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CALCULATION COVER SHEET

Project Title Building 2335 D & D **Job No.** 22192

Area 200 West

Discipline Nuclear ***Calc. No.** 0200W-CA-N0001

Subject Plutonium Concentration System Removal Criticality Review

Computer Program N/A **Program No.** N/A

Committed Calculation ☒ **Preliminary** ☐ **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
0	1-36 ATT. A: A1-A60 ATT. B: B1-B6	E Walker E WALKER	R T Smith R T SMITH		R T Jackson R.T. Jackson	11-22-96

SUMMARY OF REVISION

APR 1997 RECEIVED EDMC

Scanned:	Rev.	Date	Bar Code No.	Rev.	Date	Bar Code No.

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Calculation Sheet

Originator S/Walker Date 7-19-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYTEM REMOVAL CRITICALITY REVIEW Sheet No. 2

I. INTRODUCTION

IN NOV 1995, SEG PROVIDED A REVISED ESTIMATE OF THE PLUTONIUM INVENTORY REMAINING IN THE PROCESS VESSELS OF THE BLDG 233S PLUTONIUM CONCENTRATION SYSTEM (REF 1). BASED ON THOSE INVENTORIES, A CRITICALITY ASSESSMENT WAS COMPLETED BY LATA TO EVALUATE THE CRITICALITY SAFETY MARGINS THAT WOULD EXIST AT COMMENCEMENT OF DECONTAMINATION AND REMOVAL OPERATIONS. THE FOLLOWING IS A REVIEW OF THE LATA EVALUATION, WHICH IS INCLUDED AS ATTACHMENT A. THE REVIEW INCLUDES COMMENTS ON THE CONTENTS AS WELL AS AN INDEPENDENT CHECK OF THE CALCULATIONAL RESULTS. THE CALCULATIONAL CHECK CONSISTS OF A TWO-GROUP k_{eff} CALCULATION FOR EACH OF THE PROCESS VESSELS THAT APPEAR TO HAVE SIGNIFICANT QUANTITIES OF FISSILE MATERIAL. THE CALCULATION IS BASED ON MATERIAL PROPERTIES FROM ARH-600 (REF 2.) AND UNREFLECTED CYLINDERS CONTAINING EITHER $Pu(NO_3)_4 + H_2O$ OR $Pu + H_2O$. THIS APPROACH SHOULD BE CONSERVATIVE COMPARED TO THE MORE RIGOROUS MONTE CARLO CALCULATION BY LATA.

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Calculation Sheet

Originator E/Walker Date 7-19-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2335 D&D Job No. 22192 Checked R.L. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 3

REFERENCES

1. J.P. GONSKY, "PASSIVE NEUTRON SURVEY OF THE 233-S PLUTONIUM CONCENTRATION FACILITY", SCIENTIFIC ECOLOGY GROUP, INC - NORTHWEST OFFICE, RICHLAND, WA. 11-27-95

2. R.D. CARTER, et. al., "CRITICALITY HANDBOOK, VOL I-III", ARH-600, ATLANTIC RICHFIELD HANFORD CO., RICHLAND, WA. JUNE 30, 1968

3. NUREG/CR-0095, "NUCLEAR SAFETY GUIDE", TID-7016, REV 2; J.T. THOMAS, ed., UNION CARBIDE CORPORATION - NUCLEAR DIVISION, OAK RIDGE, TN. JUNE, 1978

4. DRAWING NO: H-2-18029 M, "PIPING - EQUIPMENT ARRANGEMENT: PRODUCT CONCENTRATION & REMOVAL: PLAN, ELEVATIONS & SECTION", VITRO CORP OF AMERICA, USAEC HANFORD WORKS - GE ISSUED FOR CONSTRUCTION 10-8-53

5. DRAWING NO: H-2-7202, "FOUNDATION, FIRST FLOOR AND ROOF PLANS: REDOX EXPANSION PHASE II", USAEC HANFORD ATOMIC PRODUCTS OPERATION - GE, ISSUED FOR CONSTRUCTION 5-10-54 (REV 2)

6. DRAWING NO: H-2-45258, "PIPING - GEN. ARRGT.: PROCESS AS-BUILT PLAN", USAEC HANFORD ATOMIC PRODUCTS OPERATION - GE, ISSUED 9-4-62

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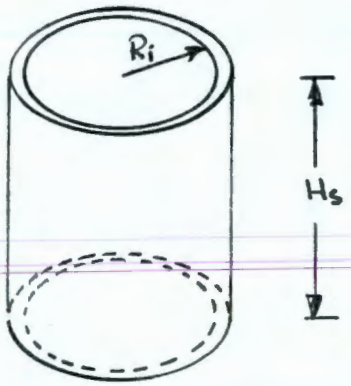
Calculation Sheet

Originator S/Walker Date 7-17-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.I. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 4

II Process Vessel Effective Multiplication (keff)

Determine keff for finite cylinder geometry for process vessels



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

$$B_g^2 = \left(\frac{2.405}{R + \lambda_R}\right)^2 + \left(\frac{\pi}{H_s + \lambda_B + \lambda_T}\right)^2$$

Assumptions

(1) Maximum keff will occur at fissile density corresponding to maximum k_∞

(2) Radial reflection (λ_R) will be from vessel wall. Use λ_R equivalent to 1 in H_2O reflection [a]

(3) Fissile mass will be located within cylinder such that full water reflection occurs on top and bottom

(4) Vessel L-16 fissile material: Pu + H_2O

(5) All other vessels: $Pu(NO_3)_4 + H_2O$, 0 M nitric acid.

(6) Pu-240 content = 5%

(7) Use data from ARH-600 pp III.A. 10 (95) 1-4

(a) This is conservative and would cover plastic wrapping the vessels

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Calculation Sheet

Originator S/W Chen Date 7-17-96 Calc. No. 0200W-CA-W0021 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.L. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 5

(1) $Pu + H_2O$ Pu-240 = 5%

(a) $k_\infty = 1.680$ (MAX)

(b) $\rho_{Pu} = 100\ gm/l$

- $B_m^2 = 0.0254\ cm^{-2}$
- RADIAL REFLECTION $\lambda_R = 4.20\ cm$
- AXIAL REFLECTION $\lambda_T, \lambda_B = 6.05\ cm$

(2) $Pu(NO_3)_4 + H_2O$ Pu-240 = 5%

(a) $k_\infty = 1.670$ (MAX)

(b) $\rho_{Pu} = 100\ gm/l$

- $B_m^2 = 0.0247\ cm^{-2}$
- RADIAL REFLECTION $\lambda_R = 4.20\ cm$
- AXIAL REFLECTION $\lambda_T, \lambda_B = 6.07\ cm$

(3) $M^2 = k_\infty - 1 / B_m^2$

- $Pu + H_2O$: $M^2 = 26.77\ cm^2$
- $Pu(NO_3)_4 + H_2O$: $M^2 = 27.13\ cm^2$

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Calculation Sheet

Originator S/Walker Date 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2335 D&D Job No. 22192 Checked R.E. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 6

Vessel Solution Height (H_s)

$$V_s = \pi R_i^2 H_s$$

$$M_f = \bar{\rho}_{Pu} * V_s$$

$$\therefore H_s = \frac{M_f\,(gm)}{\rho_{Pu}\left(\frac{gm\,Pu}{cm^3\,soln}\right) * \pi R_i^2\,(cm^2)}$$

Vessel	Solution	M_f (gm)	ρ_{Pu} (gm/cm³)	V_s (cm³)	R_i (cm)	H_s (cm)
L-4	$Pu(NO_3)_4 + H_2O$	220	0.100	2200	7.14	13.74
L-6	$Pu(NO_3)_4 + H_2O$	270	0.100	2700	5.72 (2)	26.27
L-12S	$Pu(NO_3)_4 + H_2O$	190	0.100	1900	8.07 (4)	9.29
L-12N	$Pu(NO_3)_4 + H_2O$	170	0.100	1700	8.07 (4)	8.31
L-14	$Pu(NO_3)_4 + H_2O$	425	0.100	4250	7.14	26.54
L-16	$Pu + H_2O$	780	0.100	7800	7.70 (1)	41.88
L-18	$Pu(NO_3)_4 + H_2O$	200	0.100	2000	5.41	21.75

(1) Assumes 6 in Sch 40; For 6 in Sch 10, R_i = 8.07cm, H_s = 38.12cm
(2) Column is 4in Sch 10
(3) Drawings give ID = 4.5 inch
(4) Assumed to be 6 in, Schedule 10

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Calculation Sheet

Originator: J Walker Date: 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project: Bldg 233S D&D Job No. 22192 Checked: R.T. Smith Date: 10/23/96
Subject: Pu Concentration System Removal Criticality Review Sheet No. 7

Vessel Geometric Buckling (B_g^2) - cm^{-2}

Vessel	R_i (cm)	λ_B (cm)	H_s (cm)	λ_T, λ_B (cm)	B_R^2	B_g^2	B_H^2
L-4	7.14	4.20	13.74	6.07	0.0450	0.0597	0.0147
L-6	5.72	4.20	26.27	6.07	0.0588	0.0655	0.0067
L-12S	8.07	4.20	9.29	6.07	0.0384	0.0599	0.0215
L-12N	8.07	4.20	3.31	6.07	0.0384	0.0620	0.0236
L-14	7.14	4.20	26.54	6.07	0.0450	0.0576	0.0066
L-16	7.70 (1)	4.20	41.88	6.05	0.0408	0.0442	0.0034
	8.07 (2)	4.20	38.12	6.05	0.0384	0.0423	0.0039
L-18	5.41	4.20	21.75	6.07	0.0626	0.0712	0.0086

(1) 6 in ϕ, Sch 40
(2) 6 in ϕ, Sch 10

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Calculation Sheet

Originator J/Walters Date 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.T. SMITH Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 8

VESSEL EFFECTIVE MULTIPLICATION (k_{eff})

VESSEL	FISSILE SOLUTION	B_g^2 (cm^{-2})	M^2 (cm^2)	k_∞	k_{eff}
L-4	$Pu(NO_3)_4 + H_2O$	0.0597	27.13	1.670	0.637
L-6	$Pu(NO_3)_4 + H_2O$	0.0655	27.13	1.670	0.601
L-12S	$Pu(NO_3)_4 + H_2O$	0.0599	27.13	1.670	0.636
L-12N	$Pu(NO_3)_4 + H_2O$	0.0620	27.13	1.670	0.623
L-14	$Pu(NO_3)_4 + H_2O$	0.0516	27.13	1.670	0.696
L-16	$Pu + H_2O$	0.0442 (1)	26.77	1.680	0.770
	$Pu + H_2O$	0.0423 (2)	26.77	1.680	0.788
L-18	$Pu(NO_3)_4 + H_2O$	0.0712	27.13	1.670	0.570

(1) 6 IN ϕ, SCH 40
(2) 6 IN ϕ, SCH 10

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Calculation Sheet

Originator S/ Walker Date 7-17-96 Calc. No. 200W-CA-N0001 Rev. No. 0
Project BUDC 2335 D&D Job No. 22192 Checked R. J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 9

CONSIDER CASE FOR "BARE" RADIAL REFLECTION

(1) $Pu + H_2O$ @ $\rho_{Pu} = 100\ gm/l$: $\lambda_R = 2.15\ cm$

(2) $Pu(NO_3)_4 + H_2O$ @ $\rho_{Pu} = 100\ gm/l$: $\lambda_R = 2.17\ cm$

VESSEL	B_H^2 (cm^{-2})	B_R^2 (cm^{-2})	B_g^2 (cm^{-2})	M^2	k_∞	k_{eff}	k_{eff} (LATA)
L-4	0.0147	0.0667	0.0814	27.13	1.670	0.520	0.39
L-6	0.0067	0.0929	0.0996	27.13	1.670	0.451	0.36
L-12S	0.0215	0.0552	0.0767	27.13	1.670	0.542	0.35
L-12N	0.0236	0.0552	0.0788	27.13	1.670	0.532	0.0002 (1)
L-14	0.0066	0.0667	0.0733	27.13	1.670	0.559	0.50
L-16	0.0034 (2)	0.0596	0.0630	26.77	1.680	0.625	0.58
	0.0039 (3)	0.0554	0.0593	26.77	1.680	0.649	—
L-18	0.0086	0.1007	0.1093	27.13	1.670	0.421	0.29

(1) LATA ASSUMED 1 INCH DIA PIPE. THIS IS THE SIZE OF THE INTERNAL HEAT EXCHANGER TUBES INSIDE THIS VESSEL, NOT THE DIAMETER OF THE VESSEL ITSELF

(2) 6 IN DIA, SCH 40

(3) 6 IN DIA, SCH 10

Originator 2/W Shu Date 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0

Project Bldg 233S D&D Job No. 22192 Checked R.T. Smith Date 10/23/96

Subject Pu Concentration System Removal Criticality Review Sheet No. 10

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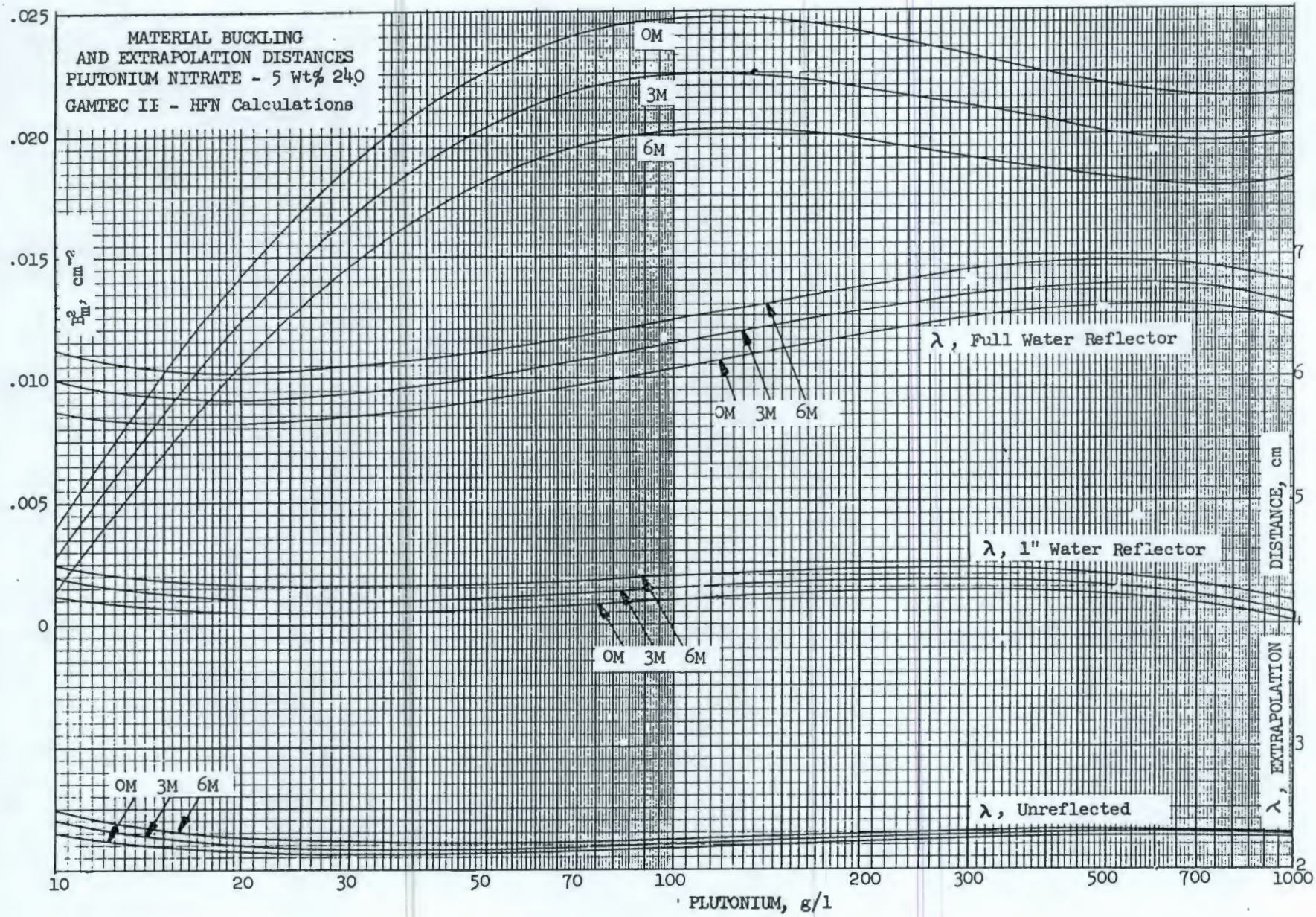

