Design Analysis Title Page

Title: APS New Fuel Rack Criticality Analysis for 5.0 w/o U-235 Value Added Pellet

Document Number: A-PV-FE-0107 Revision Number: 00

1. Verification Status:

☒ Complete ☐ Not Required ☐ Incomplete (describe below)

Internal / External Contingencies / Assumptions:

☒ None ☐ External ☐ Cleared Internal ☐ Uncleared Internal

2. Approval of Completed Analysis

This Design Analysis is complete and verified. Management authorizes the use of its results and attests to the qualification of the Cognizant Engineer(s), Mentor and Independent Reviewer(s).

	Printed Name	Signature	Date
Cognizant Engineer(s)	P. F. O'Donnell	Paul F. O'Donnell	4-15-98
Mentor ☐ None			
Independent Reviewer(s)	A. A. Alsaed	a.a. alsaed	4/15/98
Management Approval	P. H. Gavin	P. H. Gavin	4/15/98

3. Package Contents (this section may be completed after Management approval):

Total page count, including body, appendices, attachments, etc. 25

List associated CD-ROM disk Volume Numbers and path names: ☐ None

CD-ROM Volume Numbers	Path Names (to lowest directory which uniquely applies to this document)
EOCD 00157_0	/a_pv_fe/0107r00/out/

Other attachments (specify): ☒ None

4. Distribution:

QR (2)

Record Of Revisions

Revision Number	Issue Date	Author	Independent Reviewer	Management Approver	Revised Pages			Net Revised Contents		
					Replaced	Added	Deleted	Body	Apps. & Atts.	Other
00	04/15/98	P. F. O'Donnell	A. A. Alsaed	P. H. Gavin	n/a	n/a	n/a	18	App. A: 6 Att.01 1	CDROM

Table of Contents

1. Introduction

1.1 Objective

The New Fuel Racks are employed to temporarily store fresh fuel assemblies until they are placed into the Spent Fuel Racks. The current analysis of record (Reference 5) supports a maximum fresh fuel enrichment limit equal to 4.3 w/o U-235. The purpose of this analysis is to demonstrate that the K-effective value for the New Fuel Racks filled with 5.0 w/o U-235 assemblies is less than 0.98 assuming no soluble boron at the optimum moderation conditions and less than 0.95 assuming no soluble boron at fully flooded conditions.

Normally the New Fuel Racks are maintained under dry conditions, but in the case of fire, fluids could be introduced into the system at varying densities which could reach up to 1.0 g/cm^3 when the system is flooded, thus necessitating this analysis.

1.2 Methodology

The computer code system employed in the analysis is SCALE-4.3 as embodied in SCALE-PC Ver4.3/rev00 (Reference 1). Consistent with ABB CE Quality Assurance requirements, an implementation report for SCALE-PC (Reference 2) has been prepared to demonstrate that when SCALE-PC is implemented on a personal computer at CE, all sample problems do yield the same output as distributed with the code package. In addition, Reference 3 documents analyses of pertinent critical experiments so as to quantify the methodology bias and 95/95 confidence level of the methods variance when using SCALE-PC (ver. 4.3) with the 44 group ENDF/BV.A neutron cross section library. The CSAS25 module of the SCALE-PC methodology was used. The CSAS25 module invokes the computer codes NITAWL-II, BONAMI, and KENO-Va. NITAWL-II calculates resolved resonance parameters, BONAMI calculates unresolved resonance parameters and KENO-Va is a general three dimensional Monte Carlo computer code used to calculate the effective multiplication factor.

