3.0 RESULTS OF THE CRITICALITY ANALYSES

3.1 CASMO-4 and KENO V.a Reactivity Calculation Comparison

As a check of the two independent methods used for these analyses, the reactivity of each fuel type in the standard cold-core geometry (SCCG) at cold temperature conditions (68°F) has been calculated both with KENO V.a and with CASMO-4 at zero burnup. Both models are exact renderings of the assemblies in core geometry. Table 2 contains the k_∞ for each fuel lattice assembly with Gd_2O_3 rods. The reported k_∞ values include model biases which have been determined using benchmark calculations. These model biases are Δk_∞ = -0.00782 and Δk_∞ = -0.01028 for KENO V.a and CASMO-4, respectively. 2

Table 2
CASMO-4 / KENO V.a Reactivity Comparison in Standard Cold-Core Geometry at Zero Burnup

Fuel Type	Gd_2O_3 (rods, w/o)	Enrichment (w/o U-235)	k_∞	
			KENO V.a	CASMO-4
7x7	2@1.0, 2 @ 0.5	2.50	1.17469 ± 0.0004	1.17551
8x8 (2 water rods)	7 @ 4.0	3.20	1.13409 ± 0.0004	1.13403
8x8 (4 water rods)	8 @ 4.0	3.42	1.12932 ± 0.0004	1.12873
9x9	12 @ 5.0	4.00	1.08419 ± 0.0004	1.08418
9x9	12 @ 5.0	4.21	1.10256 ± 0.0004	1.10127
9x9	14 @ 6.0	4.60	1.07399 ± 0.0004	1.07273

2

The maximum difference between the Keno V.a and CASMO-4 eigenvalues is less than 0.0015 Δk_∞.

3.2 Reactivity Calculations

3.2.1 CASMO-4 Depletion Calculations

CASMO-4 was utilized to compute the reactivity of a limiting reactivity fuel lattice as a function of burnup for each fuel type. The limiting reactivity lattice with respect to planar average enrichment, number of gadolinia rods and gadolinia loading was determined from fuel assembly design reports[9,10]. Sensitivity analyses demonstrated that average power density, average fuel temperature, saturation temperature of the moderator, and zero void results in the most reactive condition (peak bundle reactivity). Accordingly, the depletion calculations were conducted under these average conditions with 0% void.

For subsequent analyses of the Boraflex modules in finite three-dimensional models, the reactivity equivalent fresh fuel enrichment (REFFE) was first determined and subsequently utilized in the calculations. The REFFE was determined by modeling each limiting fuel bundle lattice (with respect to maximum enrichment and minimum gadolinia loading) in the standard cold core and in-rack geometries. The U^{235} enrichment was varied until the bias- 2
corrected k_∞ calculated using the Keno V.a rack model at the REFFE slightly exceeded the k_∞ value calculated at the point of peak reactivity during depletion. The k_∞ of the Keno V.a model at the REFFE always exceeds the k_∞ at peak reactivity during depletion. Table 3 contains the k_∞ values for each lattice type for CASMO-4 and Keno V.a.

Table 3

Reactivity Equivalent Fresh Fuel Enrichments and Limiting Lattice k_∞ at Peak Reactivity

Array	w/o U235	No. of Gadolinia Rods	Gd_2O_3	k_∞-SCCG (CASMO)	k_∞-SCCG (KENO V.a)	REFFE	
7x7	2.5	2 , 2	1.0, 0.5	1.2428	1.2465	2.15	2
8x8	3.2	7	4.0	1.2164	1.2169	2.10	
8x8	3.42	8	4.0	1.2254	1.2258	2.20	1
8x8	3.6	9	4.0	1.2368	1.2379	2.30	
9x9	4.0	12	5.0	1.2340	1.2478	2.35	
9x9	4.21	12	5.0	1.2441	1.2478	2.35	1
9x9	4.6	14	6.0	1.2323	1.2478	2.35	

3.2.2 Reference Keno V.a Model

A reference Keno V.a model was created based upon the actual fuel assemblies loaded in the "South" Boraflex module under the tooling table. All assemblies in the "South" module are 8x8 lattices and are conservatively assumed to be at a REFFE corresponding to a burnup of peak assembly reactivity. To simplify modeling of the South module, several assemblies were conservatively modeled at higher enrichments. With the following exceptions, all "South" module cells contain 8x8 fuel at 3.2 peak planar enrichment:

- Cells 2A55 thru 2A58 and 2B72 thru 2C72 actually contain 8x8 assemblies at 2.82 w/o U-235 peak planar enrichment, however, these cells are conservatively modeled as 8x8 assemblies at 3.2 w/o peak planar enrichment.
- Cells 2B56, 2L56, 2B71 and 2L71 are empty cells containing tooling table support legs, nevertheless are conservatively modeled as 8x8 fuel assemblies at 3.2 w/o.
- Cell 2A71 and 2M72 contain 8x8 assemblies at 3.2 w/o; these cells are conservatively modeled as 3.42 w/o enrichment assemblies.
- Cells 2D71 thru 2F71 contain 8x8 fuel assemblies at 3.2 w/o; these cells are conservatively modeled as 3.42 w/o fuel assemblies.
- Cells 2G72 thru 2K72 contain 8x8 fuel assemblies at 2.82 w/o. These cells are conservatively modeled as 8x8 fuel at 3.2 w/o enrichment.
- Cells 2M59 thru 2M71 and 2K55 thru 2L55 contain 8x8 fuel assemblies at 3.42 w/o as currently loaded in the "South" module.

Figure 5 shows the fuel initial enrichment, gadolinia loading, and limiting k_∞ (SCCG) of assemblies modeled in the "South" module.

In the "North" module there are two non-fuel components residing in cells 2D37 and 2L53. For conservatism, all cells are assumed to include 9x9 fuel at peak reactivity. The analysis for the "North" module accounted for possible future reload enrichments up to 4.60 w/o U-235 with a minimum number of gadolinia rods at the minimum loading based upon reload assembly design reports[9,10]. In modeling the 9x9 assemblies in the "North" module, several conservatisms were included in the model. These include:

- The number of gadolinia rods was taken at the minimum number in any zone (e.g. vanished zones typically had one less gadolinia rod than did the dominant zones).
- For assemblies with split gadolinia loadings, the minimum loading was used.

The neighboring fuel racks to the East and North of the Boraflex modules contain BORAL as the neutron absorber material. Additional arrays of BORAL modules containing 10x10 fuel assemblies were added to the Boraflex modules to create a full pool model as shown in Figure 6. Although 10x10 assemblies are not currently loaded in the BORAL modules, the future use of this array type is possible. However, 10x10 assemblies may NOT be stored in the Boraflex modules. The following conservative assumptions were used to model the additional BORAL modules:

- As previous analyses had shown the 10x10 fuel type is more reactive than the 9x9 fuel type[2], the 10x10 fuel assemblies were modeled in the BORAL modules.
- All fuel is at a REFFE of 2.55 w/o U-235, corresponding to the tech specification limit $k_\infty \leq 1.31$ in SCCG. [5]
- The areal density of the BORAL absorber is assumed to be at the minimum certified value of 0.015 gms B-10/cm^2. [11]

The reference case is a full fuel height model with water albedoes in the axial directions. The South and West boundary conditions both incorporate a 24-inch concrete albedo and the North and East boundaries along the BORAL modules incorporate a water albedo boundary condition.

The reference case Keno V.a model was executed using 3050 neutron generations and 5,000 neutrons per generation for a total of 15 million neutron histories. The first fifty neutron generations were omitted to attain source convergence.

3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	55
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	56
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	57
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	58
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods@4w/o 1.2254	59
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	60
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	61
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	62
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	63
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	64
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	65
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	66
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	67
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	68
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	69
3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	70
3.42 8rods@4w/o 1.2254	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	3.42 8rods/4w/o 1.2254	3.42 8rods/4w/o 1.2254	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	71
3.42 8rods/4w/o 1.2254	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	3.42 8rods/4w/o 1.2254	3.42 8rods/4w/o 1.2254	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.2 7rods@4w/o 1.2164	3.42 8rods/4w/o 1.2254	72
2A	2B	2C	2D	2E	2F	2G	2H	2J	2K	2L	2M	

2

Figure 5: U-235 Enrichment and Gadolinia Distribution of 8x8 Assemblies as Modeled in the NMP1 "South" Boraflex Module.