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ARI-600

Originator 2/W Shum Date 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0

Project Pu 233S D&D Job No. 22192 Checked R.L. SMITH Date 10/23/96

Subject Pu Concentration System Removal Criticality Review Sheet No. 11

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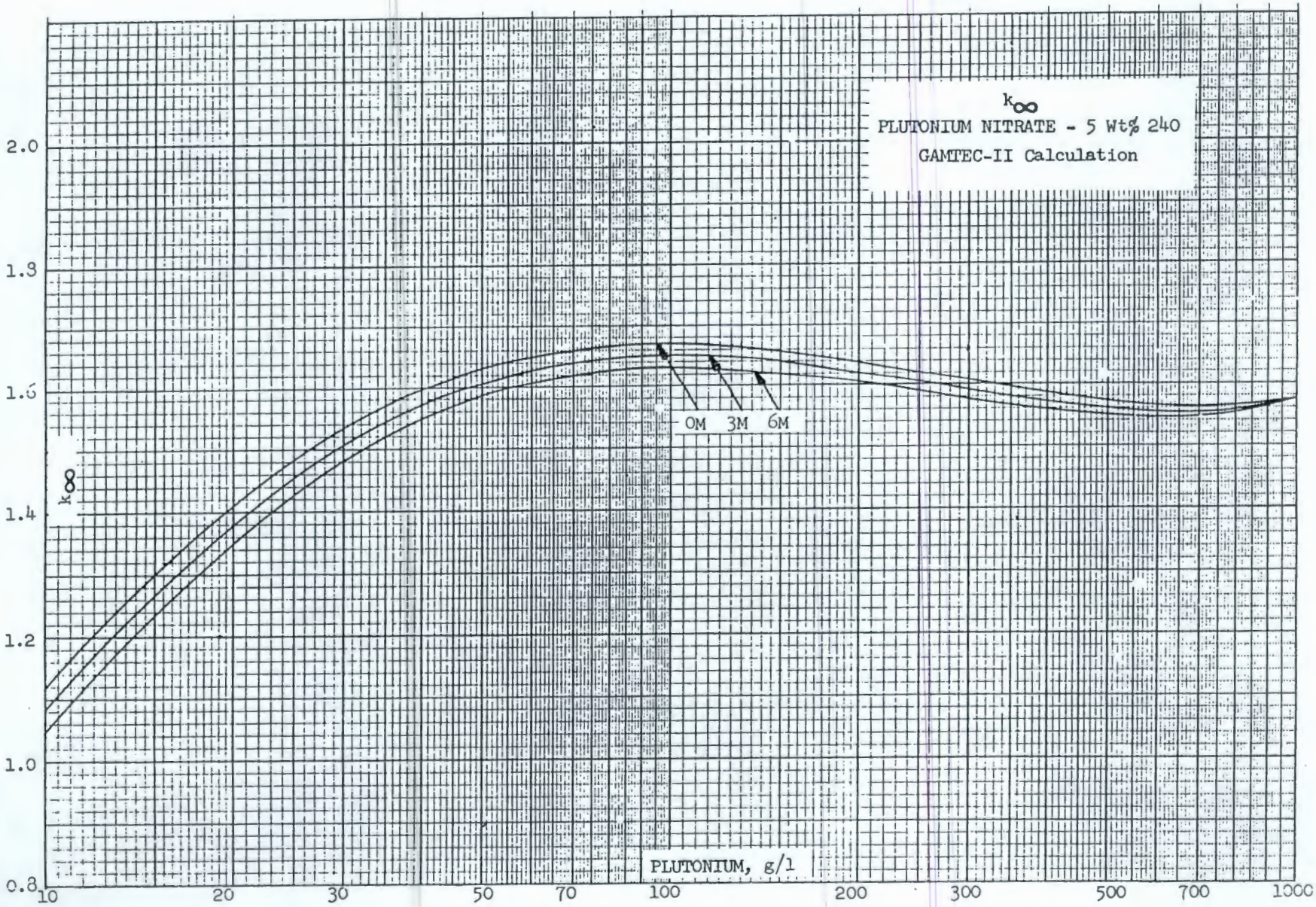

Originator 2/W Allen Date 7-17-96 Calc. No. 0200W-CA-N00016 Rev. No. 0

Project Buck 2335 D&D Job No. 22192 Checked R.L. Smith Date 10/23/96

Subject Pu Concentration System Removal Criticality Reviews Sheet No. 12

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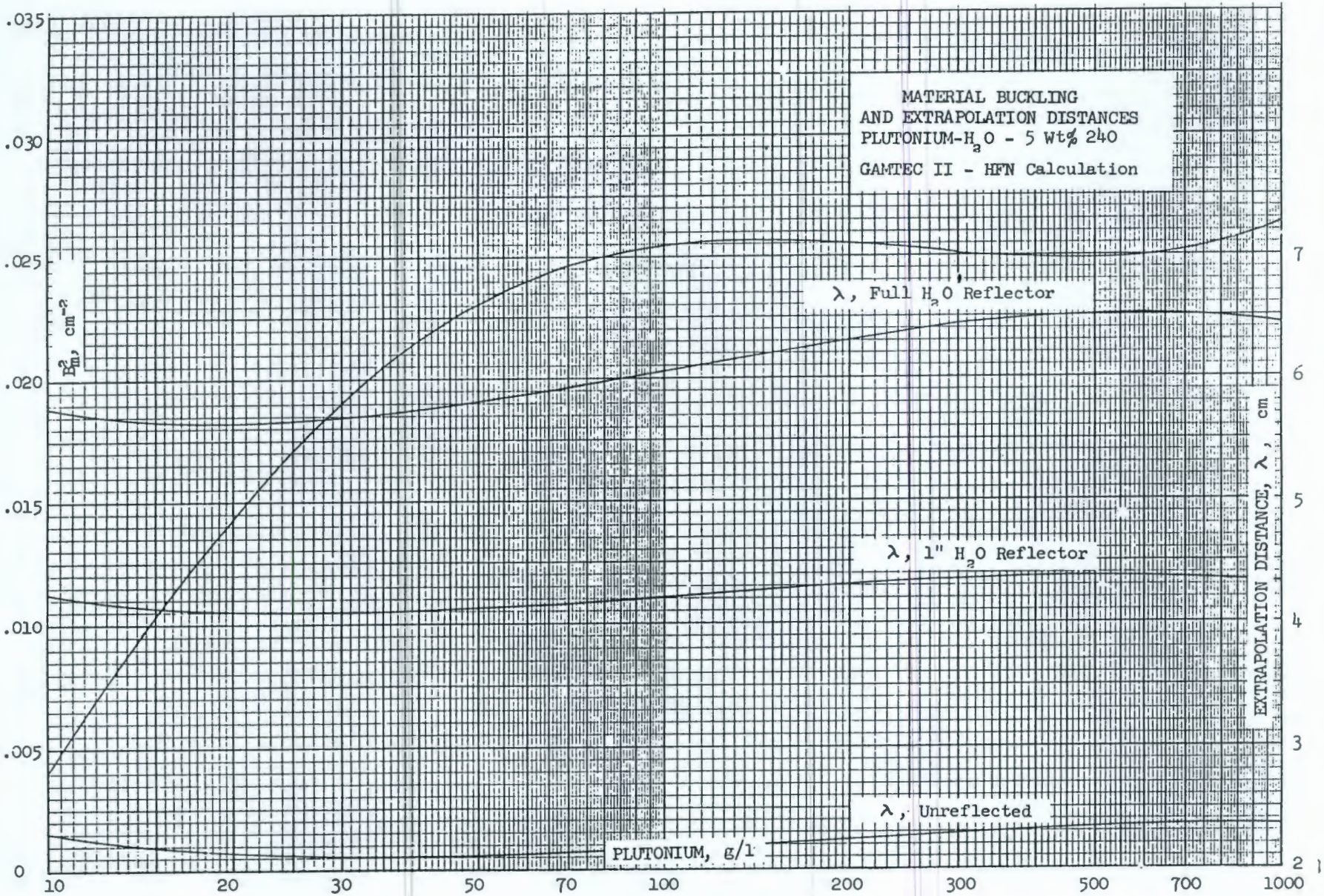

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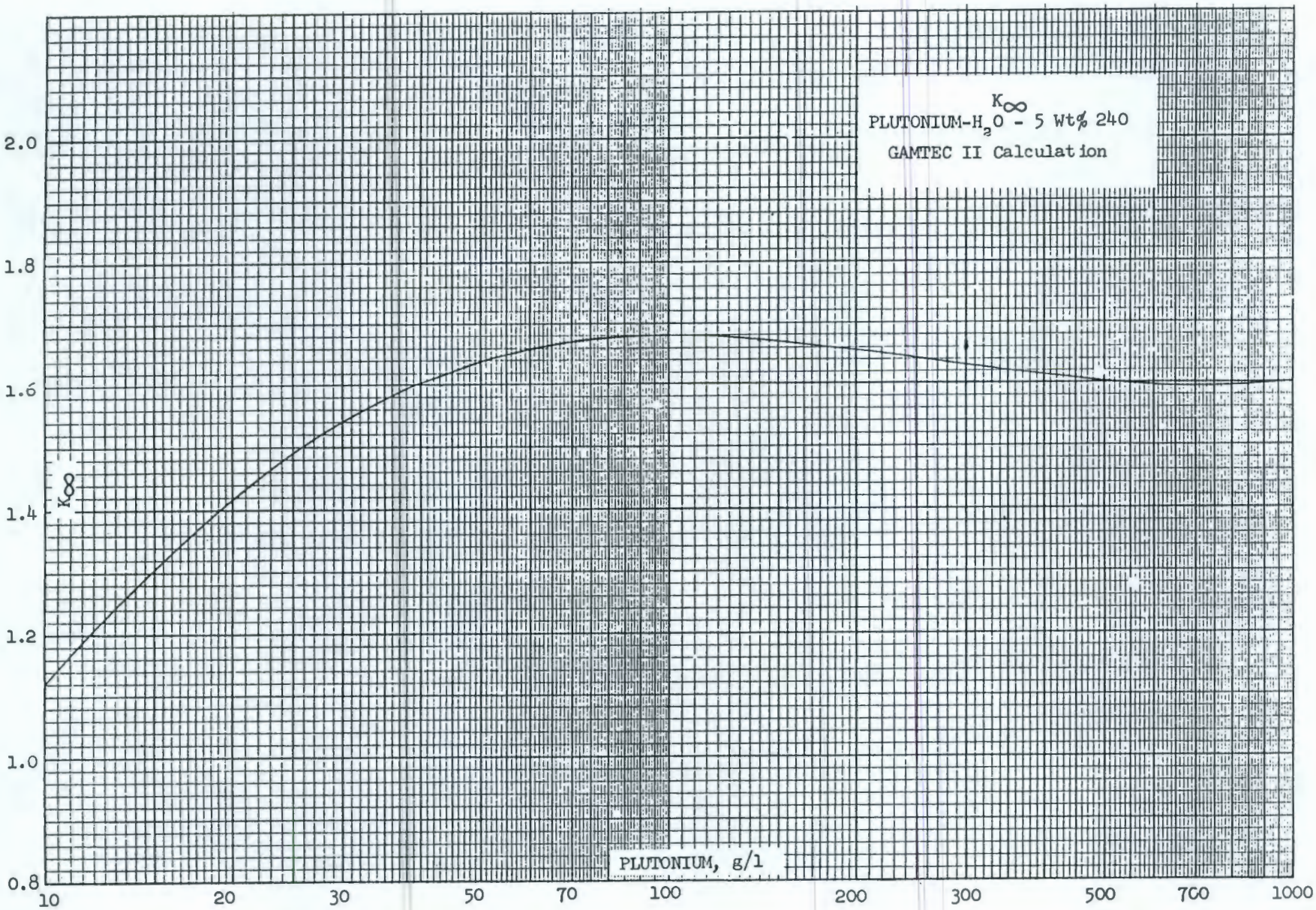
ARH-600

Originator 2/W Allen Date 7-17-96 Calc. No. 0200W-CA-N0001 Rev. No. 0

Project Blue 233S D&D Job No. 22192 Checked R.L. Smith Date 10/23/96

Subject Pu Concentration System Removal Criticality Reviews Sheet No. 13



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Calculation Sheet

Originator E/Walker Date 7-29-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2335 D&D Job No. 22192 Checked R.I. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 14

Vessel Effective Multiplication - Full Water Reflection

Vessel	λ_R	B_R^2	B_H^2	B_g^2	M^2	k_∞	k_{eff}
L-4	6.07	0.0331	0.0147	0.0478	27.13	1.670	0.727
L-6	6.07	0.0416	0.0067	0.0483			0.723
L-12S	6.07	0.0289	0.0215	0.0504			0.705
L-12N	6.07	0.0289	0.0236	0.0525			0.689
L-14	6.07	0.0331	0.0066	0.0397			0.804
L-16	6.05	0.0306 (1)	0.0034	0.0340	26.77	1.680	0.880
	6.05	0.0290 (2)	0.0039	0.0329			0.893
L-18	6.07	0.0439	0.0086	0.0525	27.13	1.670	0.689

(1) 6 IN ϕ, SCH 40
(2) 6 IN ϕ, SCH 10

(a) For fully reflected infinite cylinder with $k_{eff}(MAX) \leq 0.85$

$$B_g^2 = \frac{(k_\infty / k_{eff}) - 1}{M^2} = 0.0365 \text{ cm}^2$$

$$R_{.85} = \left(\frac{2.405}{B_g}\right) - \lambda_R = 6.54 \text{ cm} \quad (\text{Dia} = 5.1 \text{ in})$$

(b) Sphere

$$R_{0.85} = \left(\frac{\pi}{B_g}\right) - \lambda_R = 10.4 \text{ cm} \quad \text{Vol} = 4.7 \ell$$

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Calculation Sheet

Originator Z/Walker Date 7-12-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2333 D&D Job No. 22192 Checked R.L. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 15

III Comparison between ARH-600 and LATA Calculations
Process Vessel Keff Summary

Vessel ID	Mass (gm) (1)	Radius (cm) LATA	Radius (cm) This Calc	Height (cm) LATA (5)	Height (cm) This Calc (6)	Keff LATA	Keff This Calc.
L-4	220	7.14	7.14	10.03	13.74	0.386	0.520
L-6	270	5.72	5.72	19.21	26.27	0.359	0.451
L-12S	190	7.70	8.07 (2)	7.44	9.29	0.353	0.542
L-12N	170	1.33 (3)	8.07 (2)	182.54	8.31	0.009	0.532
L-14	425	7.14	7.14	19.36	26.54	0.498	0.559
L-16	780	7.70	7.70	30.55	41.88	0.583	0.625
	780	—	8.07 (4)	—	38.12	—	0.649
L-18	200	5.41	5.41	15.88	21.75	0.287	0.421

Note: The Keff from this calc are for bare radial reflection and full water axial reflection

(1) SEG NDA measurements DCC-95-2505
(2) Assume L-12 identical to L-3: 6 in dia, Sch 10 pipe
(3) LATA assumed 1 in dia pipe. This is the size of the internal heat exchanger tubes inside the vessel, not the diameter of the vessel
(4) Assumes that vessel is 6 in dia, Sch 10 pipe
LATA assumed 6 in dia, Sch 40 pipe
(5) This value corresponds to $\rho_{Pu} = 0.137$ kg/l
(6) This value corresponds to $\rho_{Pu} = 0.100$ kg/l

IV ARRAY INTERACTION - SOLID ANGLE RELATIONSHIP

REF: TID-7016 (REF 3) - ATTACHMENT E

Ω_{ALL} = 9 - 10 keff (BARE)

CONDITIONS:

(1) keff ≤ 0.80 FOR ANY UNIT

(2) keff < 1.0 FOR ANY UNIT w/ FULL WATER REFLECTION

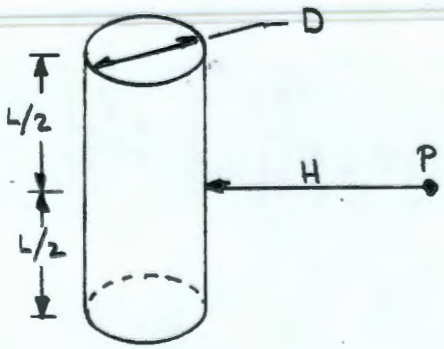
(3) DISTANCE BETWEEN UNITS ≥ 0.3 M (~12 IN)

(4) Ω_{TOTAL} ≤ 6 STERADIANS

FOR CONCRETE REFLECTED ARRAYS

Ω_{ALL} (CONC.) = (1 - 0.4) Ω_{ALL} (REF 3 para 4.34)

POINT-TO-CYLINDER (REF 3, FIG 4.1)



$$\Omega = \frac{LD}{H\sqrt{(L/2)^2 + H^2}}$$

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Calculation Sheet

Originator S/Walters Date 7-29-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.T. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 17

