Type 304L stainless steel upper ring (8.620" ID x 9.72" OD) to facilitate the poly wrap and welding of the 24 gauge outer sheath. The ICCA lid is a 16-gauge (0.0595" thick) Type 304L stainless steel cylinder and contains a molded silicon rubber gasket. The closure of the ICCAs is provided by a stainless steel band clamp assembly that utilizes a 5/16-24~~UNF-T-~~ T-bolt and nut.

Each ICCA is placed inside a 22-gauge Type 304L stainless steel cylindrical shield (silo), which is "foamed" in place on 12-inch X,Y~~x,y~~ centers within the OCA body. The OCA body assembly includes a 10-gauge (0.135" wall thickness) Type 304L stainless steel 42.81x42.81x37.66 inch outer-dimension cubic box. The nominal 37.66-inch height includes the height of eight 6x3x3/16x8.4" Type 304~~L~~ stainless steel rectangular channels located on each corner of the package to facilitate fork lifting of the package from four sides. The Type 304L stainless steel structures associated with the eight (8) tube channels and the connecting 6" × 1.5" × 3/16" × 19.6" cross member ties are conservatively ignored at the bottom of the body assembly.

The central region of the NPC housing the 3 × 3 array of ICCAs is polyurethane foam ~~at~~with a density of 7 lb/ft^3 (nominal). A 4-inch (X,Y,Z~~x,y,z~~) periphery surrounds the inner 3 × 3 array of ICCAs housed within the stainless steel silos. On the bottom and sides, a 3-inch periphery polyurethane foam ~~at~~ with a density of 11 lb/ft^3 (nominal) surrounds the 7 lb/ft^3 region. The upper-most region of the OCA body that mates to the lid includes a rigid 1-3/8" layer of 40 lb/ft^3 polyurethane foam. The final 1-inch periphery of the body assembly contains 1-inch layer of ceramic fiberboard. This material is utilized for its thermal performance (heat resistance~~t~~) properties.

The modeled OCA lid includes 10 gauge, 43.21" × 43.21" × 5.9"~~-inch~~ outer dimension Type 304L stainless steel box that is mated to the lower body assembly via 16 guide pins, which ensure proper lid seal alignment during closure. The outermost periphery again includes a modeled 1-inch ceramic fiber-board. The foam layer beneath the ceramic fiberboard includes a 3.5" layer of 15-lb/ft^3 (nominal) density polyurethane foam insulation. The lower 1-3/8" layer is rigid 40-lb/ft^3 (nominal) density polyurethane foam to protect the interface between the OCA body assembly and OCA lid assembly mating surfaces. This higher -density 40 lb/ft^3 foam section in the lid includes cutouts to accommodate the upper lock ring closure of the ICCA.

The OCA lid dimensions include additional corner support structures, flanged edges, and ~2.3-inch overlap of 10-gauge stainless steel protecting the OCA body/lid interface (which are ignored in the final model construct). Closure of the OCA is provided by (16) 1/2-13UNC socket head cap screws. The closure is further secured by the OCA closure strips and (24) 7/16-14UNC hex head bolts. The NPC packaging is illustrated in Figure 1.1-1. Full details of the NPC packaging design are provided on the drawings in Appendix 1.3.1, Packaging General Arrangement Drawings. The OCA body containing up to~~the~~ nine loaded ICCAs, coupled with the OCA lid constitutes the entire NPC package assembly.

6.2.2.1 MATERIAL SPECIFICATIONS

One of the important aspects of the criticality safety demonstration for this package is the hydrogen content in the foam and polyethylene regions. Hydrogen is important due to its moderating and neutron capture characteristics.

The minimum specified hydrogen content in the foam is 6.4 weight percent. Likewise, the polyethylene region surrounding the cadmium is based on stoichiometric CH_2, with nominal hydrogen content of 14.3%.

To account for the potential high-temperature off-gassing of hydrogen in the polyurethane foam and polyethylene regions, and to assure the hydrogen content in the modeled regions is no greater than the package after physical testing, sample analysis of both regions were conducted as described in Section 2.10.1, Certification Tests, of this application:

- Polyurethane Foam: The average measured hydrogen content of the foam regions used to fabricate the test units was 6.48%. The average of 12 replicate samples taken from residual foam in the certification test units resulted in measured hydrogen content of 6.40% with the lowest observed value at 6.07% hydrogen. The 6.07% hydrogen value corresponded to a sample taken from what appeared to be one of the hottest areas observed. This criticality safety demonstration is performed using 6.00% hydrogen content in the foam material regions for all undamaged and damaged models and is conservative relative to the observed physical package post HAC testing (refer to Section 2.10.1.2, Summary, regarding the significant results of the hydrogen stability in the foam).

- Polyethylene: The average measured value of the hydrogen content in the polyethylene material use to fabricate the certification test units was 14.23%. The average measured value from four post-test replicate samples strategically withdrawn from what was believed to be the hottest regions observed was 14.09% with the lowest observed value of 14.01%. The average of eight additional replicate samples taken from various locations showing some indications of heating in the moderator averaged 14.20% with the lowest observed value of 14.09%. The measured values show little change in the hydrogen content in the polyethylene region before and after the test even in the hottest regions. This criticality safety demonstration is performed using 14.00% hydrogen content in the polyethylene wrap region surrounding each ICCA for all undamaged and damaged models and is conservative relative to the observed physical package post HAC testing (refer to Section 2.10.1.2, Summary, regarding the significant results of the hydrogen stability in the polyethylene).

Table 6.3-2 provides a listing of the applicable material specifications used in the NPC model construct. The table conservatively applies the minimum measured hydrogen content of the NPC polyurethane foam (6.00%) and polyethylene wrap (14.00%) in the applicable packaging regions for all normal and damaged model constructs.

The minimum composition values for C, O, N, H shown in Section 8.1.4.1.1.1, Polyurethane Foam Chemical Composition, are applied. Other trace foam constituents (P, Si, Cl, and other) are ignored. Additional package material conservatism is later described in Section 6.3.1.5, Models – Actual Package Differences.

Table 6.32 - Material Specifications for the NPC Shipping Package

Material	Density (g/cm³)	Constituent	Atomic density (atoms/b-cm)
$U(5.00)O_2$ Fuel[1]	≤10.96	U-235 (max.)	1.2378E-03
		U-238 (max.)	2.3220E-02
		O (max.)	4.8916E-02
304L Stainless Steel	7.9	C	3.1691E-04
		Si	1.6940E-03
		Cr	1.6471E-02
		Fe	6.0360E-02
		Ni	6.4834E-03
		Mn	1.7321E-03
Cadmium	8.2175*	Cd	4.4000E-02
Polyethylene	0.92	H	7.6965E-02
		C	3.9504E-02
Polyurethane Foam	0.1122	C	2.8100E-03
(7 lb/ft³)		O	5.9000E-04
		N	1.9000E-04
		H	4.0200E-03
Polyurethane Foam	0.1762	C	4.4200E-03
(11 lb/ft³)		O	9.3000E-04
		N	3.0000E-04
		H	6.3200E-03
Polyurethane Foam	0.2404	C	6.0300E-03
(15 lb/ft³)		O	1.2700E-03
		N	4.1000E-04
		H	8.6100E-03
Polyurethane Foam	0.6407	C	1.6080E-02
(40 lb/ft³)		O	3.3800E-03
		N	1.1000E-03
		H	2.2970E-02
Full Density Water	1.00	H	6.68660E-02
		O	3.34330E-02

- *—95% of theoretical density
- [1] Maximum values assumed for heterogeneous contents

6.3 CRITICALITY SAFETY ANALYSIS MODELS

6.3.1 GENERAL MODEL

6.3.1.1 Material Tolerance(s)

Table 6.43 provides sheet metal thickness dimensional tolerance from ASTM A240 and ASTM A480 (the former refers to the latter for specific tolerances). The maximum tolerance reductions in gauge sheet thickness are uniformly applied in all normal and damaged NPC model constructs.

The foam density distribution throughout the body assembly and lid assembly is varied as described in Section 6.2.2, *Packaging*. The manufacturers quality assurance program ensures the tolerance on the actual foam density is +15%/-10% at all times. For conservatism, the maximum 10% reduction in foam density is uniformly applied in all normal and damaged NPC model constructs.

Table 6.43 - Dimensional Tolerances

Type 304L Stainless Steel Sheet Gauge	Nominal Thickness (in.)	Permissible Variations* (in.)	Model Thickness Used (in.) [cm] (description)
7 ga	0.188	± 0.014	0.1740 [0 4420 cm] (ICCA ring)
10 ga.	0.135	± 0.012	0.1230 [0.3124 cm] (OCA skin)
16 ga.	0 0595	± 0 006	0.0535 [0 1359] (ICCA lid)
18 ga.	0 048	± 0 005	0.0430 [0.1092] (ICCA inner skin)
22 ga	0.029	± 0.004	0.0250 [0.0635] (ICCA silo)
24 ga	0 0235	± 0.003	0.0205 [0 0521] (ICCA outer skin)

* ASTM-A240/A240M- 95a, Table A1.2, *Standard Specification for Heat Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*, August 1995.

6.3.1.2 Inner Containment Canister Assembly (ICCA)

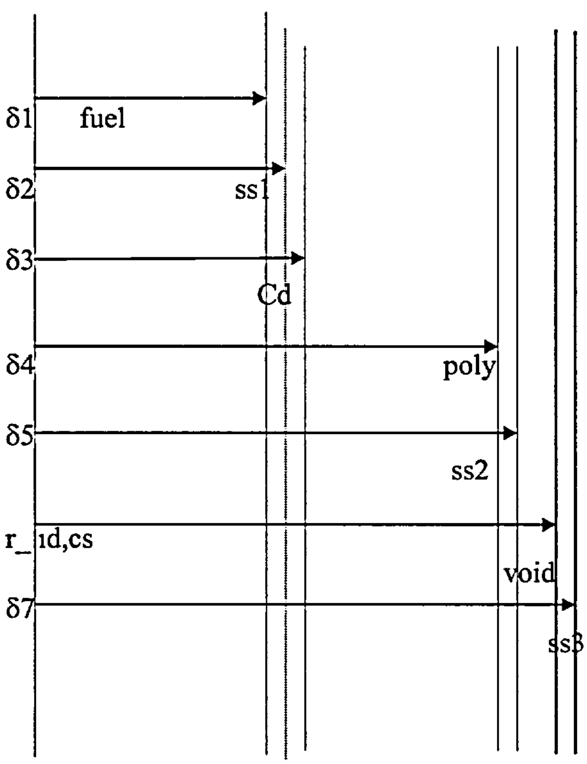
Figure 6.1 shows the material constituent radial dimensions from center of the ICCA ID (δ1) through outer radius of the contamination shield (δ7). Figure 6.2 depicts the axial version of the ICCA and contamination shield. The ICCA model construct consists of a stackup of 11 separate axial pieces. This is performed to explicitly include the 1/8" (0.3175 cm) gaps of the high denisty polyethylene wrap on each end, the maximum axial seam gap tolerance between the three separate 10-1/8" (25.7175 cm) nominal wide cadmium wraps, the axial foam distribution density changes, and the fact that the ICCA silo is installed only in the lower body assembly. The upper section of the ICCA also penetrates the lid assembly to accommodate the vertical ICCA height, lock ring and bolt closure.

The 8.515-inch (21.63 cm) ID of the 18-gauge ICCA includes the maximum manufacturing tolerance. Modeled sheet gauge dimensions incorporate the maximum manufacturing tolerance specified in ASTM–A240 specified in Table 6.3 above. Since iron, chrome, and nickel constituents of stainless steel exhibit thermal and resonance absorption, the use of minimum sheet thickness values is also conservative.

For cadmium, a 25% reduction is applied to the actual 20-mil (minimum) thickness, for a modeled thickness of 15-mils (0.0381 cm)[1] and section width of 10.025" (25.4635 cm). The as-built stackup of the axial cadmium wraps allow for a maximum seam gap of 0.1" (0.254 cm). This gap is conservatively modeled as 0.15" (0.381 cm).

The high density polyethylene (HDP) is 30.3-inch in height and uniformly surrounds the cadmium, with no gaps, and its thickness ensured to be a minimum 0.570" thickness (1.4478 cm) by continuous wrapping of 15-mil (nominal) sheets and a quality control weight confirmation. To account for the small density reduction in the layered polyethylene wrap, the HDP (0.94-0.98 g/cc density) sheet material is conservatively modeled as a uniform low density polyethylene (0.92 g/cc) over the 0.570" thick (1.4478 cm) wrap (min. hydrogen areal density = 0.199 g/cm^2). The minimum required thickness, height, and quality weight measurement confirm this effective poly thickness and density is achieved.

Figure 6.1 Inner Containment Canister Assembly – Radial Dimensions



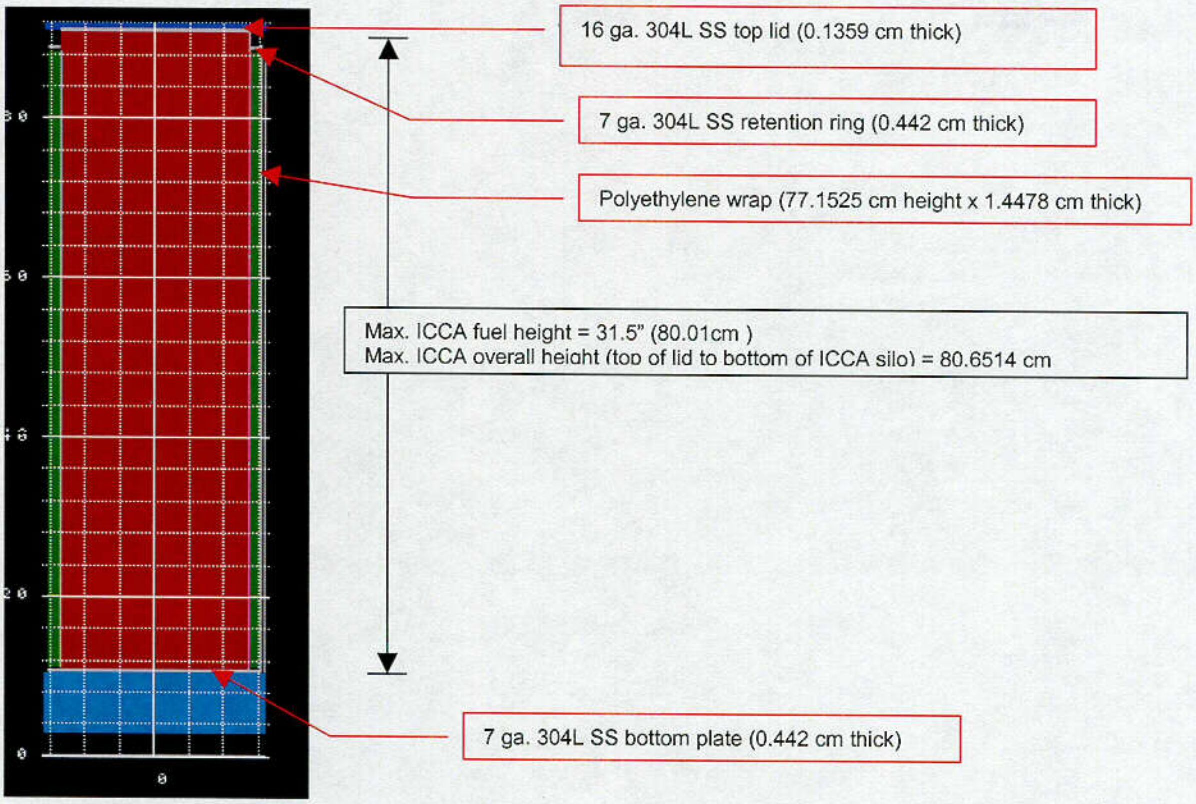
radial/material assignments:

δ1 = fuel region (e.g., UO_2+H_20)
δ1 = 10.8141 cm (4.2575")
δ2 = δ1 + δss1 δss1 = 0.1092 cm
δ3 = δ2 + δcadmium δcad = 0.0381 cm
δ4 = δ3 + δpoly δpoly = 1.4478 cm
δ5 = δ4 + δss2, δss2 = 0.0521 cm
r_id = (10 x 2.54) / 2 = 12.7000 cm
δ7 = r_id, cs + δss3 δss3 = 0.0635 cm
beyond δ7 is polyurethane foam....

~~1 Note. Limiting added absorber material credit to 75% without comprehensive tests is based on concerns for potential "streaming" of neutrons due to non-uniformities. The 75% value demonstrated by this work is conservative for several reasons: (1) cadmium is elemental and therefore homogeneous and is not distributed in granular fashion, and (2) the experimental work is based on the use of a monodirectional beam of neutrons, while in this package design, an isotropic neutron source exists, reducing intragranular transmission effects (if any).~~

[1] Note: Limiting added absorber material credit to 75% without comprehensive tests is based on concerns for potential "streaming" of neutrons due to non-uniformities. The 75% value demonstrated by this work is conservative for several reasons (1) cadmium is elemental and therefore homogeneous and is not distributed in granular fashion, and (2) the experimental work is based on the use of a monodirectional beam of neutrons, while in this package design, an isotropic neutron source exists, reducing intragranular transmission effects (if any)

Figure 6.2 ICCA Modeled Axial ~~dimensions~~Dimensions



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6.3.1.3 Body and Lid Assembly

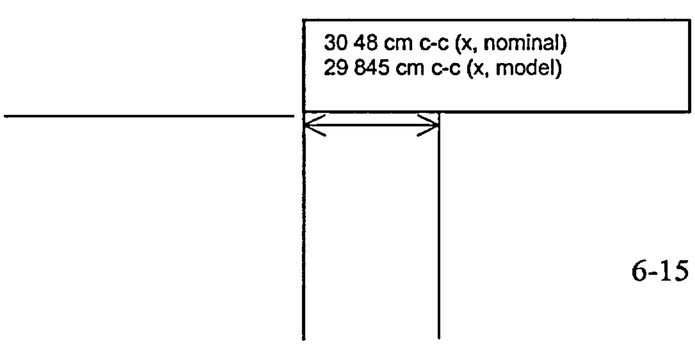
For the basic model construct, the unit outer dimensions are modeled as a 42.81x42.81 inch square box. The inner height is computed based on the stack-up dimensions of the OCA body 34.573" (87.8154 cm) and lid 5.998" (15.2349 cm) for a total modeled package height of 40.571" (103.0503 cm). These outside dimensions of the near cubic package are conservative for the following reasons:

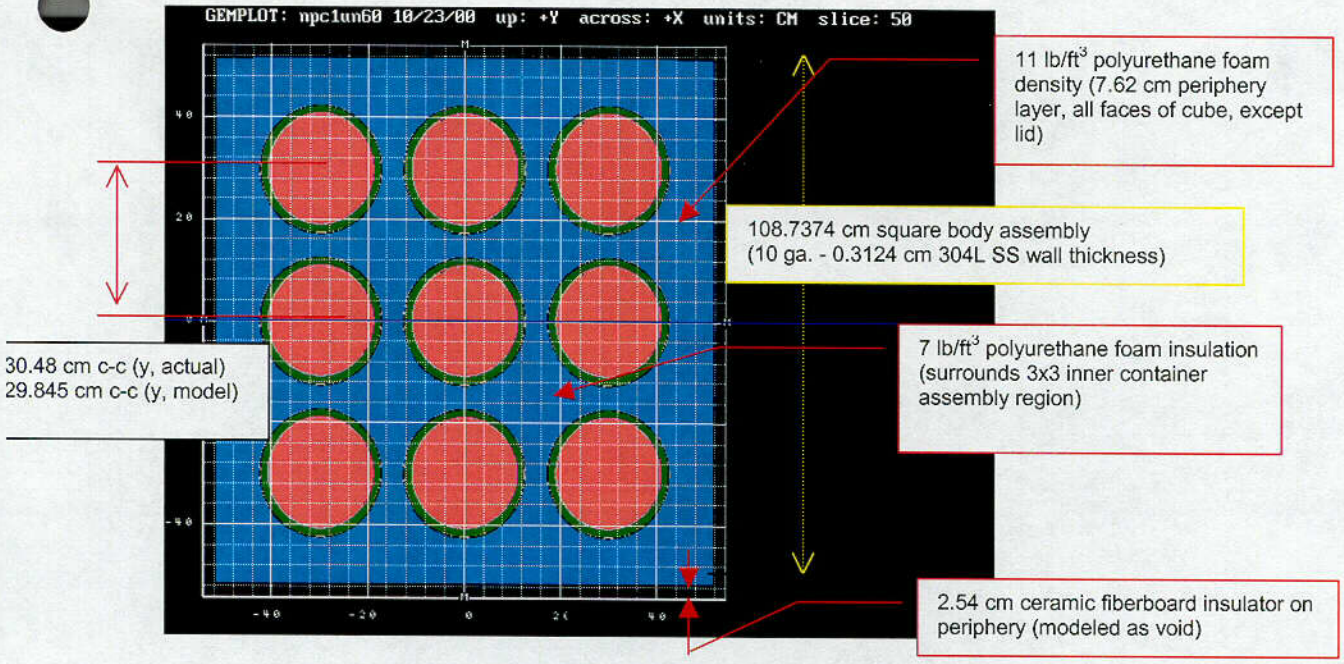
- the external corner support structure is ignored (x-y, x-z)
- the OCA locating buttons, and 16 ½-13UNC socket head cap screws are ignored (x-z)
- the lid flange overlap, OCA closure strip, and 24 7/16-14UNC hex head bolts are ignored (x-y)
- the heavy duty 6×3×3/16×8.4 rectangular fork-lift channel pocket structure is ignored (x-z)
- the affect of body/lid bowing due to HAC tests is ignored (x-y, x-z)

By ignoring the above effects, the NPC undamaged and damaged package array are modeled as close fitting and in contact, when in fact the aforementioned structure and OCA structure deformation and bowing would provide additional (x-y) and axial (x-z) spacing between individual package units.

The lighter 7-lb/ft^3 internal foam is modeled to encase the 3x3 Inner Containment Canister Assembly (ICCA) array. Important dimensions of the basic body + lid assembly, and foam density assignments are shown in the x-y and x-z cross-sectional slices of Figures 6.3a and 6.3b, respectively.

~~**Figure 6.3a Body Assembly (x,y) Dimensions and Foam Distribution**~~




GEMPLOT: npc1un60 10/23/00 up: +Y across: +X units: CM slice: 50
11 lb/ft³ polyurethane foam density (7.62 cm periphery layer, all faces of cube, except lid)
108.7374 cm square body assembly (10 ga. - 0.3124 cm 304L SS wall thickness)
30.48 cm c-c (y, actual)
29.845 cm c-c (y, model)
7 lb/ft³ polyurethane foam insulation (surrounds 3x3 inner container assembly region)
2.54 cm ceramic fiberboard insulator on periphery (modeled as void)

C03

Figure 6.3a Body Assembly (x,y) Dimensions and Foam Distribution

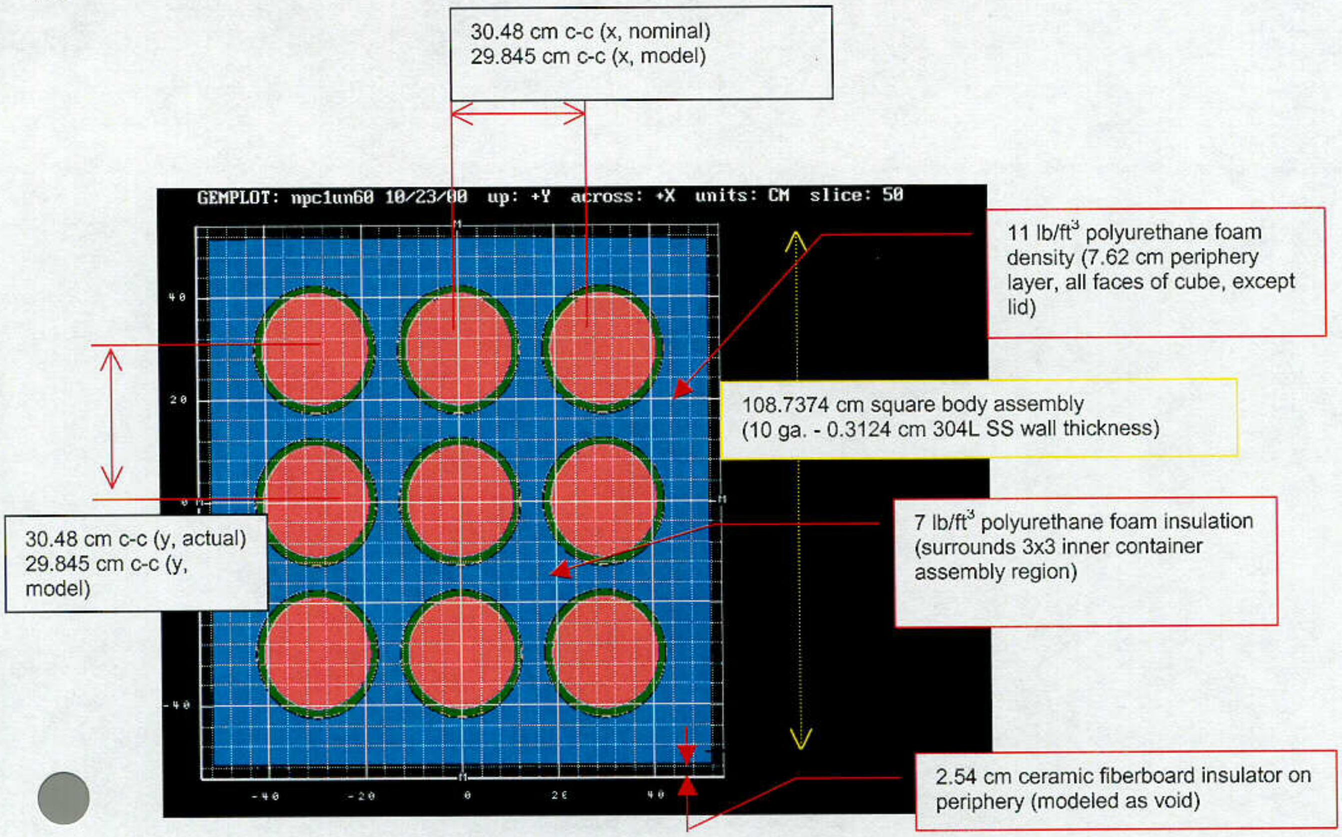
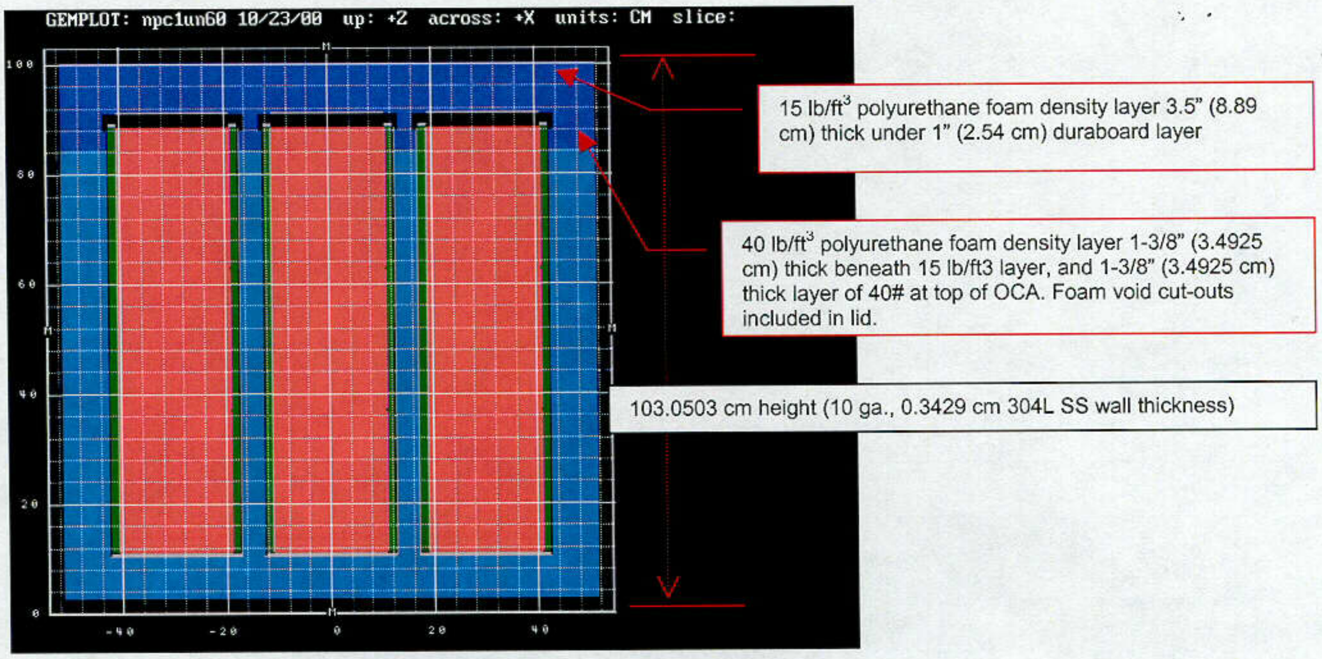