1.3 Assumptions

The following assumptions were applied for this analysis:

- No neutron interaction from any other fuel bearing system
- No shims in the fuel assemblies
- Room temperature conditions (68°F)
- Default infinite lattice Dancoff factor

2. Design Inputs

2.1 16x16 Fuel Assembly Description

The fuel assembly modeled in this design analysis is the ABB CE 16x16 Value-Added fuel assembly shown in Figure 2.1. Table 2.1 lists the ABB CE 16x16 Value-Added fuel assembly parameters as modeled in this design analysis. The vaules in Table 2.1 were obtained from reference 4 (page III.6). No credit was given for spacer grids, guide tubes or any type of integral shim design. Therefore, each assembly was modeled with 236 fuel rods.

Table 2.1
ABB CE 16x16 Value-Added Fuel Assembly Parameters

Parameter	Value
UO_2 Fuel Stack Density	10.31 g/cm^3
Pellet OD	0.3255"
Zircaloy Clad ID	0.332"
Void Gap Thickness	0.00325"
Zircaloy Clad OD	0.3820"
Pitch	0.5065"
Active Fuel Height	150.0"

Note that the cell pitch given in Table 2.1 is slightly different than the the value given in Table 4.2-1 of the UFSAR (0.506 inches). This small difference in cell pitch will not affect the conclusions of this design analysis.

2.2 New Fuel Racks Description

A schematic of the New Fuel Rack is shown in Figure 2.2. Figure 2.3 illustrates a 16X16 fuel assembly in a single storage cell. The dimensions in these figures were obtained from Figure 9.1-1 of the Updated Final Safety Analysis Report, Reference 6. The facility consists of a 15 X 6 assembly array divided into two compartments which are separated from each other by a two foot concrete wall. In the long direction there is a minimum 9 inch separation between the stainless steel box surrounding each assembly. Each stainless steel box has a nominal thickness equal to 0.109 inches and was conservatively modeled as 0.10 inches in this analysis. In the shorter direction there is a minimum 22 inches between stainless steel boxes. Fuel assemblies are centered in each storage location. The height of the fuel assemblies is 150.0 inches. A total of 90 assemblies may be stored in this facility. The storage facility was modeled as a single 15X3 array of fuel assemblies enclosed by a one foot thick solid concrete wall on all six sides in this analysis. Reflective boundary conditions were applied to the outside of the six concrete walls.