Vessel	Keff (Bare)	Ω_{ALL}	Ω_{ALL} (Concrete)	L (IN)	D (IN)	Y (IN)	X (IN)
						Ref 1	
L-4	0.520	3.80	2.28	5.41	5.62	171 (N) 138 (S)	75
L-6	0.451	4.49	2.69	10.34	4.50	303 (V)	42
L-12S	0.542	3.58	2.15	3.66	6.35	168	75
L-12N	0.532	3.68	2.21	3.27	6.35	222	75
L-14	0.559	3.41	2.05	10.45	5.62	285 (N) 252 (S)	12
L-16 (1)	0.649	2.51	1.51	15.01	6.35	312 (N) 288 (C) 267 (S)	22 28 34
L-18	0.421	4.79	2.87	8.56	4.26	258	65 (W) 89 (E)

(1) Schedule 10 pipe, results in more conservative bare keff

Originator 2/Wallace 9713537.2432 Date 9-27-96 Calc. No. 0220W-CA-N0001 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 18

Component Positions within the Process Hood

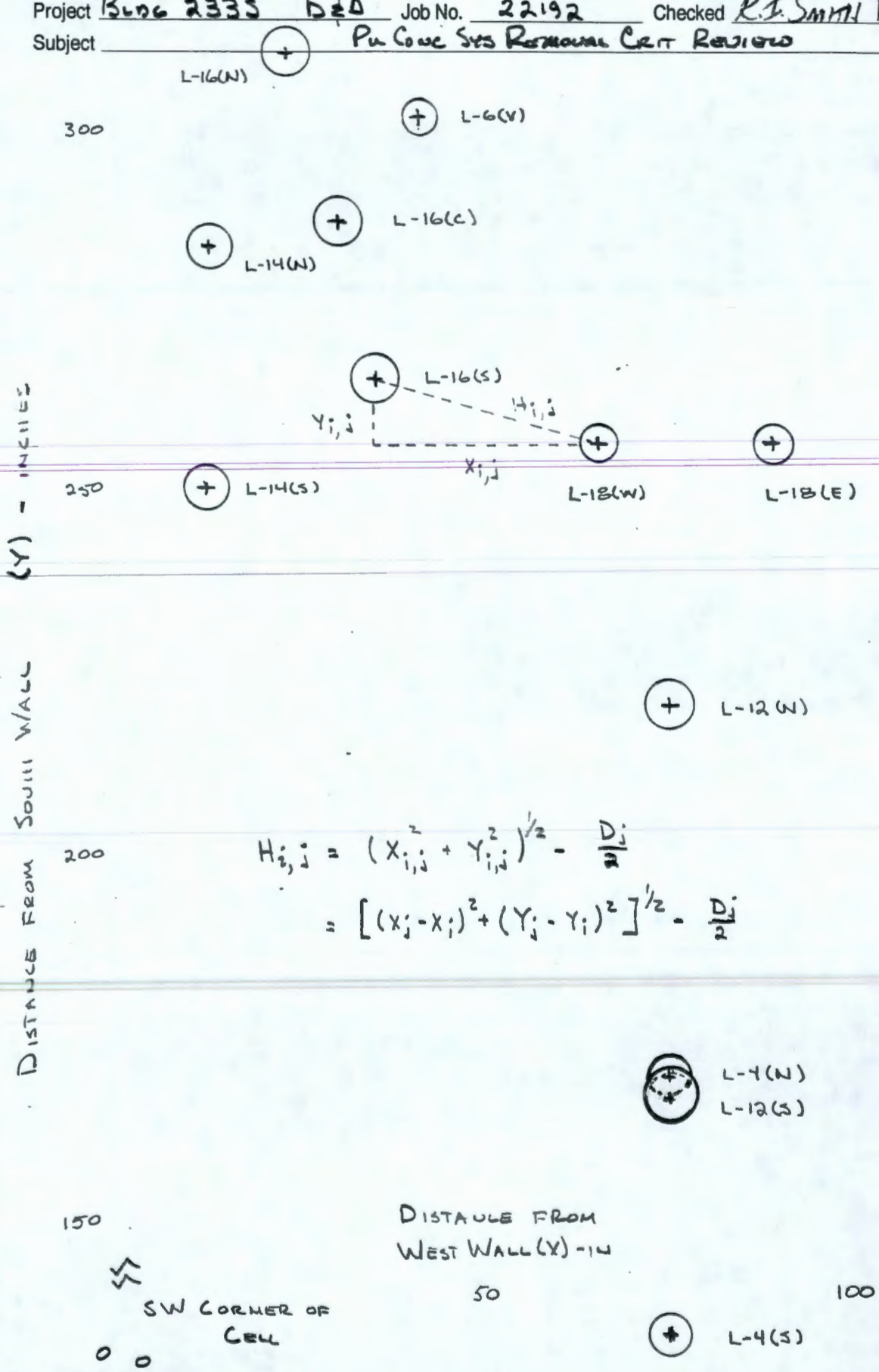
Tanks & Sections	Y Center of tank to			X	Bottom Elevation of tank	Top Elevation of tank
	South Screen	North Wall	East Screen	West Wall		
L-3 (S,L)	4'	23'4"	2'	6'3"	11'4"	16'4"
L-3 (N,L)	8'6"	18'9"	2'	6'3"	7'10"	16'
L-3 (S,U)	4'	23'4"	2'	6'3"	21'4"	28'3"
L-4 (N)	14'3"	13'	2'	6'3"	2'4"	6'10"
L-4 (S)	11'6"	15'8"	2'	6'3"	2'4"	6'10"
L-6 Horiz.	12'6"	14'10"	14'9"	3'6"	9'7"	N/A
L-6 Vertical	25'3"	2'	1'	3'6"	9'	11'
L-6 Sm. Dia. section	22'6"	4'10"	1'	3'6"	9'6"	N/A
L-10 (N) N-most sect.	17'4"	10'	7'3"	1'	6"	22'4"
L-10	14'10"	12'6"	7'3"	1'	6"	22'4"
L-10	12'4"	15'	7'3"	1'	6"	22'4"
L-10	9'10"	17'6"	7'3"	1'	6"	22'4"
L-10 (S) S-most sect.	7'4"	20'	7'3"	1'	6"	22'4"
L-12 (L,N)	18'6"	8'9"	2'	6'3"	10'10"	19'
L-12 (L,S)	14'	13'4"	2'	6'3"	14'4"	19'4"
L-12 (U,S)	14'	13'4"	2'	6'3"	21'4"	28'3"
L-14 (N)	23'9"	3'6"	3'6"	1'	12'4"	16'6"
L-14 (S)	21'	6'2"	3'6"	1'	12'4"	16'6"
L-16 (N)	26'	1'3"	2'8"	1'10"	1'2"	5'4"
L-16 (C)	24'	3'2"	2'2"	2'4"	1'2"	5'4"
L-16 (S)	22'3"	5'	1'8"	2'10"	1'2"	5'4"
L-18 (W)	21'6"	5'9"	2'10"	5'5"	4'6"	23'
L-18 (E)	21'6"	5'9"	10"	7'5"	4'6"	28'6"

Note: (N)orth (S)outh (E)ast (W)est (U)pper (L)ower (C)enter

Bechtel

Calculation Sheet

Originator Z/Walker Date 7-29-96 Calc. No. 0200W-CA-H0001 Rev. No. 0
Project Bldg 2333 D&D Job No. 22192 Checked R.I. Smith Date 10/23/96
Subject Pu Conc Sys Removal Crit Revised Sheet No. 19



$$H_{i,j} = (X_{i,j}^2 + Y_{i,j}^2)^{1/2} - \frac{D_j}{2}$$

$$= \left[(X_j - X_i)^2 + (Y_j - Y_i)^2\right]^{1/2} - \frac{D_j}{2}$$

9713537.2425

ORIGINATOR: E. WALKER DATE: 7-29-96 CALC. NO. 0200W-CA-N0001 REV. NO. 0
PROJECT: BLDG 233S D&D JOB NO. 22192 CHECKED: R.I. SMITH DATE: 10/23/96
SUBJECT: PU CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW SHEET NO. 20

INTERACTION POTENTIAL - SOLID ANGLE RELATIONSHIP

→ j ; ↓ i

VESSEL	LD	$\bar{R}$	L-4(2) $H_{i,j}$	L-4(2) $\Omega_{i,j}$	L-6 $H_{i,j}$	L-6 $\Omega_{i,j}$	L-12S $H_{i,j}$	L-12S $\Omega_{i,j}$	L-15N $H_{i,j}$	L-15N $\Omega_{i,j}$	L-14(2) $H_{i,j}$	L-14(2) $\Omega_{i,j}$	L-16(2) $H_{i,j}$	L-16(2) $\Omega_{i,j}$	L-18(2) $H_{i,j}$	L-18(2) $\Omega_{i,j}$	$\Sigma\Omega_{i,j}$	Ω_i (MAX)	Ω_{ALL} (3)
L-4(N)	30.40	186.7	—	—	133.8	0.003	37.35 (4)	0.004 (4)	47.82	0.009	99.81(S)	0.006	101.2(S)	0.009	85.44(W)	0.005	0.036	0.036	2.28
L-4(S)		157.1	—	—	[LESS INTERACTION THAN L-4(N); SEE SKETCH ON SHEET 19]														
L-6(V)	46.53	305.9	133.3(N)	0.002	—	—	135.8	0.001	84.28	0.003	32.18(N)	0.056	17.34(C)	0.291	48.41(W)	0.016	0.369	0.369	2.69
L-12S	23.24	184.0	88.22 (4)	0.003 (4)	136.7	0.003	—	—	50.82	0.008	102.2(S)	0.006	104.0(S)	0.009	88.42(W)	0.005	0.034	0.034	2.15
L-15N	20.76	234.3	48.13(N)	0.013	85.21	0.006	50.82	0.009	—	—	66.97(S)	0.012	57.70(S)	0.028	35.23(W)	0.029	0.098	0.098	2.21
L-14(N)	58.73	285.3	127.4(N)	0.002	32.74	0.043	129.7	0.001	85.92	0.003	—	—	13.10(C)	0.482	57.35(W)	0.011	0.542	0.542	2.05
L-14(S)		252.3	99.81(N)	0.003	56.92	0.014	101.8	0.002	66.60	0.005	—	—	23.45(S)	0.165	51.21(W)	0.014	0.203		
L-16(N)	95.31	312.8		—	[LESS INTERACTION THAN L-16(C) OR L-16(S); SEE SKETCH ON SHEET 19]														
L-16(C)		289.4	123.3(N)	0.002	18.27	0.134	125.7	0.002	77.34	0.003	13.47(N)	0.302	—	—	45.50(W)	0.018	0.461	0.461	1.51
L-16(S)		269.2	101.6(N)	0.003	34.63	0.038	104.0	0.002	57.70	0.006	23.31(S)	0.101	—	—	30.15(W)	0.040	0.190		
L-18(W)	36.47	266.1	84.76(N)	0.004	48.29	0.020	87.37	0.003	34.18	0.018	50.53(S)	0.023	29.10(S)	0.109	—	—	0.177	0.177	2.87
L-18(E)		272.9		—	[LESS INTERACTION THAN L-18(W); SEE SKETCH ON SHEET 19]														

(1) ASSUME ALL VESSELS ON SAME PLANE EXCEPT L-4(N) AND L-12S
(2) FOR VESSELS IN MULTIPLE LOCATIONS [e.g. L-16(N)/L-16(C)/(L-16(S)] INTERACTION IS CALCULATED WITH ONE WHICH YIELDS LARGEST SOLID ANGLE
(3) FOR CONSERVATISM, ALLOWABLE SOLID ANGLE IS BASED ON CONCRETE REFLECTED ARRAY
(4) FOR INTERACTION BETWEEN L-4(N) AND L-12S :

$$\bar{R} = (X^2 + Y^2)^{1/2}$$

$$H_{i,j} = \left[(X_i - X_j)^2 + (Y_i - Y_j)^2\right]^{1/2} - \frac{D_j}{2}$$

$$\Omega_{i,j} = \frac{(LD)_j}{H_{i,j}\sqrt{(L_j/2)^2 + H_{i,j}^2}}$$

$$H_{i,j} = \left[(Y_i - Y_j)^2 + (Z_i - Z_j)^2\right]^{1/2} - \left(\frac{L_j}{2}\right)$$

$Z_1 = 82$ IN (TOP OF L-4)
$Z_1 = 172$ IN (BOTTOM OF L-12S)

$$\Omega_{i,j} = 2\pi\left(1 - \frac{1}{\sqrt{1 + (D_j/2H_{i,j})^2}}\right)$$

POINT-TO-DISK (REF 3)

502 (6-81)

7-30-96

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Calculation Sheet

Originator E/Walker Date 9-19-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project Bldg 2335 D&D Job No. 22192 Checked R.L. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 21

IV OFF-NORMAL/ACCIDENT CONDITIONS

A. MEASUREMENT ERROR IN VESSEL WITH LARGEST INVENTORY

ASSUMPTIONS :

(1) VESSEL L-16, MAXIMUM MEASURED VALUE (REF 1, ATT F.6

$$M + 1\sigma = 679.9 \pm 682.4 \text{ gm Pu}$$

ASSUME MEASUREMENT/MODEL IS NON CONSERVATIVE BY FACTOR OF TWO, BUT ACCURACY IS THE SAME

$$M + 1\sigma = 1360 \pm 680 \text{ gm Pu}$$

(2) VESSEL CONTAINS LIQUID AT OPTIMUM MODERATION FOR Pu + H_2O

$$\rho_{Pu} = 100 \text{ gm/l}$$

(3) VESSEL IS WRAPPED IN PLASTIC THAT PROVIDES A REFLECTOR EQUIVALENT OF 1 IN OF WATER WITH THE VESSEL WALL.

(4) THE FISSILE DISTRIBUTION IS SUCH THAT FULL WATER REFLECTION EXISTS ON TOP AND BOTTOM

(5) FROM SHEET 5, THIS CALC : Pu + H_2O ; Pu-240 = 5%

(a) $k_\infty = 1.680$
(b) $B_m^2 = 0.0254 \text{ cm}^{-2}$; $M^2 = 26.77 \text{ cm}^2$
(c) $\lambda_R = 4.30$ cm
(d) $\lambda_T, \lambda_B = 6.05$ cm

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Calculation Sheet

Originator S/W Chen Date 9-19-96 Calc. No. 02000-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.T. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 22

VESSEL SOLUTION HEIGHT

$$H_s = \frac{M_f \text{ (gm)}}{\rho_{Pu}\left(\frac{\text{gm Pu}}{\text{cm}^3 \text{ sol}}\right) * \pi R_i^2 (\text{cm}^2)}$$

FOR 6" DIA, SCH 10 PIPE : R_i = 8.07 cm (MAXIMIZE keff

TAKE : M_f = 2040 gm Pu

H_s = 99.7 cm (39.3 in.) TOTAL VESSEL HEIGHT = 56 IN

VESSEL GEOMETRIC BUCKLING (B_g^2)

$$B_R^2 = \left(\frac{2.405}{R_i + \lambda_R}\right)^2 = 0.0384 \text{ cm}^{-2}$$

$$B_H^2 = \left(\frac{\pi}{H_s + \lambda_T + \lambda_R}\right)^2 = 0.0008 \text{ cm}^{-2}$$

$$B_g^2 = B_R^2 + B_H^2 = 0.0392 \text{ cm}^{-2}$$

VESSEL MULTIPLICATION (keff)

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

$$= \frac{1.680}{1 + (26.77)(.0392)} = 0.820$$

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Calculation Sheet

Originator S/Walker Date 9-19-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2336 D&D Job No. 22192 Checked R.I. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 23

THE NET CHANGE FOR A MEASUREMENT ERROR IN THE L-16 VESSEL WITH PARTIAL REFLECTION

1. NORMAL CONDITIONS : $M_{Pu} + 1\sigma = 780$ gm

$k_{eff} = 0.788$

2.) MEASUREMENT ERROR : $M_{Pu} + 1\sigma = 2040$ gm

$k_{eff} = 0.820$

NET CHANGE :

$\Delta k = 0.820 - 0.788 = 0.032$

% CHANGE = 4.1% $\Delta k/k$

B. INTERACTION POTENTIAL FOR INCREASED INVENTORY IN L-16

(1) FOR L-16 INTERACTION WITH REMAINDER OF ARRAY THE ALLOWABLE SOLID ANGLE WILL BE REDUCED

$\Omega_{ALL} = (0.6)(9-10 k_{eff})$ CONCRETE REFLECTED ARRA

keff FOR BARE UNIT

$B_R^2 = 0.0554\ cm^{-2}$ $\lambda_R = 2.15\ cm$ (NO REFLECTION)

$B_H^2 = 0.0008\ cm^{-2}$ $\lambda_T, \lambda_B = 6.05\ cm$ (WATER IN VESSEL)

$B_g^2 = 0.0562\ cm^{-2}$

$$k_{eff} = \frac{1.690}{1+(26.77)(.0562)} = 0.671$$

$\therefore \Omega_{ALL} = 1.37$ (SCHEDULE 10 PIPE)