Key:

w/o U-235
Gad rods, loading
limiting k_∞

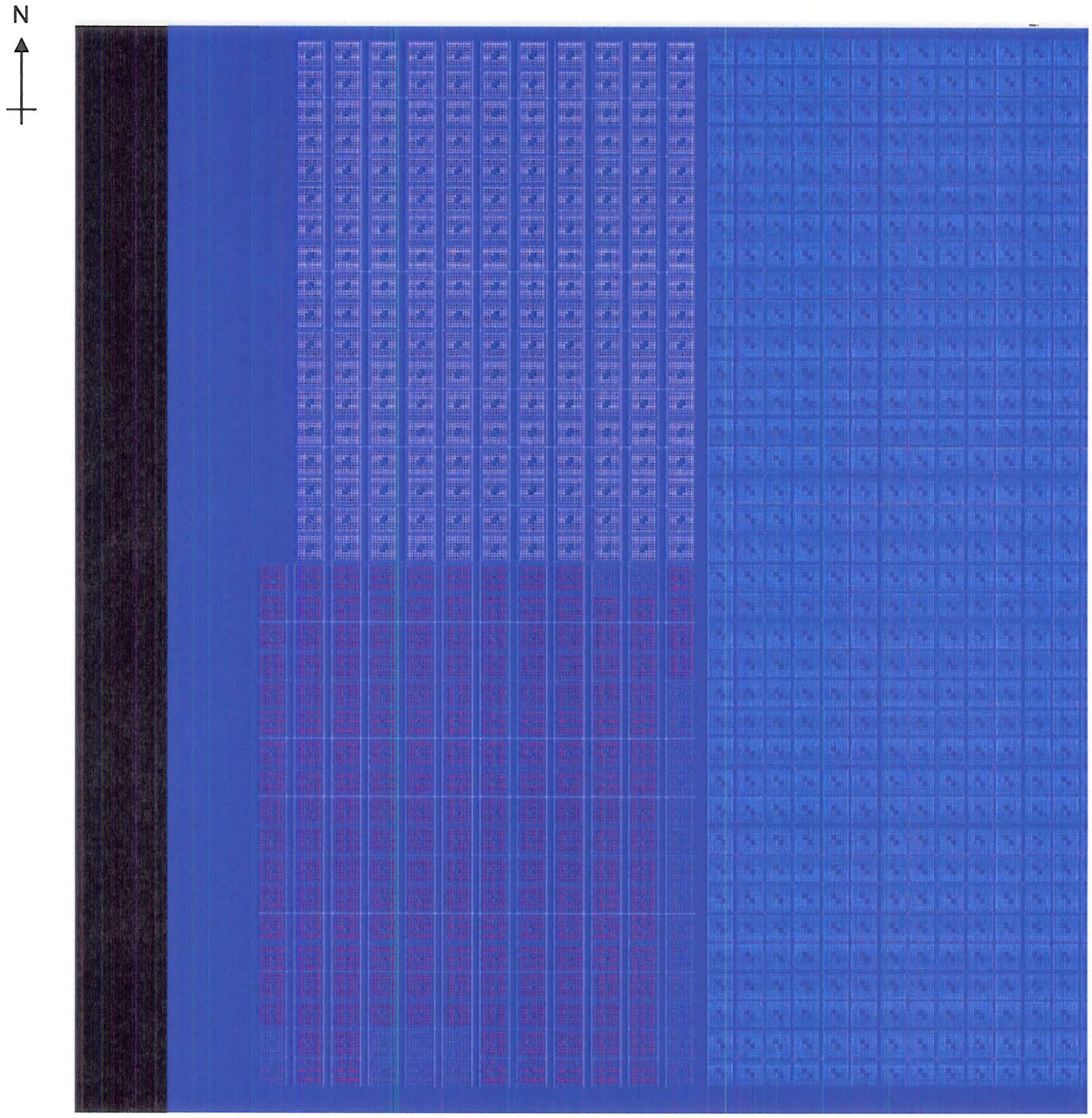

Figure 6: Reference Case Keno V.a Generated Plot of the NMP1 Boraflex Modules Loaded with 8x8 and 9x9 Fuel Assemblies and BORAL Modules Loaded with 10x10 Fuel Assemblies.

3.3 Effect of Tolerances and Uncertainties

3.3.1 Tolerances and Calculational Uncertainties

To evaluate the reactivity effects of fuel and rack manufacturing tolerances in the "North" and "South" modules, CASMO-4 and Keno V.a perturbation calculations were performed. The limiting reactivity fuel assembly 9x9 at peak burnup was used. This is conservative with respect to the tolerance effects from the lower reactivity assemblies. Additionally, tolerances were determined based on an infinite array of storage cells. The following tolerance and uncertainty components are addressed:

U-235 Enrichment: The enrichment tolerance of ± 0.088 w/o U-235 variation about the nominal reference value of 4.60 w/o U-235 was considered. [12] Reference 12 states:

> "Enrichment Variation: For enrichment variations ≥ 2.0% U^{235}. Nominal ± 0.088 w/o" Furthermore, the letter states "Process history shows an overall process standard deviation of 0.023 w/o U^{235} for enrichments ≥ 3.95% U^{235}."