Figure 2.1
Schematic of ABB-CE 16x16 Fuel Assembly

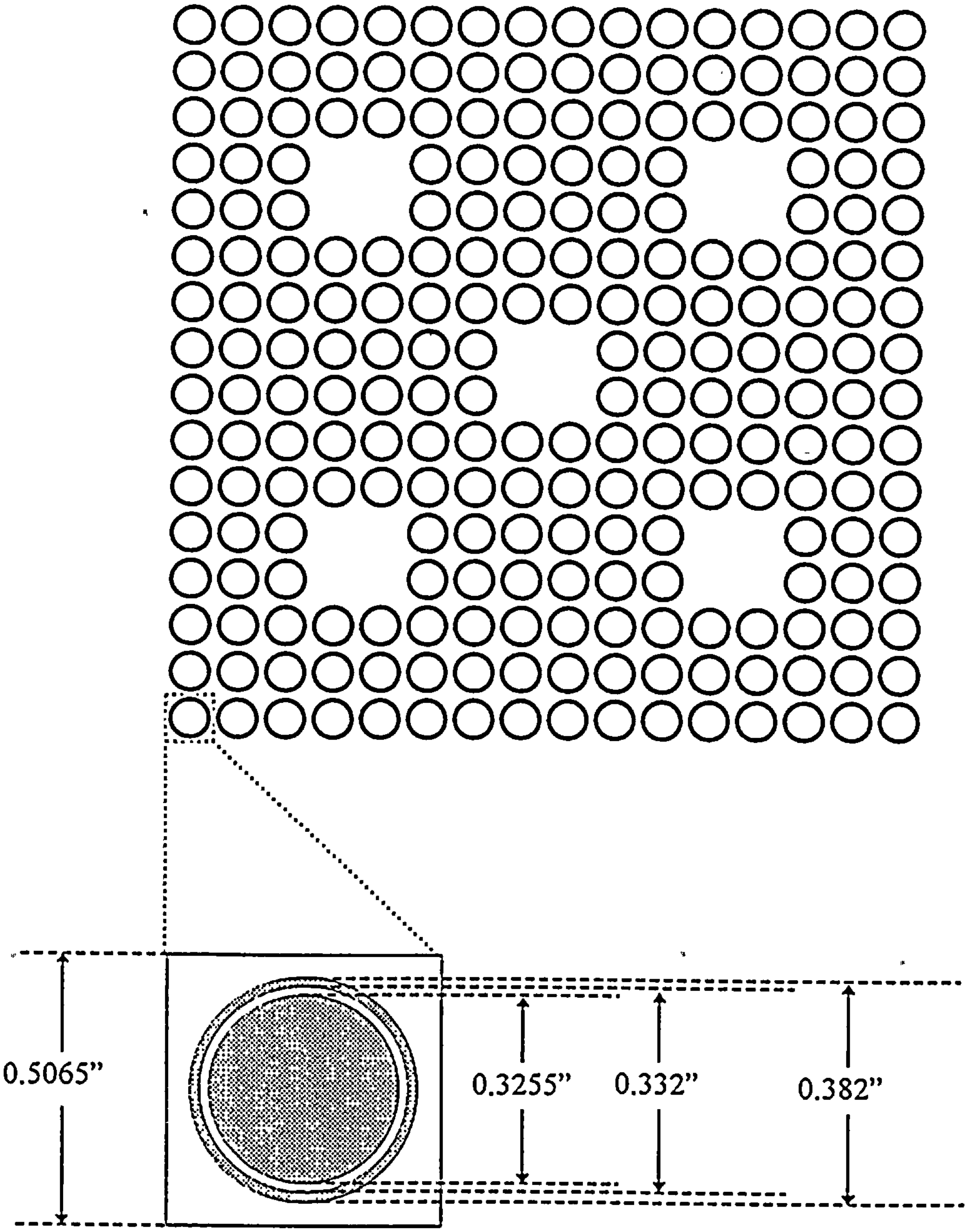


Figure 2.2