Figure 6.3b Body Assembly (x,z) Dimensions and Foam Distribution



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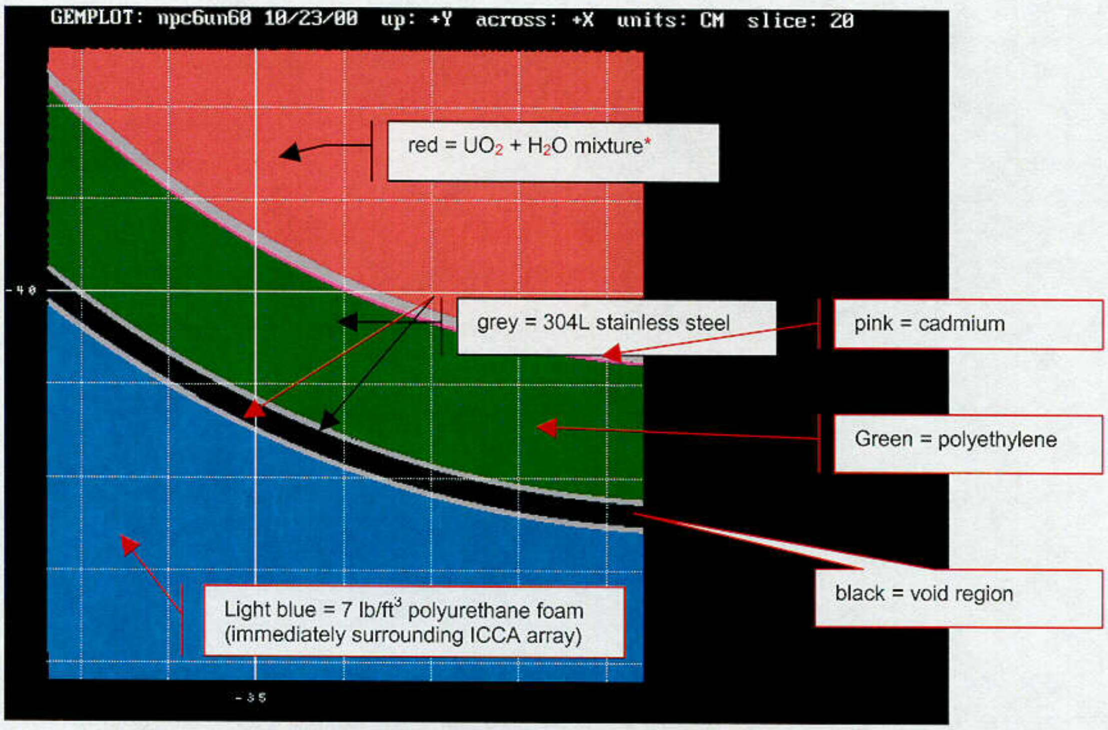
MATERIALS

6.3.1.4 Materials

Figure 6.4 shows blown up cross-section material assignment(s) of the ICCA within stainless steel silo. These mixture assignments are shown in color for illustration purposes, and used throughout this report (unless otherwise noted).

Figure 6.4 Inner Containment Canister Assembly (ICCA) within Silo - Mixture Assignments



* For a further description of the fuel regions with homogeneous mixtures and heterogeneous lattices see Section 6.4.3

The UO_2 mixture (fuel) material specifications used in the NPC criticality safety demonstrations are dependent upon the case ~~set~~ being modeled. The cases considered in the current analysis are (1) damaged single packages, (2) infinite arrays of undamaged packages and (3) 5X5X6 arrays of damaged packages. Contents include the applicable homogeneous and heterogeneous theoretical density $U(5.00)O_2$ and water mixtures, optimally moderated, and with the specified mass limits given in Table 6.1. Heterogeneous cases have been modeled as lattices of full density $U(5.00)O_2$ vertical fuel rods (with no cladding) in full density H_2O with the specified minimum diameters in column 2 of Table 6.1 and with lattice heights as determined by the lattice water to fuel (W/F) volume ratios, the Table 6.1 mass limits, and the assumed lattice boundary conditions (i.e. either overlap of the rods in the lattice with the ICCA wall, or no overlap).~~Currently the treatment of the fuel region is limited to the following three treatments:~~

~~1.Damaged single package – theoretical UO_2 and water mixture (through optimum moderation).~~
~~2.Undamaged package array – dry UO_2 powder with 5% H_2O (vary UO_2 compound density, mixture mass or compound mass fixed at 60 kgs).~~
~~3.Damaged package array – optimally moderated, mass limited UO_2 case for damaged package array geometry (vary UO_2 compound mass per ICCA).~~

C05

In the first damaged single package case set, the $UO_2 + H_2O$ mixture is modeled as a pure theoretical mixture of UO_2 (10.96 g/cc, maximum) and water. The weight fraction water is varied through optimum moderation for the fully reflected single-unit damaged package.

Table 6.54 provides the resulting mixture data summary derived from an internal utility code called UFACT. For the cases in the table except the first (which is applicable to heterogeneous pellets and rods), In this case a theoretical treatment of the fuel region is used, and the mixture height is not computed as the ICCA volume is modeled full (height fixed at 80.01 cm). Please also note that for theoretical UO_2, all voids are filled at approximately 11.5% water content – thus no density correction is required (e.g., DFACT = 1.0).

The columns in the table with the corresponding compound identification (COM), weight fraction water (WF-W), U-235 fractional enrichment (ENR), density correction factor (DFACT), mixture density (RHOMIX), compound density (RHOC), and uranium density (RHOU), uranium fraction in the compound (UFACT), ~~GEMER/GEKENO bias columns,~~ H/5 (H/U-235) and H/U atom ratios, and HEIGHT are defined ~~prescribed~~ as follows (and are equally valid for Tables ~~6.5 and~~ 6.6):

- **DFACT** = density correction factor = [MINIMUM (1.0, $RHOC_{max-credible}$)]/RHOC
- **RHOMIX** = mixture density = RHO_MIX=DFACT/[(1-WTFR_H_2O)/RHO_FUEL+WTFR_H_2O]
  where, RHO_FUEL = RHOC = RHO_UO_2 = compound density in mixture, and
  WTFR_H_2O = WF-~~F~~-W = weight fraction water in mixture
- **RHOC** = uranium compound density in mixture = (1 – WTFR_H_2O) * RHOMIX
- **$RHOC_{max-credible}$**= maximum credible density of uranium compound
- **RHOU** = uranium density in mixture = UFACT * RHOC = 0.88144 * RHOC
- **UFACT** = uranium fraction of compound = M_U / [M_U + (2*M_O)] = 0.88144 for 5 00% enriched UO_2
  where, M_i is the atomic mass of constituent i
- **H/5=H/U-235** = Atom ratio of hydrogen to U-235 = H_TO_U-235
  H_TO_U-235=W_TO_F*2*235.043928/(18.01534*RHO_FUEL*UFACT*ENR)
  where, W_TO_F=water-to-fuel ratio - WTFR_H2O*RHO_FUEL)/(1-WTFR_H2O)
  ENR=[N_U-235*235.043928]/(#+N_U-238*238.050788)
- **H/U** = Atom ratio of hydrogen to uranium = H_TO_U=WTFR_H_2O*ATM_U/[UFACT*.5*18.0153*(1-WTFR_H_2O)]
- **HEIGHT** = height of mixture in cylinder of specified radius and mixture mass [e g, HEIGHT= MASS/(PI*RAD**2*RHO_MIX)] or compound mass (e.g, HEIGHT= MASS/(PI*RAD**2*RHOC)]

Table 6.54 Fuel Material Specifications – Damaged Single Package (theoretical UO_2 + H_2O mixture)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	H/5	H/U x10	HEIGHT cm
UO2	.000	.05000	1.0000	10.9600	10.9600	9.6606	.88144	104	0	n/a
UO2	.150	.05000	1.0000	4.3945	3.7354	3.2925	.88144	104	53	n/a
UO2	.200	.05000	1.0000	3.6631	2.9305	2.5830	.88144	148	75	n/a
UO2	.250	.05000	1.0000	3.1404	2.3553	2.0761	.88144	197	100	n/a
UO2	.300	.05000	1.0000	2.7482	1.9238	1.6957	.88144	254	128	n/a
UO2	.350	.05000	1.0000	2.4432	1.5881	1.3998	.88144	319	161	n/a
UO2	.400	.05000	1.0000	2.1990	1.3194	1.1630	.88144	395	200	n/a
UO2	.450	.05000	1.0000	1.9993	1.0996	0.9692	.88144	484	245	n/a

~~In the undamaged array case set, two models are used. In the first case, the dry UO_2 + H_2O mixture is modeled representative of real-world conditions in which the UO_2 powder is known to contain a small amount (<5%) of moisture – thus 60 kgs mixture is modeled as 57 kgs UO_2 and 3 kgs of H_2O. The second model explicitly models 60 kgs UO_2 compound plus 5% H_2O mass addition.~~

~~In either case, the maximum moisture content is fixed at 5% (50,000 ppm H_2O). NOTE: The UO_2 powder derived from conversion processes limit free moisture to 0.6% (6000 ppm H_2O) water content. Post-additive addition for powder pack limits the total equivalent water moderation to a maximum of 1.5%.~~

~~Table 6.5 provides the density factor (to account for voids), mixture, compound, and uranium densities for both 60 kg mixture and 60 kg UO_2 treatments. The table shows the calculated fuel height of 60 kgs UO_2 +5% H_2O mixture within the 8.515" (21.63 cm) ID ICCA as a function of UO_2 compound density (0.0 – 4.5 g/cc). In both fuel treatments, 4.5 g/cc is used as a conservative upper limit for unpressed UO_2 powder. As expected, the fuel height of the 60 kg fuel mass treatment is slightly greater than the mixture treatment.~~

~~Table 6.5 Fuel Material Specifications – Undamaged Array (60 kgs UO_2 + 5%H_2O mixture, variable UO_2 compound density)~~

COM	WF	W FR.ENR	DFACT	RHOMIX	RHOC	RHOU	UFACT	H/5	H/U	HEIGHT
				gm/cc	gm/cc	gm/cc			x10	cm
RADIUS = 10.8141 CM				MIXTURE MASS = 60.000 KG						
UO2	.050	.05000	0.2877	2.1053	2.0000	1.7629	.88144	31	16	77.574
UO2	.050	.05000	0.3597	2.6316	2.5000	2.2036	.88144	31	16	62.059
UO2	.050	.05000	0.4316	3.1579	3.0000	2.6443	.88144	31	16	51.716
UO2	.050	.05000	0.5036	3.6842	3.5000	3.0850	.88144	31	16	44.328
UO2	.050	.05000	0.5755	4.2105	4.0000	3.5258	.88144	31	16	38.787
UO2	.050	.05000	0.6474	4.7368	4.5000	3.9665	.88144	31	16	34.477
RADIUS = 10.8141 CM				FUEL MASS = 60.000 KG						
UO2	.050	.05000	0.2877	2.1053	2.0000	1.7629	.88144	31	16	81.657
UO2	.050	.05000	0.3597	2.6316	2.5000	2.2036	.88144	31	16	65.325
UO2	.050	.05000	0.4316	3.1579	3.0000	2.6443	.88144	31	16	54.438
UO2	.050	.05000	0.5036	3.6842	3.5000	3.0850	.88144	31	16	46.661
UO2	.050	.05000	0.5755	4.2105	4.0000	3.5258	.88144	31	16	40.828
UO2	.050	.05000	0.6474	4.7368	4.5000	3.9665	.88144	31	16	36.292

In the undamaged and damaged package array cases, ~~the~~ homogeneous $UO_2 + H_2O$ mixtures are ~~is~~ modeled as ~~a~~ mass and geometry limited systems. The UO_2 compound density is treated as theoretical (10.96 g/cc). The weight fraction water is computed such that the UO_2 + water mixture completely fills a volume up to the maximum of the Inner Containment Canister Assembly (ICCA). For the NPC package ~~under accident (damaged array) conditions~~, ~~this~~these mass and geometry limited conditions are ~~is~~ demonstrated to be the most reactive ~~condition~~.

Table 6.6 provides the corresponding mixture, compound, and uranium densities for this treatment of the fuel region. The weight fraction of~~s~~ water for each UO_2 fuel mass limit is computed to just fill the ICCA volume. The UO_2 compound mass in the $UO_2 + H_2O$ mixture is varied to determine the maximum acceptable payload of the package under hypothetical accident conditions. In the case of 60 kgs UO_2, additional cases at lower weight fraction water were run to confirm the most reactive condition. Higher weight fraction water conditions resulting in lower UO_2 mass are included in this table.

Table 6.6 Fuel Material Specifications – Undamaged and Damage Package Arrays ($UO_2 + H_2O$, optimal moderation, variable UO_2 mass)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	H/5	H/U x10	HEIGHT cm
undamaged package array cases:										
RADIUS = 10.8141 CM				FUEL MASS = 60.000 KG						
UO2	.150	.05000	1.0000	4.3945	3.7354	3.2925	.88144	104	53	43.721
UO2	.200	.05000	1.0000	3.6631	2.9305	2.5830	.88144	148	75	55.729
UO2	.250	.05000	1.0000	3.1404	2.3553	2.0761	.88144	197	100	69.339
UO2	.260	.05000	1.0000	3.0533	2.2594	1.9915	.88144	208	105	72.281
UO2	.270	.05000	1.0000	2.9708	2.1687	1.9116	.88144	219	111	75.304
UO2	.285	.05000	1.0000	2.8549	2.0411	1.7992	.88144	236	119	80.010(*)
damaged package array cases:										
RADIUS = 10.8141 CM				FUEL MASS = 40.000 KG						
UO2	.392	.05000	1.0000	2.2366	1.3608	1.1995	.88144	381	193	80.010
RADIUS = 10.8141 CM				FUEL MASS = 45.000 KG						
UO2	.360	.05000	1.0000	2.3912	1.5309	1.3494	.88144	333	168	80.010
RADIUS = 10.8141 CM				FUEL MASS = 50.000 KG						
UO2	.332	.05000	1.0000	2.5457	1.7009	1.4993	.88144	294	149	80.010
RADIUS = 10.8141 CM				FUEL MASS = 55.000 KG						
UO2	.307	.05000	1.0000	2.7004	1.8711	1.6492	.88144	262	133	80.010
RADIUS = 10.8141 CM				FUEL MASS = 60.000 KG						
UO2	.285	.05000	1.0000	2.8549	2.0411	1.7992	.88144	236	119	80.010 (*)
RADIUS = 10.8141 CM				FUEL MASS = 65.000 KG						
UO2	.265	.05000	1.0000	3.0095	2.2113	1.9491	.88144	214	108	80.010
~~**** extra cases ******~~										
~~RADIUS = 10.8141 CM~~				~~FUEL MASS = 60.000 KG~~						
~~UO2~~	~~.150~~	~~.05000~~	~~1.0000~~	~~4.3945~~	~~3.7354~~	~~3.2925~~	~~.88144~~	~~104~~	~~53~~	~~43.721~~
~~RADIUS = 10.8141 CM~~				~~FUEL MASS = 60.000 KG~~						
~~UO2~~	~~.200~~	~~.05000~~	~~1.0000~~	~~3.6631~~	~~2.9305~~	~~2.5830~~	~~.88144~~	~~148~~	~~75~~	~~55.729~~
~~RADIUS = 10.8141 CM~~				~~FUEL MASS = 60.000 KG~~						
~~UO2~~	~~.250~~	~~.05000~~	~~1.0000~~	~~3.1404~~	~~2.3553~~	~~2.0761~~	~~.88144~~	~~197~~	~~100~~	~~69.339~~

(*) ICCA full condition, wf-w = 0.28504

6.3.1.5 Models - Actual Package Differences

The criticality safety analysis model of the loaded NPC differs from the actual package in 1) the allowance for water intrusion into the ICCA containment, 2) center-to-center canister spacing, 3) insulating foam distribution, 4) the modeled stainless steel structure, 5) the modeled cadmium thickness, and 6) the modeled poly density.

1) For homogeneous UO_2, t~~T~~he ICCA fuel region is modeled with variable UO_2 compound mass and variable H_2O content as described in the fuel material specifications above. In the limiting (damaged package array) models, the UO_2 compound mass is varied from 40-65 kgs UO_2 per ICCA. The water content is also varied to optimally moderate the ICCA for the mass limited damaged package array. This optimal internal moderation treatment is a known conservatism.

2) For heterogeneous materials, the ICCA fuel region is modeled as a lattice of variably spaced UO_2 fuel in the form of right circular cylindrical elements (rods) ~~rods h~~having a fixed total (UO_2) mass with full density H_2O in the ICCA region outside of the cylindrical elements~~rods~~. The fixed mass, either 55 kgs, 53 kgs or 46 kgs, is based on the minimum diameter of the pellets or particles size ~~fuel rod~~ specified in Table 6.1. Similar to the homogeneous case, the degree of moderation in the individual fuel rod lattices is varied through optimum, which is done as a function of the lattice water--to--fuel volume ratios by varying the spacing between the rods. As in the homogeneous case, the modeling of accumulations of pellets or other random

oriented high-density clumps or particles as uniform lattices of UO_2 cylindrical elements (rods) is a known conservatism.

23) The center-to-center spacing of the ICCAs is also different from the as-built package. The nominal spacing (X,Yx,y) between the individual ICCA units in the 3 × 3 array of ICCAs is 12-inches (30.48 cm). All models use a nominal conservative ICCA center-to-center spacing of 11.75" (29.845 cm). For the limiting damaged package array models, sensitivity of the canister center-to-center spacing is quantified, by modeling the ICCAs from 11.75" (29.845 cm) to 11.25" (28.575 cm) spacing for a specified foam burn condition. Effects on system reactivity are assessed.

43) The insulating foam distribution within the package also differs from the actual package contents. In all cases, the minimum chemical composition in the foam is assumed. In addition, the density of the polyurethane foam is reduced by the maximum 10% manufacturing tolerance. Thus, the 7, 11, 15, and 40 lb/ft^3 foam densities are actually modeled as 6.3, 9.9, 13.5, and 36 lb/ft^3, respectively. This 10% foam density reduction results in a corresponding reduction in the hydrogen atom density. This is a known conservatism, as sensitivity studies demonstrate the more hydrogen between the ICCAs, the lower the overall system reactivity (due to hydrogen moderating and capture characteristics).

The foam distribution also differs in the mass of foam included. In the damaged single package and arrays, the effects of non-uniform foam burn are based on measured CTU-1 and CTU-2 test results. The limiting condition damaged array reactivity is based on the maximum burn observed in either certification test unit. The maximum burn treatment results in zero residual foam thickness on all 6-faces of the cube, as measured radially and axially from the ICCA centerline (refer to Sections 2.10.1.7.1.6 and 2.10.1.7.2.6).

The maximum burn condition, coupled with the minimum hydrogen content, uniform application of maximum foam density tolerance, and 2% reduction in poly density effectively results in conservative treatment of damaged package physical condition post HAC testing. The maximum foam burn results in minimum interstitial hydrogen between packages – which is shown to increase package reactivity.

The 1-inch periphery ceramic fiberboard is modeled as a void in all models. This material consists of approximately 44% Al_2O_3, and the balance as SiO_2 –both compounds are neutronically insignificant.

4) The amount of stainless steel structure used in the model also differs from the actual package. Since the maximum sheet gauge tolerance reductions were applied (refer to Table 6.43), and significant external structure ignored, the mass of stainless steel in the model is significantly lower than actual. Reducing amount of stainless steel in the model is conservative because there is less material to compete with the uranium for neutron absorption reactions (refer also to Section 6.6.2.7, Sensitivity Study – Damaged Package Array Structure).

5) The nuclear poison cadmium thickness is modeled at 0.015" (0.0381 cm) thick, which represents only 75% of the minimum absorber thickness of 0.020" (0.0508 cm).

6) In all damaged package array models, a 2% reduction in polyethylene density (0.92 * 0.98) is uniformly applied. This reduction in density effectively covers the observed 0.6% weight loss post HAC testing and 0.25% mass allowance for minimum specified poly height of 30.3" verses the modeled 30.375" height (refer also Section 6.6.2.8, Sensitivity Study – Damaged Package Array Poly Gap).

6.3.2 CONTENTS MODEL

A general discussion of the NPCThe package contents in the configured for normal (undamaged) transport condition and hypothetical (damaged) accident conditions case are describedis given in Section 6.3.1.4, *Materials*, Tables 6.54 through and Table 6.6. The following sections presents a discussion of the fissile material contents under these conditions of transport, along with In the damaged single package and damaged package array calculations, an assessment of the foam burn distribution effects in the damaged single and array packages.are assessed.

6.3.3 DAMAGED SINGLE-PACKAGE MODELS

A model of the single package damaged condition considers unlimited moderator intrusion into the ICCA containing UO_2 product. The single package was subjected to hypothetical accident condition tests per IAEA and 10 CFR §71.73 as specified in Section 2.7, *Hypothetical Accident Conditions*. The UO_2 contents of the single package were analyzed in accord with the Section 6.3.1.4, *Materials*, Table 6.54. The ICCAs within the package were modeled in the homogeneous case containing theoretical UO_2 and water mixtures, and in the heterogeneous case as water moderated lattices of UO_2 cylindrical elements (rods)rods, with the corresponding and the weight fraction H_2O and water to fuel ratios varied through optimal moderation. In all damaged single package models, the unit is surrounded by a ≥full 30.48-cm thick water reflector.

6.3.3.1 Damaged Single Package with Theoretical Homogeneous UO_2 +and H_2O Mixtures

For homogeneous UO_2 and H_2O fuel mixtures, fFour sets of damaged single package model constructs are considered. Two damage single package models are run using the limiting CTU-1 and CTU-2 observed foam burn conditions in which the average residual foam is modeled on each face of the cube. The third case conservatively applies a maximum observed burn on each face of the cube. The fourth damaged single package model applies a tight water reflector to the package for the limiting condition derived from the first three case sets.

The first three cases replace observed foam burn region with void. The fourth and final case replaces the burned foam region with water to assess the impacts of a fully flooded damaged package (applied to limiting burn condition). Figures 6.5a – 6.5d show vertical slices of the CTU-1, CTU-2, maximum observed burn, and the flooded damaged single package models.