UO_2 Pellet Density: A variation of -2.0%/+1.0 (absolute) about the nominal reference theoretical density of 97%.[13] Reference 13 states:

> " As you can see by the attached email from GE, we are currently loading pellets with 97% theoretical U density. The tolerance on this range is –2%
> to +1% meaning that the maximum density range of theoretical densities is 2
> from 95% to 98%."

Pellet Dishing: The pellets were assumed to be undished. This is a conservative assumption in that it maximizes the U-235 loading per axial centimeter of the fuel stack. No sensitivity analyses were completed with respect to the variations in the pellet dishing factor.

Pellet Diameter: The tolerance value of ±0.002 inches was used. Bundle Announcement Reports [9.10] state that the maximum tolerance for the 7x7, 8x8, or 9x9 fuel types is ±0.001 inches.

Clad Inside Diameter: The tolerance value of ±0.002 inches was used. Bundle Announcement Reports [9.10] state that the maximum tolerance for the 7x7, 8x8, or 9x9 fuel types is ±0.001 inches.

Clad Outside Diameter: Clad OD is bounded by the combination of wall thickness tolerance and inner diameter tolerance. Each of these is addressed separately, thus no further analysis is required.

Clad Thickness: The value of ±0.004 inches was used in Reference 12. Bundle Announcement Reports [9.10] state that the maximum tolerance for the 7x7, 8x8, or 9x9 fuel types is ±0.004 inches.

Gd_2O_3 Loading: In the maximum reactivity assembly at 14.0 GWD/MTU the Gd_2O_3 is depleted; however, the burnup at peak reactivity depends on the initial Gd_2O_3 loading. The 2
tolerance of ±10% (relative) in the Gd_2O_3 loading has been used[12]. Reference 12 further states:

> "...the 95% confidence limits on the mean gadolinia loading content shall be within ±7.5% (relative) of nominal. Individual pellet gadolinia content is limited to ±10% (relative) of nominal."
> Therefore, the tolerance value of ±0. 5 w/o gadolinia (10% relative) employed in this analysis is conservative.

Cell Inside Dimension: The manufacturing tolerance of ± 0.030 inch for the variations in cell wall inside dimensions was used[15].

Stainless Steel Thickness: A stainless steel sheet tolerance of ± 0.004 inches was used.[15]

Flux Trap Width: The manufacturing tolerance on the flux trap width of -0.038 inch was used.[15]

Cell-to-Cell Pitch: Cell-to-cell pitch is determined by the cell wall thickness, cell inside dimensions and flux trap width in the NMP1 fuel rack. Each of these is addressed separately and no further allowances are required.

Assembly Location: The reference KENO V.a reactivity calculations are based on a model with each assembly symmetrically positioned in each storage cell. The effect of four adjacent assemblies with minimum separation distance has been considered.

Calculational Uncertainty: The 95% probability / 95% confidence level uncertainty associated with the reference KENO V.a calculation has been applied.

Methodology Uncertainty: The 95% probability / 95% confidence level uncertainty of 0.0078 as determined from benchmark calculations (see Appendix) has been considered.

3.3.2 Uncertainty Introduced by Depletion Calculations

Critical experiment data are generally not available for spent fuel and, accordingly, some judgment must be used to assess those uncertainties introduced by the depletion calculations. CASMO-4 and the 70 group cross section library used for these analyses have been used extensively to generate assembly average cross sections for core follow calculations and reload fuel design in both BWRs and PWRs. Any significant error in those depletion calculations would be detectable either by incore instrumentation measurements of core power distribution or cycle energy output or both. Significant deviations between the predicted and actual fuel cycle lengths and core power distributions using CASMO-4 generated cross sections are not observed.

For the purpose of assessing the effects of uncertainties introduced by depletion calculations, it is useful to estimate the magnitude of depletion uncertainties in k_∞ and compare this uncertainty with margins inherent in the present calculation. It is assumed that depletion calculations introduce an uncertainty in k_∞ which is a linear function of burnup such that at a burnup of 40,000 MWD/MTU the Δk_{unc} due to depletion effects is 0.02. So that for the limiting reactivity assembly at 14 GWD/MTU, the uncertainty introduced by depletion is 0.00700 in Δk_∞. This uncertainty is included in the statistical treatment of tolerances and uncertainties in Table 4. Additional methods for determining the uncertainty in depletion calculations have been proposed.[14] These methods result in a Δk due to burnup of ~ +0.0067, therefore the 0.00700 Δk used is bounding. 2

3.4 Summary of Reactivity Calculations

3.4.1 Reference Loading

The explicit model developed in Section 3.2 was executed to determine the reactivity of the two remaining NMP1 Boraflex spent fuel racks while taking no credit for Boraflex.