Schematic of New Fuel Racks

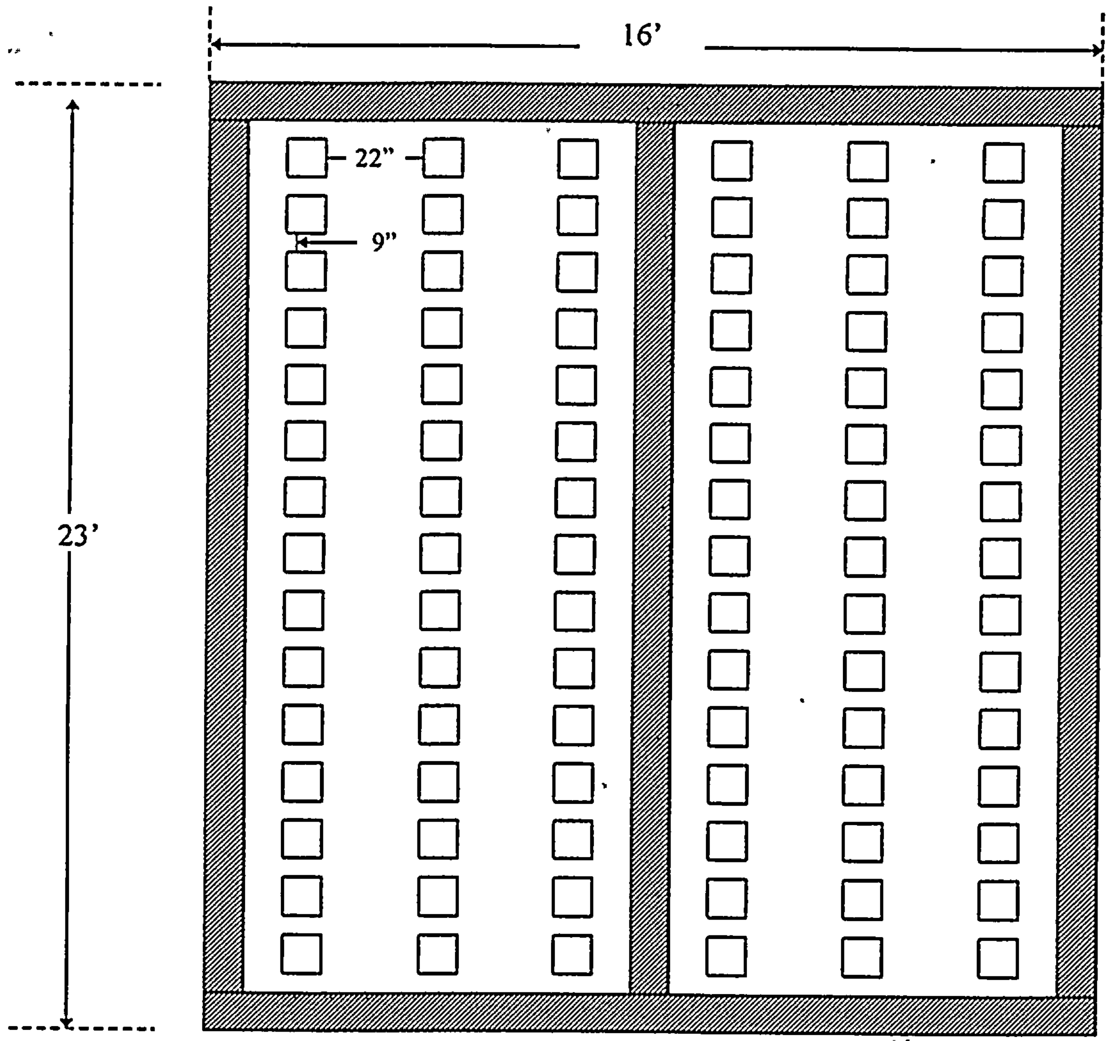
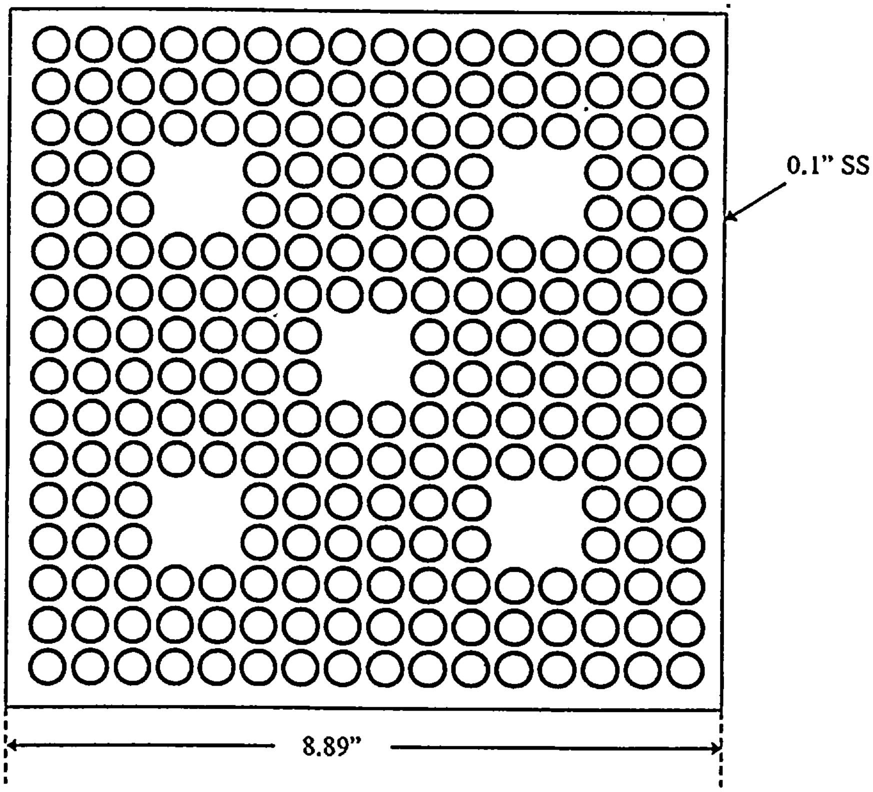