Figure 6.5a – Fully reflected damaged single package, theoretical UO_2 + H_2O mixture, CTU-1 observed burn

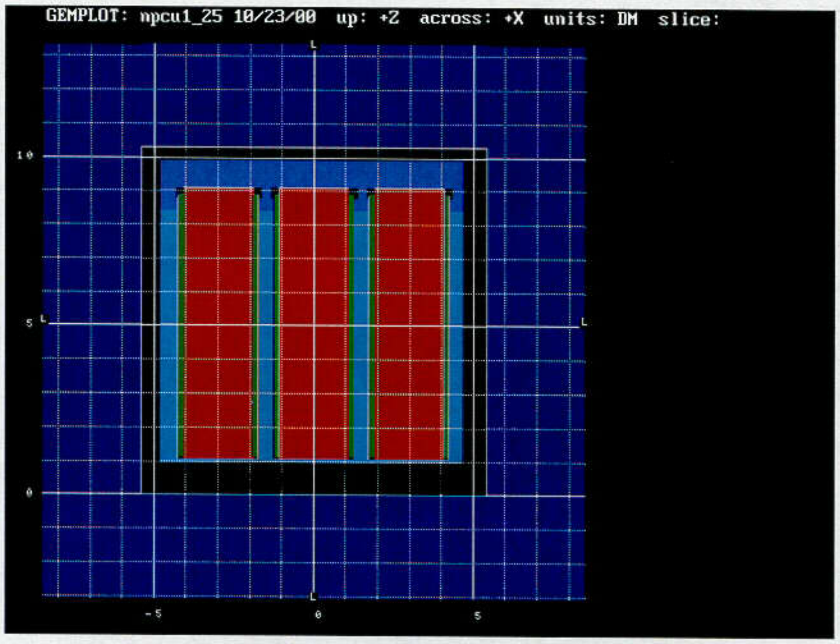
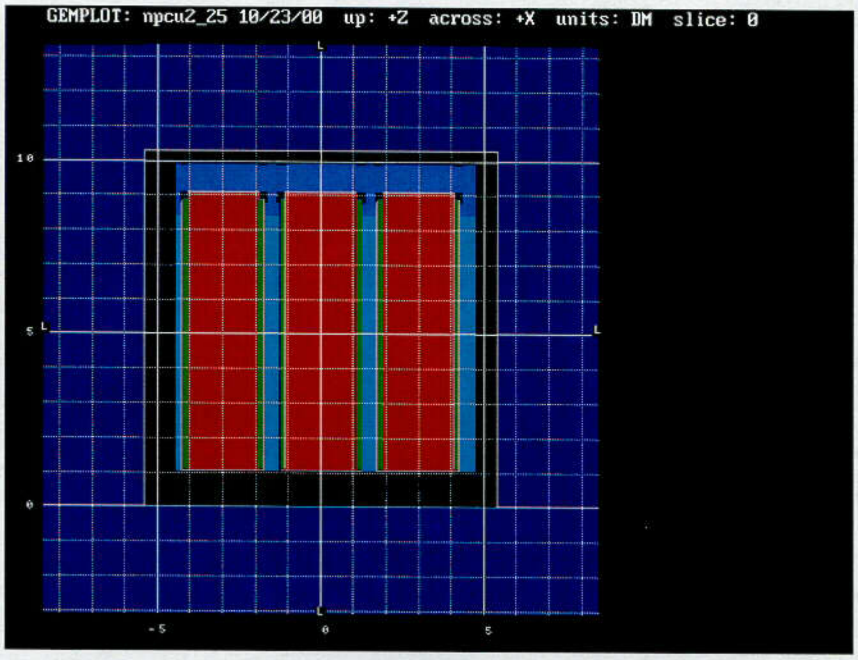


Figure 6.5b – Fully reflected damaged single package, theoretical UO_2 + H_2O mixture, CTU-2 observed burn



C06

Figure 6.5c – Fully reflected damaged single package, theoretical $UO_2 + H_2O$ mixture, maximum burn

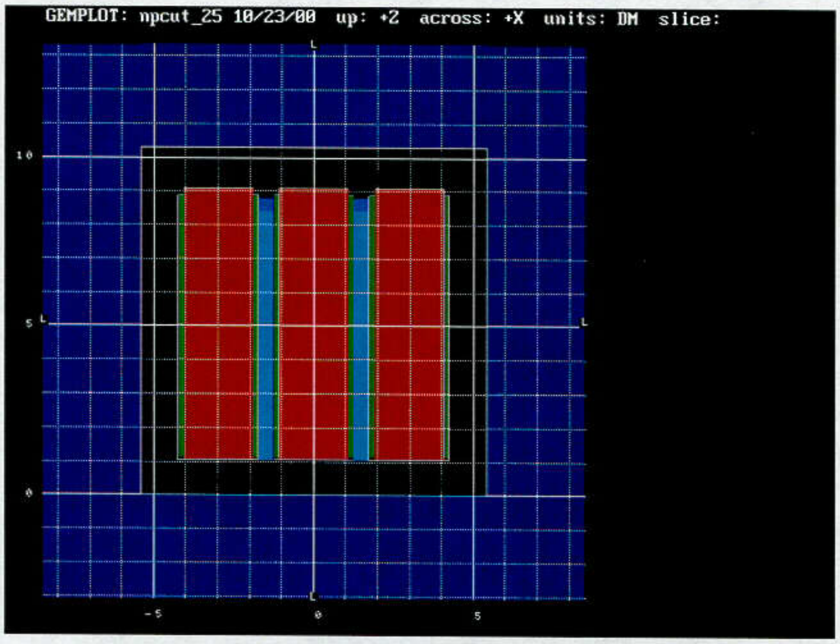
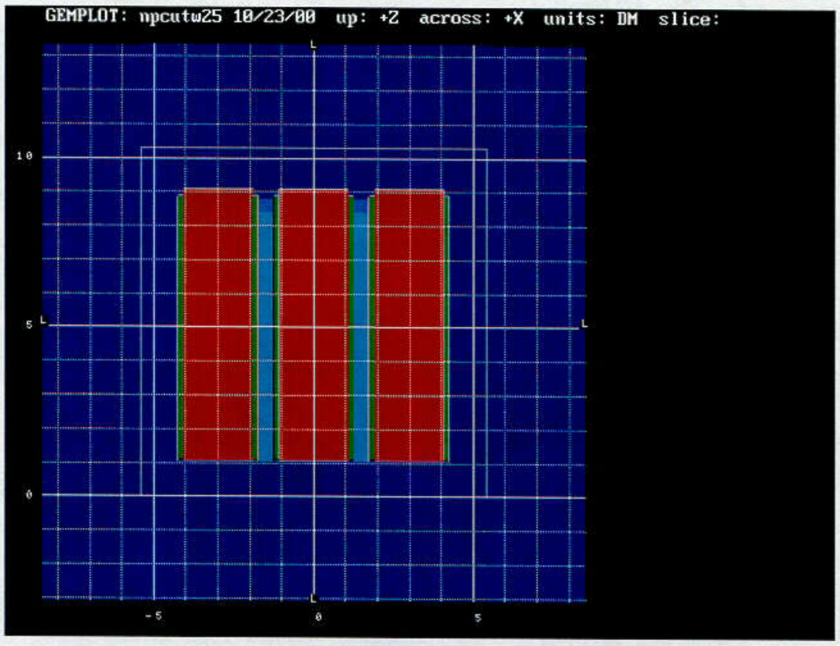


Figure 6.5d – Fully reflected damaged single package, theoretical $UO_2 + H_2O$ mixture, maximum burn, flooded package



C07

6.3.3.2 Damaged Single Package with Heterogeneous UO_2 ~~Rods~~ in H_2O

The package models for damaged single packages with heterogeneous UO_2 cylindrical elements (rods) in H_2O are the same as the worse case configuration as determined in the analyses for homogeneous mixtures, but with the fuel region less than or equal to the maximum ICCA inner height based upon the specified cylindrical rod ~~fuel rod~~ lattice and UO_2 mass limit. This model is the one shown in Figure 6.5c, the "Fully reflected damaged single package … maximum burn" construct, except for the potentially smaller fuel element lattice height. For less than maximum height lattices, the regions in the ICCAs above the lattice are modeled as voids.

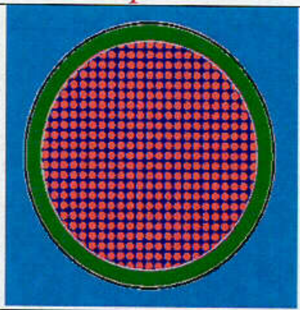
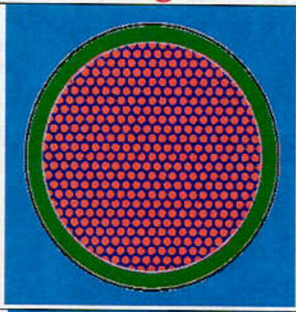
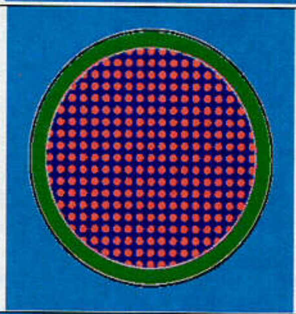
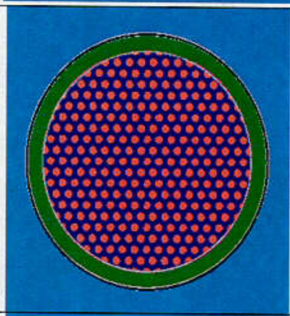
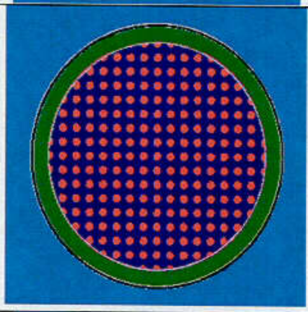
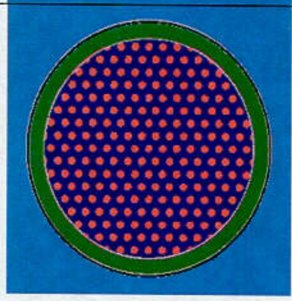
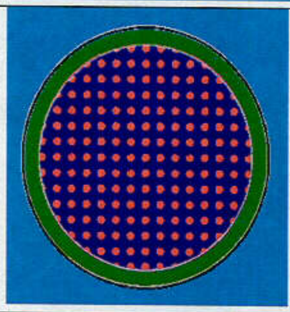
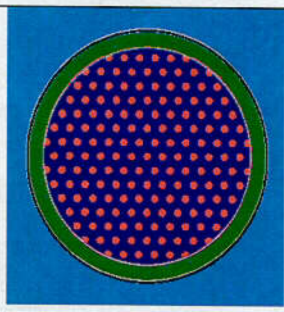
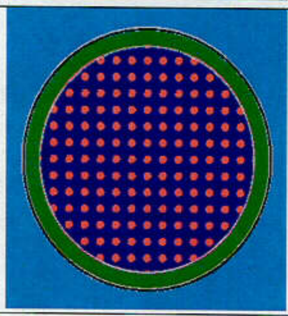
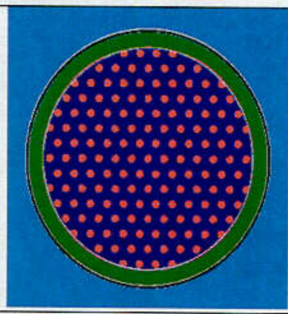
In the evaluation of the NPC package with heterogeneous UO_2 fuel, three different types of models constructs have been used to represent the heterogeneous material contained in the ~~have been used for the~~ ICCA fuel regions. Each type of model is then evaluated using ~~has been used with~~ both square and triangular lattice treatmentss, covering ~~and for~~ 26 different W/F ratios (from 0.58 to 8.00) and 4 different pellet ~~p~~outer diameters (ODs)~~ellet/rod types~~.

The first type of model consists of lattices of right circular cylinder elements (rods) ~~fuel rods~~ in which the rods ~~rods~~ are permitted to overlap the ICCA boundary, with the parts of the rods internal to the ICCA kept in the model. Figure 6.6a shows XY depictions of the ICCA fuel regions for "17X17" cyclindrical ~~fuel rod l~~lattices as the W/F ratios of the lattices are increased. Figure 6.6b shows the XZ layout (at Y = 0.0) of the same fuel regions with the decrease in the UO_2 mass in the ICCA noted when the maximum container height is reached. In this exact treatment with overlap, a total of 4 pellet ODs are considered. These include the ~~Besides the "~~"17x17", ~~17X17" rod lattices, the model overlap cases have also considered~~ "10X10", "9X9" and "8X8" pellet sizes, ~~e rod types, e~~ach of which has progressively larger pellet diameters ~~than the "17X17" type.~~. ~~(~~The minimum diameter for the 17X17 PWR pellets~~rods~~ is 0.300 inches; that for the BWR 10X10, 9X9 and 8X8 is 0.342 inches, 0.373 inches and 0.408 inches, respectively~~)~~. In this analysis, ~~each~~ pellet ~~of rod types with larger~~ diameters which are larger than the 17x17 lattices are ~~s is~~ shown to be progressively less reactive ~~than the "17X17" case~~.

The second type of model is similar to the first type except that right circular cylinder elements (rods) ~~fuel rods~~ are not permitted to overlap the ICCA boundary and are deleted from the lattice if any part intersects with the ICCA wall. A comparison of the Overlap and Without Overlap models is given in Figure 6.6c. Except for the absence of the overlapping rods (which for the same UO_2 mass and W/F ratio results in a slightly higher lattice height), the Without Overlap models are entirely similar to the Overlap ones and the variation with W/F is the same as illustrated in Figures 6.6a and 6.6b.

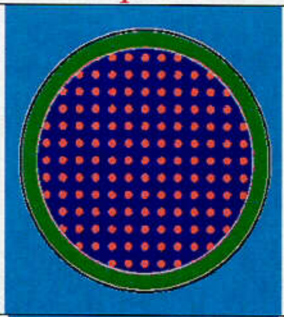
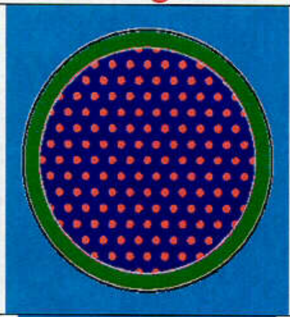
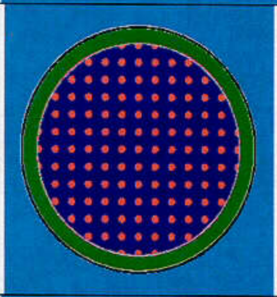
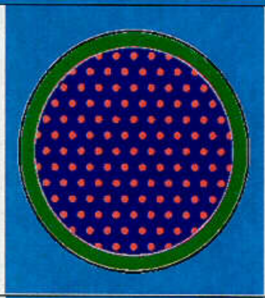
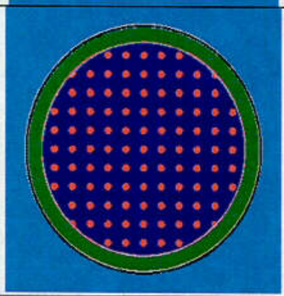
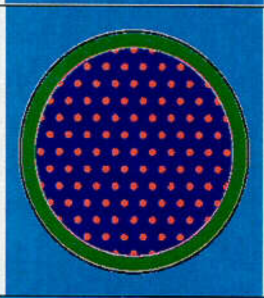
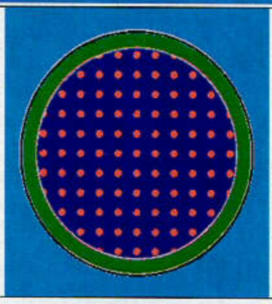
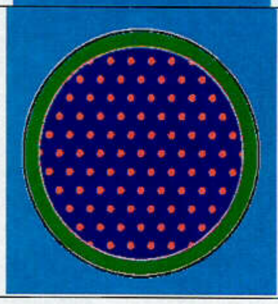
The third type of model is one in which the right circular cylinder elements (rod) lattices are modeled in the ICCA using the Virtual Fill Option (VFO - see Section 6.4.3). Using this option, each individual neutron that is tracked in the ICCA fuel region is presented with the virtual equivalent of a rod lattice with overlap (as in the first type of model discussed above), but the rod lattice has its central point randomly displaced from the one seen by all other neutrons tracked in the region. Because of this random effect, the ~~normal~~ geometry plotting routines ~~in two and three dimensions~~ do not show the actual lattice geometry but ~~give a weighted average of all possible displaced lattices in the region.~~ assure that the neutron enters the Big Region at the center of a fuel region. Examples of this are shown in Figure 6.6d, in which the XY plots actually shows a type of ~~interference~~ pattern resulting from the way the plot routine (GEMPLOT) steps through the XY plane. The same interference pattern is not seen in the XZ plots because the Fill Region plotting is treated differently when parallel to right circular the fuel lattices are modeled as one unit high in cylinders in the z-direction.the region and hence there is only a single cell in the Z direction.

Figure 6.6a – NPC Container Square and Triangular 17X17 Fuel Rod Lattice XY Models With Overlap

W/F	Square		Triangular
1.00			
2.00			
3.00			
4.00			
4.50			

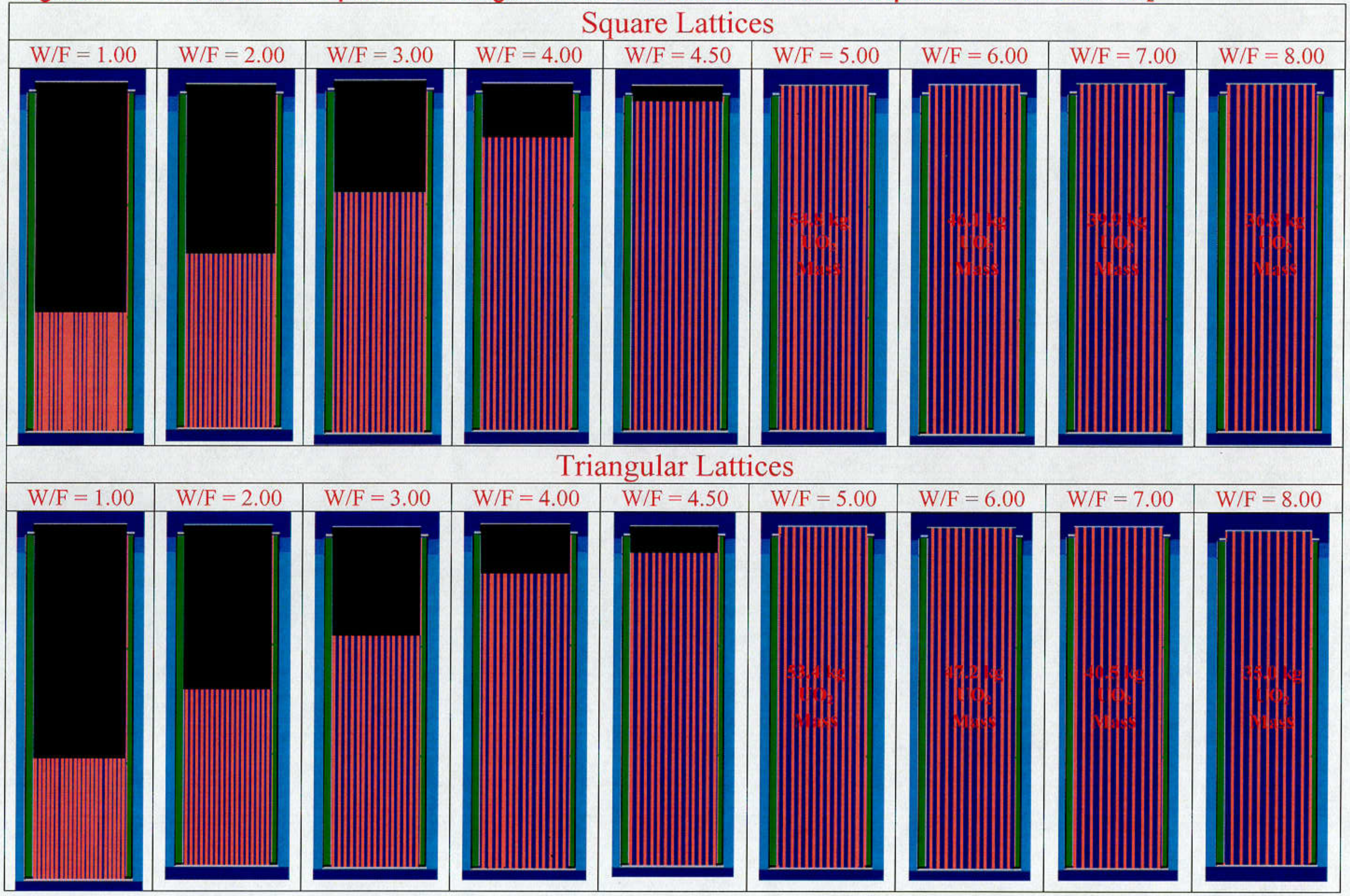
C08

Figure 6.6a – NPC Container Square and Triangular 17X17 Fuel Rod Lattice XY Models With Overlap - Continued

W/F	Square		Triangular
5.00			
6.00			
7.00			
8.00			

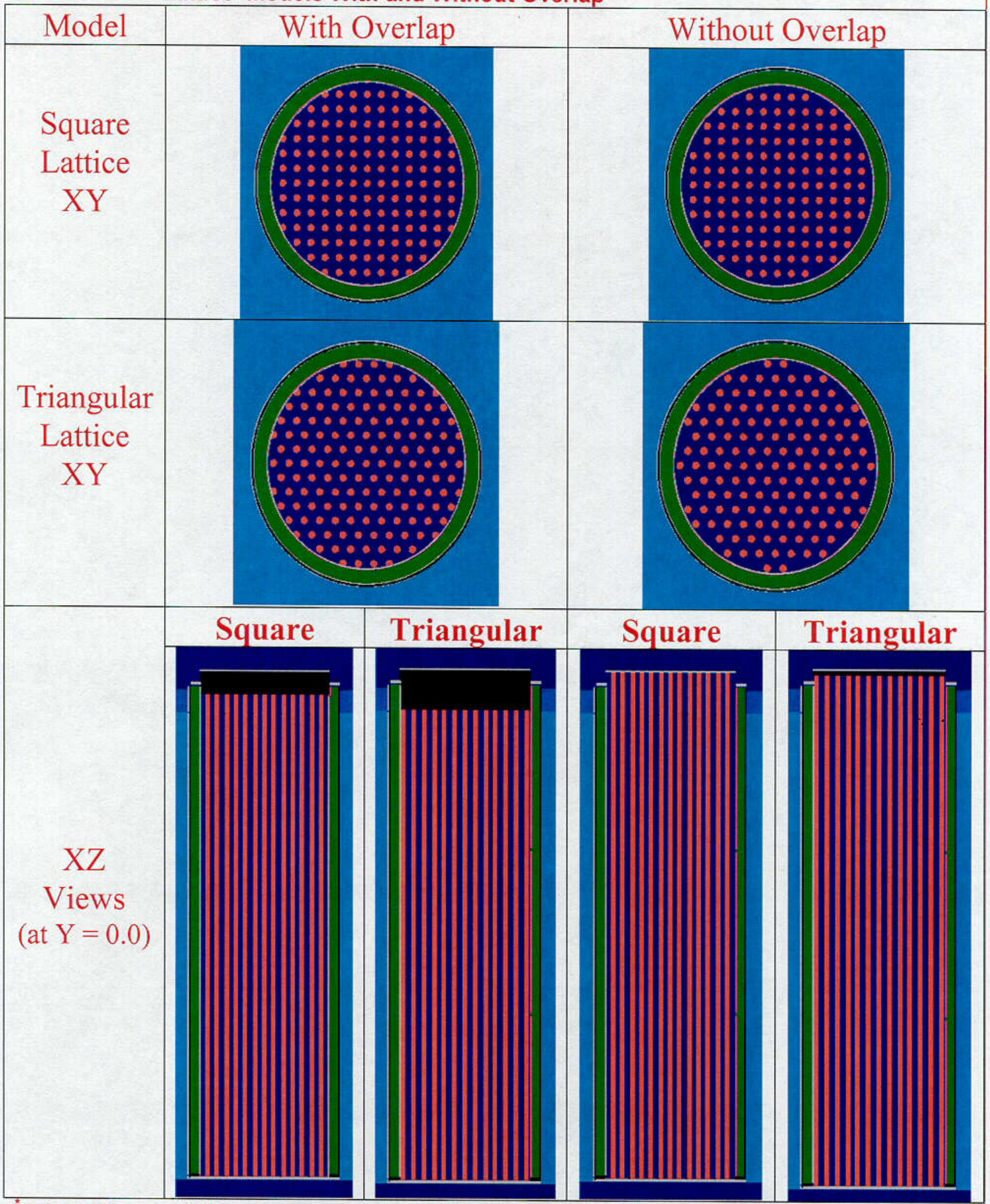
C09

Figure 6.6b – NPC Container Square and Triangular 17X17 Fuel Rod Lattice XZ Overlap Models With 55 KG UO_2



C10

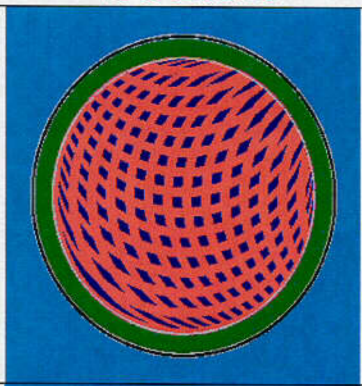
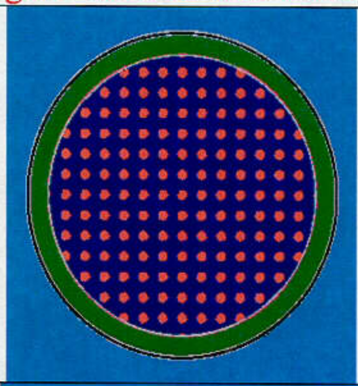
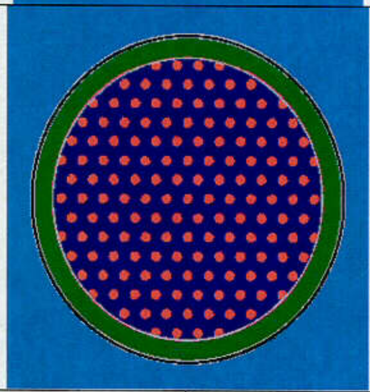
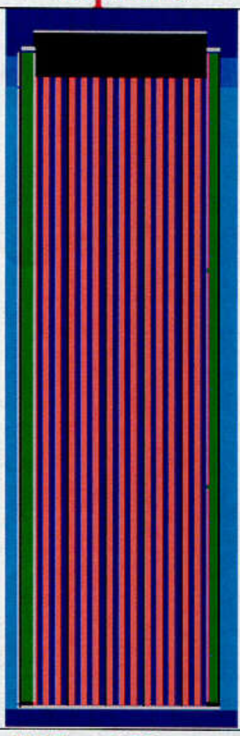
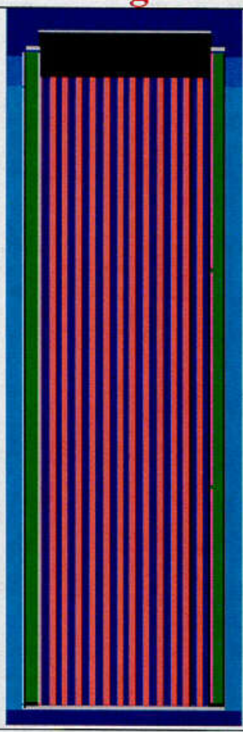
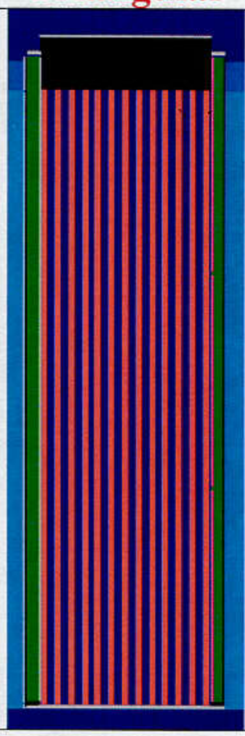
Figure 6.6c – Comparison of NPC Container Square and Triangular 17X17 Fuel Rod Lattice* Models With and Without Overlap



*55kgs UO_2 at a W/F = 4.50

C11

Figure 6.6d –NPC Container Square and Triangular 17X17 Fuel Rod Lattice* Models With the Virtual Fill Option

Model	VFO Lattice		Regular Lattice with Overlap	
Square Lattice XY				
Triangular Lattice XY				
	Square	Triangular	Square	Triangular
XZ Views (at Y = 0.0)				

*55kgs UO_2 at a W/F = 4.50

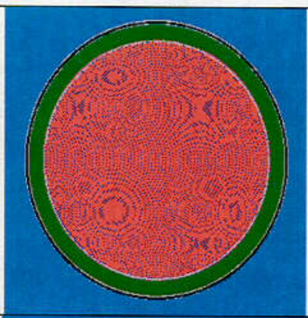
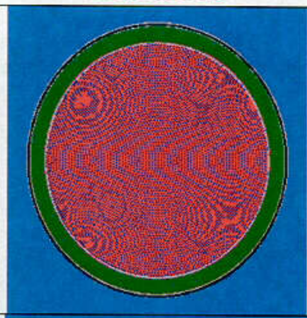
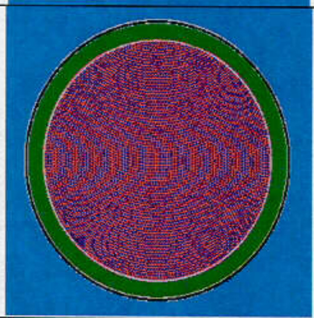
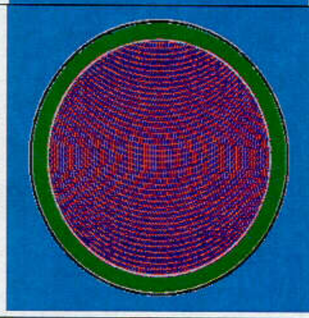
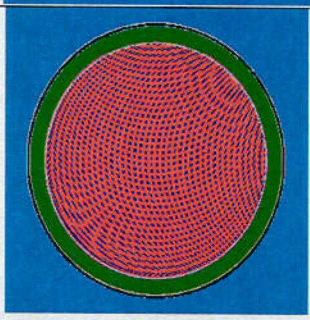
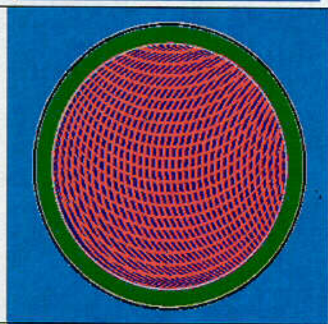
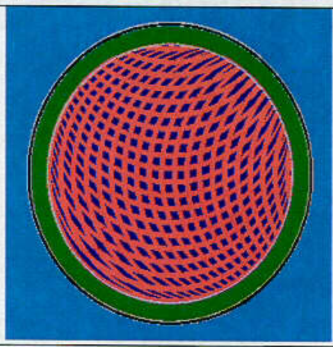
C12

The Virtual Fill Option (VFO) has been used in this analysis because it permits modeling of fuel lattices with a very large number of cylindrical elementsfuel (rods). Since only one geometry unit is actually used stored in the fuel region for the lattice (and the lattice is created by mirror reflection boundary conditions on the unit) the size of the array that can be modeled is essentially unlimited.