FROM SHEET 20,

$\Omega_{ACT} = 0.461$

AND SO,

$\Omega_{ACT} < \Omega_{ALL}$

(2) CONSIDER INCREASED SOLID ANGLE PROJECTED BY L-16 DUE TO SOLUTION HEIGHT INCREASE ON NEXT MOST REACTIVE VESSEL IN ARRAY, L-14 WHICH IS ALSO CLOSEST UNIT TO L-16

FOR L-16, SCHEDULE 10

$D = 6.35$ IN, $L = 39.3$ IN

$$\Omega = \frac{LD}{H\sqrt{\left(\frac{L}{2}\right)^2 + H^2}}$$

H - DISTANCE FROM POINT TO CYLINDER

$H_{14,16} = 13.10$ IN (FROM SHEET 20)

$\Omega_{14,16} = 0.807$

$\Delta\Omega_{14,16} = 0.807 - 0.482 = 0.325$

$\Omega_{ACT} = [\Omega_{14}(MAX)^{(a)} + \Delta\Omega_{14,16}]$

$= 0.542 + 0.325$

$= 0.867$

$\Omega_{ALL} = 2.05$ FROM SHEET 20

$\therefore \Omega_{ACT} < \Omega_{ALL}$

(a) FROM SHEET 20

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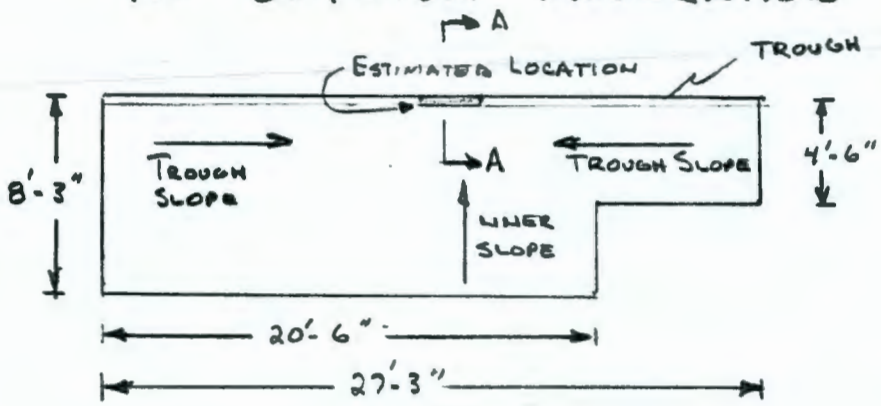
Calculation Sheet

Originator E/W Allen Date 9-19-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 26

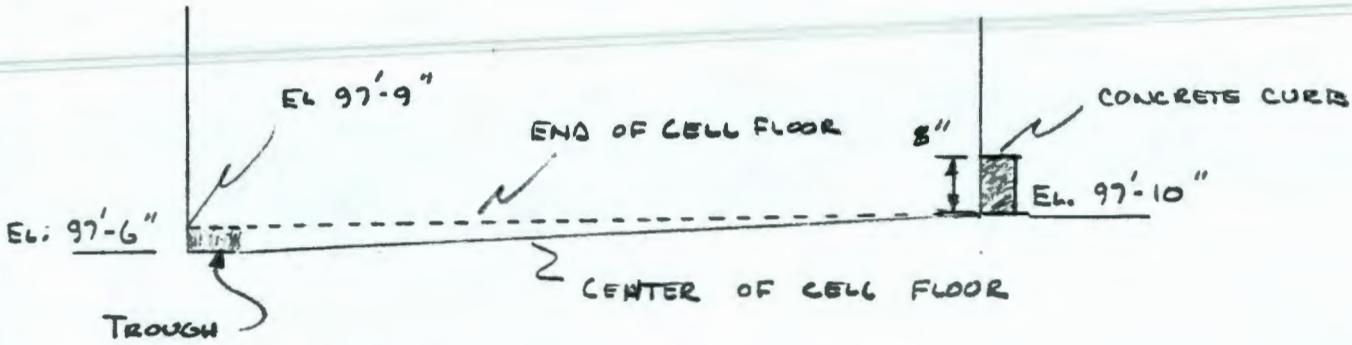
C. VESSEL CONTENTS RELEASED DURING REMOVAL OPERATIONS

DETERMINE THE CRITICALITY SAFETY MARGIN IF THE FISSILE MATERIAL WITHIN THE VESSELS IS IN LIQUID FORM. ASSUME THE ENTIRE ESTIMATED RESIDUAL INVENTORY IS RELEASED

ASSUME CONTENTS COLLECT IN PROCESS CELL SUMP AT OPTIMUM MODERATION



REF: DWG H-2-18029 M 8-7-53
DWG H-2-7202 10-28-53
DWG H-2-45238 9-4-62



SECTION A-A

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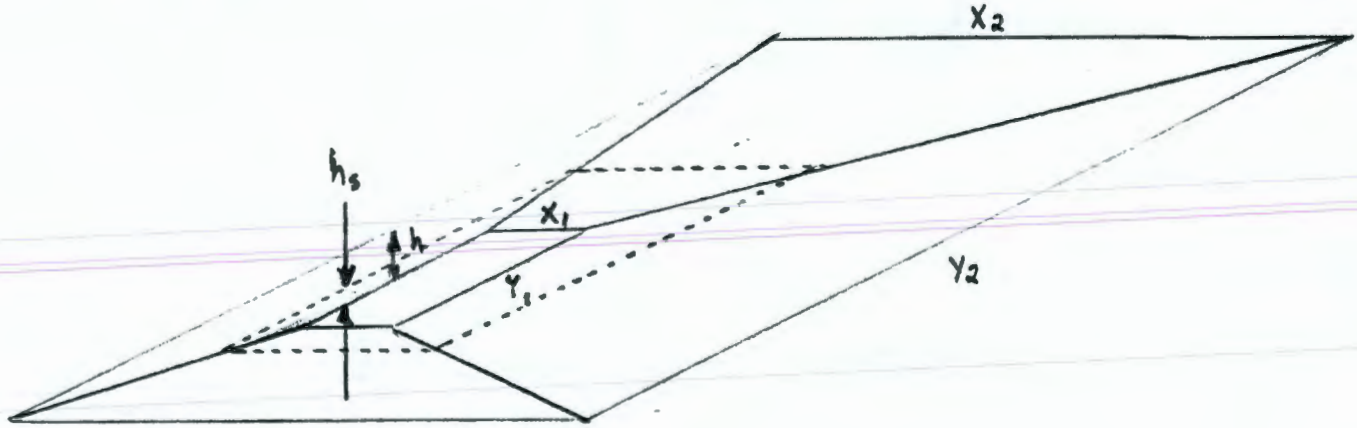
Calculation Sheet

Originator S/Walker Date 9-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project Bldg 2335 D&D Job No. 22192 Checked R.T. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 27

PYRAMIDAL FRUSTRUM



$$\text{VOLUME} = \tfrac{1}{3} h \left(A_1 + A_2 + \sqrt{A_1 A_2} \right)$$

$$= \tfrac{1}{3} h . A_1 \left[1 + \left(P_2/P_1 \right) + \left(P_2/P_1 \right)^2 \right]$$

$A_1 = X_1 * Y_1$ AREA OF LOWER BASE
$P_1 = 2(X_1 + Y_1)$ PERIMETER OF LOWER BASE

$A_2 = X_2 * Y_2$ AREA OF UPPER BASE
$P_2 = 2(X_2 + Y_2)$ PERIMETER OF UPPER BASE

(1) FOR THE LOWER BASE (TROUGH) DESIGNATED AS SUMP S-1 THE DIMENSIONS ARE ESTIMATED AS

X_1 = 6 INCH
Y_1 = 2 FT - 6 IN

(2) FOR UPPER BASE, IGNORE THE OFFSET SECTION OF PROCESS CELL FLOOR (CONSERVATIVE) FOR THE TOTAL SUMP VOLUME ESTIMATE

X_2 = 8 FT - 3 INCH
Y_2 = 20 FT - 6 INCH

(3) THE EFFECTIVE HEIGHT (h) OF THE SUMP IS

$h = (97'-10'') - (97'-6'')$

$= 4$ INCH

(4) TOTAL VOLUME

$V = \frac{1}{3}(4.0)\left[(246\text{ in})(99\text{ in}) + (30\text{ in})(6\text{ in}) + \sqrt{(246)(99)(30)(6)}\right]$

$= \frac{1}{3}(4)\left[(24354) + (180) + \sqrt{(24354)(180)}\right]$

$= \frac{1}{3}(4)\left[24534 + 2094\right]$

$= 35{,}504\ \text{in}^3$

$= 581{,}800\ \text{cm}^3$

(5) VOLUME OF CELL FISSILE INVENTORY AT OPTIMUM MODERATION

$M_{Pu} = 2255$ gm [FROM SHEET 6]

$\rho_{Pu} = 0.10\ \text{gm/cm}^3$ [FROM SHEET 5]

$V_{Pu} = 22550\ \text{cm}^3$

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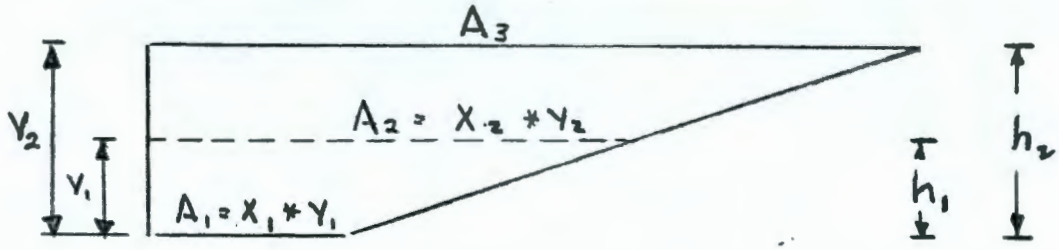
Calculation Sheet

Originator Z Walker Date 10-10-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2333 D&D Job No. 22192 Checked R.T. Smith Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 29

(6) VOLUME OF SOLUTION IN SUMP



$$V_1 = \tfrac{1}{3} h_1 \left(A_1 + A_2 + \sqrt{A_1 A_2} \right)$$

$$V_2 = \tfrac{1}{3} h_2 \left(A_1 + A_3 + \sqrt{A_1 A_3} \right)$$

(a) X - DIRECTION

$$\frac{\Delta Z}{\Delta X} = \left(\frac{4 \text{ IN}}{99 \text{ IN} - 6 \text{ IN}} \right) = \frac{4}{93} \; ; \quad \Delta X = \frac{93}{4} \Delta Z$$

FOR $\Delta Z = h_1$; $X_2 = X_1 + \Delta X = 6 + 23.25 h_1$

(b) Y - DIRECTION

$$\frac{\Delta Z}{\Delta Y} = \left(\frac{4 \text{ IN}}{246 \text{ IN} - 30 \text{ IN}} \right) = \frac{4}{216} \; ; \quad \Delta Y = \frac{216}{4} \Delta Z$$

FOR $\Delta Z = h_1$; $Y_2 = Y_1 + \Delta Y = 30 + 54 h_1$

$$V_1 = \tfrac{1}{3} h_1 \left(A_1 + A_2 + \sqrt{A_1 A_2} \right)$$

$$= 22550 \text{ cm}^2$$

$$= 1376 \text{ IN}^2$$

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Calculation Sheet

Originator E/Walters Date 10-10-96 Calc. No. 02040-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.F. Smith Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 30

$$A_1 = (30 \text{ IN})(6 \text{ IN}) = 180 \text{ IN}^2$$

$$A_2 = X_2 * Y_2 = (6 + 23.25\, h_1)(30 + 54\, h_1) \text{ IN}^2$$

SOLVE ITERATIVELY:

h_1 (IN)	V_1 (IN^3)
1.00	1100
1.10	1362
1.11	1390
1.105	1376

THE MAXIMUM SOLUTION HEIGHT h_s IN THE SUMP CORRESPONDING TO A SOLUTION MASS OF 2255 gm Pu AT OPTIMUM MODERATION IS

$$h_s = 1.105 \text{ IN} = 2.8 \text{ CM}$$

(7) THE THICKNESS (T_s) OF AN INFINITE SLAB REFLECTED BY CONCRETE ON ONE SIDE AND AIR ON THE OTHER MAY BE ESTIMATED FROM THE RELATIONSHIP

$$B_m^2 = B_g^2 = \left(\frac{\pi}{T_s + \lambda_c + \lambda_A}\right)^2$$

λ_c = EXTRAPOLATION DISTANCE FOR CONCRETE (CONSERVATIVE)

= 7.2 CM FOR PLUTONIUM NITRATE AT ρ = 100 gm Pu/l AND Pu-240 = 3% (REF 3, FIG II.E-8)

λ_A = 2.20 CM FOR PLUTONIUM NITRATE AT ρ = 100 gm Pu/l AND Pu-240 = 5% (REF 3, FIG III.A.10(95)-1)

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Calculation Sheet

Originator E/Walker Date 9-30-96 Calc. No. 0200W-CA-N0000 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.F. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 31

For Plutonium Nitrate at ρ = 100 gm Pu/l
and Pu^{240} = 5%

$B_m^2 = 0.0247\ cm^{-2}$ [From Sheet 5]

$$(0.0247) = \left(\frac{\pi}{T_c + (7.2) + (2.20)} \right)^2$$

$T_c + 9.40 = 19.99$

$T_c = 10.59$ cm

∴ The total process cell inventory at optimum moderation will form a slab with a maximum depth (h_s) that is

h_s = 26.4 % of a critical slab thickness

V COMMENTS ON LATA CALCULATIONS

THE LATA CRITICALITY ANALYSIS REPORT (ATTACHMENT A) WAS REVIEWED FOR TECHNICAL CONTENT AND TYPOS. THIS REVIEW RESULTED IN SEVERAL COMMENTS, DISCUSSED BELOW AND IDENTIFIED IN THE ATTACHMENT

1. FIRST SUMMARY PAGE, ASSUMPTIONS, para 2.

A REFERENCE SHOULD BE IDENTIFIED FOR THE 40% REDUCTION IN ALLOWED SOLID ANGLE TO ACCOUNT FOR ADDITIONAL ARRAY REFLECTION; e.g. TID-7016

2. SECOND SUMMARY PAGE, TABLE - VESSEL L-12N

k_{eff} IS GIVEN AS 0.0002. IN CALC #5, SHEET 32, k_{eff} IS GIVEN AS 0.009.

3. CALC NO. 5, SHEET NO. 7: EXTRAPOLATION 2.

IT IS STATED THAT 1.7 M ACID IS USED FOR ALL COMPONENT CALCULATIONS BASED ON $Pu(NO_3)_4$ SOLUTION. THIS IS NOT THE BASIS AGREED TO DURING DISCUSSIONS BETWEEN BHI AND LATA, 4/29/96. THE SOLUTION TO BE USED TO MODEL ALL VESSELS EXCEPT L-16 WAS TO BE $Pu(NO_3)_4 + H_2O$ WITH 0 M ACID CONTENT. THIS NEEDS TO BE RECONCILED WITH RESPECT TO THE RESULTS PROVIDED BY LATA. DELETING EXCESS ACID WILL INCREASE INDIVIDUAL UNIT MULTIPLICATION. THIS, IN TURN, IMPACTS THE ARRAY REACTIVITY AND TRANSIENT INTERACTION DURING COMPONENT REMOVALS. LATA MUST PROVIDE CLARIFICATION/JUSTIFICATION OF MODEL USED.

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Calculation Sheet

Originator E/Walker Date 7-29-96 Calc. No. 02000-CA-V0001 Rev. No. 0
Project Bldg 233S D&D Job No. 22192 Checked R.J. Smith Date 10/23/96
Subject Pu Concentration System Removal Criticality Review Sheet No. 33

4. Calc No. 5, Sheet No 2

The vessel ID, run numbers are given for
L-12S, Run #11
L-12N, Run #12

The actual calculations were performed as follows:

Run #11 is for Vessel L-12N (sheet No. 31)
Run #12 is for Vessel L-12S (sheet No. 37)

5. The model used by LATA to evaluate Keff for Vessel L-12N is incorrect. LATA assumed the fissile material to be contained in a 1" dia tube. There are 12 of these tubes inside a 6" dia, schedule 10 pipe. A more appropriate model would be the 6-inch pipe, since the exact distribution of the fissile material inside the vessel is unknown.

6. The relationship used to calculate solid angle between units by LATA does not agree with point-to-cylinder relationship in Ref 3. The expression in Calculation No. 7, sheet 2 results in smaller solid angle than values on sheet 20 of this evaluation using Ref 3. The relationship used by LATA appears more appropriate for point-to-plane. LATA incorrectly applied the concrete reflection reduction to allowable solid angle on sheet 2 of Calculation No. 7.