Figure 2.3
Schematic of a Single Storage Cell in the New Fuel Racks



3. Analysis

3.1 KENO-Va Model and Assumptions

The KENO-Va model is a three dimensional representation of the New Fuel Racks and fuel assemblies as described in Sections 2.1 and 2.2. The assemblies are modeled with the parameters given in Table 2.1 inserted in the storage cells shown in Figure 2.3. The 15X3 fuel assembly array is modeled with a close-fitting one foot thick concrete wall on all six sides of the array. The clad is modeled as zirconium instead of zircaloy, which slightly overestimates K-effective. An additional conservatism is also added by not modeling the guide tubes. There are no shims modeled in any of the fuel assemblies. The system is modeled at room temperature conditions (68 °F). The system reactivity is evaluated at eleven moderator densities ranging from full density (0.9982 g/cc) down to very low values simulating mist conditions. A total of 601,800 neutron histories were modeled with 1003 generations and 600 neutrons per generation.

3.2 Methodology Bias and Uncertainty

The methodology bias and uncertainty are discussed and evaluated in Reference 3. The calculational bias, ΔK_B is determined to be 0.00259 and the calculational uncertainty, CU, is given in the following equation:

$$CU = M_{95/95}\left(\sigma_m^2 + \sigma_{KENO}^2\right)^{1/2}$$

where:

$M_{95/95}$ is the 95/95 multiplier appropriate to the degrees of freedom for the number of validation analyses.
= 2.22

σ_m is the mean calculational method variance deduced from the validation analyses.
= 0.00288

σ_{KENO} is the standard deviation appropriate to the KENO multiplication factor of interest, and is assumed to be less than 0.0011.

For KENO Va calculated standard deviations less than 0.0011, the total calculational uncertainty is equal to 0.00684 delta K-effective units. This value will be used in Section 4 to detemine the final K-effective values for the new fuel storage vault.

3.3 Physical Tolerances and Uncertainties

The following physical tolerances and uncertainties are considered in this design analysis:

- UO_2 Density Tolerance (±2%)
- Cell ID (±1/16 inch)
- U-235 Enrichment (+0.05 w/o)

The Change in K-effective (ΔK) is determined by subtracting the KENO-Va calculated K-effective at nominal conditions from the KENO-Va calculated K-effective at adverse conditions as shown in the following equation:

$$\Delta K_i = (K_i + \sigma_i) - (K_{nominal} - \sigma_{nominal})$$

where K_i and σ_i are the KENO-Va calculated multiplication factor and deviation at the adverse condition and $K_{nominal}$ and $\sigma_{nominal}$ are the KENO-Va calculated multiplication factor and deviation at the nominal conditions (0.89835+/-0.00102 from Job #1). Table 3.1 contains the results of these calculations at the fully flooded condition. It will be shown in Section 4 that the fully flooded condition produces the highest K-effective value over the range of water densities evaluated.