This analytic capability is in particular required when analyzing the most reactive fuel lattice without regard to particle size outer diameterrod diameter (OD) or W/F ratio since the optimum outer rod diameter for 5.00% enriched UO_2 rods is in the range of 0.05 inches to 0.15 inches. Explicit m-Modeling of fixed arrays of these sizes of cylindrical elements fuel rods in the ICCAs would require hundreds of thousands of elements rods in the lattice. In the present analysis, the range of cylindrical rod diameters analyzed for the optimum case is derived from four separate particle size diameters through optimum heterogeneity (e.g., 0.20", 0.10", 0.05", and 0.025" diameters).has been taken from 0.025 inches to 0.200 inches (4 cases). Examples 2D plots of the GEMPLOTs for these cases are shown in Figure 6.6e. ((tThe XZ models are those for the square lattices; the models for the triangular lattices are entirely similar.).

This analysis demonstrates that optimum heterogeneity occurs at (or very near) particle size diameter of 0.100". An actual 'random' array of particles of unrestricted diameter is no more reactive than the 'ordered' arrays of heterogeneous cylindrical elements analyzed herein under optimum diameter and spacing (W/F ratio) conditions. This is the basis of applying these results to heterogeneous fuel mixtures of unrestricted particles sizes.

Figure 6.6e – NPC Container Models for the VFO Analysis of Optimum Rod Diameters*

Rod Diameter (Inches)	XY Square Lattices	XZ Model (Y = 0)	XY Triangular Lattices
0.025			
0.050			
0.100			
0.200			

*46 kgs UO_2 at W/F = 5.2

C13

6.3.4 UNDAMAGED AND DAMAGED PACKAGE ARRAYS

Two basic package array model constructs are included in this evaluation - undamaged and damaged.

6.3.4.1 Undamaged Package Arrays with Homogeneous UO_2 and H_2O

In the undamaged array case for homogeneous UO_2 and H_2O, 60 kgs theoretical UO_2 compound plus variable water moderation is modeled through optimal moderation conditions in which the ICCA becomes effectively "full". No restriction on water moderation in the undamaged model is required, provided that each ICCA is limited to not greater than 60 kgs total material weight.

Table 6.7 provides the calculated fuel height for 60 kgs UO_2 compound and water mixtures within the ICCA inner canister as a function of weight fraction H_2O added (up through optimum, full ICCA conditions). In these undamaged models, homogeneous theoretical density UO_2 compound density is used (rho_uo2 = 10.96 g/cc). The weight fraction H_2O corresponding to a full ICCA occurs at wt.fr._h2o = 0.28504.

Table 6.7 Fuel Material Specifications – Undamaged Package Array (60 kgs UO_2 + H_2O theoretical mixture, unrestricted H2O)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	G-BIAS	K-BIAS	H/5	H/U x10	HEIGHT cm
	RADIUS = 10.814 CM				FUEL MASS = 60.000 KG							
UO2	.150	.05000	1.0000	4.3945	3.7354	3.2925	.88144	0.0002	0.0125	104	53	43.721
UO2	.200	.05000	1.0000	3.6631	2.9305	2.5830	.88144	-.0020	0.0098	148	75	55.729
UO2	.250	.05000	1.0000	3.1404	2.3553	2.0761	.88144	-.0044	0.0070	197	100	69.339
UO2	.260	.05000	1.0000	3.0533	2.2594	1.9915	.88144	-.0049	0.0065	208	105	72.281
UO2	.270	.05000	1.0000	2.9708	2.1687	1.9116	.88144	-.0054	0.0059	219	111	75.304
UO2	.280	.05000	1.0000	2.8927	2.0828	1.8358	.88144	-.0059	0.0053	230	117	78.411
UO2	.285~~04~~	.05000	1.0000	2.8549	2.0411	1.7992	.88144	-.0062	0.0050	236	119	80.01 (*)

(*) ICCA full condition, wf-w = 0.28504
~~(*) full ICCA condition~~

The ~~first package array~~ homogeneous UO_2 and H_2O models for undamaged arrays consist of ~~an~~ infinite arrays of ~~undamaged,~~ normal condition~~,~~ NPC packages. Per the applicable IAEA and 10 CFR §71.59~~,~~ standards ~~for arrays of fissile material packages~~, ~~stipulate~~ the undamaged package arrays are ~~to be~~ evaluated with the individual units close-packed ~~void between the packages, and fully reflected.~~

m~~M~~odeling of the 5N = infinite arrays is accomplished by ~~The undamaged array is modeled~~ using a single unit with mirror boundary conditions on all 6 ~~. This effectively models an infinite array of close-packed undamaged NPC packages (5N = ∞) containing dry powder at 50,000 ppm H_2O. This infinite (zero neutron leakage) treatment of the undamaged package array is~~ sides, which is -conservative relative to the model for a fully reflected finite system.

The undamaged package array considers limited moderator content within the Inner Containment Canister Assembly (ICCA) containing UO_2 product as described in Section 6.3.1.4, *Materials*, Table 6.5. Each ICCA is modeled containing 60 kgs of UO_2 + 5% H_2O mixture, using variable UO_2 compound density.

Figures 6.76a-6.76f depicts the models used to assess normal conditions of transport, and show illustrate the resulting increasing fuel height – up to the 80.01 cm maximum -decrease as the UO_2 compound density is increased to the as the weight fraction of WF of H_2O (WF-W) is increased. maximum credible value. In Tthese sample plots, apply to the 60 kg UO_2 + 5% H_2O mixture is usedmass limit.

The package was subjected to the tests specified in IAEA and 10 CFR §71.71, normal conditions of transport, and, as reported in Chapters 2, *Structural Evaluation* and Chapter 3, *Thermal*, the geometric form of the package was not substantially altered. No water leakage into the ICCAs occurred, and no substantial reduction in the effectiveness of the packaging was observed. The damage incurred will not affect the technical evaluation, and the package contents under normal conditions of transport will be less reactive than the contents under hypothetical accident (damaged) conditions.

Figure 6.7a – Infinite undamaged array: 60 kgs UO_2 + 15% H2O, theoretical mixture

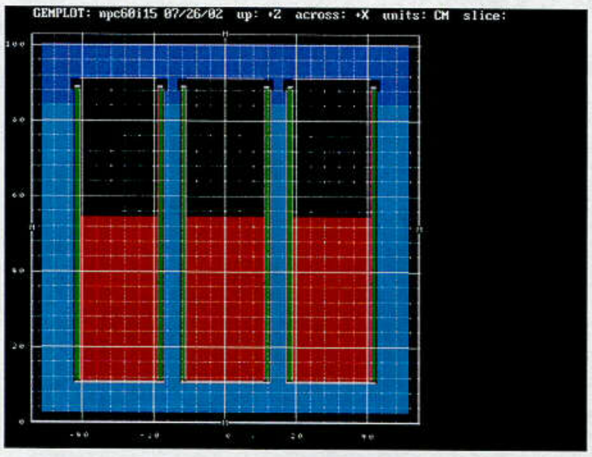
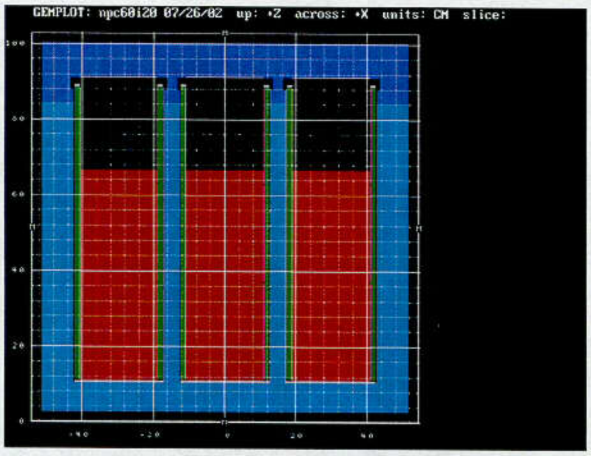


Figure 6.7b – Infinite undamaged array: 60 kgs UO_2 + 20% H_2O, theoretical mixture



C14

Figure 6.7c – Infinite undamaged array: 60 kgs UO_2 + 25% H_2O, theoretical mixture

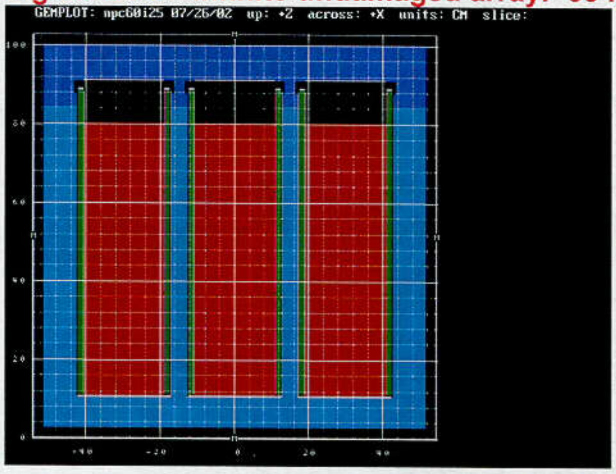


Figure 6.7d – Infinite undamaged array: 60 kgs UO_2 + 26% H_2O, theoretical mixture

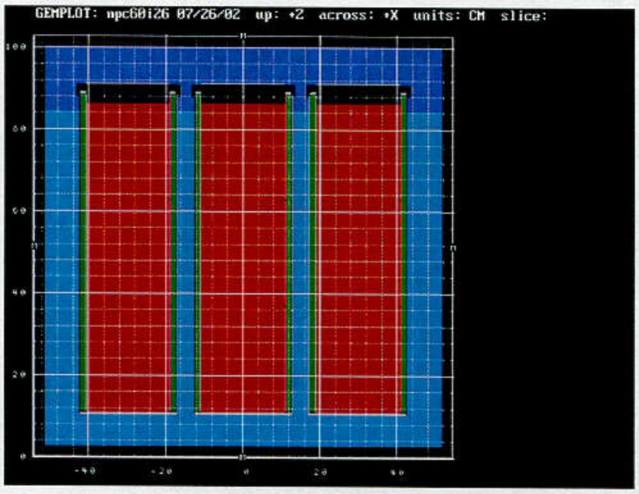
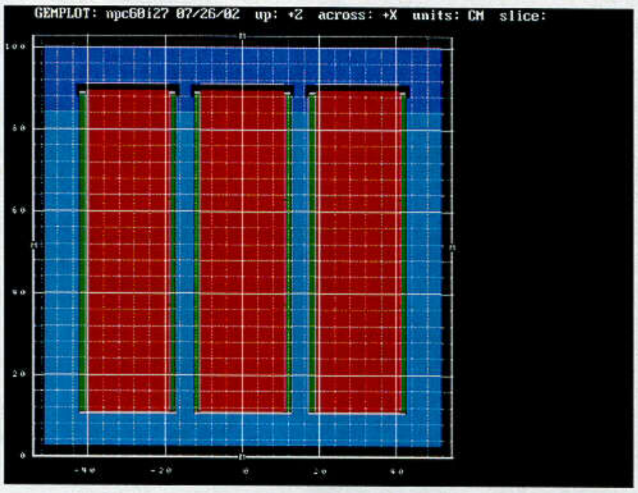
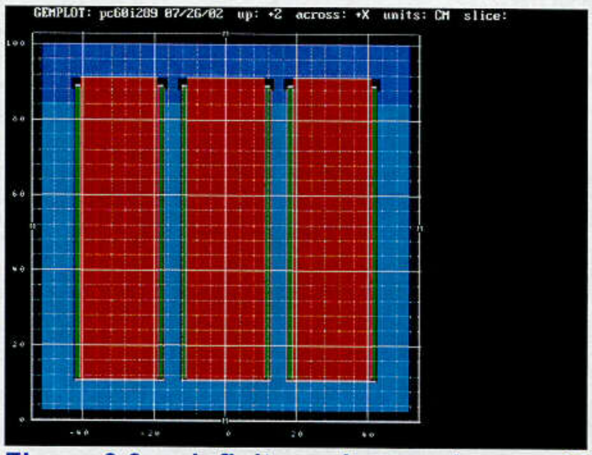


Figure 6.7e – Infinite undamaged array: 60 kgs UO_2 + 27% H_2O, theoretical mixture

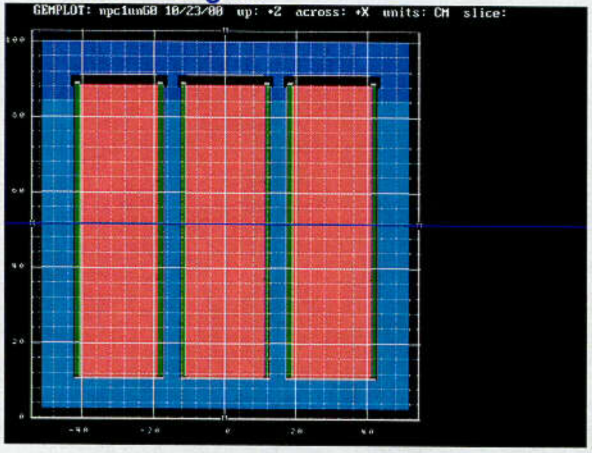


C15

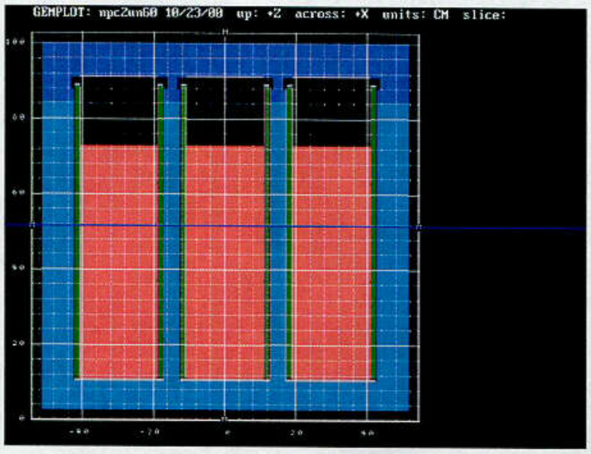
Figure 6.7f – Infinite undamaged array: 60 kgs UO_2 + 28.504% H_2O, theoretical mixture (ICCA full)



~~**Figure 6.6a – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 2.0 g/cc**~~

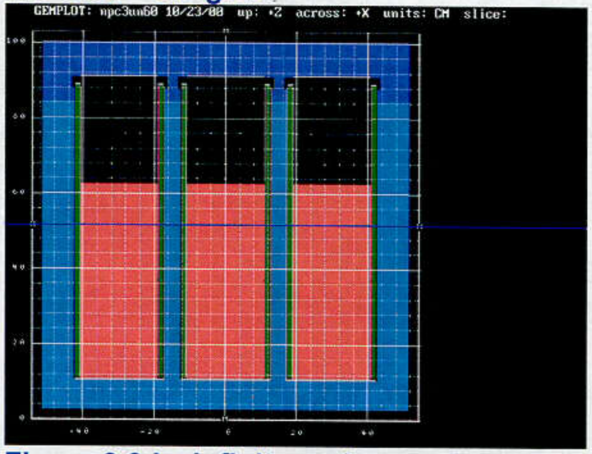


~~**Figure 6.6b – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 2.5 g/cc**~~

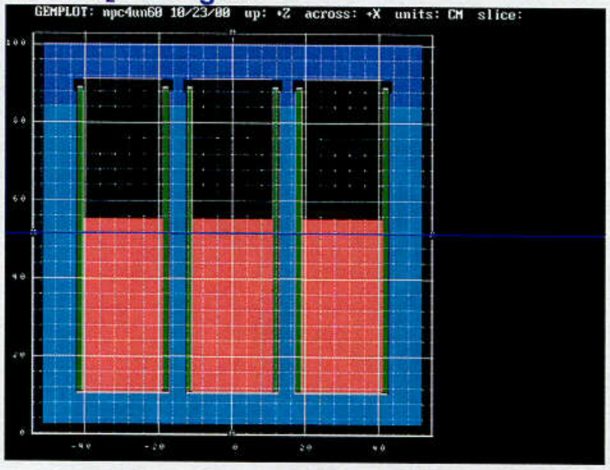


C16

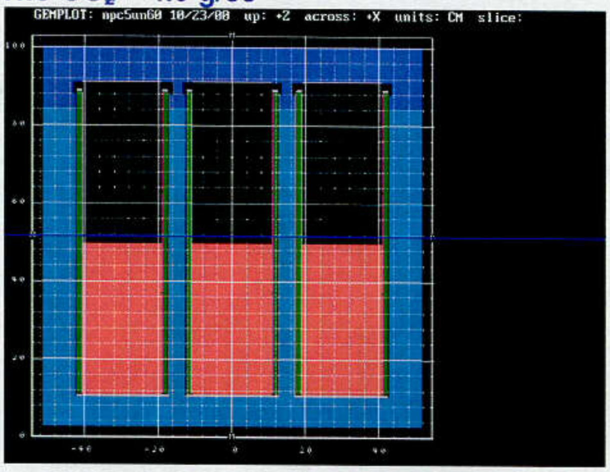
~~Figure 6.6c – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 3.0 g/cc~~



~~Figure 6.6d – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 3.5 g/cc~~

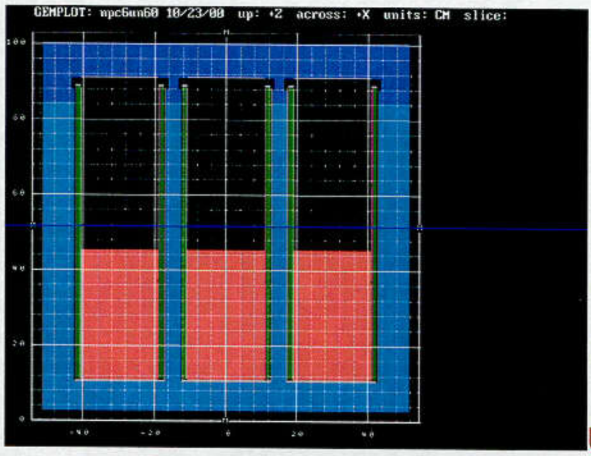


~~Figure 6.6e – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 4.0 g/cc~~



C17

Figure 6.6f – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 4.5 g/cc (max. credible density)



6.3.4.2 Undamaged Package Arrays with Heterogeneous UO_2 Rods in H_2O

The container model for undamaged arrays with heterogeneous UO_2 right circular cylinder elements rods in H_2O is the same as that shown in Figures 6.7a through 6.7f, but with the fuel lattices as described in Section 6.3.3.2. As in the homogeneous case, the undamaged arrays were modeled as infinite by mirror reflecting the single package at its six (6) 6 boundaries.

6.3.5 DAMAGED PACKAGE ARRAYS

6.3.4.2 6.3.5.1 Damaged Package Arrays with Homogeneous UO_2 and H_2O

The NPC package was subjected to the tests specified in IAEA and 10 CFR §71.73, Hypothetical Accident Condition (HAC) testing and the geometric form of the package was not substantially altered. The four individual Certification Test Units (CTUs) were fabricated that underwent testing summarized in detail in Section 2.7, *Hypothetical Accident Conditions*.

Certification Test Units CTU-1 and CTU-2 were subjected to required IAEA and 10 CFR §71.73(c)(4) thermal excursion with an average flame temperature of 1,475 °F (800 °C) for a period of at least 30 minutes. In both tests, the fuel was ignited and the test item was subjected to a minimum of 30 minutes of a fully engulfing hydrocarbon pool fire.

A modified CTU-1 unit with reinforced corners was retest of the CTU-3 HAC test sequence (CG-over lid-corner orientation). A 10-guage (0.135-inch) doubler plate was added to reinforce the corners. CTU-1 was subjected to a Jet-A pool fire test. The Jet-A fuel was placed in the tank at a level sufficient to initiate the burn. Additional fuel was pumped into the tank during the testing as necessary to maintain the burn for 30-minutes. During the CTU-1 Jet-A burn test, the overall average flame temperature was 1,809 deg. F (in excess of the required 1,475 deg. F). The maximum surface temperature recorded was recorded as 2,319 deg. F.

C18

The CTU-1 residual foam thickness measurements are reported in Appendix 2.10.1.7.1.6. The –x (left), +x (right), -y (rear), and +y (front) average cube face residual foam thickness values were determined to be 1.01, 1.71, 2.19, and 0.89-inches, respectively. The –z (bottom) and +z (top lid) average thickness' were -0.23, and 3.09-inches, respectively. The cube face averages were modeled to assess observed CTU-1 non-uniform foam burn effects on package reactivity.

For CTU-2, a diesel fuel pool fire test was used. During the CTU-2 diesel burn test, the overall average flame temperature was 1,972 °F (in excess of the required 1,475 °F). The maximum surface temperature recorded was recorded as 2,308 °F.

The CTU-2 residual foam thickness measurements are reported in Appendix 2.10.1.7.2.6. The –x (left), +x (right), -y (rear), and +y (front) average cube face residual foam thickness values were determined to be 0.26, 1.41, 0.23, and 0.58-inches, respectively (refer to Appendix 2.10.1.7.2.6). The –z (bottom) and +z (top lid) average thickness' were 0.0, and 3.0-inches, respectively. The cube face averages were modeled to assess observed CTU-2 non-uniform foam burn effects on package reactivity.

For the final damaged package array model, the maximum observed foam burn is uniformly applied on all six faces of the cube. This results in zero residual foam on all six faces of the cube as measured from the ICCA radial and axial centerline. The total face burn model construct conservatively bounds the observed package performance under HAC testing. This is underscored by the fact that the minimum hydrogen content in both the poly and foam regions is used, and the maximum 10% density tolerance is applied in all foam regions.

In all damaged package array models, a 2% reduction in polyethylene density (0.92 * 0.98) is uniformly applied. This reduction in density effectively covers the observed 0.6% weight loss and 0.25% mass allowance for minimum specified poly height of 30.3" verses the modeled 30.375" height.

The minor x-y and x-z movement of the 3 × 3 ICCA array contained within the OCA are compensated by the physical deformation of the OCA body itself, coupled with the conservatism's described in Section 6.3.1.5, Models- Actual Package Differences.

The observed damage incurred to the packaging and its contents did not affect this technical evaluation - as the packaging and its contents post HAC testing is determined to be within the bounding assumptions and analyzed conditions of this evaluation.

The damaged package array models consist of finite, near cubic 5x5x6 close packed arrays (2N = 150) to minimize neutron leakage. Additional close packed arrays using a 6x5x5 (2N = 150) and 9x9x2 (2N =162) are assessed to confirm the aspect ratio of the basic 5x5x6 array is most reactive.

In all cases, the close packed array is surrounded by 12" (30.48-cm) full-density water reflector. As required by IAEA and 10 CFR §71.59, the damaged packages are evaluated as if each package was subjected to the tests specified in 10 CFR §71.73, hypothetical accident conditions, with optimum interspersed moderation, and full water reflection.

The damaged package Inner Containment Canister Assembly (ICCA) contents are modeled per Section 6.3.1.4, *Materials*, Table 6.6.

The UO_2 compound mass per canister, internal moderation, observed foam burn conditions (CTU-1, CTU-2), and maximum foam burn conditions are modeled to determine an acceptable package Transport Index (TI) based on criticality control.

In addition, supplemental NPC damaged package array models are constructed based on the limiting acceptable payload and foam burn conditions derived above to study certain reactivity effects. These sensitivity studies include:

Effect of the package array shape (aspect ratio) on system reactivity. A 6 × 5 × 5 array (2N = 150) and a 9 × 9 ×x 2 array (2N = 162) are both assessed using the limiting burn condition and acceptable payload.