VI. CONCLUSIONS

1. THIS CONSERVATIVE CHECK SHOWS ALL VESSELS ARE SUBCRITICAL, EVEN FOR FULL WATER REFLECTION. THIS WILL ALLOW FOR NO PACKAGING RESTRICTIONS WHEN REMOVING COMPONENTS [SEE SHEET 14]

2. THE ARRAY IS WELL SUBCRITICAL IN THE CURRENT CONFIGURATION BASED ON THE CONSERVATIVE ASSUMPTION THAT THE FISSILE MATERIAL DISTRIBUTION RESULTS IN AN OPTIMUM MODERATED ACCUMULATION IN EACH VESSEL THAT IS ON THE SAME PLANE FOR ALL UNITS. [SEE SHEET 20]

3. THE MOST REACTIVE UNIT IN THE ARRAY IS L-16. THE NEXT MOST REACTIVE UNIT IS L-14. IT IS RECOMMENDED L-16 BE REMOVED AS SOON AS FEASIBLE ALONG A PATH THAT BRINGS IT NO CLOSER TO THE REMAINING UNITS IN THE ARRAY THAN THE CURRENT GEOMETRY. THIS IS PARTICULARLY SIGNIFICANT FOR L-14 AND L-6

4. THE UNIT WITH THE LARGEST ESTIMATED FISSILE CONTENT (L-16) WAS ANALYZED FOR A MEASUREMENT ERROR OF A FACTOR OF TWO (2) ON THE MAXIMUM ESTIMATED MASS. THE RESULTING CHANGE TO UNIT EFFECTIVE MULTIPLICATION WAS

$$\% \text{ CHANGE} < 5\% \ \Delta k/k$$ [SEE SHEET 23]

5. THE EFFECT ON THE INTERACTION POTENTIAL OF THE ARRAY OF A FACTOR OF TWO MEASUREMENT ERROR WAS AS FOLLOWS

L-16 : ALLOWABLE SOLID ANGLE Ω_{ALL} DECREASES FROM $\Omega_{ALL} = 1.51$ TO 1.37

THE ACTUAL SOLID ANGLE, Ω_{ACT}, IS 0.461 WHICH IS BELOW THE ALLOWABLE [SEE SHEET 24]

L-14 : THE ACTUAL SOLID ANGLE INCREASES FROM $\Omega_{ACT} = 0.542$ TO 0.867, WHICH IS STILL BELOW THE ALLOWABLE SOLID ANGLE OF $\Omega_{ALL} = 2.05$ [SEE SHEET 25]

6. THE PROCESS CELL SUMP WAS EVALUATED FOR THE CONSERVATIVE ASSUMPTION OF OPTIMUM MODERATION FOR THE FISSILE CONTENTS IN EACH VESSEL AND THE TOTAL CONTENTS IN THE PROCESS SYSTEM DRAINED TO THE CELL FLOOR. THE MAXIMUM SLAB THICKNESS THAT WOULD BE FORMED IN THE PYRAMIDAL FRUSTRUM GEOMETRY OF THE SUMP WOULD BE:

$$t_{SOL} = 2.8 \text{ cm}$$

THE CRITICAL SLAB THICKNESS FOR THIS FISSILE COMPOSITION IS:

$$t_{CRIT} = 10.59 \text{ cm}$$

THE SUMP IS CRITICALLY SAFE FOR THE ESTIMATED PROCESS CELL INVENTORY. [SEE SHEET 30]

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Calculation Sheet

Originator S/Walker Date 10-1-96 Calc. No. CROOW-CA-N0001 Rev. No. 0
Project BLDG 2333 D&D Job No. 22192 Checked R.L. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. 36

7. THE INDIVIDUAL UNITS AND THE PROCESS CELL ARRAY RETAIN SUFFICIENT CRITICALITY SAFETY MARGIN FOR A MEASUREMENT ERROR ESTIMATE OF A FACTOR OF TWO

8. THE SUMP HAS SUFFICIENT CRITICALITY SAFETY MARGIN IN THE HIGHLY UNLIKELY EVENT THAT THE CONTENTS OF EVERY PROCESS VESSEL ARE DRAINED ONTO THE PROCESS CELL FLOOR AT OPTIMUM MODERATION.

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Calculation Sheet

Originator E/Walker Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A1

ATTACHMENT A

CRITICALITY EVALUATION OF THE PROPOSED DISMANTLEMENT OF THE HANFORD 233-S FACILITY

PERFORMED BY LATA, INC.

RICHLAND, WA

JUNE, 1996

Originator Edward 9713537.2443 Date 7-30-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A2

Additional Criticality Evaluation of the Proposed Dismantlement of the Hanford 233-S Facility

Performed for the Hanford ERC Under Contract #0200W-SC-G0018

Purpose

These calculations have been developed to investigate further the potential for a criticality event during the dismantlement of the 233-S process vessel array. They supplement the previous set of calculations performed under this same contract, which were performed on March 13, 1996.

Analytical Methods

These calculations were performed using the same MCNP computer code as for the previous set; the validation calculations performed then are valid for this set as well. Hand calculations, using the method of Solid Angle, were also developed. The references are the same as for the previous set as well.

Assumptions

The partially reflected K_{eff} of each of the seven vessels listed in the SEG, 1995 report are the only reactive elements of concern. The fissile material amounts to be used in the calculations are those listed in the SEG report, plus one standard deviation. Partial reflection will be taken into account by including the vessel walls in the calculation. Each vessel will be assumed to be a simple right circular cylinder, with diameter as stated in the attachment to the RFP labeled "miscellaneous documentation". Pu-239/240 ratios are as shown in the SEG report (ie., 6% Pu-240). All calculations assume that the Pu is present as dissolved $Pu(NO_3)_4$, with the exception of the tank L-16, which will be assumed to contain elemental Pu suspended in water. In all cases, the optimum H/Pu ratio will be used.

Reference !?

For the solid angle calculations, the maximum allowed solid angle will be reduced by 40% to take into account the reflection of the concrete walls and worker's bodies. The location of the vessels will be as shown in the facility drawings which were provided to support these calculations. The locations will be verified using the vessel locations shown in the SEG report, however where conflict is noted, the drawings will take precedence. All vessels will be assumed to be located such that the center of the fissile volumes are on the same plane. e.g TID-7016

Results

The results of the K_{eff} calculations are shown in the table below.

Vessel Identification	K_{eff}
L-4	0.39
L-6	0.36
L-12S	0.35
L-12N	0.0002
L-14	0.50
L-16	0.58
L-18	0.29

CALC #5, 5431 K = 0.009

TYPO ?

← ?

A special case was also modeled in which the L-16 vessel was moved up directly against another (hypothetical) identical vessel. The purpose of this calculation was to investigate the affect on vessel multiplication factors of moving them around in the array. The results of this calculation showed a negligible increase in the K_{eff}.

Solid angle calculations were performed to assess the degree of subcriticality of the array in it's present state. These calculations showed, as expected, that the array is extremely subcritical. A Solid Angle calculation was also performed to investigate the potential effect of moving the L-16 vessel closer to several other vessels, and finally, a calculation was performed in which the vessels were hypothetically rearranged such that each one was 12" away from each of the remaining ones (this is a physically impossible arrangement). The results of all of these calculations were that, within the limits of the method, the array remained subcritical under any postulated vessel removal schemes.

9713537.2445

Originator Edwards Date 1-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A4

CALCULATION LOG

Discipline Criticality Evaluation **Page No.** 1

Project 0200W-SC-G0018 **Job No.** BH101

Calculation Number	Subject	Originator and Date	Type*		
			C	P	S
for 85	Optimum MCNP calculations	DL 6/13/96		X	
6	Special MCNP calculation	DL 6/20/96		X	
7	Surface Density Calculations	JH 6/17/96		X	

*C = Committed P = Preliminary S = Superseded

EDPI-4.37

Originator [illegible] 9713537.2446 Date 1-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A5

CALCULATION COVER SHEET

Project Title 0200W-SC-G0018 2335 D&D **Job No.** BH101

Area 200W

Discipline Criticality Analysis **Calc. No.** 5

Subject Optimum MCNP calculations

Computer Program MCNP **Program No.** 4A

Committed Calculation ☐ **Preliminary** ☑ **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
A	42	D. Lowe	J. Hinkley			

SUMMARY OF REVISION

Microfilmed:	Rev.	Date	Reel Number	Rev.	Date	Reel Number

Originator Edward 9713537.2447 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A6

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/3/96	1

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS.	DL	

THIS SET OF MCNP RUNS WILL BE PERFORMED AS A PART OF MODIFICATION TO THE ORIGINAL SCOPE PROPOSED ON 5/6/96. A TOTAL OF 7 PARTIALLY REFLECTED K-EFF MCNP CALCULATIONS WILL BE CONDUCTED, WITH THE FOLLOWING GUIDELINES:

A. MODEL EACH COMPONENT AS A RIGHT CIRCULAR CYLINDER.

B. USE SEG 1995 REPORT VALUE + 1σ.

C. ASSUME Pu RESIDUE TO BE $Pu(NO_3)_4$, EXCEPT FOR L-16 TANK (Pu METAL ASSUMED).

D. ASSUME 6 WT% Pu240 CONTENT.

E. ASSUME OPTIMAL MODERATION IN Pu RESIDUE SO THAT Pu IS IN SOLUTION/SUSPENSION IN WATER AT A CONCENTRATION WHICH YIELDS OPTIMAL MODERATION, IN TURNS GIVE A MAXIMUM K-EFF APPROXIMATELY.

F. FILL UNOCCUPIED SPACE OF THE CYLINDER WITH WATER SO THAT CALCULATIONS ARE PARTIALLY REFLECTED.

G. ASSUME NO REFLECTION OUTSIDE THE CYLINDER.

REFERENCES

ASTM 1979, "1979 ANNUAL BOOK OF ASTM STANDARDS, PART 1 STEEL PIPING, TUBING, AND FITTINGS," ASTM, PHILADELPHIA.

MSD 1996, "MISCELLANEOUS SUPPORTING DOCUMENTATION," A REFERENCE DOC WHILE PREPARING THE PROPOSAL.

PH 1980, "PLUTONIUM HANDBOOK," ANS.

LAMARSH, 1975, "INTRODUCTION TO NUCLEAR ENGINEERING," ADDISON-WESLEY, MA.

SEG 1995, "PASSIVE NEUTRON SURVEY OF THE 233 S PLUTONIUM CONCENTRATION FACILITY," DCC#95-2505.

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/3/96	2

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

PU INVENTORY & COMPONENT DESCRIPTIONS (SEG 1995)

COMPONENT	PU MASS + 1 σ (GRAMS)	GEOMETRY DESC
L-16 (RUN #6)†	780	3 (6" X 56" H) PIPES
L-14 (RUN #7)†	425	2 (6" X 4.5' H) PIPES
L-6 (RUN #9)†	270	3" X 5' HORIZ. 5" X 30" VERT.
L-4 (RUN #8)†	220	2 (6" X 4.5' H) PIPES
L-18 (RUN #10)†	200	4" SCH. 10 PIPING 24' OVERALL
L-12S (RUN #11)†	190	6" X 22' H W/ 9" SIDE STH COL
L-12N (RUN #12)†	170	5' W OVERALL (6' TUBE BUNDLE)

† RUN NUMBER

OPTIMUM MODERATION VALUE DETERMINATION

ONE OF THE REQUIREMENTS IN THIS SET OF MCNP RUNS WAS TO USE A H/PU RATIO IN PU RESIDUE SO THAT THE OPTIMUM MODERATION CAN BE ACHIEVED, IN THE OTHER WORDS, THE K_{eff} DETERMINED SHOULD BE AT MAXIMUM.

BECAUSE THE EXISTING SUBCRITICAL LIMIT CURVES FOUND IN MANY REFERENCES WERE TOO SPECIFIC ABOUT THEIR APPLICATIONS, A SENSITIVITY STUDY WAS CONDUCTED FOR THE L-16 COMPONENT, SINCE IT HAS THE MOST PU MASS AND IT IS THE ONLY ONE WITH PU METAL AS PU RESIDUE. NOTE THAT ONLY A LIMITED RUNS CAN BE PERFORMED DUE TO THE AVAILABLE RESOURCES, AND

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO	DATE	SHEET NO.
22192	5	A	6/5/96	3

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

FOLLOWING ASSUMPTIONS WERE MADE:

1. ALTHOUGH FIG 27.13 OF PH1980 (SEE SHEET No. 4) APPLIES TO ONLY TO A BARE INFINITE CYLINDERS, THE CORRESPONDING TOTAL Pu DENSITY & H/Pu ATOMIC RATIO ARE ASSUMED TO BE APPLIED TO THE L-16 SENSITIVITY STUDY.

2. FIG 27.18 OF PH1980 (SEE SHEET NO. 4) IS ASSUMED TO BE USED IN DETERMINING THE SIMILARITY BETWEEN RESIDUE CHARACTERICS (L-16 AS Pu METAL & OTHER COMPONENTS AS $Pu(NO_3)_4$).

3. ONCE THE OPTIMUM MODERATION VALUES ARE DETERMINED FOR THE L-16, EXTRAPOLATION OF THE SIMILAR VALUES CAN BE APPLIED TO ALL OTHER COMPONENTS, DESPITE VARIATIONS MAY OCCUR DUE TO THE DEPENDENCES OF MASS CONTENT & GEOMETRY.

4. BECAUSE BESIDE L-16 CONTAINED MOST Pu MASS, L-14 CONTAINED THE SECOND HIGHEST MASS, IT IS ASSUMED THAT ONCE A OPTIMUM MODERATION IS CALCULATED FOR L-14, THE SAME MODERATION CAN BE APPLIED TO OTHER NITRATE RESIDUE COMPONENTS.

BECAUSE ON THESE ASSUMPTIONS, A TABLE SHOWS THE RESULTS OF THE SENSITIVITY STUDY ON THE OPTIMUM MODERATION (SEE SHEET NO. 5).

Originator Edward 9713537.2450 Date 7-30-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A9

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO	REV NO	DATE	SHEET NO.
22192	5	A	6/5/96	4

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

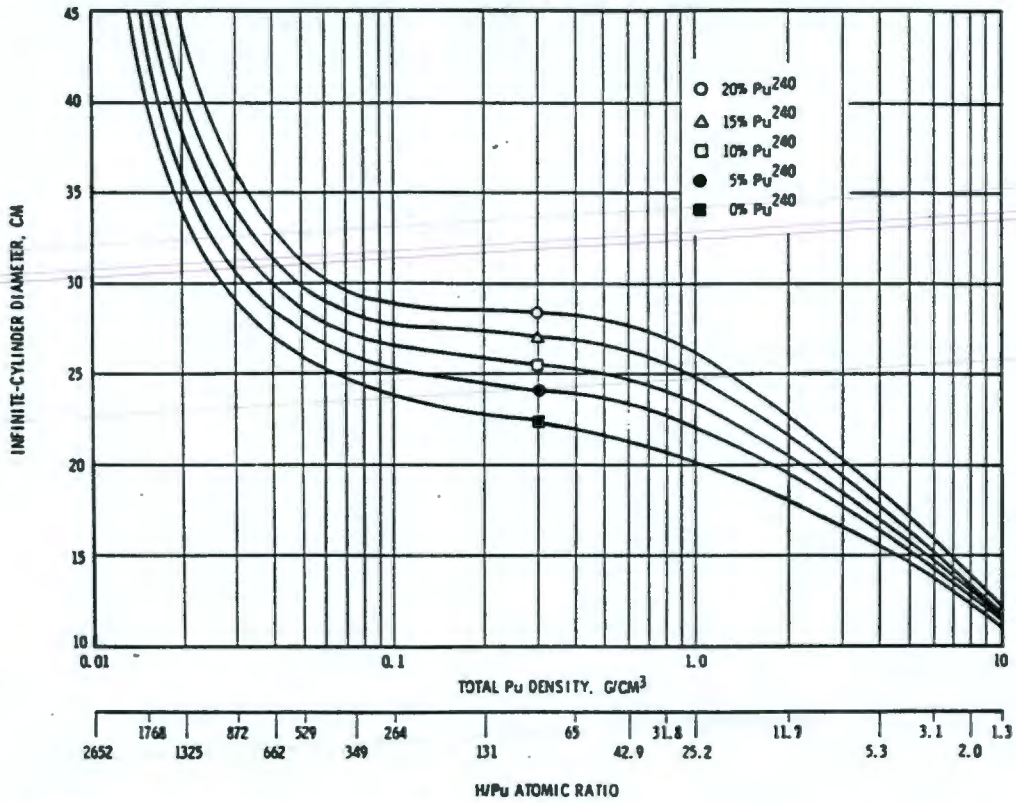

Fig. 27.13—Calculated critical diameters of water-moderated bare infinite cylinders with Pu^{240} content up to 20%.