Table 3.1

Physical Tolerances and Uncertainties for the New Fuel Racks

Job Number	Tolerance and Uncertainty	Moderator Volume Fraction	K-effective	Deviation	ΔK+2σ
12	UO_2 Density Tolerance (+2%)	1.0	0.91031	0.00104	0.01402
14	UO_2 Enrichment (+0.05 w/o)	1.0	0.90714	0.00103	0.01084
13	Cell ID (-1/16 inch)	1.0	0.90490	0.00101	0.00858

The total biases and uncertainties to be added to the individual KENO Va calculated K-effective values is determined for the following equation :

$$K_{final} = K_{kenova} + 0.00259 + [(0.00684)^2 + Sum\ of\ (delta\ Keffective)^2]^{1/2}.$$

The square root term plus the 0.00259 bias term equals 0.02343 delta K-effective units. Therefore, the final K-effective values are equal to the unbiased K-effective values plus 0.02343.

4. Results and Conclusions

4.1 Analysis Results

The data listed in Table 4.1 and plotted in Figure 4.1 are the KENO-Va calculated multiplication factors as a function of water volume fractions without uncertainties or biases. Note that the volume fraction equal to 1.0 corresponds to full density water, 0.9982 g/cc. The final K-effective values, including biases and uncertainities, are obtained by adding 0.02343 to the values contained in Table 4.1. Table 4.2 contains the final K-effective values for the new fuel storage vault including biases and uncertainties and these values are plotted in Figure 4.2.

The maximum fresh fuel enrichment limit for the New Fuel Storage Racks is determined to be 5.00 w/o U-235 since the final K-effective value at this enrichment is less than 0.98 at optimum moderation conditions, and less that 0.95 at the fully flooded condition assuming no soluble boron.

Table 4.1
K-effective as a Function of Moderator Volume Fraction in the New Fuel Racks (no Bias or Uncertainty Included, nominal full density equal to 0.9982 g/cc)

Job Number	Moderator Volume Fraction	K-effective	Deviation
1	1.0	0.89835	0.00102
2	0.8	0.82873	0.00099
3	0.6	0.73118	0.00098
4	0.4	0.64771	0.00092
5	0.2	0.65552	0.00086
6	0.09	0.83166	0.00088
7	0.07	0.86062	0.00089
8	0.05	0.86291	0.00086
9	0.03	0.81323	0.00086
10	0.01	0.69200	0.00078
11	0.0001	0.62205	0.00078

Figure 4.1
K-effective as a Function of Moderator Volume Fraction in the New Fuel Racks
(no Bias or Uncertainty Included, nominal full density equal to 0.9982 g/cc)