Effect of internal moderator content and payload contained in the UO_2 + H_2O mixture region contained within the ICCA.

Effect of 100% foam burn and subsequent replacement by optimal interspersed water moderation. In this set, the water density is varied from void through 12.5% of full density water to determine the hydrogen content necessary to demonstrate safety of the package, and determine if the damaged package is over or under-moderated.

Effect of ICCA center-to-center movement on reactivity for a specified damaged condition. For these cases, the nominal 11.75" (29.8450 cm) center-to-center ICCA spacing is uniformly reduced by 1/8" (0.3175 cm) increments to 11.25" (28.575 cm) to quantify the effect (if any) on ICCA spacing within the damaged package.

Effect of including external Type 304L stainless steel structure used for fork truck lifting of the package. This structure is quantified and effectively "smeared" onto the bottom layer of the OCA body.

Effect of polyethylene gap as determined from the physical measurements of the ICCA's post HAC testing is assessed to confirm the modeled poly height and density assumptions. The modeled poly height of is reduced by 75 mils to minimum specified height of 30.3". The maximum gap formation at top/bottom is also modeled and compared with the modeled limiting damaged package array calculation.

The following 2D images are provide to clarify the damaged package array model constructs and associated sensitivity studies:

- Figure 6.8~~7~~a and 6.8~~7~~b depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array to determine acceptable UO_2 equivalent payload under postulated damaged conditions of transport, using the observed CTU-1 and CTU-2 non-uniform foam burn conditions, respectively.

- Figure 6.87c depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array to determine acceptable UO_2 equivalent payload under postulated damaged conditions of transport, applying the maximum burn condition.

- Figures 6.87d and 6.86e depict horizontal/vertical slices of the damaged 6 × 5 × 5 and 9 × 9 × 2 package array size respectively, to confirm the close packed 5 × 5 × 6 aspect ratio is the most reactive array configuration.

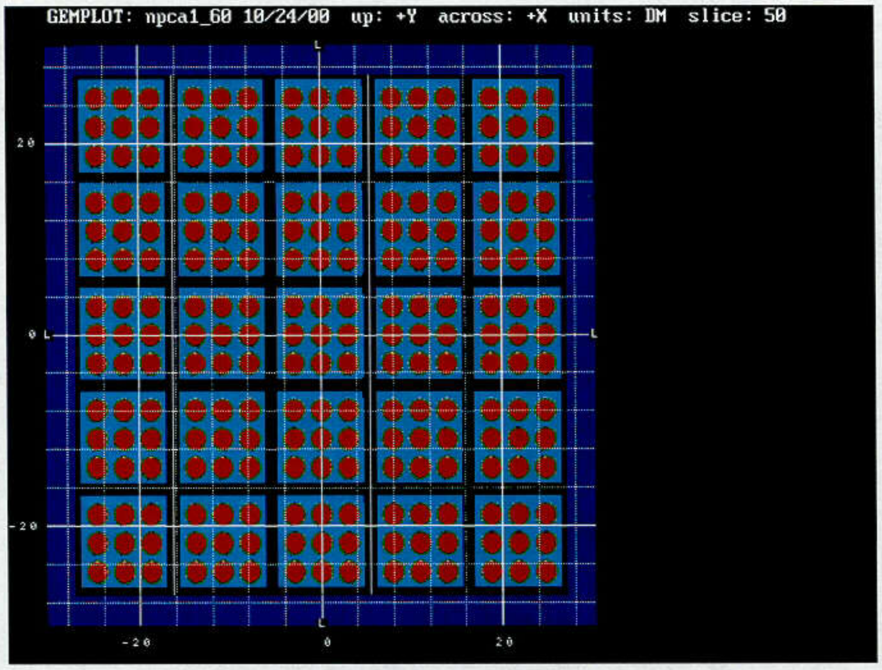
- Figure 6.87f depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array used to quantify the required hydrogen content necessary for demonstrating package safety.

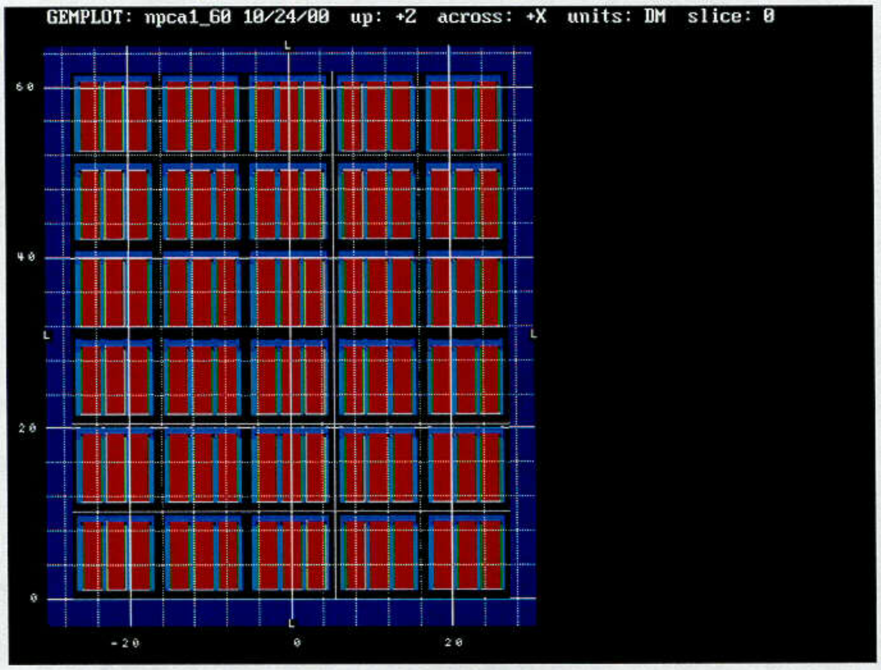
- Figure 6.87g depicts horizontal zoom of the damaged 5 × 5 × 6 package array for the 11.25" (28.575 cm) ICCA center-to-center spacing to quantify the ICCA (x,y) movement effect.

- Figure 6.87h depicts vertical zoom of the damaged 5 × 5 × 6 damaged package array that include the additional external stainless steel structure.

- Figure 6.87i depicts vertical top/bottom zoom of the damaged 5 × 5 × 6 damaged package array that includes the maximum polyethylene gap formation.

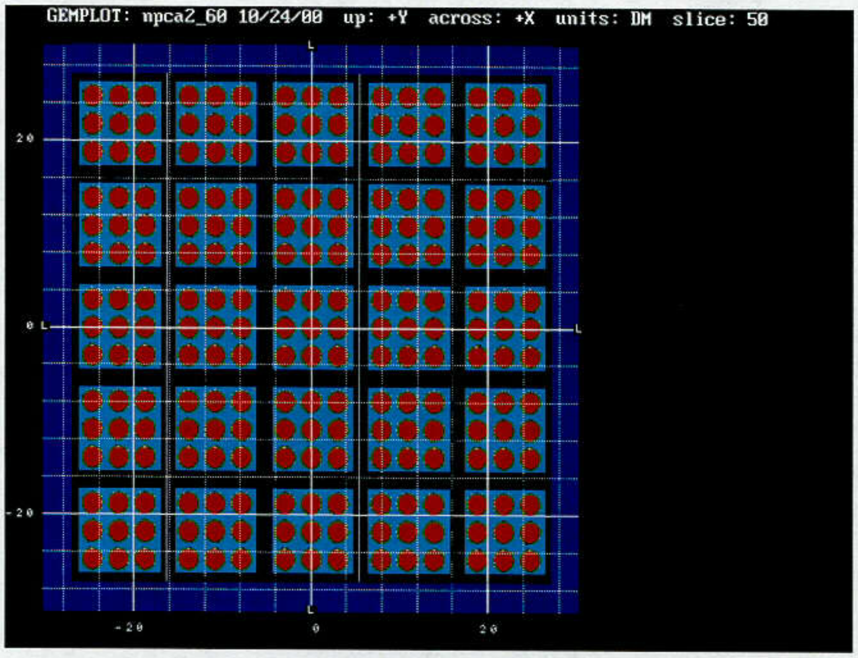
Figure 6.8~~7~~a – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, CTU-1 observed non-uniform burn (horizontal and vertical views)

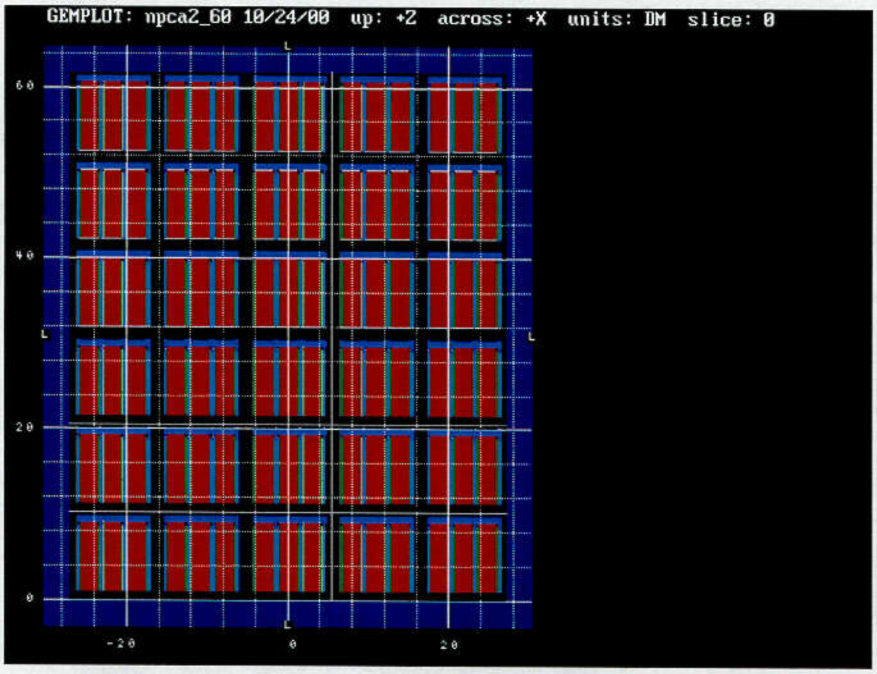




C19

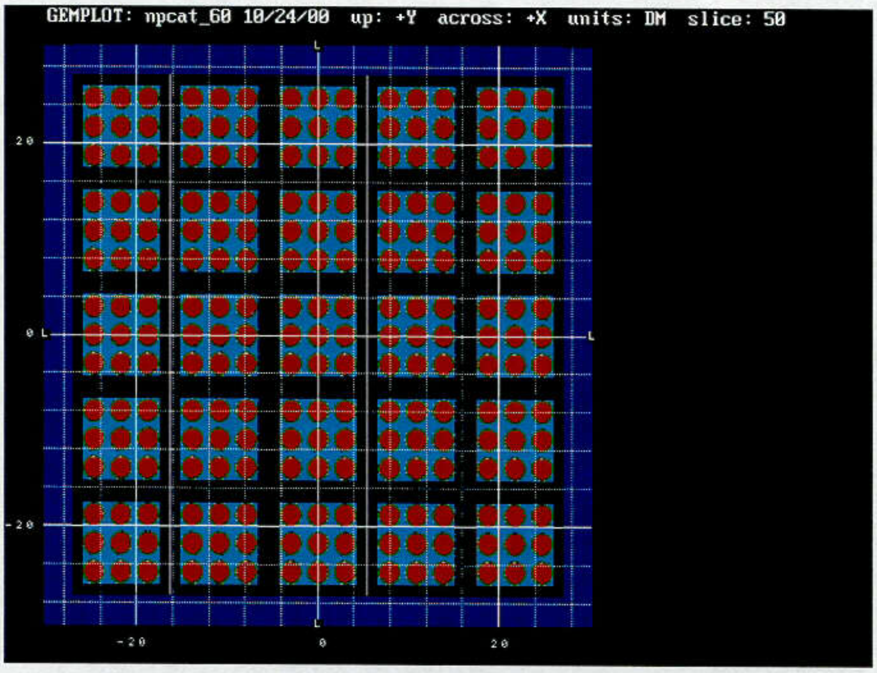
Figure 6.87b – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, CTU-2 observed non-uniform burn (horizontal and vertical views)

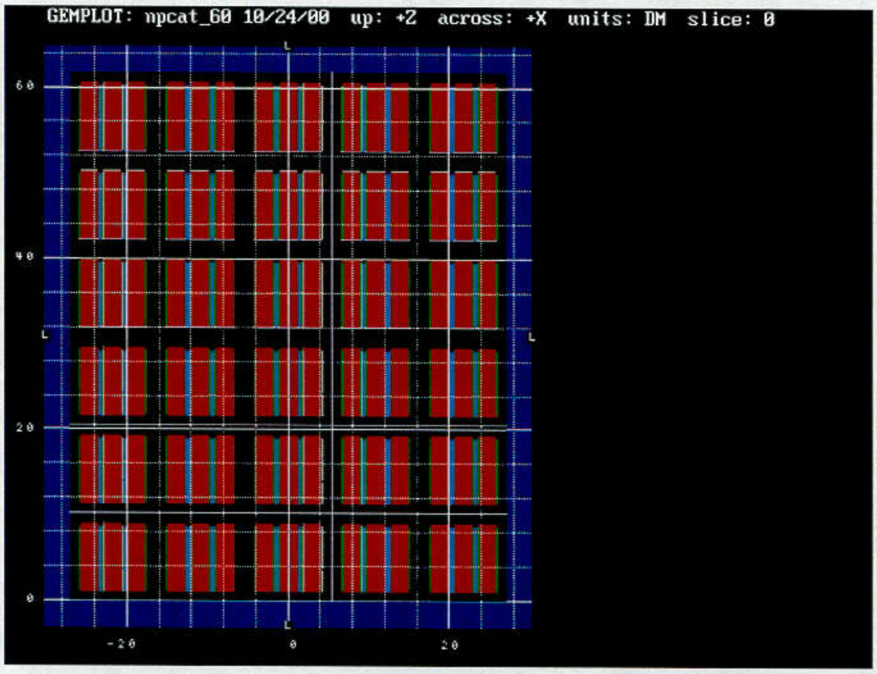




C20

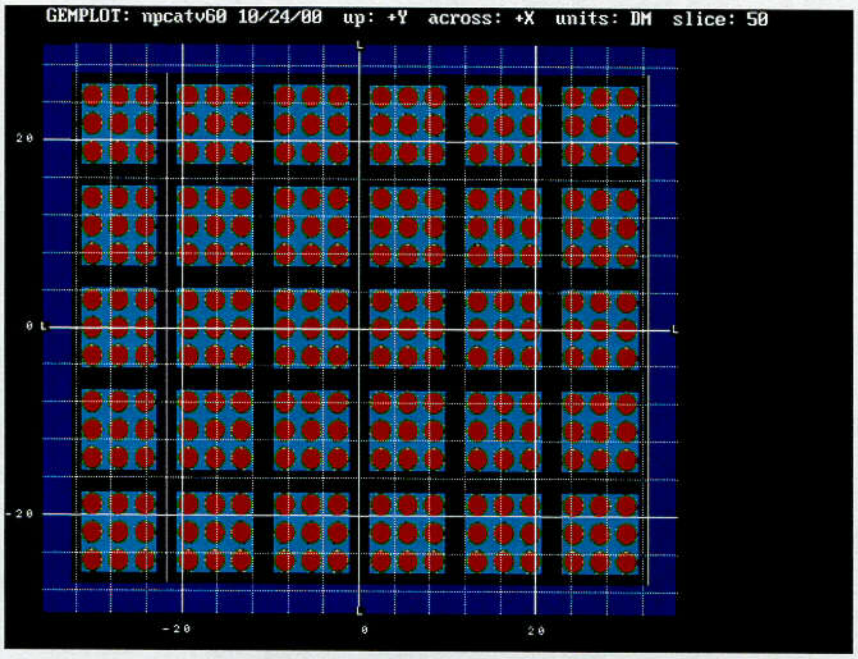
Figure 6.8~~7~~c – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)

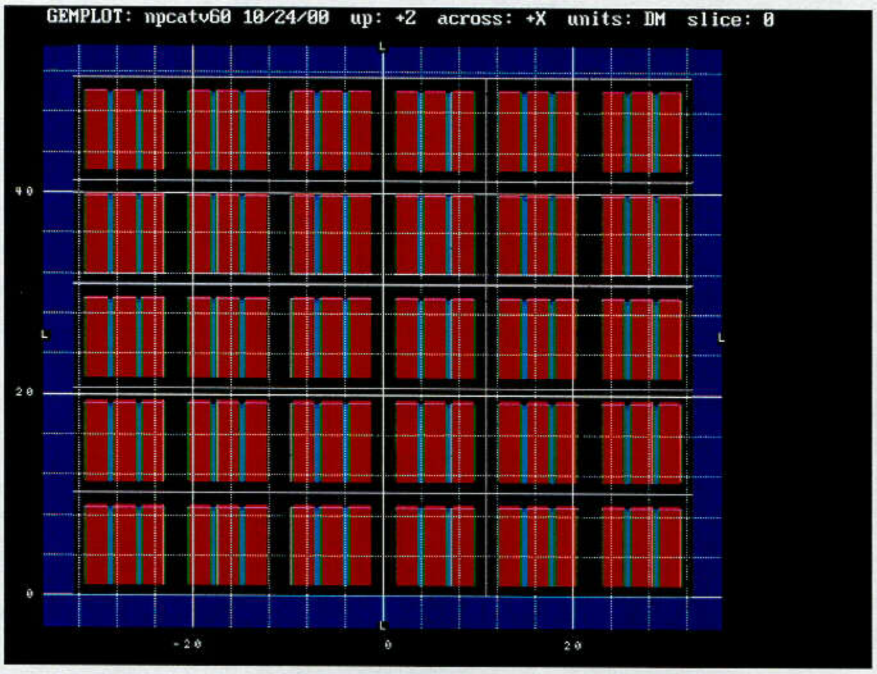




C21

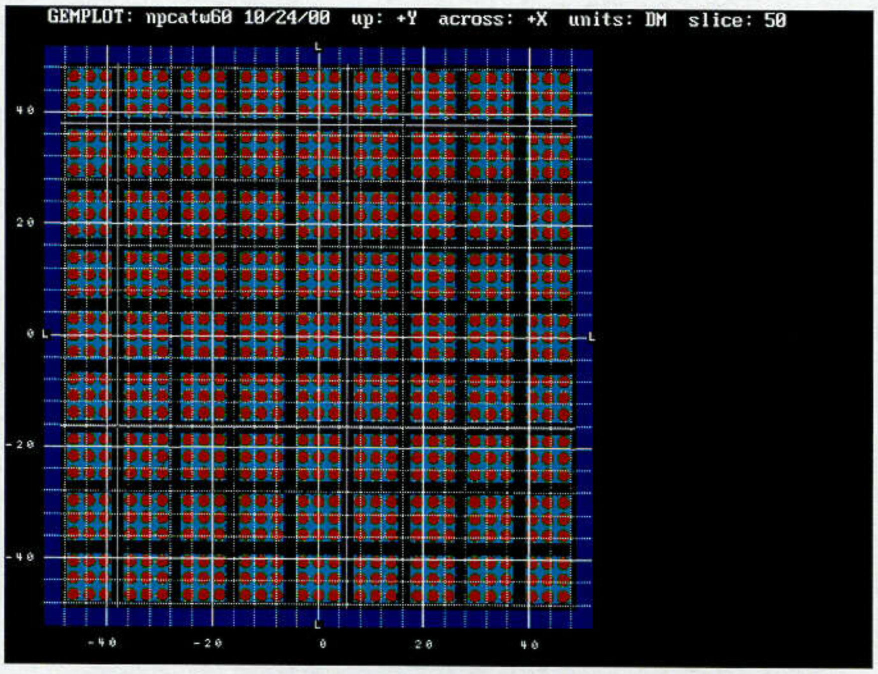
Figure 6.8~~7~~d – Fully reflected damaged 6 × 5 × 5 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)

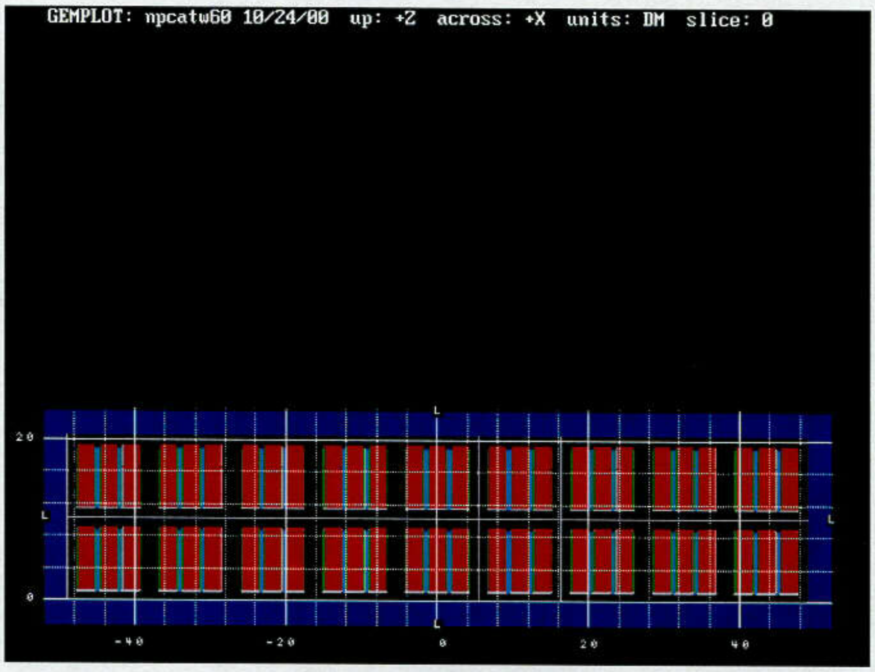




C22

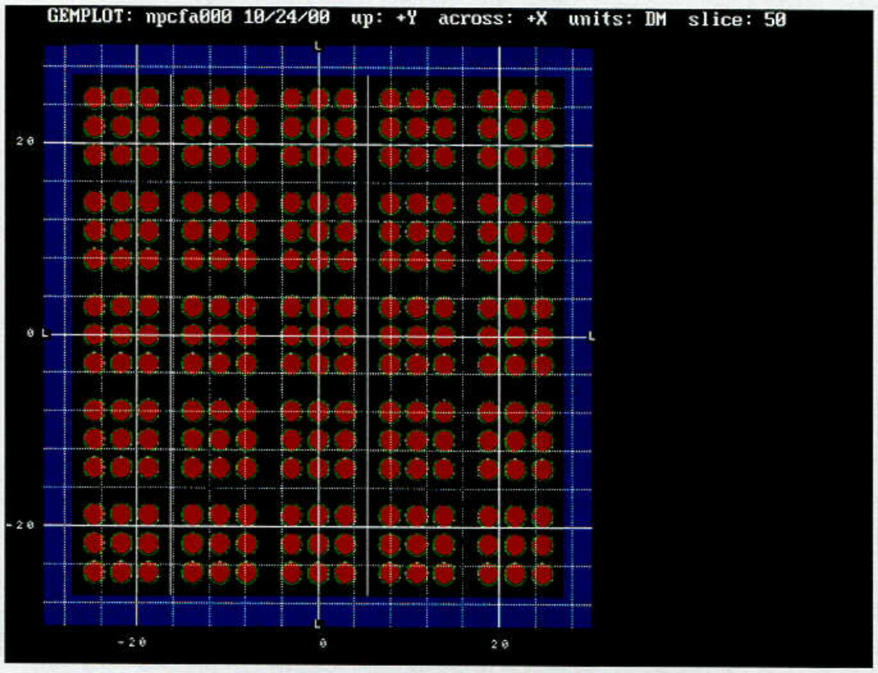
Figure 6.8~~7~~e – Fully reflected damaged 9 × 9 × 2 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)

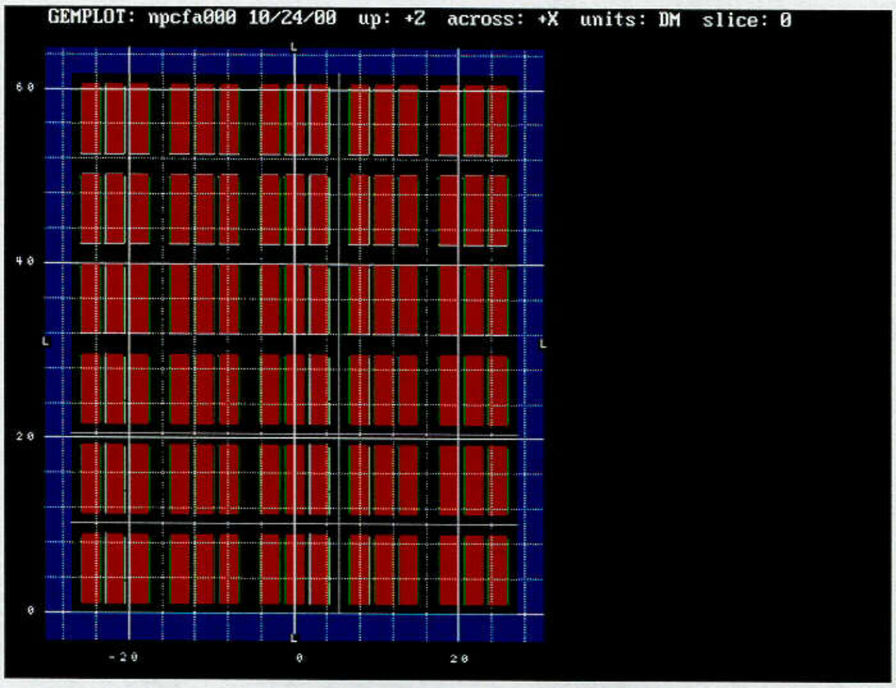




C23

Figure 6.8~~7~~f – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, 100% foam burn, void replacement (horizontal and vertical views)





C24

Figure 6.8~~7~~g – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, 11.25" c-c ICCA spacing (horizontal zoom, lower left array corner)