For the reference case with the "South" module conservatively modeled as described in Section 3.2 and the "North" module loaded with 9x9 fuel at maximum reactivity, the calculated k_{eff} was 0.92217. Additional cases were run with various UO_2 1 2
enrichment/gadolinia combinations to confirm that the reference case k_{eff} is bounding. Table 4 contains a summary of the criticality analyses results for the NMP1 spent fuel racks. Table 5 contains the required minimum gadolinia loading as a function of enrichment for the 9x9 fuel resident in the "North" module. 2

Table 4

Summary of Criticality Calculation Results for the NMP1 Boraflex Spent Fuel Racks with North Module Containing Peak Reactivity 9x9 Fuel at a REFFE of 2.35 1
w/o (corresponding to 4.21 w/o, 12 Gadolinia Rods @ 5 w/o, 150° F) 2

Reference Case k_{eff}	0.91435
Methodology Bias	+0.00786
Nominal k_{eff} (best estimate)	0.92217
<u>Tolerances and Uncertainties:</u>	
Fuel Material	
- U-235 Enrichment	+0.00412
- UO2 Density	+0.00024
-Gd_2O_3 Loading	+0.00995
-Pellet Diameter	+0.00160 2
-Clad Diameter/thickness	+0.00514
<u>Rack Construction</u>	
- Flux Trap Width Pitch	+0.00594
- Cell ID	+0.00237
- Cell Wall Thickness	+0.00000
Burnup Uncertainty	+0.00700
Assembly Placement	+0.00062
Methodology Bias Uncertainty (95/95)	+0.00963
Calculational Uncertainty (95/95)	+0.00032
Square Root of Sum of Squares:	+0.01812
Maximum k_∞ (95x 95)	0.94028
Effect of Worst Case Accident	+0.00901
Maximum k_∞ (95x 95, Including Accident)	0.94930
Margin	+0.00070

The reactivity effects of tolerances and uncertainties were evaluated with an infinite array of 9x9 assemblies at peak reactivity and when combined in a root-mean-square sense yield $\Delta k = 0.01812$. The difference between these values and the 0.95 design limit represents 2
margin, which would be available to accommodate reactivity increases as may be the result of postulated accidents.

Table 5
Minimum Gadolinia Loading as a Function of Initial Peak Planar Enrichment for 9x9 Fuel[9,10]

w/o U-235	Number of Gadolinia Rods	w/o Gadolinia	Limiting k_∞ (SCCG)
4.0	12	5.0	1.2340
4.21*	12	5.0	1.2441
4.6+	14	6.0	1.2323

2

* Reference Case/Limiting k_∞

\+ Predicted for Future Reloads

3.5 Abnormal/Accident Conditions

The reactivity effects of the following abnormal/accident conditions have been conservatively evaluated:

- Fuel Assembly Drop
- Fuel Assembly Inadvertent Positioning Alongside Rack
- Fuel Assembly Misload
- Moderator Temperature Variations

The drop of a 10x10 reload fuel assembly assumed to come to rest in a horizontal position on top of the "North" module has been evaluated with all assemblies in place as shown in Figure 6 (on page 19). The reactivity effect is negligible ($\Delta k_{eff} < 0.00021$). 1

The inadvertent positioning or drop of a fuel assembly alongside of the Boraflex modules in the corner of the "North" module and above the "South" module and the pool wall as shown in Figure 7 has been evaluated. The increase in rack reactivity as determined by KENO V.a is negligible ($\Delta k_{eff} < 0.00082$). 1 2

For both the assembly drop and inadvertent positioning, the reactivity effect is well within the margin inherent in the design of the NMP1 spent fuel racks assuming 100% Boraflex loss.

The misloading of a 10x10 fuel assembly in the "North" Boraflex module has been evaluated for multiple positions within the Boraflex module. The maximum reactivity effect was determined to occur when the 10x10 reload assembly is centered in the "North" module shown in Figure 8, with the resulting reactivity effect $\Delta k_{eff} = 0.00090$. Under the 1
conservative assumptions of these analyses, the maximum fuel rack k_{eff} (at a 95% 2
probability with a 95% confidence level) has been determined to be 0.94118. 1

The effect of variations in moderator density and temperature on the reactivity of the NMP1 fuel storage racks has been analyzed[1]. These analyses were performed at 220°F, the point of boiling at the depth of the fuel racks and with approximately 20% void. The maximum reactivity effect is +0.00901Δk. For these conditions, the maximum k_{eff} is 2
0.94930 (at 95% probability/95% confidence level). Therefore, within the moderator 1
temperature variations analyzed, adequate subcritical margin is maintained.