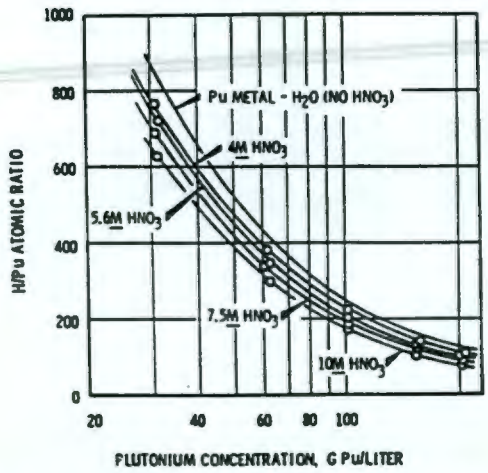

Fig. 27.18—Hydrogen/plutonium atomic ratio as a function of plutonium concentration for $Pu(NO_3)_4$ solutions containing 4, 5, 6, 7.5, and 10 M HNO_3.

Originator [illegible] 9713537.2451 Date 1-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A10

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALC NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/5/96	5

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

SENSITIVITY STUDY ON H/Pu RATIO – ρ_{Pu}

RUN[1]	H/Pu[2]	ρ_{Pu} (KG/L)[2]	K_{EFF} (95%)
6A	1325	0.02	0.44661 ± 00168
6B	872	0.03	0.50170 ± 0.00180
6C	662	0.04	0.50044 ± 0.00203
6D	529	0.05	0.56092 ± 0.00212
6E	264	0.1	0.58245 ± 0.00238
6F	131	0.2	0.53261 ± 0.00219
6G	42.9	0.6	0.37700 ± 0.00175
6H	25.2	1	0.31228 ± 0.00153
6I	11.9	2	0.24603 ± 0.00144
6J	5.3	4	0.21942 ± 0.00118
1A[3]	186	0.137	0.58728 ± 0.00235
6S	197	0.137	0.58278 ± 0.00207

1 ALL RUNS ARE REFERENCED TO RUN #6, USING GEOMETRY OF CAL 2 RUN #1 FOR Pu WATER MODERATED, WITH A PARTIALLY WATER REFLECTED IN UNOCCUPIED COMPONENT SPACE.
2. SEE SHEET No 6 FOR VALUES USED
3. ASSUMED THE RESIDUE AS 1.7 M HNO_3 OF $Pu(NO_3)_4$
4. EQUIVALENT OF RUN 1A, IN Pu-WATER MIXTURE.

JOB	CALNO	REVNO	DATE	SHEET NO.
22192	5	A	6/6/96	6
DESCRIPTION: OPTIMUM MCNP CALCULATIONS			CALC BY DL	APP BY

L -16 Optimum Moderation, unreflected geometry, inside with water

mass (g)= 780 Radius (cm)= 7.7026 Pu-240 wt%= 6

RUN #	H/Pu Ratio	Rho-Pu (Kg/l)	Res Heigh(cm)	Pu 239 (g)	Pu 240 (g)	H (g)	O (g)	Rho-tot (g/cm3)	Pu 239 wt fr	Pu 240 wt fr	H wt fr	O wt fr
6A	1325	0.02	2.0924E+02	1.8800E-02	1.2000E-03	1.0506E-01	8.3379E-01	9.5885E-01	1.9607E-02	1.2515E-03	1.0957E-01	8.6957E-01
6B	872	0.03	1.3949E+02	2.8200E-02	1.8000E-03	1.0371E-01	8.2309E-01	9.5680E-01	2.9473E-02	1.8813E-03	1.0839E-01	8.6025E-01
6C	662	0.04	1.0462E+02	3.7600E-02	2.4000E-03	1.0498E-01	8.3316E-01	9.7814E-01	3.8440E-02	2.4536E-03	1.0733E-01	8.5178E-01
6D	529	0.05	8.3695E+01	4.7000E-02	3.0000E-03	1.0486E-01	8.3221E-01	9.8708E-01	4.7615E-02	3.0393E-03	1.0623E-01	8.4311E-01
6E	264	0.1	4.1848E+01	9.4000E-02	6.0000E-03	1.0466E-01	8.3064E-01	1.0353E+00	9.0795E-02	5.7954E-03	1.0109E-01	8.0232E-01
6F	131	0.2	2.0924E+01	1.8800E-01	1.2000E-02	1.0387E-01	8.2435E-01	1.1282E+00	1.6663E-01	1.0636E-02	9.2066E-02	7.3066E-01
6G	42.9	0.6	6.9746E+00	5.6400E-01	3.6000E-02	1.0205E-01	8.0987E-01	1.5119E+00	3.7304E-01	2.3811E-02	6.7495E-02	5.3566E-01
6H	25.2	1	4.1848E+00	9.4000E-01	6.0000E-02	9.9906E-02	7.9288E-01	1.6928E+00	4.9662E-01	3.1699E-02	5.2782E-02	4.1890E-01
6I	11.9	2	2.0924E+00	1.8800E+00	1.2000E-01	9.4356E-02	7.4883E-01	2.8432E+00	6.6123E-01	4.2206E-02	3.3187E-02	2.6338E-01
6J	5.3	4	1.0462E+00	3.7600E+00	2.4000E-01	8.4048E-02	6.6703E-01	4.7511E+00	7.9140E-01	5.0515E-02	1.7690E-02	1.4040E-01
6S	197	0.137	3.0546E+01	1.2878E-01	8.2200E-03	1.0700E-01	8.4917E-01	1.0932E+00	1.1780E-01	7.5194E-03	9.7879E-02	7.7680E-01

Originator Edwards 11/97 13537.2456 Date 7-30-96 Calc. No. 0200WCA-W0001 Rev. No. 0

Project BLDG 2335 D&D Job No. 22192 Checked R.L. Smith Date 10/23/96

Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A11

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALC NO	REV NO.	DATE	SHEET NO.
22192	5	A	6/5/96	7

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

SENSITIVITY STUDY SHOWS:

1. FOR L-16, THE MAXIMUM K_{EFF} OCCURS AT $H/Pu = 197$ & $\rho_{Pu} = 0.137$ KG/L BASED ON SHEET NO 5. NOTE THAT A MORE REFINED CAN BE DONE IF DESIRED.

2. BASED ON THE RESULTS TABULATED ON SHEET NO 5, FOR THE $Pu(NO_3)_4$ RESIDUE AT THE SAME H/Pu & ρ_{Pu} AS IN PU-WATER RESIDUE (RUN 1A & RUN 6S, RESPECTIVELY), THEY BOTH YIELD APPROXIMATELY SAME K_{EFF}.

EXTRAPOLATION OF THIS STUDY FOR NITRATE RESIDUE CALS

1. IT IS ASSUMED THAT THE NITRATE OPTIMUM MODERATION BEHAVES THE SAME AS PU-WATER IN RUN #6.

2. IT IS ALSO ASSUMED THAT SINCE INCREASING M IN THE NITRATE SOLN WILL INCREASE THE CRITICAL MASS, THE REFERENCED 1.7 M ACID OF RUN 1A IS USED FOR ALL OTHER COMPONENT CALCULATIONS

3. IN THIS EXTRAPOLATION, THE EFFECT OF GEOMETRY, PU MASS & DIAMETER OF COMPONENT WERE IGNORED.

4. SINCE L-16 CONTAINED THE MOST MASS OF PU & ITS GEOMETRY SHOULD YIELD A MAXIMUM K_{EFF}, IT IS ASSUMED THAT THE EXTRAPOLATION IS APPLICABLE TO OTHER COMPONENT WITH NITRATE SOLUTIONS.

5. BASED ON THE ASSUMPTIONS ABOVE, THE ASSUMED COMPOSITION OF THE NITRATE SOLN FOR SUBSEQUENCE CALCULATIONS IS SAME AS RUN 1A.

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Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL No.	REV NO	DATE	SHEET NO.
22192	5	A	6/6/96	8

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #6 BRIEF DESCRIPTION

THE INPUT DESCRIPTION OF THIS RUN IS THE SAME AS IN CAL NO. 2 RUN #1, EXCEPT

1. THE VOID IN THE VESSEL WAS REPLACED WITH WATER
2. NO REFLECTION OUTSIDE THE VESSEL.

SINCE THIS RUN WAS USED IN THE SENSITIVITY STUDY, THE RESULTS & THE IMPORTANT INPUT PARAMETERS ARE SHOWN IN SHEET NO. 5-#6.

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALC NO	REV NO.	DATE	SHEET NO.
22192	5	A	6/6/96	9

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS.	DL	

RUN #7 INPUT DESCRIPTION

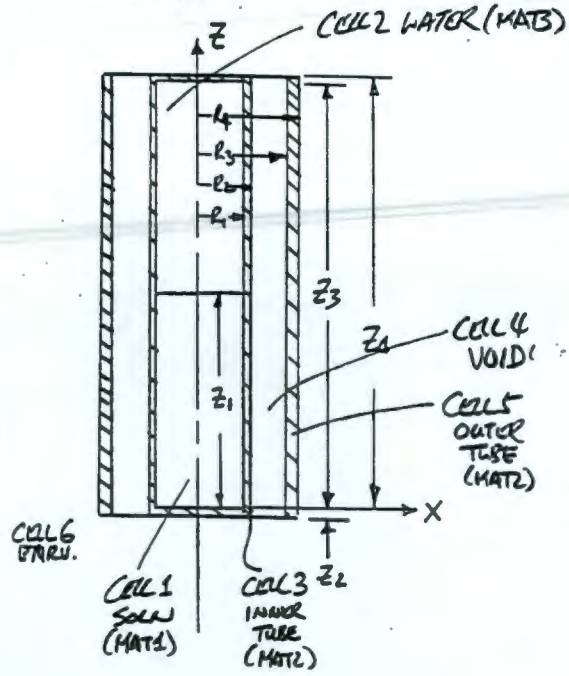
ASSUMPTION:

1. SINCE L-14 CONTAINS 2 VERTICAL PIPES, IT IS ASSUMED Pu MASS IS RETAINED IN ONE OF THIS PIPE.

2. BECAUSE NO SPECIFIC MATERIALS FOR THE PIPE, IT IS ASSUMED IT IS 347SS (SEE CALC NO 2 RUN 1 FOR ITS COMPOSITION).

GEOMETRY INPUT:

ACCORDING TO FIG 8 OF MSD 1996, L-14 PIPE CONTAINS A TUBE WITHIN ANOTHER TUBE, IT IS ASSUMED THE FOLLOWING:



$R_1 = 7.1438$ CM
$R_2 = 7.6200$ CM
$R_3 = 9.5250$ CM
$R_4 = 10.1600$ CM
$Z_1 = 19.3574$ CM *
$Z_2 = 0.4762$ CM (SAME AS THICKNESS OF TUBE)
$Z_3 = 116.3638$ CM
$Z_4 = 116.8400$ CM

* Pu MASS = 425 G, ρ_{Pu}(RUN #1) = 0.1368 G/CM^3
$\therefore$ VOL = 425G/0.1368 = 3107 CM^3

$$Z_1 = \frac{3107\,CM^3}{\pi(7.1438)^2} = 19.3574\ CM$$

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALNO.	REVNO	DATE	SHEET NO.
22192	5	A	6/6/96	10

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #7 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF RUN 7 IS PROVIDED IN SHEET NO 11-14.

THE MCNP CALCULATION PREDICTS

$$K_{EFF} = 0.49786 \pm 0.00202 \quad 95\%$$

RUN #8 INPUT DESCRIPTION

L-4 GEOMETRY IS IDENTICAL TO L-14, SO USE RUN #7 SETUP EXCEPT:

$$z_1 = 10.0295 \text{ CM}^*$$

* Pu MASS = 220 G, ρ_{Pu}(RUN #1) = 0.1368 G/CM^3

$\therefore$ VOL = 220G / 0.1368 = 1608 CM^3

$$z_1 = \frac{1608 \text{ CM}^3}{\pi (7.1408)^2} = \underline{10.0295 \text{ CM}}$$

RUN #8 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN IS PROVIDED IN SHEET 15-18.

MCNP PREDICTS:

$$K_{EFF} = 0.38605 \pm 0.00191 \quad 95\%$$

Originator Z/Warner 9713537.2457 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A16

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET No. 11
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1problem summary

run terminated when 165 kcode cycles were done.

+ 06/06/96 10:11:20

title - a Pu soln optimal moderation L-14 Vessel bare, Case R7 probid = 06/06/96 09:41:26

0

neutron creation	tracks	weight (per source particle)	energy	neutron loss	tracks	weight (per source particle)	energy
source	165069	9.9958E-01	2.1065E+00	escape	113284	6.6289E-01	8.8596E-01
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	8.3526E-03	1.0895E-07	weight cutoff	51769	8.3437E-03	1.0980E-07
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	3.2901E-08	downscattering	0	0.	1.1968E+00
				capture	0	1.6431E-01	1.6680E-02
(n,xn)	8	3.6440E-05	3.7513E-05	loss to (n,xn)	4	1.8220E-05	1.8666E-04
fission	0	0.	0.	loss to fission	0	1.7241E-01	6.8867E-03
total	165077	1.0080E+00	2.1066E+00	total	165077	1.0080E+00	2.1066E+00

number of neutrons banked	4	average lifetime, shakes		cutoffs	
neutron tracks per source particle	1.0000E+00	escape	2.2027E+02	tco	1.0000E+34
neutron collisions per source particle	1.6246E+01	capture	1.6146E+03	eco	0.0000E+00
total neutron collisions	2681734	capture or escape	6.8995E+02	wc1	-5.0000E-01
net multiplication	1.0000E+00 0.0003	any termination	7.7032E+02	wc2	-2.5000E-01

computer time so far in this run	29.89 minutes	maximum number ever in bank	1
computer time in mcrun	29.60 minutes	bank overflows to backup file	0
source particles per minute	5.5771E+03	field length	0
random numbers generated	33327197	most random numbers used was	6455 in history 142531

range of sampled source weights = 7.2886E-01 to 1.4065E+00

1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	196679	165072	1528816	8.8763E+00	2.3924E-03	1.0755E+00	9.8076E-01	2.2607E+00
2	2	30427	21800	1019290	4.0648E+00	1.2371E-04	4.6929E-01	7.5493E-01	1.2058E+00
3	3	152315	124032	71356	3.9568E-01	2.4789E-03	1.0796E+00	9.5282E-01	2.8096E+00
4	4	130433	106779	0	0.0000E+00	2.6323E-03	1.0917E+00	9.4671E-01	0.0000E+00
5	5	115767	104382	62272	3.4152E-01	3.0372E-03	1.1063E+00	9.4949E-01	2.9428E+00
total		625621	522065	2681734	1.3678E+01				

Originator Edwards 9713537.2458 Date 1-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A17

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET No. 12
DESC. Optimum MCNP Calculations CAL By. DL APP By.
lkeff results for: title - a Pu soln optimal moderation L-14 Vessel bare, Case R7 probid = 06/06/96 09:41:26

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14325 neutron histories and 150 active cycles with 150744 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 165069 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

---

the final estimated combined collision/absorption/track-length keff = 0.49786 with an estimated standard deviation of 0.00202

the estimated 68, 95, & 99 percent keff confidence intervals are 0.49583 to 0.49989, 0.49383 to 0.50189, and 0.49251 to 0.50321

the estimated collision/absorption neutron removal lifetime = 6.95E-06 seconds with an estimated standard deviation of 9.71E-08

---

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.49854	0.00287	0.49566 to 0.50141	0.49282 to 0.50426	0.49095 to 0.50613	
absorption	0.49777	0.00202	0.49575 to 0.49979	0.49375 to 0.50179	0.49243 to 0.50310	
track length	0.49887	0.00297	0.49589 to 0.50184	0.49294 to 0.50479	0.49101 to 0.50673	
col/absorp	0.49783	0.00202	0.49581 to 0.49985	0.49381 to 0.50185	0.49249 to 0.50316	0.6363
abs/trk len	0.49786	0.00202	0.49584 to 0.49988	0.49384 to 0.50188	0.49253 to 0.50319	0.6007
col/trk len	0.49860	0.00288	0.49573 to 0.50148	0.49288 to 0.50433	0.49101 to 0.50620	0.9417
col/abs/trk len	0.49786	0.00202	0.49583 to 0.49989	0.49383 to 0.50189	0.49251 to 0.50321	