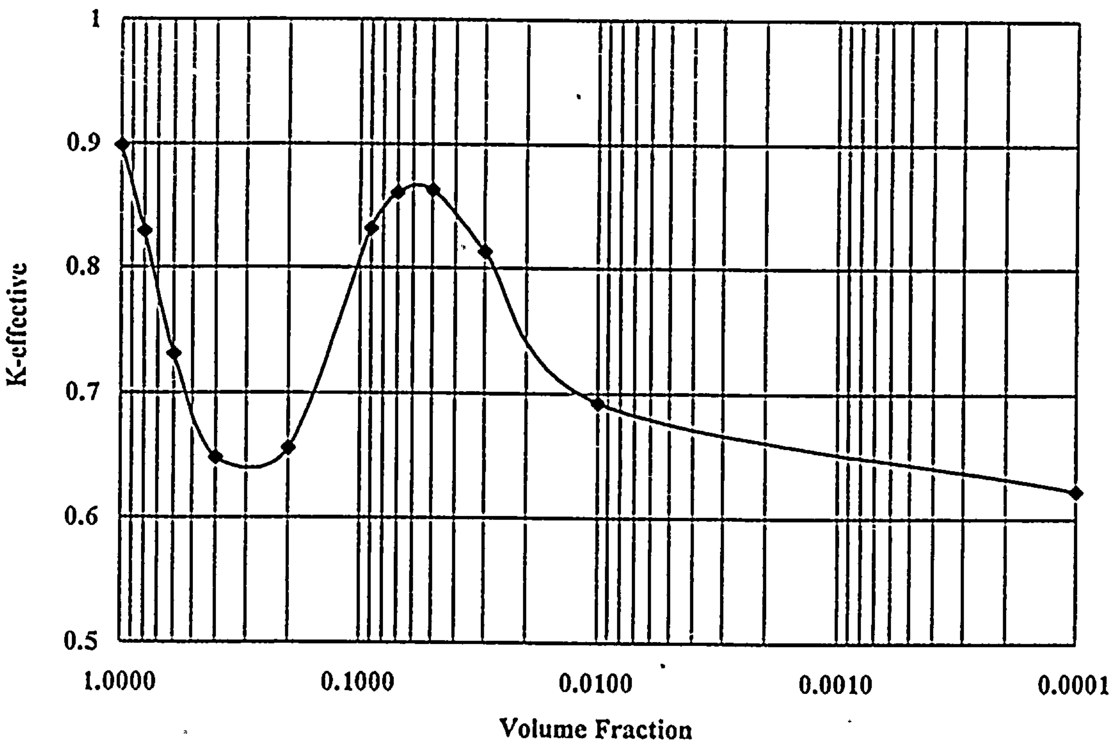
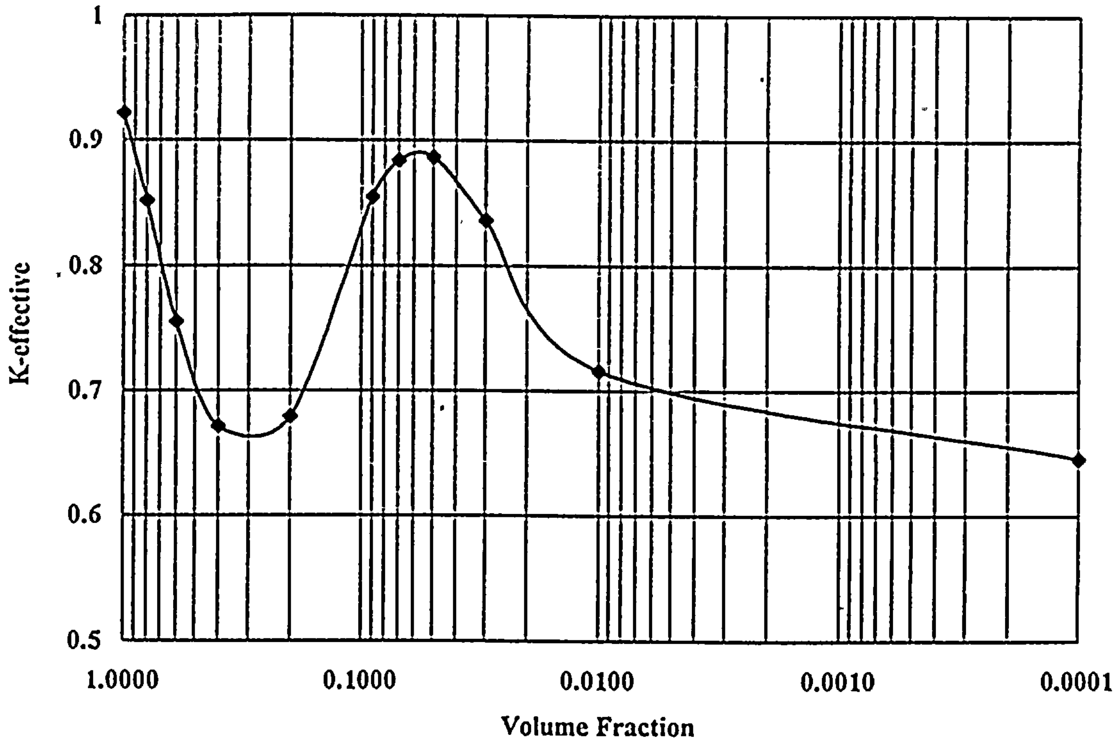