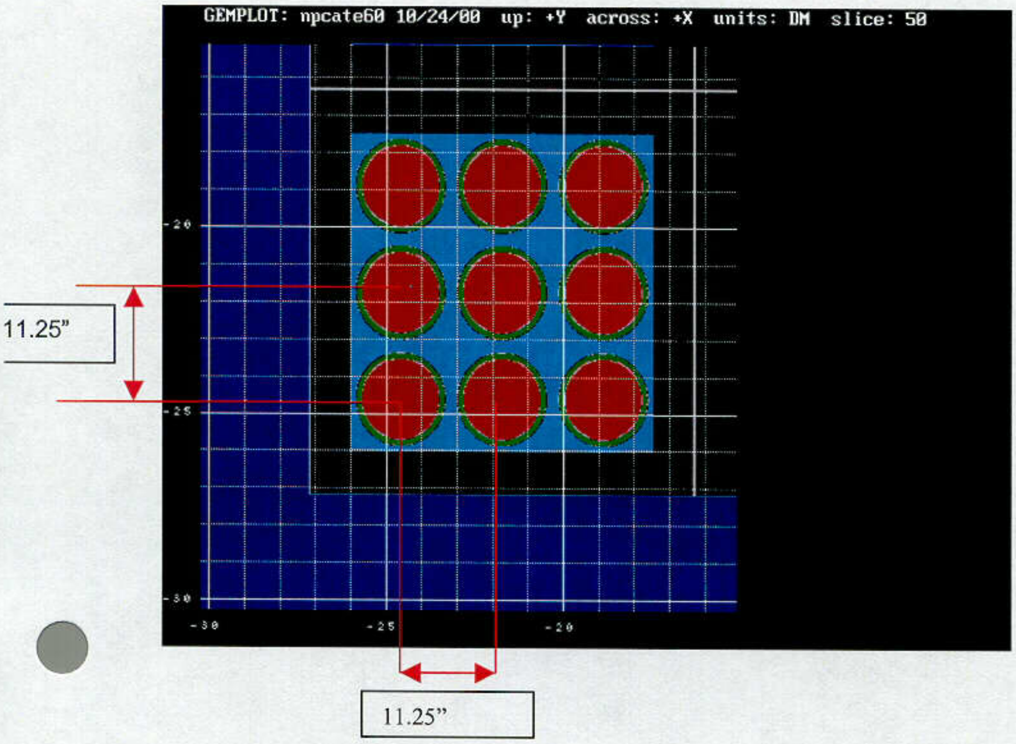
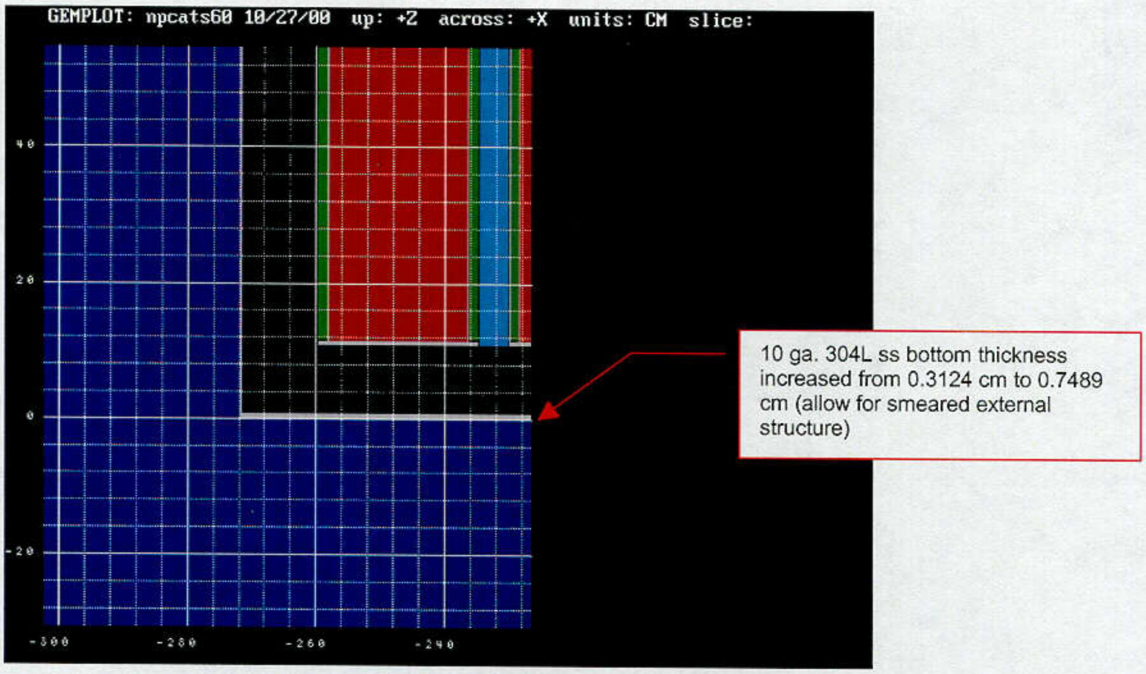


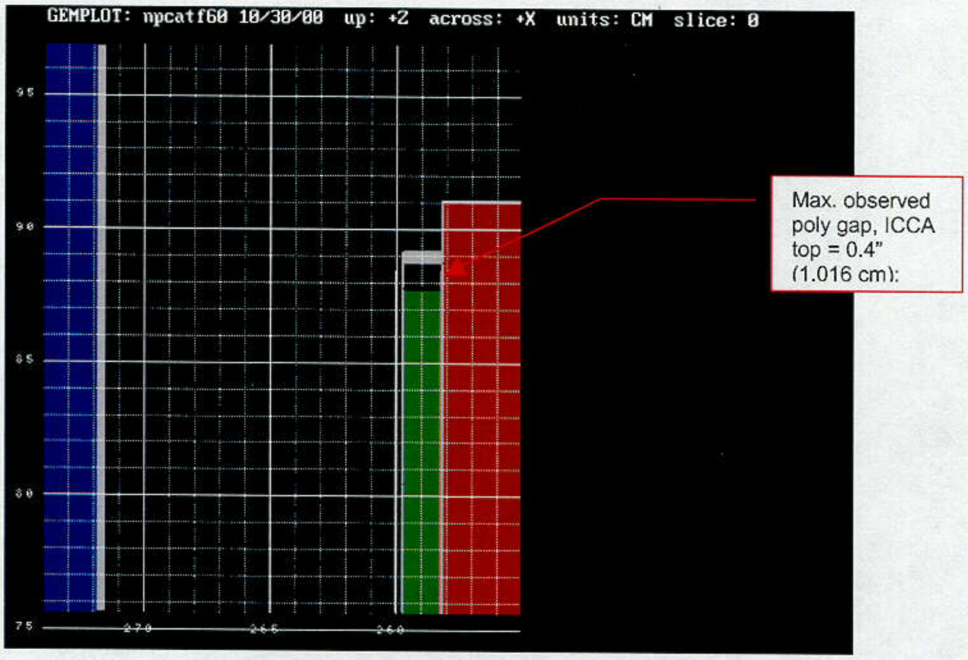
Figure 6.8~~7~~h – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, external structure add-on to bottom of OCA body (vertical zoom, lower left array corner)

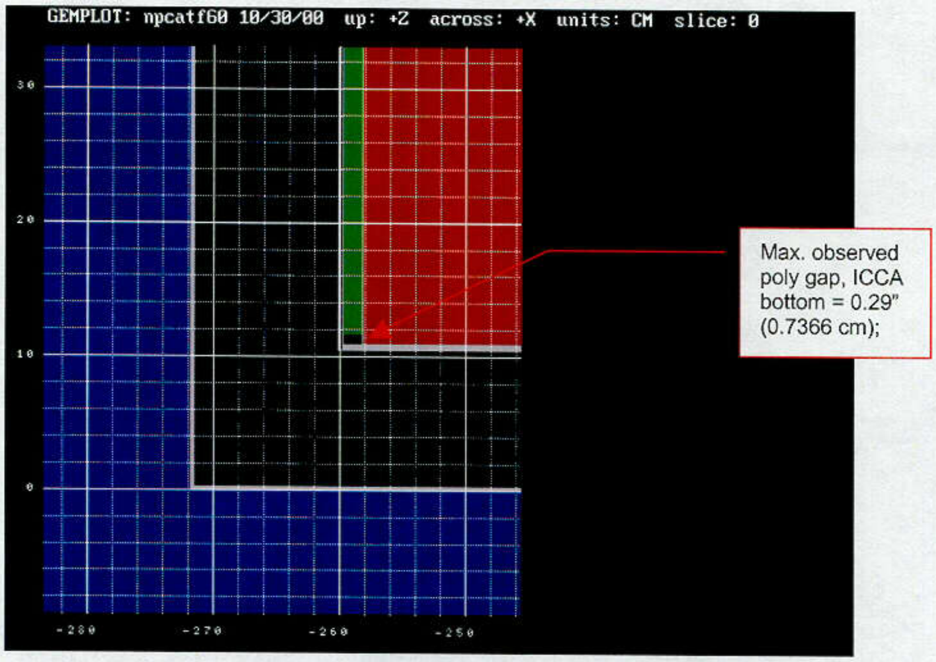
C25


GEMPLOT: npcats60 10/27/00 up: +Z across: +X units: CM slice:
40
20
0
-20
-300
-280
-260
-240
10 ga. 304L ss bottom thickness increased from 0.3124 cm to 0.7489 cm (allow for smeared external structure)

C26

Figure 6.8~~7~~i – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, observed maximum poly gap at top/bottom (vertical zoom, ICCA)





C27

6.3.5.2 Damaged Package Arrays with Heterogeneous UO_2 ~~Rods~~ in H_2O

Damaged package arrays with heterogeneous UO_2 cylindrical elements ~~rods~~ (rods) have been analyzed with the same applicable worse case container array model as used in the homogeneous analyses. This is the array model shown in Figure 6.8c in the preceding section. The models for the heterogeneous ~~rod~~ lattices for these cases are the same as described in Section 6.3.3.2.

6.4 METHOD OF ANALYSIS

GEMER, a proprietary Global Nuclear Fuel company criticality analysis computer code was used in the analysis of these computational models (Ref. 1). All calculations were performed on verified workstations using Pentium processors running under Windows NT.

6.4.1 COMPUTER CODE SYSTEM

GEMER is a Monte Carlo program, which solves the neutron transport equation as an eigenvalue or a fixed source problem including the neutron-shielding problem. GEMER adds an advanced geometry input package to the problem solving capability of the Monte Carlo code that is very similar in capability to KENO Va.

6.4.2 CROSS SECTIONS AND CROSS-SECTION PROCESSING

GEMER uses cross-sections processed from the ENDF/B-IV library. These cross-sections are prepared in 190-group format and the values in the resonance region may have the form of the resonance parameters or Doppler broadened multigroup cross-section. This treatment of cross-sections with explicit resonance parameters is especially suited to the analysis of uranium compounds in the form of heterogeneous accumulations or lattices. Thermal scattering of hydrogen is represented by the $S(\alpha,\beta)$ data in the ENDF/B-IV library. The types of reactions considered in the Monte Carlo calculation are fission, elastic, inelastic, and (n,2n) reactions; the absorption is implicitly treated by reducing the neutron weight by the non-absorption probability on each collision.

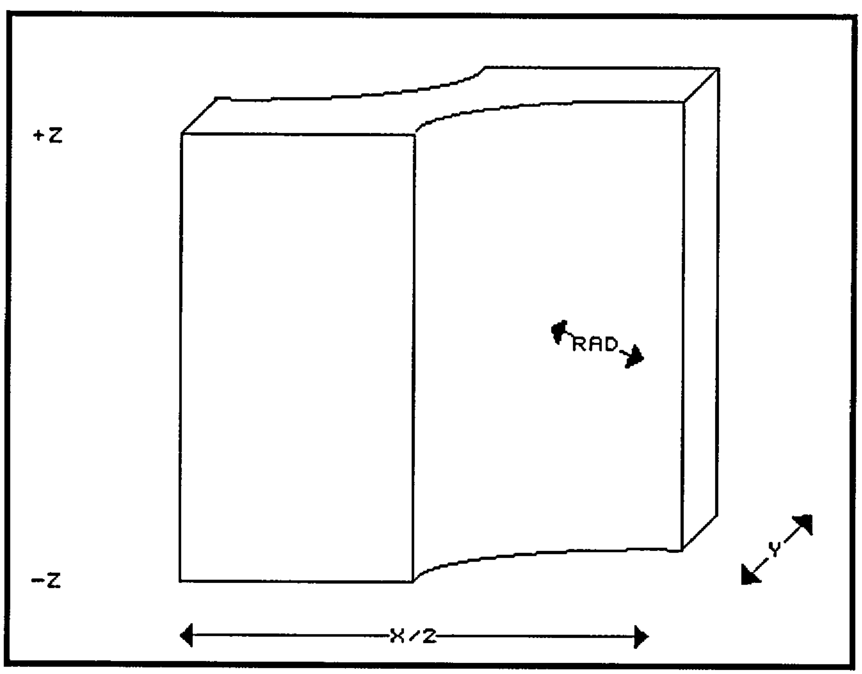
6.4.3 GEOMETRY MODELING OF FUEL REGIONS

The previous Section 6.3 gives a detailed description of the NPC shipping container geometry models used in this analysis. This section expands on the descriptions of the fuel regions, especially regions containing lattices of cylindrical fuel elements (rods). ~~fuel rods.~~ As noted in the prior sections, the provision for heterogeneous fuel in the NPC is conservatively based on the analysis of lattices of UO_2 fuel in the form of right circular cylinder elements (rods) in the ICCAs. Both square and triangular lattices have modeled in the heterogeneous cases, together with consideration of lattice boundary conditions in which cylindrical elements ~~rods~~ in the lattices are either permitted or not permitted to overlap the internal ICCA wall boundary.

6.4.3.1 The INTERS and GEMER VFO Geometry Options

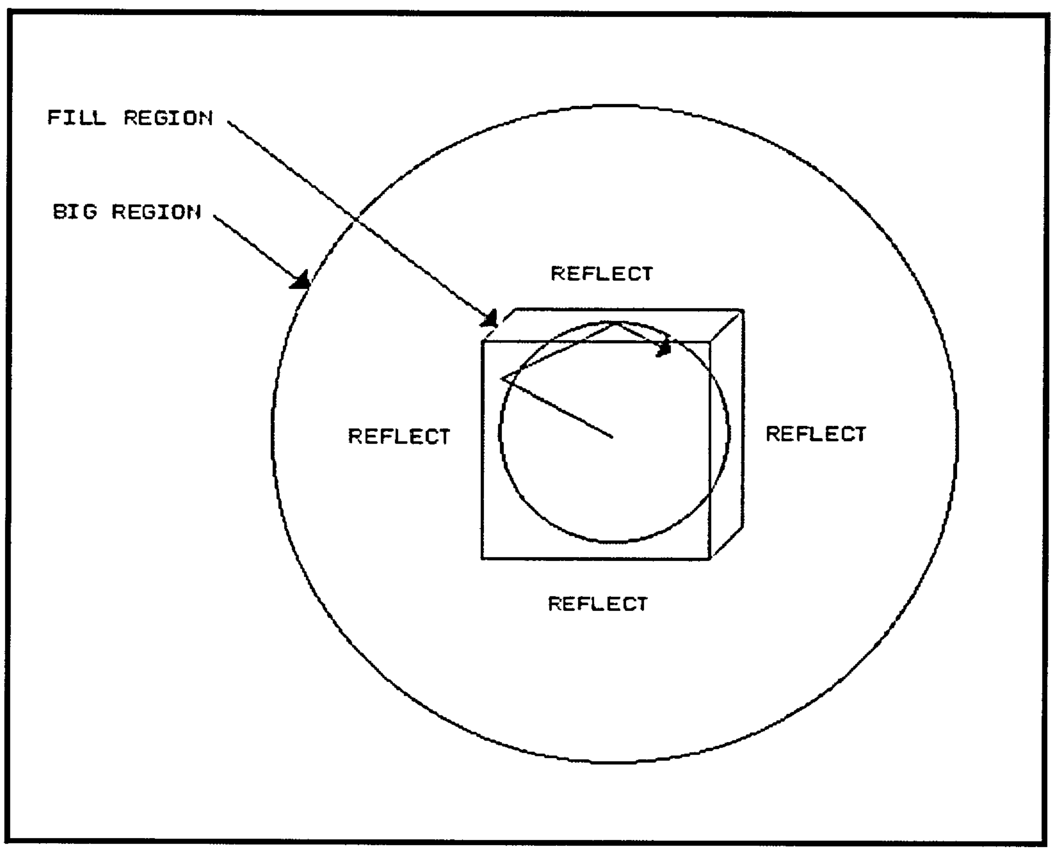
In addition to its standard geometry capabilities, the GEMER Monte Carlo code has two additional geometry options that are particularly useful in modeling rod lattices. The first is a special regular geometry construct called INTERS. As shown in Figure 6.9a, the INTERS region is a CUBOID with quarter cylinders missing along two opposite XY edges. The centerline of this region always passes through the X=0, Y=0 origin. Like regular geometry regions such as CUBOIDs or CYLINDERs, INTERS regions may be nested within each other, but the last region in the Box must be a CUBOID. The purpose of the INTERS region is to permit modeling of a triangular lattice of cylindrical rods by use of simple regular geometry input. This can be done two ways. One is to mirror reflect the INTERS box on its ±X and ±Y axes. (The +Z, -Z dimensions then define the height of the rods in the lattice.) The second way is to use two separate INTERS regions that differ by the location of quarter cylinder~~center~~ cutouts. As provided for by the INTERS input parameters, one region can be described by cutouts on~~in~~ the –X,+Y and +X,-Y edges~~corners~~, and the second with the cutouts at the –X,-Y and +X,+Y edges~~corners~~. Placing these two regions in alternate X and Y locations in an array will then create a two-dimensional triangular lattice of cylinders. Because of its geometry definition, the INTERS constructs are for all practical purposes limited to use either with infinite triangular lattices, or with lattices in which the geometry is permitted to overlap a region (e.g. an ICCA) that the lattice is contained in. (GEMER does not currently have a boundary condition that would prevent overlap of part of an INTERS region.)

Figure 6.9a – The INTERS Geometry Region



The second GEMER geometry option is the Virtual Fill Option (VFO). This option allows geometry regions to be automatically filled with a virtual representation of a separate region. As depicted in Figure 6.9b, the VFO ~~allows placing in a larger region (the "BIG REGION")~~ of a complete Box Type (the "FILL REGION") that is itself mirror reflected on all six of its sides, allows placing in a larger region (the "BIG REGION") which is any regulary geometry region. When a neutron enters the Big Region, it is translated into the Fill Region and tracked via the standard Monte Carlo methods (e.g. importance weighing, splitting, Russian roulette) in the Fill Region until the code determines that the neutron's path has reached one of the Big Region's boundaries. It is then translated back to the Big Region where regular tracking resumes. This option is called "Virtual" because in reality, no Ffill Rregion exists (i.e. is stored in the run-time memory) until a neutron enters the Big Region. When a neutron is translated into the Fill region, it is randomly located and then remains in this region, reflecting from wall to wall, until its track would take it back out of the Big Region. This wall-to-wall reflection effectively presents a fixed array of the Fill Region Boxes to the neutron tracking and hence can be used to model both square pitch and triangular pitch (via the INTERS Box) lattices in the Fill Region. One feature of note about VFO is that since each neutron entering the Big Region is randomly placed in the ~~BOX in the~~ Fill Region, each neutron sees the same overall Fill~~ILL~~ Region lattice, but each of these lattices has a different location for its central unit. Over an entire calculation, the effect of this is to average the results of the tracking over all possible central locations.

Figure 6.9b – The Virtual Fill Option



6.4.3.2 Water to Fuel Volume Ratios and Rod to Rod Spacings in Lattices of Fuel Rods

In uniform but heterogeneous fuel regions, the relative amount of moderator is specified as the Water to Fuel volume ratio (W/F ratio) in the unit cell. For uniform square and triangular pitched arrays of cylindrical (unclad) fuel rods in which the unit cells are two dimensional squares or triangles (since the heights of the rods in a given lattice are all the same), these W/F ratios are determined completely by the radii of the fuel rods and the center-to-center spacings between adjacent units. Figure 6.9c shows examples of the unit cells (the areas bounded by the dotted lines) for these two types of arrays from which it can be seen that the relationship between the W/F ratios and the radii (~~r~~R_f) and spacings (L) are:

Square Lattices: $$W/F = \frac{L^2 - \pi \times \cancel{r}R_f^2}{\pi \times \cancel{r}R_f^2}$$

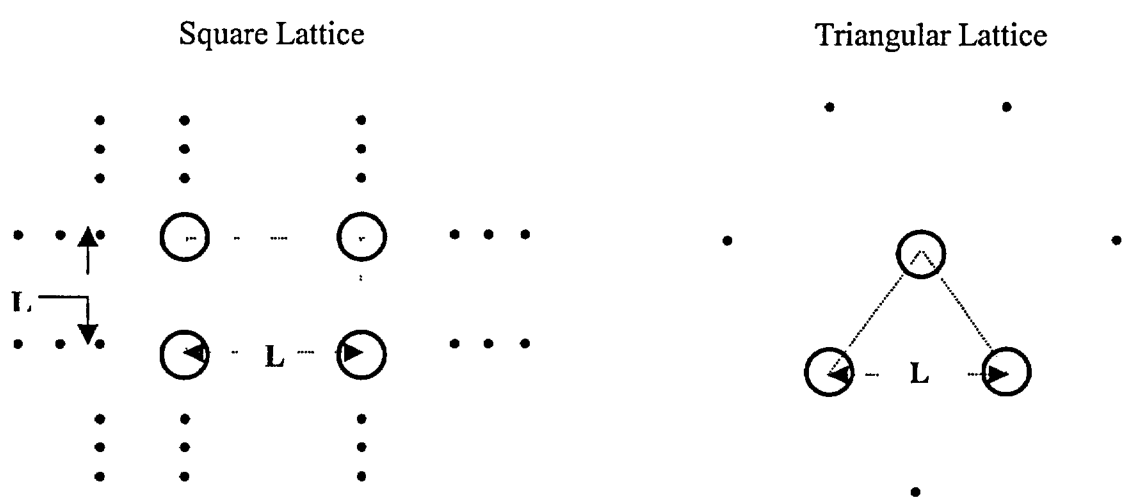
and

Triangular Lattices: $$W/F = \frac{0.866 \times L^2 - \pi \times \cancel{r}R_f^2}{\pi \times \cancel{r}R_f^2}$$

[0.866 in these equations is Sqrt(3.0)/2.0.]

Comparing these two formulas, it can be seen that if a Square and Triangular lattice with the same diameter fuel rods have the same W/F ratios, the triangular lattice will have a greater pitch (i.e. L) between rods. In the ICCAs, this means that for the same W/F ratios, triangular lattices will have fewer rods and thus for the same fissile mass, will be taller.

Figure 6.9c – Square and Triangular Lattices



6.4.3.3 Fuel Heights of Homogeneous Fuel Mixtures in the ICCAs

A brief description is given is Section 6.3.1.4 of the treatment of homogeneous UO_2 and water mixtures in the ICCA fuel region. In summary, this method is

i. For a (binary) fuel mixture with a given weight fraction of H_2O, determine the corresponding UO_2 density, ρ, assuming a maximum theoretical density of UO_2 of 10.96 gm/cm^3.

ii. For a given mass, M, of UO_2 in the ICCA, determine the Volume, V, of the $UO_2 + H_2O$ mixture by

$$\rho \times V = M$$

iii. Since the ICCA is cylindrical, V is equal to the base area, $\pi \times R_{ICCA}^2$, times the height, h, of the mixture, and hence

$$H = M/(\rho \times \pi \times R_{ICCA}^2).$$

Since the maximum height in the ICCA is 80.01 cm, and its radius is 10.8141 cm, this means that for a given UO_2 mass there is a minimum UO_2 density below which the contents of the ICCA will be less than the specified mass. The following Table 6.8 tabulates these minimum densities for the mass limits applicable to this analysis.

Table 6.8 Minimum UO_2 Densities for Homogeneous UO_2 and H_2O Mixtures in the ICCA

UO_2 Mass Limit (kgs)	Minimum UO_2 Density (gm/cm^3)
60.0	2.041
55.0	1.871
53.0	1.803
46.0	1.565

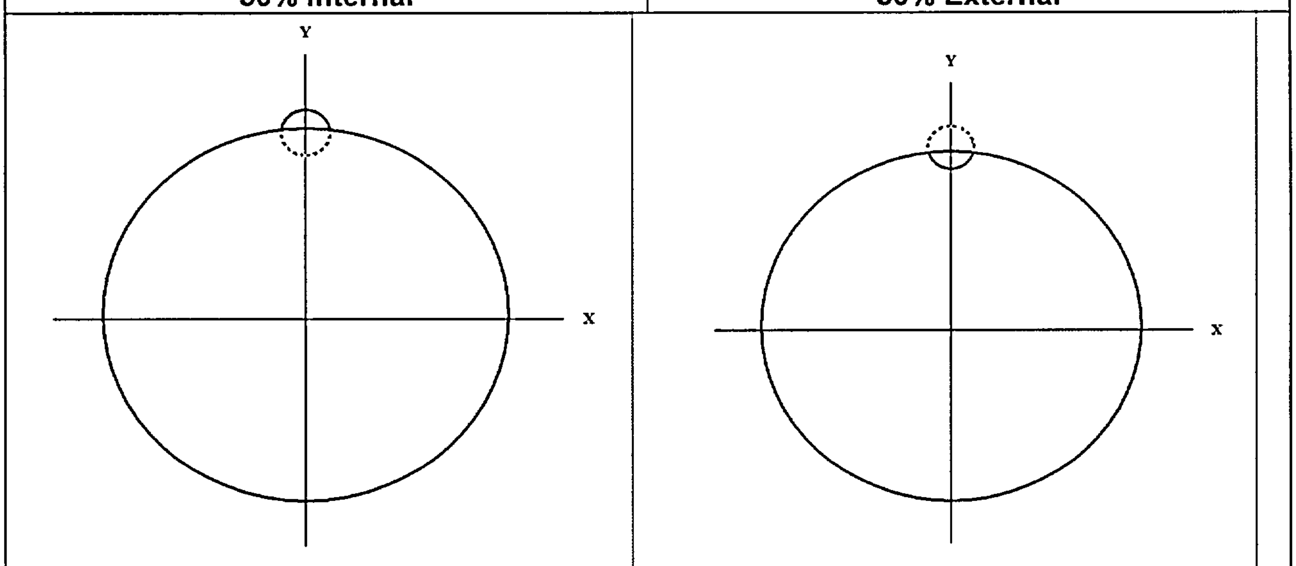
6.4.3.4 Fuel Heights of Heterogeneous Fuel Lattices in the ICCAs

In heterogeneous uniform square or triangular fuel rod lattices, the fuel heights are still related to the W/F ratios (i.e. the cylinderrod-to-cylinder or rod-to-rod spacings) and the cylinder rod diameters via the relationship $\rho \times$ Area $\times$ hHeight = Mass, but the formula used to determine the $\rho \times$ Area depends on the assumed boundary conditions and the way in which the regions are modeled. In this analysis, three different cases have been considered.