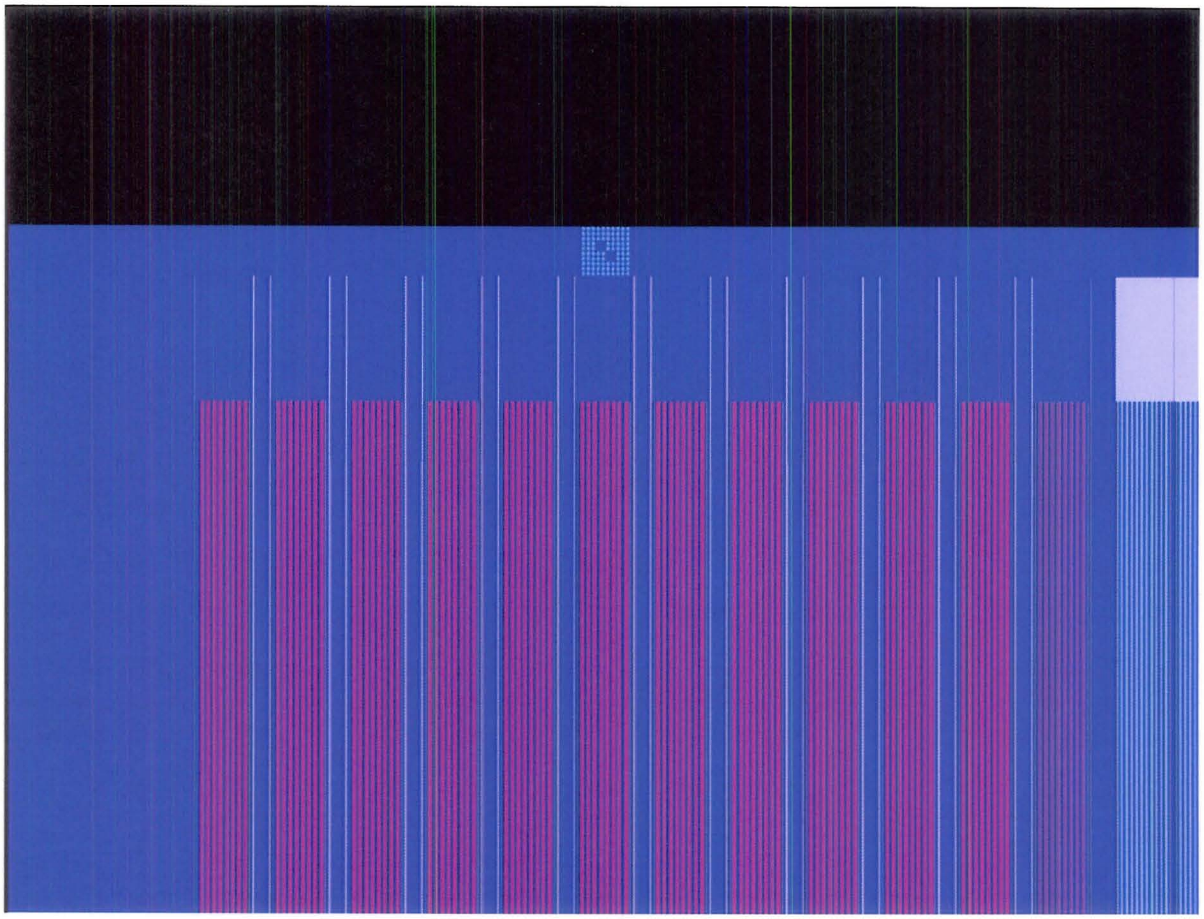

Figure 7: Keno V.a Generated Plot of a Dropped Assembly Resting on Top of "North" Boraflex Module.