Table 4.2
K-effective as a Function of Moderator Volume Fraction in the New Fuel Racks (Including Bias and Uncertainty, nominal full density equal to 0.9982 g/cc)

Moderator Volume Fraction	K-effective 5.00 w/o U-235
1	0.92178
0.8	0.85216
0.6	0.75461
0.4	0.67114
0.2	0.67895
0.09	0.85509
0.07	0.88405
0.05	0.88634
0.03	0.83666
0.01	0.71543
0.0001	0.64548

Figure 4.2
K-effective as a Function of Moderator Volume Fraction in the New Fuel Racks
(Including Bias and Uncertainty, nominal full density equal to 0.9982 g/cc)



5. CDROM and Computer Code Lists

5.1 Computer Codes used in the Design Analyses

Code Name	Computer Type	Revision Identification (i.e. Code Version)
SCALE-PC	PC	Ver4.3/rev00

5.2 Computer Jobs on CDROM

Job Number	CDROM File	Job Date	File Description
1	eq5b5d93.cdf	02-26-98	NFSV 5.0%, Vf= 1.0 g/cc, Keff = 0.89835
2	eq5b3xze.cdf	02-25-98	NFSV 5.0%, Vf = 0.8 g/cc, Keff = 0.82873
3	eq5b170a.cdf	02-25-98	NFSV 5.0%, Vf = 0.6 g/cc, Keff = 0.73118
4	eq5ayswu.cdf	02-25-98	NFSV 5.0%, Vf = 0.4 g/cc, Keff = 0.64771
5	eq59ydvt.cdf	02-26-98	NFSV 5.0%, Vf = 0.2 g/cc, Keff = 0.65552
6	eq59xfs8.cdf	02-26-98	NFSV 5.0%, Vf = 0.09 g/cc, Keff = 0.83166
7	eq59wjl9.cdf	02-26-98	NFSV 5.0%, Vf = 0.07 g/cc, Keff = 0.86062
8	eq59vlhy.cdf	02-25-98	NFSV 5.0%, Vf = 0.05 g/cc, Keff = 0.86291
9	eq59unen.cdf	02-25-98	NFSV 5.0%, Vf = 0.03 g/cc, Keff = 0.81323
10	eq59syaz.cdf	02-25-98	NFSV 5.0%, Vf = 0.01 g/cc, Keff = 0.69200
11	eq59rn8p.cdf	02-25-98	NFSV 5.0%, Vf = 0.0001 g/cc, Keff=0.62205
12	eq5b7vhh.cdf	02-26-98	NFSV 5.0%, Higher Stack Density, Keff =0.91031
13	eq55ougo.cdf	03-02-98	NFSV 5.0%, Smaller Cell Id, Keff = 0.90490
14	eq5b6kfq.cdf	02-26-98	NFSV 5.05%, Higher Enrichment, Keff = 0.90714
Computer output stored in directory and CDROM volume identified on the cover sheet.			

6. References

1. RSIC Code Package CCC-619, "SCALE-PC: Modular Code System for Performing Criticality Safety Analyses for Licensing Evaluation, Version 4.3," September 1995.
2. S. Harding, "Implementation Report for SCALE-PC," VV-FE-0365, Rev. 00, October 7, 1997.
3. S. Harding, "SCALE 4.3 Criticality Benchmarking Analyses," A-GM-FE-0069, October, 1997.
4. Gavin, "Cross Section Tableset Generation Methodology Manual ",CE-CES-124 Rev. 2-P, June, 1994.
5. C. Noderer,"System 80 Fuel Racks for B.O.P", 3800-PHD-055 Rev.0, June20,1977; Rev.01,August 17,1981
6. Updated Final Safety Analysis Report, Palo Verde Nuclear Generating Station, Revision 9, December 1997.

ATTACHMENT 2

A-PV-FE-0108, Rev. 01, "APS Criticality Analysis for Fuel Handling Equipment" December 2, 1998