Case 1 is for arrays in which it is assumed that the right circular cylinder fuel elements (rods) can overlap the (ICCA) boundary. This assumption means that if a given fuel element~~rod~~ in the lattice is such that part of it overlaps the ICCA region boundary, the external overlap part is deleted from the model but the part internal to the ICCA is kept. For this exact modeling, ρ = 10.96 gm/cm^3 and the Area is given by the sum of the partial areas of the rods that overlap the boundary + the sum of the areas of the internal rods that do not intersect the boundary. This latter sum is just N × A_R, with N equal to the number of internal rods and A_R equal to the area of a single cylinder~~rod~~ (i.e. π×~~r~~R_f^2). For the first term, the sum is more complicated since individual fuel cylinder elements~~rods~~ will intersect the boundary at different points. However, the internal partial area of each cylindrical element ~~rod~~ can be determined by integration, and the integration can be made simple by considering the ICCA and fuel ~~rod~~ cylinder (rod) in question to be rotated so that the center of the overlapping rod is at X = 0.0. Figure 6.9d shows a depiction of the two situations that can result.

Figure 6.9d – Partial Areas of Overlapping Fuel Cylinders ~~Rods~~

Overlapping Fuel Cylinder~~Rod~~* More that 50% Internal	Overlapping Fuel Cylinder~~Rod~~* More than 50% External



*Center of fuel rod having radius R_f is assumed to be located at (0.0, Y_0); Center of ICCA is 0.0, 0.0.

[N.B. "More than 50% Internal" or "More than 50% External" should be interpreted to mean that the curve for the ICCA boundary and the cylindrical fuel element ~~rod~~ intersects at a value of $Y \leq Y_0$ or $Y > Y_0$, respectively.] Separation into these two situations is necessary since the functional form of the overlapping rod used in the integration can only be the top half of the cylinder [i.e. ~~y~~Y_{r1} = ~~y~~Y_0 + Sqrt (~~r~~R_f^2 – ~~x~~X^2)] or the bottom half [i.e. ~~y~~Y_{r2} = ~~y~~Y_0 - Sqrt (~~r~~R_f^2 – ~~x~~X^2)]. The dotted line parts of the partial rods in Figure 6.9d are the parts ~~that are~~ not included in the area integration. In the "More than 50% Internal" situation, this integration is from X = 0.0 to X = ~~R~~X_1 (the +X point of intersection of the ICCA boundary and the cylindrical elment [~~fuel~~ rod] curve) of the quantity (~~y~~Y_{r1} – ~~y~~Y_{ICCA}~~;~~), with ~~y~~Y_{ICCA} = Sqrt(~~r~~R_{ICCA}^2 – ~~x~~X^2). If the result of this integral is A_p, the corresponding value for the internal partial area for the cylindrical fuel element ~~rod~~ is $A_R - 2 \times A_p$.

For the situation when more than 50% or the cylindrical fuel element (rod) ~~rod~~ is external, the integral is made from X = 0.0 to ~~R~~X_i of ~~y~~Y_{ICCA} – ~~y~~Y_{r2}, and the internal partial area of the fuel cylinder~~rod~~ is equal to two times the value of this integral. Both of these integrals have results that can be expressed in closed form (involving arcsines), and hence the partial fuel cylinder~~rod~~ determinations can readily be computed.

The 2nd array case considered is that of fuel element (rod) ~~rod~~ lattices in which the elements ~~rods~~ in the lattice are not permitted to overlap the ICCA boundary. If any part of a fuel cylinder ~~rod~~ intersects the ICCA boundary at any point, it is deleted from the array. All fuel cylinders~~rods~~ are thus completely internal, and the total fuel ~~rod~~ area is just $N \times A_R$. As in case 1, the density ρ for this case is 10.96 gm/cm^3.

The third case is that in which the fuel element (rod) ~~rod~~ lattices are modeled with the Virtual Fill Option (VFO). In this case, each neutron that enters the internal ICCA fuel region sees a fuel rod lattice with an overlapping boundary condition like that in Case 1, but each lattices of these has a randomly location in the XY plane so that each will have a different number of overlapping and internal rods. Since the effect of this over an entire calculation is to average the arrays over all locations, the method used to determine the lattice heights is that used for the homogeneous case. This is done by correlating the given W/F ratio of the heterogeneous lattice with an equivalent WF H_2O for a homogeneous mixture by the relationship

$$\text{WF } H_2O = \frac{W/F}{10.96 + W/F},$$

which then determines the UO_2 density in the equivalent homogeneous mixture. [Note that this WF H_2O determined by this method is independent of the diameter of the fuel rod.]

~~6.4.3~~6.4.4 CODE INPUT

All problems were started with a flat initial neutron distribution over the fissile material regions only. Except as noted, c~~C~~alculations were ~~nominally~~ run with 200 generations of~~at~~ 2000 neutrons each, skipping the first 10 generations before starting the statistical output processing, for a total of 380,000 histories used in the final eigenvalue calculation. Appendix 6.9 ~~Figures 6.8a – 6.8d~~ contains sample GEMER input files ~~according to the description in Table 6.7 as follows:~~for both the homogeneous and heterogeneous cases considered in this analysis.

~~**Table 6.7 – Sample input summary**~~

~~**Figure 6.8a – Sample input file = npcut_25.in**~~

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR-VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
 200 2000   10    0    0    1    0    0
    0  293    0    0
\CSXSEC\UO2\GUO2 50.25
\CSXSEC\NOU\GNOU 0.SS
\CSXSEC\NOU\GNOU 0.CAD
\CSXSEC\NOU\GNOU 0.POL 0.98
```

```
\CSXSEC\NOU\GNOU-0.F07-0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11-0.90
\CSXSEC\NOU\GNOU-0.F15-0.90
\CSXSEC\NOU\GNOU-0.F40-0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO-GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      0.0     0.0     0.0     0.0     0.0     0.0
BOX TYPE     1  /* inner canister, bottom fuel_region #1 w/ gap, body assy
CYLINDER     1  10.8141  0.31750  0.00000                       16*.5
CYLINDER     2  10.9233  0.31750  0.00000                       16*.5
CYLINDER     0  12.4092  0.31750  0.00000                       16*.5
CYLINDER     2  12.4092  0.31750  0.44200                       16*.5
CYLINDER     2  12.4612  0.31750  0.44200                       16*.5
CYLINDER     0  12.7000  0.31750  0.44200                       16*.5
CYLINDER     2  12.7635  0.31750  0.50550                       16*.5
BOX TYPE     2  /* inner canister, fuel_region #2, body assy
CYLINDER     1  10.8141  25.4635  0.0000                        16*.5
CYLINDER     2  10.9233  25.4635  0.0000                        16*.5
CYLINDER     3  10.9614  25.4635  0.0000                        16*.5
CYLINDER     4  12.4092  25.4635  0.0000                        16*.5
CYLINDER     2  12.4612  25.4635  0.0000                        16*.5
CYLINDER     0  12.7000  25.4635  0.0000                        16*.5
CYLINDER     2  12.7635  25.4635  0.0000                        16*.5
BOX TYPE     3  /* inner canister, fuel_region #3, 0.15" cd gap, body assy
CYLINDER     1  10.8141  0.38100  0.00000                       16*.5
CYLINDER     2  10.9233  0.38100  0.00000                       16*.5
CYLINDER     0  10.9614  0.38100  0.00000                       16*.5
CYLINDER     4  12.4092  0.38100  0.00000                       16*.5
CYLINDER     2  12.4612  0.38100  0.00000                       16*.5
CYLINDER     0  12.7000  0.38100  0.00000                       16*.5
CYLINDER     2  12.7635  0.38100  0.00000                       16*.5
BOX TYPE     4  /* inner canister, fuel_region #4, body assy
CYLINDER     1  10.8141  25.4635  0.0000                        16*.5
CYLINDER     2  10.9233  25.4635  0.0000                        16*.5
CYLINDER     3  10.9614  25.4635  0.0000                        16*.5
CYLINDER     4  12.4092  25.4635  0.0000                        16*.5
CYLINDER     2  12.4612  25.4635  0.0000                        16*.5
CYLINDER     0  12.7000  25.4635  0.0000                        16*.5
CYLINDER     2  12.7635  25.4635  0.0000                        16*.5
BOX TYPE     5  /* inner canister, fuel_region #5, 0.15" cd gap, body assy
CYLINDER     1  10.8141  0.38100  0.00000                       16*.5
CYLINDER     2  10.9233  0.38100  0.00000                       16*.5
CYLINDER     0  10.9614  0.38100  0.00000                       16*.5
CYLINDER     4  12.4092  0.38100  0.00000                       16*.5
CYLINDER     2  12.4612  0.38100  0.00000                       16*.5
CYLINDER     0  12.7000  0.38100  0.00000                       16*.5
CYLINDER     2  12.7635  0.38100  0.00000                       16*.5
BOX TYPE     6  /* inner canister, fuel region #6, body assy
CYLINDER     1  10.8141  21.3385  0.0000                        16*.5
CYLINDER     0  10.8141  21.3385  0.0000                        16*.5
CYLINDER     2  10.9233  21.3385  0.0000                        16*.5
CYLINDER     3  10.9614  21.3385  0.0000                        16*.5
CYLINDER     4  12.4092  21.3385  0.0000                        16*.5
CYLINDER     2  12.4612  21.3385  0.0000                        16*.5
CYLINDER     0  12.7000  21.3385  0.0000                        16*.5
CYLINDER     2  12.7635  21.3385  0.0000                        16*.5
BOX TYPE     7  /* inner canister, fuel region #7, body assy
CYLINDER     1  10.8141  3.4925  0.0000                         16*.5
CYLINDER     0  10.8141  3.4925  0.0000                         16*.5
CYLINDER     2  10.9233  3.4925  0.0000                         16*.5
CYLINDER     3  10.9614  3.4925  0.0000                         16*.5
CYLINDER     4  12.4092  3.4925  0.0000                         16*.5
CYLINDER     2  12.4612  3.4925  0.0000                         16*.5
CYLINDER     0  12.7000  3.4925  0.0000                         16*.5
CYLINDER     2  12.7635  3.4925  0.0000                         16*.5
BOX TYPE     8  /* inner canister   fuel region #8, lid assy
CYLINDER     1  10.8141  0.63250  0.00000                       16*.5
CYLINDER     0  10.8141  0.63250  0.00000                       16*.5
CYLINDER     2  10.9233  0.63250  0.00000                       16*.5
CYLINDER     3  10.9614  0.63250  0.00000                       16*.5
CYLINDER     4  12.4092  0.63250  0.00000                       16*.5
CYLINDER     2  12.4612  0.63250  0.00000                       16*.5
CYLINDER     0  12.7000  0.63250  0.00000                       16*.5
CYLINDER     2  12.7635  0.63250  0.00000                       16*.5
BOX TYPE     9  /* inner canister   fuel region #9 w/ gap, lid assy
CYLINDER     1  10.8141  0.31750  0.00000                       16*.5
CYLINDER     2  10.9233  0.31750  0.00000                       16*.5
CYLINDER     0  12.4092  0.31750  0.00000                       16*.5
CYLINDER     2  12.4612  0.31750  0.00000                       16*.5
BOX TYPE    10  /* inner canister   fuel region #10 w/ ring, lid assy
CYLINDER     1  10.8141  0.44200  0.00000                       16*.5
CYLINDER     2  10.9233  0.44200  0.00000                       16*.5
CYLINDER     2  12.4092  0.44200  0.00000                       16*.5
CYLINDER     2  12.4612  0.44200  0.00000                       16*.5
BOX TYPE    11  /* inner canister   fuel region #11 w/ top, lid assy
CYLINDER     1  10.8141  1.78050  0.00000                       16*.5
CYLINDER     2  10.9233  1.91640  0.00000                       16*.5
CYLINDER     0  12.4092  1.91640  0.00000                       16*.5
BOX TYPE    12  /* inner canister cuboid, body section (7# region)
CUBOID       5  12.7636  12.7636  12.7636  12.7636  73.3450  0.5055  16*.5
BOX TYPE    13  /* inner canister cuboid, body section (40# region)
```

```
CUBOID        9  12.7636  12.7636  12.7636  12.7636  3.49260  0.00000  16*.5
BOX-TYPE    14  /* inner canister upper cylinder: lid section
CYLINDER     0  12.7636  3.30840  0.00000                              16*.5
BOX-TYPE    15  /* foam cutout (void)  40 #/ft3 foam lid section
CYLINDER     0  13.5510  3.30840  0.00000                              16*.5
BOX-TYPE    16  /* npc body or lid  10 ga. 304ss layer
CUBOID       2  54.3687  54.3687  54.3687  54.3687  0.31240  0.00000  16*.5
BOX-TYPE    17  /* npc body or lid  1" duraboard (void) layer, 10 ga. 304ss
CUBOID       0  51.5163  51.5163  51.5163  51.5163  2.54000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  2.54000  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  2.54000  0.00000  16*.5
BOX-TYPE    18  /* npc body  4" bot. foam layer (11 #/ft3)       face burn
CUBOID       7  42.6086  42.6086  42.6086  42.6086  0.00000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  0.00000  7.62000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  0.00000  7.62000  16*.5
BOX-TYPE    19  /* npc body  29.0750" foam layer (7,11 #/ft3)   face burn
CUBOID       5  42.6086  42.6086  42.6086  42.6086  73.8505  0.0000  16*.5
CUBOID       7  42.6086  42.6086  42.6086  42.6086  73.8505  0.0000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  73.8505  0.0000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  73.8505  0.0000  16*.5
BOX-TYPE    20  /* npc body  1.375 " foam layer (40 #/ft3)       face burn
CUBOID       9  42.6086  42.6086  42.6086  42.6086  3.49250  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX-TYPE    21  /* npc body  30.45" two part body
CUBOID       0  54.3687  54.3687  54.3687  54.3687  77.3430  0.0000  16*.5
BOX-TYPE    22  /* npc lid  1.375 " foam layer (40 #/ft3)      lid burn
CUBOID       0  43.8963  43.8963  43.8963  43.8963  3.49250  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX-TYPE    23  /* npc lid  3.5" foam layer (15 #/ft3)         lid burn
CUBOID       0  43.8963  43.8963  43.8963  43.8963  2.54000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  8.89000  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  8.89000  0.00000  16*.5
BOX-TYPE    24  /* complete npc  body assembly
CUBOID       0  54.3688  54.3688  54.3688  54.3688  87.8154  0.0000  16*.5
BOX-TYPE    25  /* complete npc  lid assembly
CUBOID       0  54.3688  54.3688  54.3688  54.3688  15.2349  0.0000  16*.5
BOX-TYPE    26  /* global unit: damaged unit, full h2o reflection
CUBOID       0  54.3688  54.3688  54.3688  54.3688  103.0503  0.0000  16*.5
CUBOID       6  84.8488  84.8488  84.8488  84.8488  133.5303  30.480  16*.5
 26   1  1  1   1  1  1   1  1  1   1
BEGIN COMPLEX
/* build inner canister  main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister  upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister  lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid: 11.75" centers
COMPLEX  15 14  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs:11.75" centers
COMPLEX  22 15  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body: 11.75" centers
COMPLEX  19 12  29.8450  29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc  body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc  lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup  single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
END GEOM
DEFAULTS=YES
END GEMER
```

~~Figure 6.8b — Sample input file = npc6um60.in~~

```
2000:NPC,,,,CYL,,UO2,5.00%,WTFR=0.05,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
     0  293    0    0
\CSXSEC\UO2\GUO2 50.05 0.6474
\CSXSEC\NOU\GNOU 0.SS
\CSXSEC\NOU\GNOU 0.CAD
```

```
\CSXSEC\NOU\GNOU-0.POL
\CSXSEC\NOU\GNOU-0.F07-0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11-0.90
\CSXSEC\NOU\GNOU-0.F15-0.90
\CSXSEC\NOU\GNOU-0.F40-0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO-GEOM
     0  /* # OF REGIONS OR ZERO
     0  /* # OF BOX TYPES OR ZERO
     1  /* # OF BOXES IN X DIRECTION
     1  /* # OF BOXES IN Y DIRECTION
     1  /* # OF BOXES IN Z DIRECTION
     1  /* BOUNDARY CONDITION OPTION
     1  /* STARTING SOURCE OPTION
     1  /* COMPLEX EMBEDDED OPTION
     0  /* # OF PRINT PLOTS
        1.0      1.0      1.0      1.0      1.0      1.0
BOX TYPE     1  /* inner canister: bottom fuel_region #1 w/ gap: body assy
CYLINDER     1  10.8141  0.31750  0.00000                       16*.5
CYLINDER     2  10.9233  0.31750  0.00000                       16*.5
CYLINDER     0  12.4092  0.31750  0.00000                       16*.5
CYLINDER     2  12.4092  0.31750  0.44200                       16*.5
CYLINDER     2  12.4612  0.31750  0.44200                       16*.5
CYLINDER     0  12.7000  0.31750  0.44200                       16*.5
CYLINDER     2  12.7635  0.31750  0.50550                       16*.5
BOX TYPE     2  /* inner canister: fuel_region #2: body assy
CYLINDER     1  10.8141  25.4635   0.0000                       16*.5
CYLINDER     2  10.9233  25.4635   0.0000                       16*.5
CYLINDER     3  10.9614  25.4635   0.0000                       16*.5
CYLINDER     4  12.4092  25.4635   0.0000                       16*.5
CYLINDER     2  12.4612  25.4635   0.0000                       16*.5
CYLINDER     0  12.7000  25.4635   0.0000                       16*.5
CYLINDER     2  12.7635  25.4635   0.0000                       16*.5
BOX TYPE     3  /* inner canister: fuel_region #3, 0.15" ed gap: body assy
CYLINDER     1  10.8141  0.38100  0.00000                       16*.5
CYLINDER     2  10.9233  0.38100  0.00000                       16*.5
CYLINDER     0  10.9614  0.38100  0.00000                       16*.5
CYLINDER     4  12.4092  0.38100  0.00000                       16*.5
CYLINDER     2  12.4612  0.38100  0.00000                       16*.5
CYLINDER     0  12.7000  0.38100  0.00000                       16*.5
CYLINDER     2  12.7635  0.38100  0.00000                       16*.5
BOX TYPE     4  /* inner canister: fuel_region #4: body assy
CYLINDER     1  10.8141  10.1300   0.0000                       16*.5
CYLINDER     0  10.8141  25.4635   0.0000                       16*.5
CYLINDER     2  10.9233  25.4635   0.0000                       16*.5
CYLINDER     3  10.9614  25.4635   0.0000                       16*.5
CYLINDER     4  12.4092  25.4635   0.0000                       16*.5
CYLINDER     2  12.4612  25.4635   0.0000                       16*.5
CYLINDER     0  12.7000  25.4635   0.0000                       16*.5
CYLINDER     2  12.7635  25.4635   0.0000                       16*.5
BOX TYPE     5  /* inner canister: fuel_region #5, 0.15" ed gap: body assy
CYLINDER     0  10.8141  0.38100  0.00000                       16*.5
CYLINDER     2  10.9233  0.38100  0.00000                       16*.5
CYLINDER     0  10.9614  0.38100  0.00000                       16*.5
CYLINDER     4  12.4092  0.38100  0.00000                       16*.5
CYLINDER     2  12.4612  0.38100  0.00000                       16*.5
CYLINDER     0  12.7000  0.38100  0.00000                       16*.5
CYLINDER     2  12.7635  0.38100  0.00000                       16*.5
BOX TYPE     6  /* inner canister: fuel region #6: body assy
CYLINDER     0  10.8141  21.3385   0.0000                       16*.5
CYLINDER     2  10.9233  21.3385   0.0000                       16*.5
CYLINDER     3  10.9614  21.3385   0.0000                       16*.5
CYLINDER     4  12.4092  21.3385   0.0000                       16*.5
CYLINDER     2  12.4612  21.3385   0.0000                       16*.5
CYLINDER     0  12.7000  21.3385   0.0000                       16*.5
CYLINDER     2  12.7635  21.3385   0.0000                       16*.5
BOX TYPE     7  /* inner canister: fuel region #7: body assy
CYLINDER     0  10.8141   3.4925   0.0000                       16*.5
CYLINDER     2  10.9233   3.4925   0.0000                       16*.5
CYLINDER     3  10.9614   3.4925   0.0000                       16*.5
CYLINDER     4  12.4092   3.4925   0.0000                       16*.5
CYLINDER     2  12.4612   3.4925   0.0000                       16*.5
CYLINDER     0  12.7000   3.4925   0.0000                       16*.5
CYLINDER     2  12.7635   3.4925   0.0000                       16*.5
BOX TYPE     8  /* inner canister   fuel region #8: lid assy
CYLINDER     0  10.8141  0.63250  0.00000                       16*.5
CYLINDER     2  10.9233  0.63250  0.00000                       16*.5
CYLINDER     3  10.9614  0.63250  0.00000                       16*.5
CYLINDER     4  12.4092  0.63250  0.00000                       16*.5
CYLINDER     2  12.4612  0.63250  0.00000                       16*.5
CYLINDER     0  12.7000  0.63250  0.00000                       16*.5
CYLINDER     2  12.7635  0.63250  0.00000                       16*.5
BOX TYPE     9  /* inner canister   fuel region #9 w/ gap: lid assy
CYLINDER     0  10.8141  0.31750  0.00000                       16*.5
CYLINDER     2  10.9233  0.31750  0.00000                       16*.5
CYLINDER     0  12.4092  0.31750  0.00000                       16*.5
CYLINDER     2  12.4612  0.31750  0.00000                       16*.5
BOX TYPE    10  /* inner canister   fuel region #10 w/ ring: lid assy
CYLINDER     0  10.8141  0.44200  0.00000                       16*.5
CYLINDER     2  10.9233  0.44200  0.00000                       16*.5
CYLINDER     2  12.4092  0.44200  0.00000                       16*.5
CYLINDER     2  12.4612  0.44200  0.00000                       16*.5
BOX TYPE    11  /* inner canister   fuel region #11 w/ top: lid assy
CYLINDER     0  10.8141  1.78050  0.00000                       16*.5
CYLINDER     2  10.9233  1.91640  0.00000                       16*.5
CYLINDER     0  12.4092  1.91640  0.00000                       16*.5
BOX TYPE    12  /* inner canister cuboid: body section (7# region)
CUBOID       5  12.7636  12.7636  12.7636  12.7636  73.3450   0.5055  16*.5
BOX TYPE    13  /* inner canister cuboid: body section (40# region)
CUBOID       9  12.7636  12.7636  12.7636  12.7636  3.49260  0.00000  16*.5
```