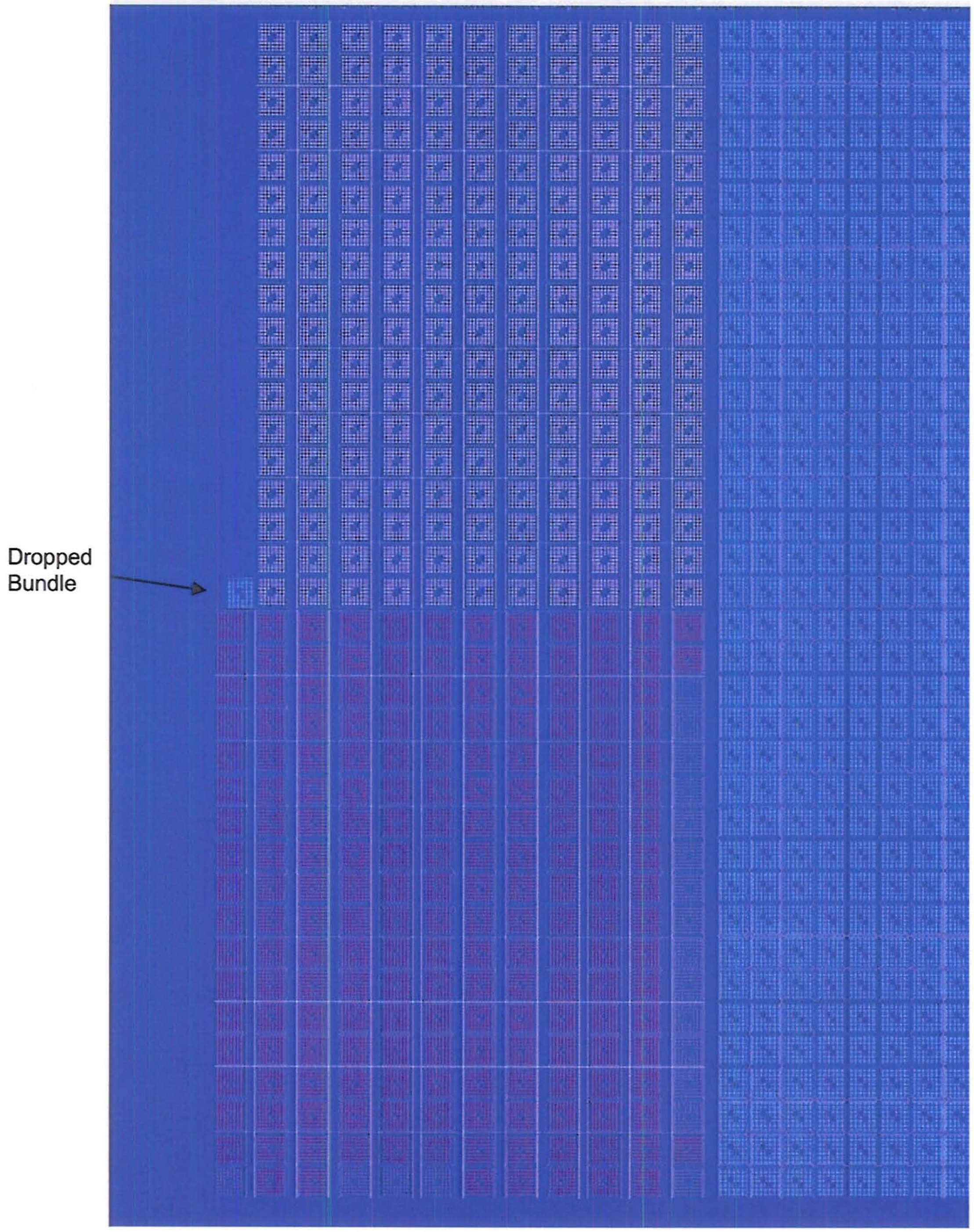

Figure 8: Keno V.a Generated Plot of a Dropped Fuel Assembly Alongside of the "North" and "South" Boraflex Modules.