```
BOX TYPE    14  /* inner canister upper cylinder, lid section
CYLINDER     0  12.7636  3.30840  0.00000                                   16*.5
BOX TYPE    15  /* foam cutout (void)   40 #/ft3 foam lid section
CYLINDER     0  13.5510  3.30840  0.00000                                   16*.5
BOX TYPE    16  /* npc body or lid   10 ga. 304ss layer
CUBOID       2  54.3687  54.3687  54.3687  54.3687  0.31240  0.00000  16*.5
BOX TYPE    17  /* npc body or lid   1" duraboard (void) layer, 10 ga. 304ss
CUBOID       0  51.5163  51.5163  51.5163  51.5163  2.54000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  2.54000  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  2.54000  0.00000  16*.5
BOX TYPE    18  /* npc body   3" bot. foam layer (11 #/ft3), 10 ga. 304ss
CUBOID       7  51.5163  51.5163  51.5163  51.5163  7.62000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  7.62000  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  7.62000  0.00000  16*.5
BOX TYPE    19  /* npc body   29.0750" foam layer (7,11 #/ft3),10 ga. 304ss
CUBOID       5  43.8963  43.8963  43.8963  43.8963  73.8505   0.0000  16*.5
CUBOID       7  51.5163  51.5163  51.5163  51.5163  73.8505   0.0000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  73.8505   0.0000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  73.8505   0.0000  16*.5
BOX TYPE    20  /* npc body   1.375 " foam layer (40 #/ft3), 10 ga. 304ss
CUBOID       9  51.5163  51.5163  51.5163  51.5163  3.49250  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE    21  /* npc body   30.45" two part body
CUBOID       0  54.3687  54.3687  54.3687  54.3687  77.3430   0.0000  16*.5
BOX TYPE    22  /* npc lid   1.375 " foam layer (40 #/ft3), 10 ga. 304ss
CUBOID       9  51.5163  51.5163  51.5163  51.5163  3.49250  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE    23  /* npc lid   3.5" foam layer (15 #/ft3), 10 ga. 304ss
CUBOID       8  51.5163  51.5163  51.5163  51.5163  8.89000  0.00000  16*.5
CUBOID       0  54.0563  54.0563  54.0563  54.0563  8.89000  0.00000  16*.5
CUBOID       2  54.3687  54.3687  54.3687  54.3687  8.89000  0.00000  16*.5
BOX TYPE    24  /* complete npc   body assembly
CUBOID       0  54.3688  54.3688  54.3688  54.3688  87.8154   0.0000  16*.5
BOX TYPE    25  /* complete npc   lid assembly
CUBOID       0  54.3688  54.3688  54.3688  54.3688  15.2349   0.0000  16*.5
BOX TYPE    26  /* global unit, npc infinite system
CUBOID       0  54.3700  54.3700  54.3700  54.3700  103.051    0.000  16*.5
 26   1 1 1   1 1 1   1 1 1   1
BEGIN COMPLEX
/* build inner canister   main body section (7 #/ft3 region)
COMPLEX 12  1  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 12  2  0.00000  0.00000  0.31750   1  1  1  0.0   0.0   0.0
COMPLEX 12  3  0.00000  0.00000  25.7810   1  1  1  0.0   0.0   0.0
COMPLEX 12  4  0.00000  0.00000  26.1621   1  1  1  0.0   0.0   0.0
COMPLEX 12  5  0.00000  0.00000  51.6256   1  1  1  0.0   0.0   0.0
COMPLEX 12  6  0.00000  0.00000  52.0066   1  1  1  0.0   0.0   0.0
/* build inner canister   upper body section (40 #/ft3 section)
COMPLEX 13  7  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
/* build inner canister   lid section
COMPLEX 14  8  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 14  9  0.00000  0.00000  0.63250   1  1  1  0.0   0.0   0.0
COMPLEX 14 10  0.00000  0.00000  0.95000   1  1  1  0.0   0.0   0.0
COMPLEX 14 11  0.00000  0.00000  1.39200   1  1  1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid, 11.75" centers
COMPLEX 15 14  29.8450  29.8450  0.00000   3  3  1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs,11.75" centers
COMPLEX 22 15  29.8450  29.8450  0.00000   3  3  1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body, 11.75" centers
COMPLEX 19 12  29.8450  29.8450  0.50550   3  3  1  29.8450  29.8450  0.0
COMPLEX 20 13  29.8450  29.8450  0.00000   3  3  1  29.8450  29.8450  0.0
/* embed two part body section stackup
COMPLEX 21 19  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 21 20  0.00000  0.00000  73.8505   1  1  1  0.0   0.0   0.0
/* build npc   body assembly
COMPLEX 24 16  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 24 17  0.00000  0.00000  0.31240   1  1  1  0.0   0.0   0.0
COMPLEX 24 18  0.00000  0.00000  2.85240   1  1  1  0.0   0.0   0.0
COMPLEX 24 21  0.00000  0.00000  10.4724   1  1  1  0.0   0.0   0.0
/* build npc   lid assembly
COMPLEX 25 22  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 25 23  0.00000  0.00000  3.49250   1  1  1  0.0   0.0   0.0
COMPLEX 25 17  0.00000  0.00000  12.3825   1  1  1  0.0   0.0   0.0
COMPLEX 25 16  0.00000  0.00000  14.9225   1  1  1  0.0   0.0   0.0
/* complete npc stackup   single unit
COMPLEX 26 24  0.00000  0.00000  0.00000   1  1  1  0.0   0.0   0.0
COMPLEX 26 25  0.00000  0.00000  87.8154   1  1  1  0.0   0.0   0.0
END GEOM
DEFAULTS=YES
END GEMER
```

Figure 6.8c — Sample input file = npca2_60.in

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
     0  293     0    0
\CSXSEC\UO2\GUO2 50.285
\CSXSEC\NOU\GNOU 0.SS
\CSXSEC\NOU\GNOU 0.CAD
\CSXSEC\NOU\GNOU 0.POL 0.98
\CSXSEC\NOU\GNOU 0.F07 0.90
```

```
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11-0.90
\CSXSEC\NOU\GNOU-0.F15-0.90
\CSXSEC\NOU\GNOU-0.F40-0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO-GEOM
      0  /* # OF REGIONS OR ZERO
      0  /* # OF BOX TYPES OR ZERO
      1  /* # OF BOXES IN X DIRECTION
      1  /* # OF BOXES IN Y DIRECTION
      1  /* # OF BOXES IN Z DIRECTION
      1  /* BOUNDARY CONDITION OPTION
      1  /* STARTING SOURCE OPTION
      1  /* COMPLEX EMBEDDED OPTION
      0  /* # OF PRINT PLOTS
         0.0       0.0       0.0       0.0       0.0       0.0
BOX-TYPE      1  /* inner canister, bottom fuel_region #1 w/ gap, body assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4092  0.31750  0.44200                          16*.5
CYLINDER      2  12.4612  0.31750  0.44200                          16*.5
CYLINDER      0  12.7000  0.31750  0.44200                          16*.5
CYLINDER      2  12.7635  0.31750  0.50550                          16*.5
BOX-TYPE      2  /* inner canister, fuel_region #2, body assy
CYLINDER      1  10.8141  25.4635  0.0000                           16*.5
CYLINDER      2  10.9233  25.4635  0.0000                           16*.5
CYLINDER      3  10.9614  25.4635  0.0000                           16*.5
CYLINDER      4  12.4092  25.4635  0.0000                           16*.5
CYLINDER      2  12.4612  25.4635  0.0000                           16*.5
CYLINDER      0  12.7000  25.4635  0.0000                           16*.5
CYLINDER      2  12.7635  25.4635  0.0000                           16*.5
BOX-TYPE      3  /* inner canister, fuel_region #3, 0.15"-cd gap, body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX-TYPE      4  /* inner canister, fuel_region #4, body assy
CYLINDER      1  10.8141  25.4635  0.0000                           16*.5
CYLINDER      2  10.9233  25.4635  0.0000                           16*.5
CYLINDER      3  10.9614  25.4635  0.0000                           16*.5
CYLINDER      4  12.4092  25.4635  0.0000                           16*.5
CYLINDER      2  12.4612  25.4635  0.0000                           16*.5
CYLINDER      0  12.7000  25.4635  0.0000                           16*.5
CYLINDER      2  12.7635  25.4635  0.0000                           16*.5
BOX-TYPE      5  /* inner canister, fuel_region #5, 0.15"-cd gap, body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX-TYPE      6  /* inner canister, fuel region #6, body assy
CYLINDER      1  10.8141  21.3385  0.0000                           16*.5
CYLINDER      0  10.8141  21.3385  0.0000                           16*.5
CYLINDER      2  10.9233  21.3385  0.0000                           16*.5
CYLINDER      3  10.9614  21.3385  0.0000                           16*.5
CYLINDER      4  12.4092  21.3385  0.0000                           16*.5
CYLINDER      2  12.4612  21.3385  0.0000                           16*.5
CYLINDER      0  12.7000  21.3385  0.0000                           16*.5
CYLINDER      2  12.7635  21.3385  0.0000                           16*.5
BOX-TYPE      7  /* inner canister, fuel region #7, body assy
CYLINDER      1  10.8141   3.4925  0.0000                           16*.5
CYLINDER      0  10.8141   3.4925  0.0000                           16*.5
CYLINDER      2  10.9233   3.4925  0.0000                           16*.5
CYLINDER      3  10.9614   3.4925  0.0000                           16*.5
CYLINDER      4  12.4092   3.4925  0.0000                           16*.5
CYLINDER      2  12.4612   3.4925  0.0000                           16*.5
CYLINDER      0  12.7000   3.4925  0.0000                           16*.5
CYLINDER      2  12.7635   3.4925  0.0000                           16*.5
BOX-TYPE      8  /* inner canister   fuel region #8, lid assy
CYLINDER      1  10.8141  0.63250  0.00000                          16*.5
CYLINDER      0  10.8141  0.63250  0.00000                          16*.5
CYLINDER      2  10.9233  0.63250  0.00000                          16*.5
CYLINDER      3  10.9614  0.63250  0.00000                          16*.5
CYLINDER      4  12.4092  0.63250  0.00000                          16*.5
CYLINDER      2  12.4612  0.63250  0.00000                          16*.5
CYLINDER      0  12.7000  0.63250  0.00000                          16*.5
CYLINDER      2  12.7635  0.63250  0.00000                          16*.5
BOX-TYPE      9  /* inner canister   fuel region #9 w/ gap, lid assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4612  0.31750  0.00000                          16*.5
BOX-TYPE     10  /* inner canister   fuel region #10 w/ ring, lid assy
CYLINDER      1  10.8141  0.44200  0.00000                          16*.5
CYLINDER      2  10.9233  0.44200  0.00000                          16*.5
CYLINDER      2  12.4092  0.44200  0.00000                          16*.5
CYLINDER      2  12.4612  0.44200  0.00000                          16*.5
BOX-TYPE     11  /* inner canister   fuel region #11 w/ top, lid assy
CYLINDER      1  10.8141  1.78050  0.00000                          16*.5
CYLINDER      2  10.9233  1.91640  0.00000                          16*.5
CYLINDER      0  12.4092  1.91640  0.00000                          16*.5
BOX-TYPE     12  /* inner canister cuboid, body section (7# region)
CUBOID        5  12.7636  12.7636  12.7636  12.7636  73.3450   0.5055  16*.5
BOX-TYPE     13  /* inner canister cuboid, body section (40# region)
CUBOID        9  12.7636  12.7636  12.7636  12.7636  3.49260  0.00000  16*.5
```

```
BOX TYPE      14  /* inner canister upper cylinder, lid section
CYLINDER       0  12.7636  3.30840  0.00000                              16*.5
BOX TYPE      15  /* foam cutout (void)    40 #/ft3 foam lid section
CYLINDER       0  13.5510  3.30840  0.00000                              16*.5
BOX TYPE      16  /* npc body or lid   10 ga. 304ss layer
CUBOID         2  54.3687  54.3687  54.3687  54.3687  0.31240  0.00000  16*.5
BOX TYPE      17  /* npc body or lid   1" duraboard (void) layer, 10 ga. 304ss
CUBOID         0  51.5163  51.5163  51.5163  51.5163  2.54000  0.00000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  2.54000  0.00000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  2.54000  0.00000  16*.5
BOX TYPE      18  /* npc body   3" bot. foam layer (11 #/ft3)   *** SN002 burn
CUBOID         7  47.4777  44.5567  45.3695  44.4805  0.00000  0.00000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  0.00000  7.62000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  0.00000  7.62000  16*.5
BOX TYPE      19  /* npc body   29.0750" foam layer (7,11 #/ft3)***SN002 burn
CUBOID         5  43.8963  43.8963  43.8963  43.8963  73.8505   0.0000  16*.5
CUBOID         7  47.4777  44.5567  45.3695  44.4805  73.8505   0.0000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  73.8505   0.0000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  73.8505   0.0000  16*.5
BOX TYPE      20  /* npc body   1.375 " foam layer (40 #/ft3)  *** SN002 burn
CUBOID         9  47.4777  44.5567  45.3695  44.4805  3.49250  0.00000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE      21  /* npc body   30.45" two part body
CUBOID         0  54.3687  54.3687  54.3687  54.3687  77.3430   0.0000  16*.5
BOX TYPE      22  /* npc lid   1.375 " foam layer (40 #/ft3)   *** SN002 burn
CUBOID         9  47.4777  44.5567  45.3695  44.4805  3.49250  0.00000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE      23  /* npc lid   3.5" foam layer (15 #/ft3)        *** SN002 burn
CUBOID         8  47.4777  44.5567  45.3695  44.4805  7.62000  0.00000  16*.5
CUBOID         0  54.0563  54.0563  54.0563  54.0563  8.89000  0.00000  16*.5
CUBOID         2  54.3687  54.3687  54.3687  54.3687  8.89000  0.00000  16*.5
BOX TYPE      24  /* complete npc   body assembly
CUBOID         0  54.3688  54.3688  54.3688  54.3688  87.8154   0.0000  16*.5
BOX TYPE      25  /* complete npc   lid assembly
CUBOID         0  54.3688  54.3688  54.3688  54.3688  15.2349   0.0000  16*.5
BOX TYPE      26  /* npc single unit cuboid
CUBOID         0  54.3688  54.3688  54.3688  54.3688  103.0503  0.0000  16*.5
BOX TYPE      27  /* global unit, 2N=150,5x5x6 cuboid, 30.48 cm h2o refl.
CUBOID         0  271.8440  271.8440 271.8440  271.8440 618.3018  0.000  16*.5
CUBOID         6  302.3240  302.3240 302.3240  302.3240 648.7818  30.48  16*.5
 27    1  1  1    1  1  1    1  1  1    1
BEGIN COMPLEX
/* build inner canister   main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister   upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister   lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid, 11.75" centers
COMPLEX  15 14  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs,11.75" centers
COMPLEX  22 15  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body, 11.75" centers
COMPLEX  19 12  29.8450  29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc   body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc   lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup   single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
/* embed 5x5x6 closed packed array
COMPLEX  27 26   217.4752  217.4752 0.000  5 5 6 108.7376 108.7376 103.0503
END GEOM
DEFAULTS=YES
END GEMER
```

Figure 6.8d – Sample input file = npcat_60.in

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
     0  293    0    0
\CSXSEC\UO2\GUO2-50.285
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL-0.98
\CSXSEC\NOU\GNOU-0.F07-0.90
\CSXSEC\NOU\GNOU-0.WAT
```

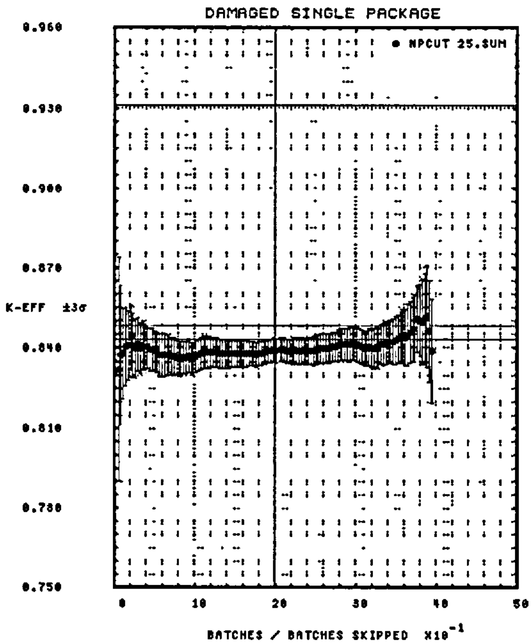
```
\CSXSEC\NOU\GNOU 0.F11 0.90
\CSXSEC\NOU\GNOU 0.F15 0.90
\CSXSEC\NOU\GNOU 0.F40 0.90
\CSXSEC\NOU\GNOU 0.ORC
KENO GEOM
      0  /* # OF REGIONS OR ZERO
      0  /* # OF BOX TYPES OR ZERO
      1  /* # OF BOXES IN X DIRECTION
      1  /* # OF BOXES IN Y DIRECTION
      1  /* # OF BOXES IN Z DIRECTION
      1  /* BOUNDARY CONDITION OPTION
      1  /* STARTING SOURCE OPTION
      1  /* COMPLEX EMBEDDED OPTION
      0  /* # OF PRINT PLOTS
        0.0       0.0       0.0       0.0       0.0       0.0
BOX TYPE      1  /* inner canister, bottom fuel_region #1 w/ gap, body assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4092  0.31750  0.44200                          16*.5
CYLINDER      2  12.4612  0.31750  0.44200                          16*.5
CYLINDER      0  12.7000  0.31750  0.44200                          16*.5
CYLINDER      2  12.7635  0.31750  0.50550                          16*.5
BOX TYPE      2  /* inner canister, fuel_region #2, body assy
CYLINDER      1  10.8141  25.4635  0.0000                           16*.5
CYLINDER      2  10.9233  25.4635  0.0000                           16*.5
CYLINDER      3  10.9614  25.4635  0.0000                           16*.5
CYLINDER      4  12.4092  25.4635  0.0000                           16*.5
CYLINDER      2  12.4612  25.4635  0.0000                           16*.5
CYLINDER      0  12.7000  25.4635  0.0000                           16*.5
CYLINDER      2  12.7635  25.4635  0.0000                           16*.5
BOX TYPE      3  /* inner canister, fuel_region #3, 0.15" cd gap, body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX TYPE      4  /* inner canister, fuel_region #4, body assy
CYLINDER      1  10.8141  25.4635  0.0000                           16*.5
CYLINDER      2  10.9233  25.4635  0.0000                           16*.5
CYLINDER      3  10.9614  25.4635  0.0000                           16*.5
CYLINDER      4  12.4092  25.4635  0.0000                           16*.5
CYLINDER      2  12.4612  25.4635  0.0000                           16*.5
CYLINDER      0  12.7000  25.4635  0.0000                           16*.5
CYLINDER      2  12.7635  25.4635  0.0000                           16*.5
BOX TYPE      5  /* inner canister, fuel_region #5, 0.15" cd gap, body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX TYPE      6  /* inner canister, fuel region #6, body assy
CYLINDER      1  10.8141  21.3385  0.0000                           16*.5
CYLINDER      0  10.8141  21.3385  0.0000                           16*.5
CYLINDER      2  10.9233  21.3385  0.0000                           16*.5
CYLINDER      3  10.9614  21.3385  0.0000                           16*.5
CYLINDER      4  12.4092  21.3385  0.0000                           16*.5
CYLINDER      2  12.4612  21.3385  0.0000                           16*.5
CYLINDER      0  12.7000  21.3385  0.0000                           16*.5
CYLINDER      2  12.7635  21.3385  0.0000                           16*.5
BOX TYPE      7  /* inner canister, fuel region #7, body assy
CYLINDER      1  10.8141   3.4925  0.0000                           16*.5
CYLINDER      0  10.8141   3.4925  0.0000                           16*.5
CYLINDER      2  10.9233   3.4925  0.0000                           16*.5
CYLINDER      3  10.9614   3.4925  0.0000                           16*.5
CYLINDER      4  12.4092   3.4925  0.0000                           16*.5
CYLINDER      2  12.4612   3.4925  0.0000                           16*.5
CYLINDER      0  12.7000   3.4925  0.0000                           16*.5
CYLINDER      2  12.7635   3.4925  0.0000                           16*.5
BOX TYPE      8  /* inner canister   fuel region #8, lid assy
CYLINDER      1  10.8141  0.63250  0.00000                          16*.5
CYLINDER      0  10.8141  0.63250  0.00000                          16*.5
CYLINDER      2  10.9233  0.63250  0.00000                          16*.5
CYLINDER      3  10.9614  0.63250  0.00000                          16*.5
CYLINDER      4  12.4092  0.63250  0.00000                          16*.5
CYLINDER      2  12.4612  0.63250  0.00000                          16*.5
CYLINDER      0  12.7000  0.63250  0.00000                          16*.5
CYLINDER      2  12.7635  0.63250  0.00000                          16*.5
BOX TYPE      9  /* inner canister   fuel region #9 w/ gap, lid assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4612  0.31750  0.00000                          16*.5
BOX TYPE     10  /* inner canister   fuel region #10 w/ ring, lid assy
CYLINDER      1  10.8141  0.44200  0.00000                          16*.5
CYLINDER      2  10.9233  0.44200  0.00000                          16*.5
CYLINDER      2  12.4092  0.44200  0.00000                          16*.5
CYLINDER      2  12.4612  0.44200  0.00000                          16*.5
BOX TYPE     11  /* inner canister   fuel region #11 w/ top, lid assy
CYLINDER      1  10.8141  1.78050  0.00000                          16*.5
CYLINDER      2  10.9233  1.91640  0.00000                          16*.5
CYLINDER      0  12.4092  1.91640  0.00000                          16*.5
BOX TYPE     12  /* inner canister cuboid, body section (7# region)
CUBOID        5  12.7636  12.7636  12.7636  12.7636  73.3450   0.5055  16*.5
BOX TYPE     13  /* inner canister cuboid, body section (40# region)
CUBOID        9  12.7636  12.7636  12.7636  12.7636  3.49260  0.00000  16*.5
BOX TYPE     14  /* inner canister upper cylinder, lid section
```

```
CYLINDER    0  12.7636  3.30840  0.00000                                  16*.5
BOX TYPE   15  /* foam cutout (void)    40 #/ft3 foam lid section
CYLINDER    0  13.5510  3.30840  0.00000                                  16*.5
BOX TYPE   16  /* npc body or lid   10 ga. 304ss layer
CUBOID      2  54.3687  54.3687  54.3687  54.3687  0.31240  0.00000  16*.5
BOX TYPE   17  /* npc body or lid   1" duraboard (void) layer, 10 ga. 304ss
CUBOID      0  51.5163  51.5163  51.5163  51.5163  2.54000  0.00000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  2.54000  0.00000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  2.54000  0.00000  16*.5
BOX TYPE   18  /* npc body    4" bot. foam layer (11 #/ft3)        face burn
CUBOID      7  42.6086  42.6086  42.6086  42.6086  0.00000  0.00000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  0.00000  7.62000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  0.00000  7.62000  16*.5
BOX TYPE   19  /* npc body    29.0750" foam layer (7,11 #/ft3)    face burn
CUBOID      5  42.6086  42.6086  42.6086  42.6086  73.8505   0.0000  16*.5
CUBOID      7  42.6086  42.6086  42.6086  42.6086  73.8505   0.0000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  73.8505   0.0000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  73.8505   0.0000  16*.5
BOX TYPE   20  /* npc body    1.375 " foam layer (40 #/ft3)        face burn
CUBOID      9  42.6086  42.6086  42.6086  42.6086  3.49250  0.00000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE   21  /* npc body    30.45" two part body
CUBOID      0  54.3687  54.3687  54.3687  54.3687  77.3430   0.0000  16*.5
BOX TYPE   22  /* npc lid   1.375 " foam layer (40 #/ft3)      lid burn
CUBOID      0  43.8963  43.8963  43.8963  43.8963  3.49250  0.00000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  3.49250  0.00000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  3.49250  0.00000  16*.5
BOX TYPE   23  /* npc lid   3.5" foam layer (15 #/ft3)          lid burn
CUBOID      0  43.8963  43.8963  43.8963  43.8963  2.54000  0.00000  16*.5
CUBOID      0  54.0563  54.0563  54.0563  54.0563  8.89000  0.00000  16*.5
CUBOID      2  54.3687  54.3687  54.3687  54.3687  8.89000  0.00000  16*.5
BOX TYPE   24  /* complete npc   body assembly
CUBOID      0  54.3688  54.3688  54.3688  54.3688  87.8154   0.0000  16*.5
BOX TYPE   25  /* complete npc   lid assembly
CUBOID      0  54.3688  54.3688  54.3688  54.3688  15.2349   0.0000  16*.5
BOX TYPE   26  /* npc single unit cuboid
CUBOID      0  54.3688  54.3688  54.3688  54.3688  103.0503  0.0000  16*.5
BOX TYPE   27  /* global unit: 2N=150:5x5x6 cuboid, 30.48 cm h2o refl.
CUBOID      0  271.8440  271.8440 271.8440  271.8440 618.3018  0.000  16*.5
CUBOID      6  302.3240  302.3240 302.3240  302.3240 648.7818  30.48  16*.5
 27    1  1  1   1  1  1   1  1  1   1
BEGIN COMPLEX
/* build inner canister   main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister   upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister   lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid: 11.75" centers
COMPLEX  15 14  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs:11.75" centers
COMPLEX  22 15  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body: 11.75" centers
COMPLEX  19 12  29.8450  29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13  29.8450  29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc   body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc   lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup   single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
/* embed 5x5x6 closed packed array
COMPLEX  27 26   217.4752  217.4752 0.000  5 5 6 108.7376 108.7376 103.0503
END GEOM
DEFAULTS=YES
END GEMER
```

6.4.46.4.5 CONVERGENCE OF CALCULATIONS

Problem convergence was determined by examining plots of k_{eff} by generation run and skipped, as well as the final k_{eff} edit tables. No abnormal trends were observed to indicate non-convergence of the eigenvalue solution. Representative convergence plots for the individual damaged single package, undamaged array, and damaged array models are shown in Figures 6.109a- 6.109d. (The plots shown are for cases with homogeneous UO_2 and H_2O mixtures, but the results are also representative of the results for heterogeneous lattices.)

Figure 6.109a – Sample k_{eff} convergence: damaged unit – npcut_25.in



~~**Figure 6.9b – Sample k_{eff} convergence: undamaged array – npc6um60.in**~~

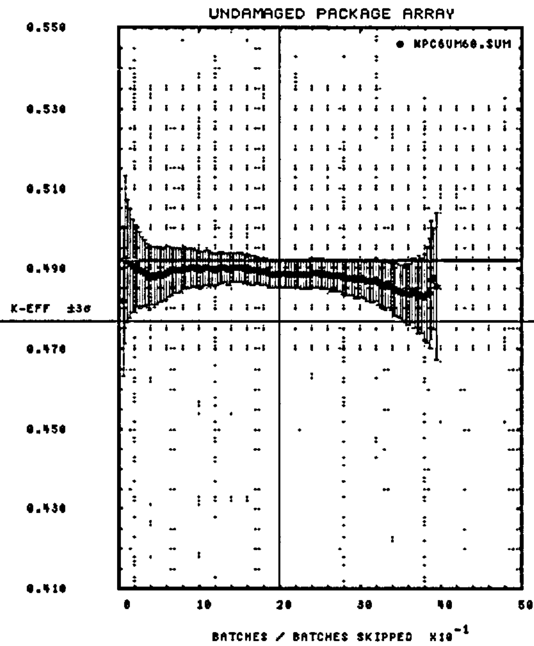


Figure 6.10b – Sample k_{eff} convergence: undamaged array - npc60i28.in

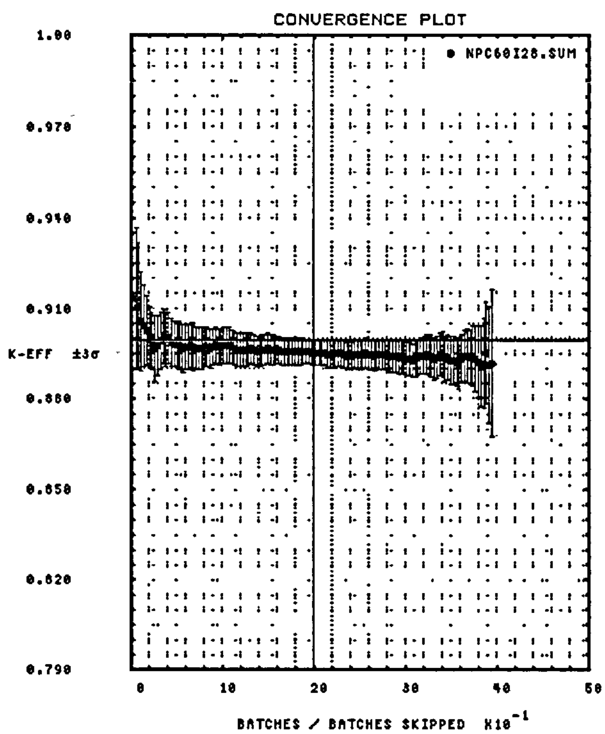


Figure 6.109c – Sample k_{eff} convergence: damaged array – npca2_60.in (CTU-2 observed burn)

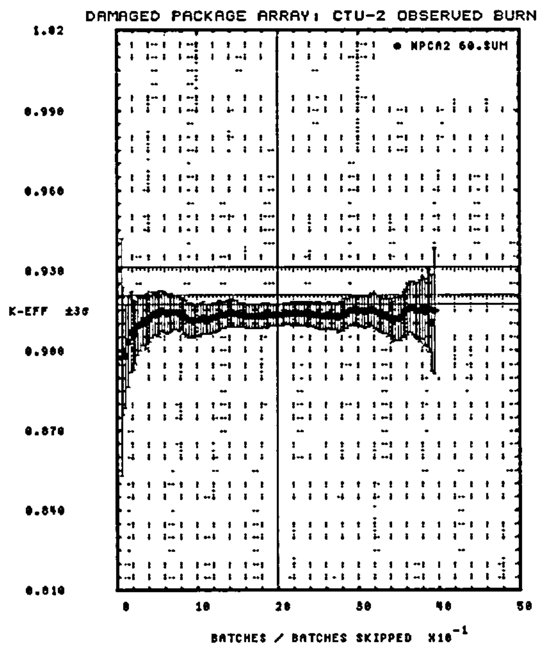


Figure 6.109d – Sample k_{eff} convergence: damaged array - npcat_60.in (maximum burn)