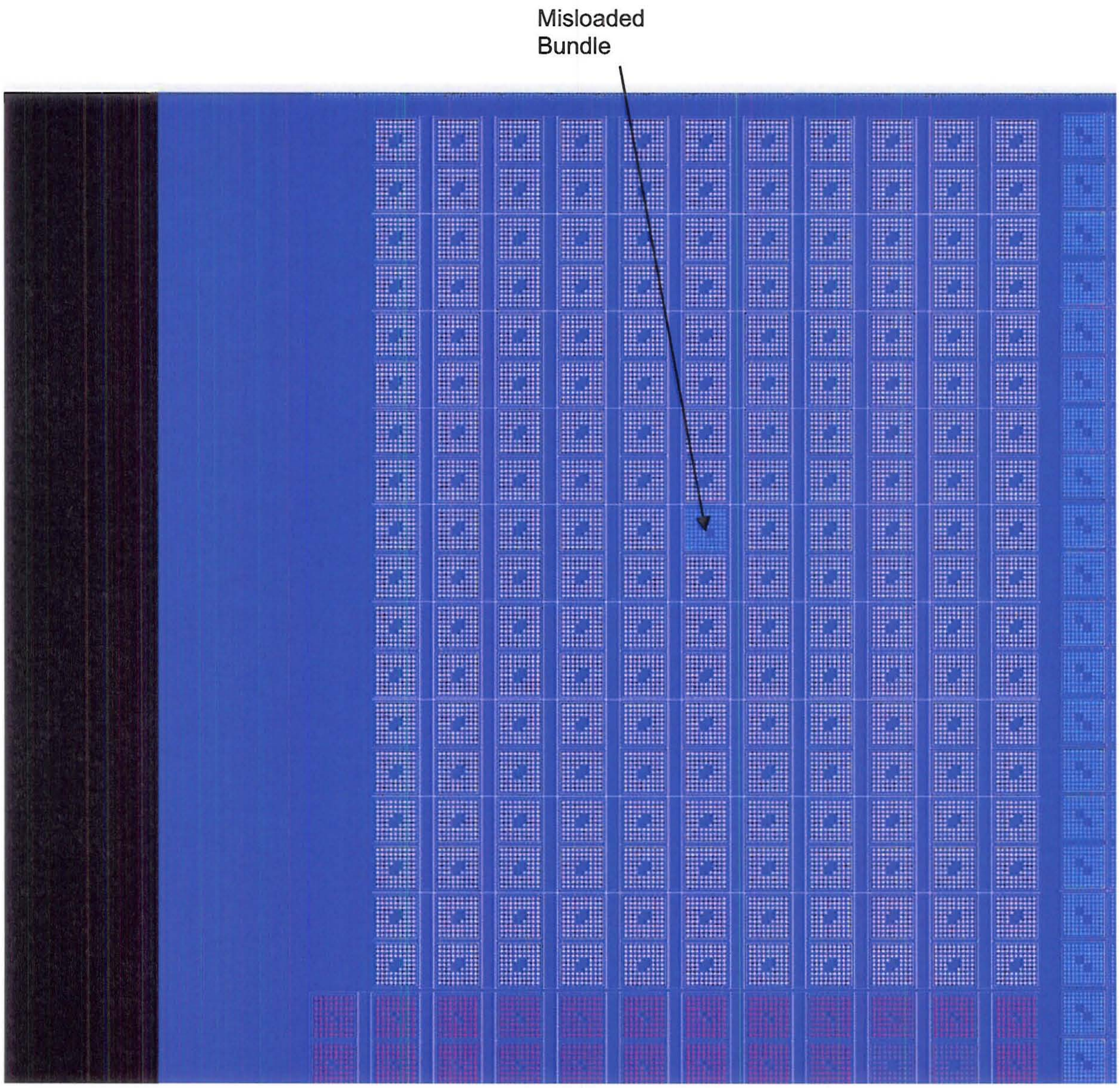

Figure 9: Keno V.a Generated Plot of a Reload Assembly (10x10) Misloaded Adjacent to the "North" BORAL Modules.

4.0 CONCLUSIONS

The reactivity state of the NMP1 spent fuel storage pool has been analyzed and k_{eff} has been conservatively evaluated. This analysis is based on the following: 1) no reactivity credit for Boraflex, 2) the existing fuel loading configuration below the tooling table, and 3) bounding reactivity (9x9) fuel loaded in the "North" module. With respect to the "North"
module, the bounding 9x9 fuel type is characterized by an initial enrichment of 4.21 w/o U- 2
235, a minimum Gd_2O_3 loading of 12 rods at 5.0 w/o. Analyses have demonstrated that for the NMP1 spent fuel racks the maximum k_{eff} is less than 0.95, after conservatively including the reactivity effects of tolerances, uncertainties, code biases and the effects of postulated accidents.

Based upon the analyses described above, the maximum k_{eff} of the NMP1 spent fuel racks 2
is shown to satisfy the 0.95 limit provided that:

1. The "South" Boraflex module is loaded with 8x8 assemblies containing U-235 2
   enrichments and gadolinia contents as shown in Figure 5.

2. The "North" Boraflex module is loaded:
   - with existing 7x7 or 8x8 fuel assemblies, or 2
   - with future 9x9 fuel type assemblies at peak planar enrichment with a minimum number of Gd_2O_3 bearing rods and at a minimum gadolinia loading as specified in Table 5.

Provided that these conditions are met, the total loss of the Boraflex concurrent with the 2
worst case accident scenarios can be safely accommodated in the NMP1 spent fuel Boraflex racks.

5.0 REFERENCES

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