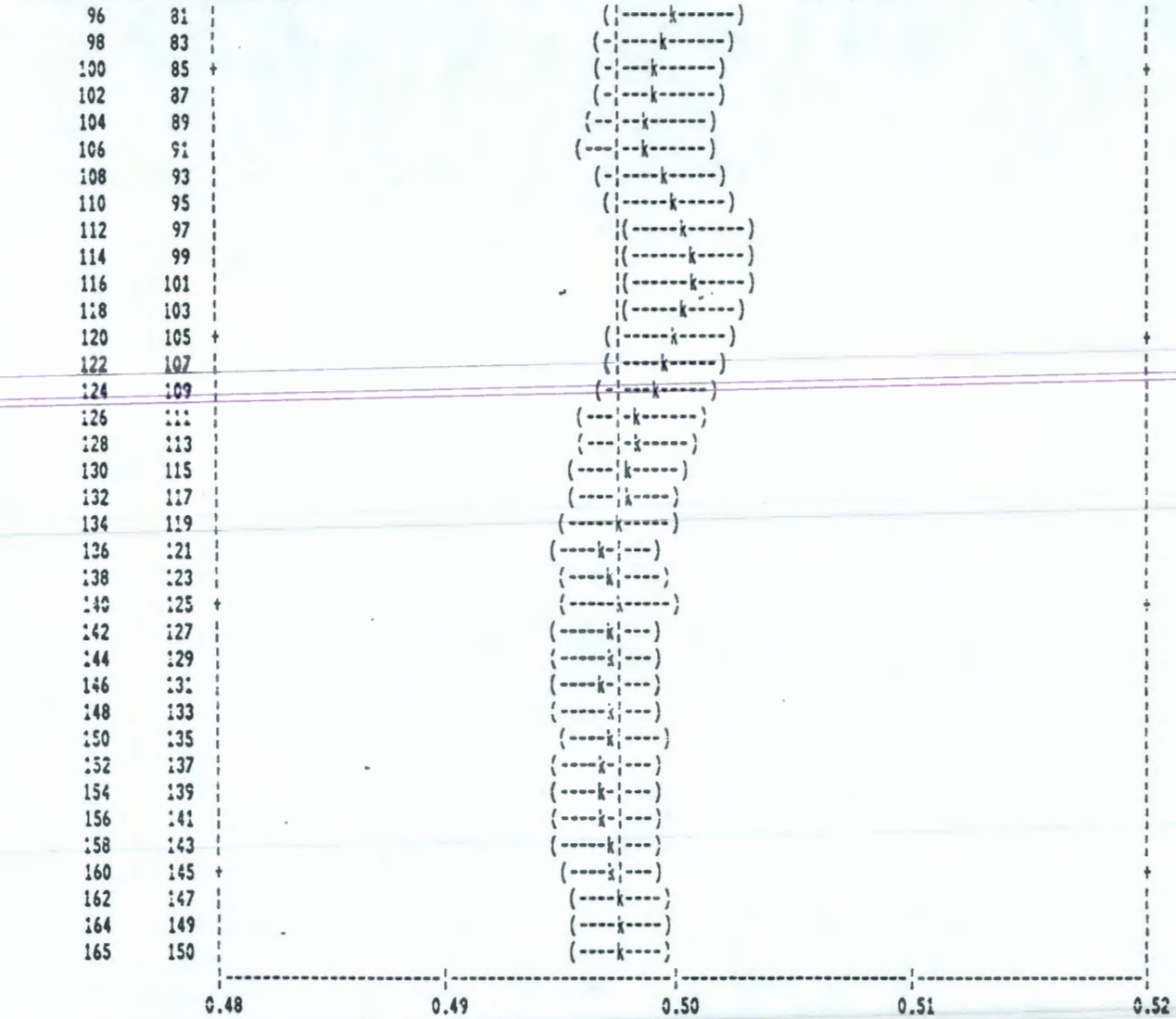
Originator Edwards 11/9713537.2459 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A18

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET No. 13
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (¦ = final keff = 0.49786)

```
 cycle   active 0.48                 0.49                 0.50                 0.51                 0.52
 number   cycles |--------------------¦--------------------¦--------------------¦--------------------|
    22        7 ¦              (-----------------k----¦-------------)                                ¦
    24        9 ¦                           (-------¦------------k-------------------)              ¦
    26       11 ¦                           (-------¦--------k-----------------)                    ¦
    28       13 ¦                            (------¦------k-------------)                           ¦
    30       15 ¦                                (-¦-----------k-------------)                       ¦
    32       17 ¦                                  ¦ (-------------k-----------)                     ¦
    34       19 ¦                                  ¦ (-------------k-------------)                   ¦
    36       21 ¦                             (----¦--------k-------------)                          ¦
    38       23 ¦                             (----¦--------k-------------)                          ¦
    40       25 +                                 (¦-------------k-------------)                     +
    42       27 ¦                                  ¦(------------k------------)                      ¦
    44       29 ¦                                  ¦    (----------k-----------)                     ¦
    46       31 ¦                                  ¦-----------k----------)                          ¦
    48       33 ¦                              (---¦-------k----------)                              ¦
    50       35 ¦                             (-----¦----k----------)                                ¦
    52       37 ¦                                 (¦---------k----------)                            ¦
    54       39 ¦                                  ¦---------k---------)                             ¦
    56       41 ¦                               (---¦------k----------)                              ¦
    58       43 ¦                               (---¦------k---------)                               ¦
    60       45 +                              (----¦----k---------)                                 +
    62       47 ¦                           (--------¦k---------)                                   ¦
    64       49 ¦                            (------¦--k--------)                                   ¦
    66       51 ¦                              (----¦---k---------)                                 ¦
    68       53 ¦                              (----¦---k--------)                                  ¦
    70       55 ¦                                 (-¦-------k--------)                              ¦
    72       57 ¦                                 (-¦------k-------)                                ¦
    74       59 ¦                                (--¦-----k-------)                                 ¦
    76       61 ¦                                 (-¦------k--------)                               ¦
    78       63 ¦                                  (¦-------k-------)                               ¦
    80       65 +                                  ¦(-------k-------)                               +
    82       67 ¦                                  ¦(-------k-------)                               ¦
    84       69 ¦                                  ¦-------k-------)                                ¦
    86       71 ¦                                  ¦-------k------)                                 ¦
    88       73 ¦                                 (¦------k------)                                  ¦
    90       75 ¦                                (-¦-----k------)                                   ¦
    92       77 ¦                                 (¦-----k------)                                   ¦
    94       79 ¦                                (-¦----k-------)                                   ¦
```

Originator Edward 9713537.2460 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A19

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET No. 14
DESC. Optimum MCNP Calculations CAL By. DL APP By.



Originator Elwell 9713537.2461 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A20

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET: 15
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1problem summary

run terminated when 165 kcode cycles were done.

+ 06/06/96 10:44:29

title - a Pu soln optimal moderation L-14 Vessel bare, Case R8 probid = 06/06/96 10:04:11

0

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron-loss	tracks	weight (per source particle)	energy (per source particle)
source	165167	9.9899E-01	2.1120E+00	escape	122265	7.0925E-01	9.4868E-01
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	1.0275E-02	8.7261E-08	weight cutoff	42905	9.9857E-03	9.0605E-08
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	5.1052E-08	downscattering	0	0.	1.1414E+00
				capture	0	1.5620E-01	1.5841E-02
(n,xn)	6	3.1391E-05	3.7551E-05	loss to (n,xn)	3	1.5696E-05	2.0392E-04
fission	0	0.	0.	loss to fission	0	1.3384E-01	5.8784E-03
total	165173	1.0093E+00	2.1120E+00	total	165173	1.0093E+00	2.1120E+00

number of neutrons banked	3	average lifetime, shakes		cutoffs	
neutron tracks per source particle	1.0000E+00	escape	3.3259E+02	tco	1.0000E+34
neutron collisions per source particle	2.0175E+01	capture	2.7314E+03	ecc	0.0000E+00
total neutron collisions	3332278	capture or escape	1.0288E+03	wc1	-5.0000E-01
net multiplication	1.0000E+00 0.0003	any termination	1.1843E+03	wc2	-2.5000E-01

computer time so far in this run	40.24 minutes	maximum number ever in bank	1
computer time in mcrun	39.19 minutes	bank overflows to backup file	0
source particles per minute	4.2146E+03	field length	0
random numbers generated	36653954	most random numbers used was	7720 in history 10740

range of sampled source weights = 7.3368E-01 to 1.7699E+00

1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	202809	165168	1224044	7.0787E+00	2.5856E-03	1.1223E+00	9.8063E-01	2.3284E+00
2	2	57579	41384	1969970	7.8059E+00	1.2565E-04	4.8046E-01	7.5246E-01	1.2194E+00
3	3	162676	132454	77769	4.1687E-01	1.9395E-03	1.0843E+00	9.3831E-01	2.8114E+00
4	4	125721	103049	0	0.0000E+00	1.8811E-03	1.0873E+00	9.2787E-01	0.0000E+00
5	5	109112	98397	60495	3.1726E-01	2.1386E-03	1.0982E+00	9.2944E-01	2.9177E+00
total		657897	540452	3332278	1.5619E+01				

Originator [illegible] 1/97 13537.2462 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A21

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET: 16
DESC. Optimum MCNP Calculations CAL By. DL APP By.
lkeff results for: title - a Pu soln optimal moderation L-14 Vessel bare, Case R8 probid = 06/06/96 10:04:11

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14188 neutron histories and 150 active cycles with 150979 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 165167 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

the final estimated combined collision/absorption/track-length keff = 0.38605 with an estimated standard deviation of 0.00191

the estimated 68, 95, & 99 percent keff confidence intervals are 0.38414 to 0.38796, 0.38224 to 0.38986, and 0.38100 to 0.39110

the estimated collision/absorption neutron removal lifetime = 1.03E-05 seconds with an estimated standard deviation of 1.05E-07

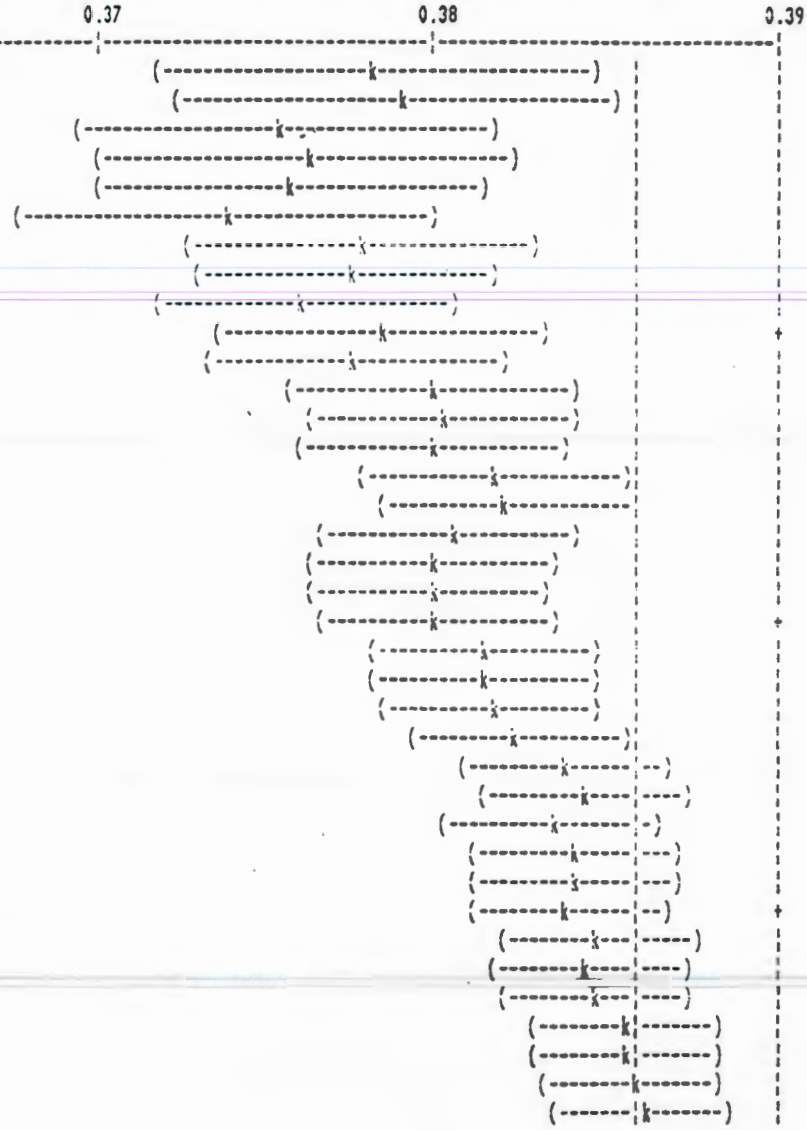
the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.38784	0.00244	0.38539 to 0.39028	0.38297 to 0.39271	0.38136 to 0.39429	
absorption	0.38603	0.00191	0.38412 to 0.38794	0.38223 to 0.38983	0.38099 to 0.39107	
track length	0.38630	0.00250	0.38379 to 0.38880	0.38131 to 0.39126	0.37966 to 0.39291	
col/absorp	0.38636	0.00189	0.38447 to 0.38825	0.38260 to 0.39012	0.38137 to 0.39135	0.6382
abs/trk len	0.38608	0.00188	0.38420 to 0.38796	0.38234 to 0.38982	0.38112 to 0.39104	0.5978
col/trk len	0.38743	0.00247	0.38496 to 0.38991	0.38251 to 0.39236	0.38090 to 0.39397	0.9490
col/abs/trk len	0.38605	0.00191	0.38414 to 0.38796	0.38224 to 0.38986	0.38100 to 0.39110	

Originator Edward 9713537.2463 Date 7-30-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A22

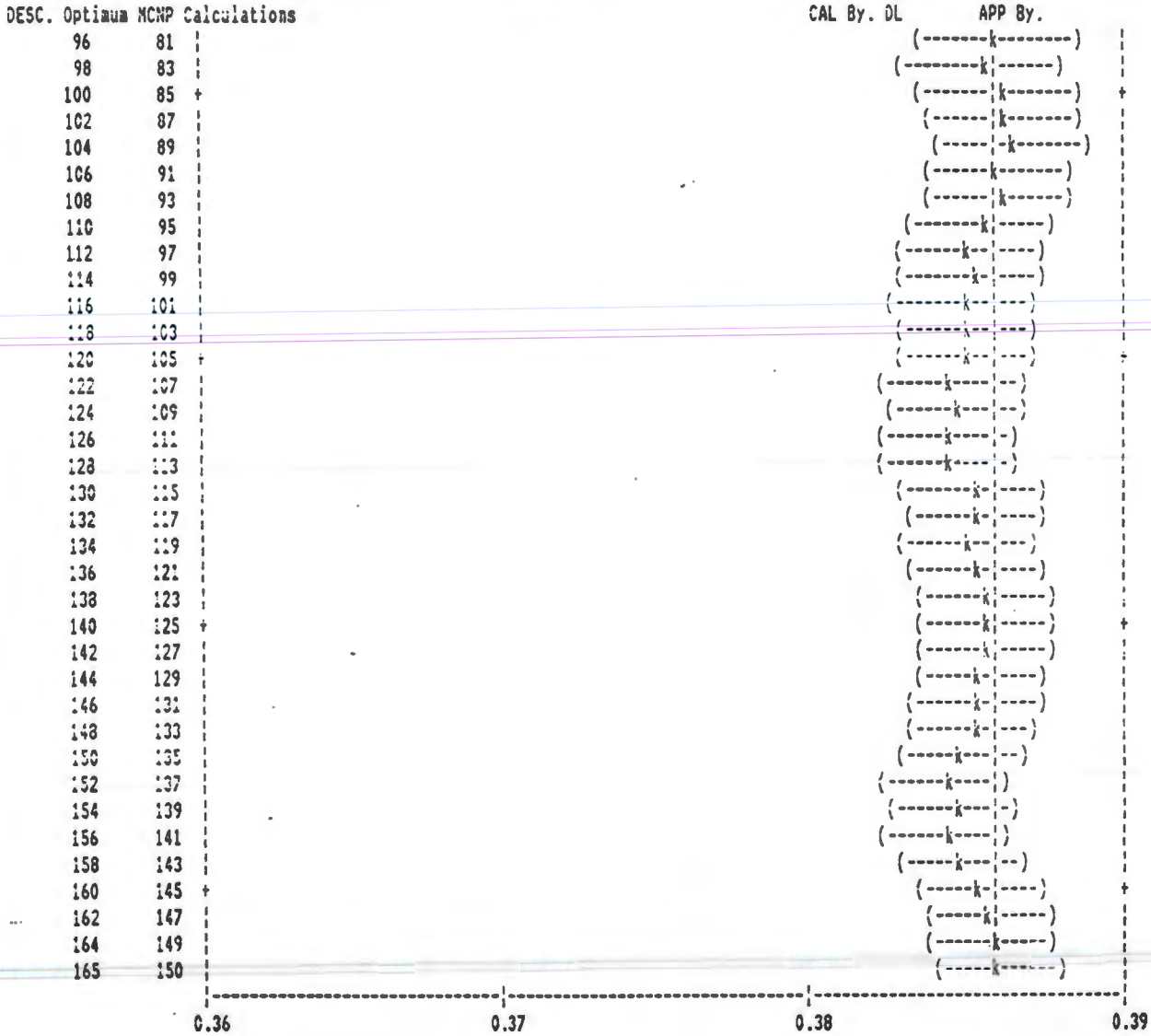
JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET: 17
DESC. Optimum MCNP Calculations CAL By. DL APP By.
iplot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (¦ = final keff = 0.38605)

cycle number	active cycles
22	7
24	9
26	11
28	13
30	15
32	17
34	19
36	21
38	23
40	25
42	27
44	29
46	31
48	33
50	35
52	37
54	39
56	41
58	43
60	45
62	47
64	49
66	51
68	53
70	55
72	57
74	59
76	61
78	63
80	65
82	67
84	69
86	71
88	73
90	75
92	77
94	79



Originator Edward 11 9713537.2464 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A23

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/6/96 SHEET: 18
DESC. Optimum MCNP Calculations CAL By. DL APP By.



Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALC No.	REV No.	DATE	SHEET NO.
22192	5	A	6/6/96	19

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #9 INPUT DESCRIPTION

ACCORDING FIG 2 OF MSD 1996, L-6 CONSISTS OF A 14' HORIZ. PIPE WHICH TERMINATES AT A 2' VERTICAL SECTION OF PIPE, & ALL PIPE WERE MADE OF 304L S.S.

ASSUMPTIONS:

1. ALL Pu MASS IS ASSUMED TO BE RESIDED IN THE VERTICAL SECTION OF THE PIPE.

2. FITTINGS & ELBOWS ARE ASSUMED TO HAVE ZERO Pu MASS

3. THE SS 304L IS ASSUMED TO HAVE THE FOLLOWING (STANDARD COMPOSITION LIB INFORMATION TABLE OF SCALE 4.3 PACKAGE, NUREG/CR-0200 VOL 3, REV 5).

$\rho = 7.92\ g/cm^3$

NUCLIDE (ELEMENT)		WT %
24000	(CR)	0.1900
25055	(MN)	0.0200
26000	(FE)	0.6950
28000	(NI)	0.0950

GEOMETRY:

FIG 2 OF MSD 1996 GIVES THE VERTICAL SECTION THE FOLLOWING DIM.

HEIGHT = 24.5"
I.D. = 4.5"
THICKNESS = 0.25"

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/6/96	20

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

THE GEOMETRY SETUP OF THIS RUN IS SAME AS RUN #1 (SEE CAL #2) EXCEPT

1. $R_1 = 5.7150$ CM
   $R_2 = 6.3500$ CM
   $Z_6 = \dfrac{270\,G/(0.137\,G/CC)}{\pi\,(5.7150\,CM)^2}$
   $= 19.207\,CM$
   $Z_3 = 0.6350$ CM
   $Z_1 = 62.2300\,CM - 0.6350\,CM = 61.5950\,CM$
   $Z_2 = 62.2300\,CM$

2. OUTSIDE PIPE IS UNREFLECTED.

MATERIAL SETUP:

1. REPLACE VOID IN CELL 2 W/ WATER (MAT 3)

2. MAT 2 USES WT % & NUCLIDE OF ASSUMPTION 3 ABOVE.

RUN #9 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN IS PROVIDED IN SHEET 21-24.

MCNP PREDICTS:

$$\boxed{K_{EFF} = 0.35877 \pm 0.00213 \qquad 95\%}$$

Originator Z/Wallin 9713537.2467 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A26

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/7/96 SHEET No. 21
DESC. Optimum MCNP Calculations CAL By: DL APP By:
1problem summary

run terminated when 165 kcode cycles were done.

+ 06/06/96 11:36:46
title - a Pu soln optimum moderation L-6 Vessel bare, Case R9 probid = 06/06/96 11:15:05
0

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron loss	tracks	weight (per source particle)	energy (per source particle)
source	165116	9.9930E-01	2.1161E+00	escape	129230	7.6372E-01	1.0599E+00
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	4.8177E-03	8.6664E-08	weight cutoff	35868	4.7832E-03	8.3669E-08
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	1.8533E-08	downscattering	0	0.	1.0358E+00
				capture	0	1.1158E-01	1.4122E-02
(n,xn)	4	1.7073E-05	1.8226E-05	loss to (n,xn)	2	8.5363E-06	7.8500E-05
fission	0	0.	0.	loss to fission	0	1.2404E-01	6.1608E-03
total	165120	1.0041E+00	2.1161E+00	total	165120	1.0041E+00	2.1161E+00

number of neutrons banked	2		average lifetime, shakes		cutoffs		
neutron tracks per source particle	1.0000E+00		escape	1.1736E+02	tco	1.0000E+34	
neutron collisions per source particle	1.0896E+01		capture	1.1623E+03	eco	0.0000E+00	
total neutron collisions	1799037		capture or escape	3.5845E+02	wc1	-5.0000E-01	
net multiplication	1.0000E+00	0.0000	any termination	3.9466E+02	wc2	-1.5000E-01	

computer time so far in this run	21.67 minutes	maximum number ever in bank	1
computer time in mcrun	21.34 minutes	bank overflows to backup file	0
source particles per minute	7.7389E+03	field length	0
random numbers generated	24304995	most random numbers used was	4709 in history 95161

range of sampled source weights = 7.1378E-01 to 1.3416E+00
1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	190801	165118	1204451	7.0369E+00	2.9484E-03	1.1420E+00	9.8389E-01	2.3564E+00
2	2	22005	16718	507745	2.1460E+00	1.7711E-04	5.8959E-01	8.0056E-01	1.3994E+00
3	3	151983	137127	86841	4.9615E-01	3.8184E-03	1.1909E+00	9.6847E-01	2.9392E+00
total		364789	318963	1799037	9.6790E+00				

Originator Edwarthur 9713537.2468 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A27

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/7/96 SHEET No. 22
DESC. Optimum MCNP Calculations CAL By: DL APP By:
keff results for: title - a Pu soln optimum moderation L-6 Vessel bare, Case R9 probid = 06/06/96 11:15:05

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14179 neutron histories and 150 active cycles with 150937 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 165116 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

the final estimated combined collision/absorption/track-length keff = 0.35877 with an estimated standard deviation of 0.00213

the estimated 68, 95, & 99 percent keff confidence intervals are 0.35664 to 0.36090, 0.35453 to 0.36301, and 0.35315 to 0.36439

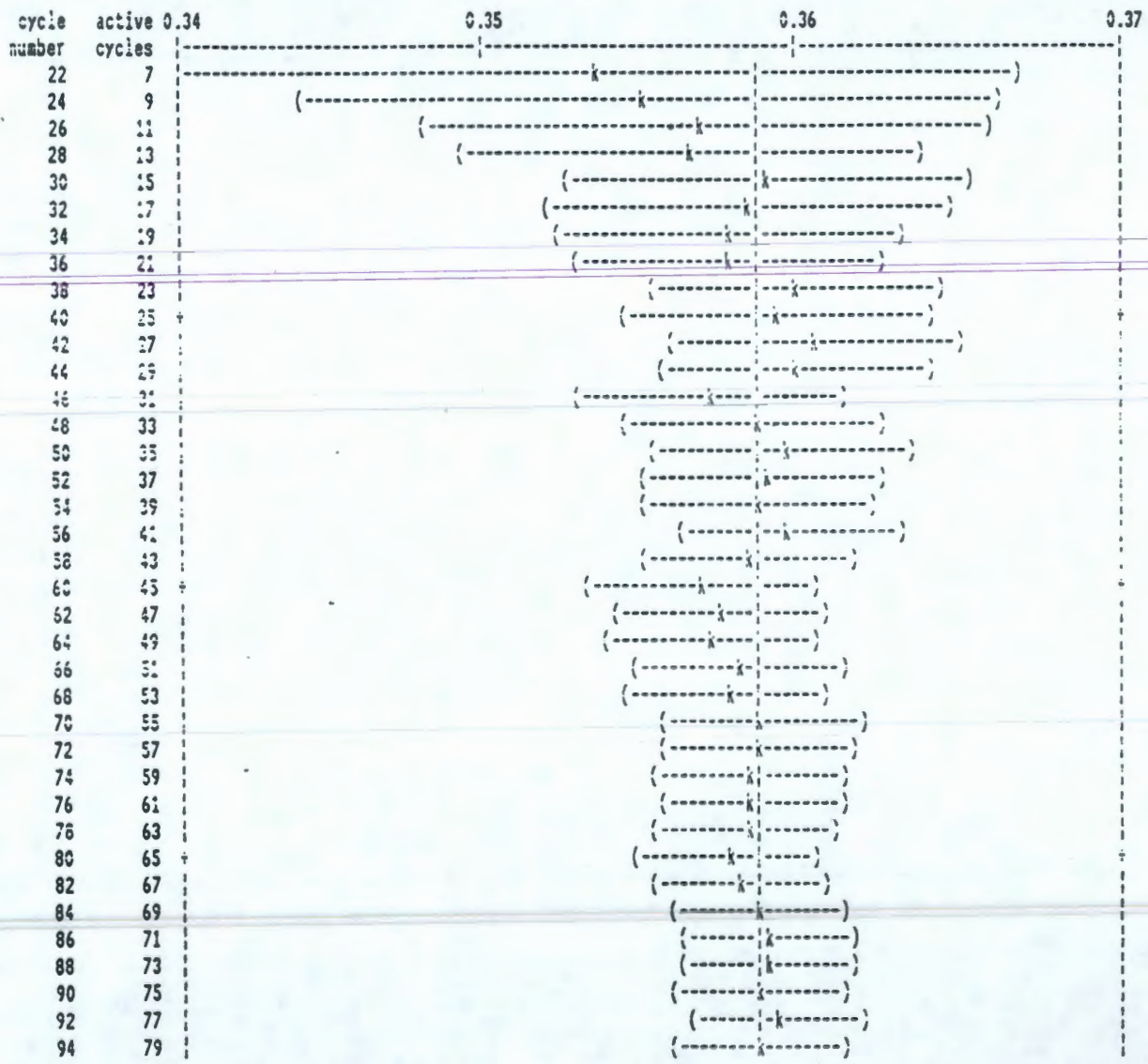
the estimated collision/absorption neutron removal lifetime = 3.69E-06 seconds with an estimated standard deviation of 4.90E-08

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.35940	0.00242	0.35698 to 0.36182	0.35458 to 0.36422	0.35301 to 0.36580	
absorption	0.35842	0.00216	0.35626 to 0.36059	0.35412 to 0.36273	0.35271 to 0.36414	
track length	0.36071	0.00256	0.35815 to 0.36326	0.35562 to 0.36580	0.35395 to 0.36746	
col/absorp	0.35873	0.00210	0.35662 to 0.36083	0.35454 to 0.36291	0.35317 to 0.36428	0.7217
abs/trk len	0.35901	0.00212	0.35689 to 0.36113	0.35479 to 0.36323	0.35341 to 0.36461	0.6660
col/trk len	0.35940	0.00245	0.35695 to 0.36185	0.35452 to 0.36428	0.35293 to 0.36587	0.9472
col/abs/trk len	0.35877	0.00213	0.35664 to 0.36090	0.35453 to 0.36301	0.35315 to 0.36439	

Originator Edwards 9713537.2469 Date 1-30-96 Calc. No. 0200W-CA-N0091 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A28

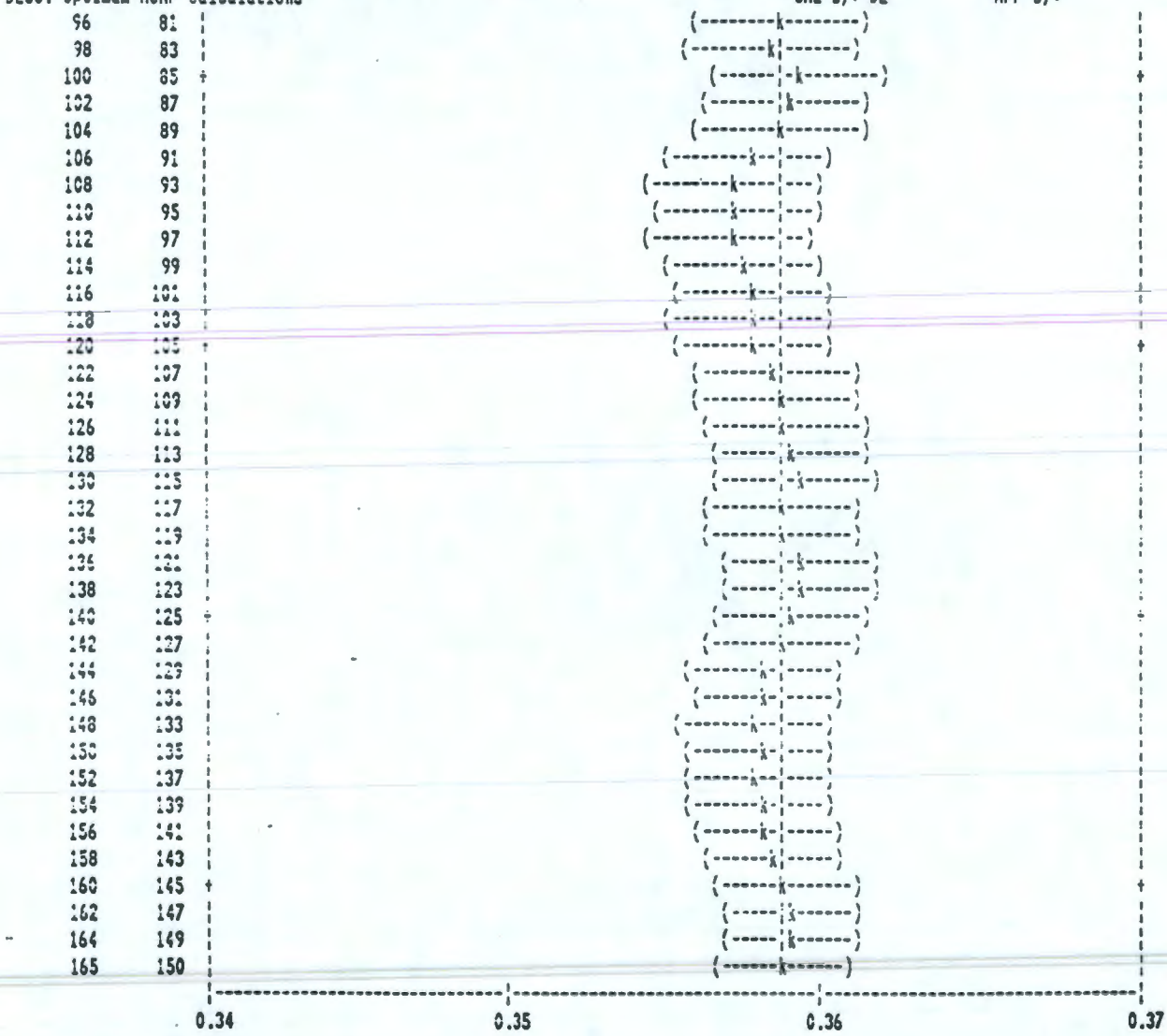
JOB No. 22192 CAL No. 5 REV No. A DATE: 6/7/96 SHEET No. 23
DESC. Optimum MCNP Calculations CAL By: DL APP By:
Plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (| = final keff = 0.35877)



Originator [illegible] Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A29

1/97/3537.2470

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/7/96 SHEET No. 24
DESC. Optimum MCNP Calculations CAL By: DL APP By:



19213537.2471

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL No.	REV NO	DATE	SHEET NO.
22192	5	A	6/14/96	25

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #10 INPUT DESCRIPTION

L-18 DESCRIPTION WAS NOT AVAILABLE IN MSD96, SO USE DATA PROVIDED IN SEG 1995:

ATTACHMENT I.1 SHOWS THAT L-18'S OVERALL HEIGHT IS:

BOTTOM: EL = 101'-0"
TOP: EL = 125'-0" > 24'

ATTACHMENT 4.1 SHOWS

L-18 IS ANION IX COLUMN 4" SCH 10 PIPING 24' TALL

SINCE NO MATERIAL WAS SPECIFIED, SS 304 L WAS ASSUMED.

GEOMETRY: 4" DIA X 24' HEIGHT SCH 10 PIPE. WAS ASSUMED. ACCORDING TO ASTM 1979, 4" SCH 10 PIPE HAS A OD = 4.5" WALL THICKNESS = 0.12"

∴ THE GEOMETRY SETUP OF THIS RUN IS SAME AS RUN #9 EXCEPT:

$R_1 = 5.4102\,CM$

$R_2 = 5.7150\,CM$

$Z_6 = \dfrac{200G/(0.137G/cc)}{\pi\,(5.4102\,CM)^2} = 15.8757\,CM$

$Z_3 = 0.3048\,CM$

$Z_1 = 731.52 - 0.3048 = 731.22\,CM$

$Z_2 = 731.52\,CM$

MATERIAL: SAME AS THOSE IN RUN #9

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/15/96	26

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #10 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN IS PROVIDED IN SHEET 27-30

MCNP PREDICTS:

$K_{EFF} = 0.28675 \pm 0.00168$ 95%

Originator Elwalt 9713537.2473 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A32

Job No. 22192 CAL No. 5 REV No. A DATE: 6/15/96 SHEET No. 27
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1problem summary

run terminated when 165 kcode cycles were done.

+ 06/14/96 11:16:43

title - a Pu soln optimum moderation L-18 Vessel bare, Case R10 probid = 06/14/96 10:53:54

0

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron loss	tracks	weight (per source particle)	energy (per source particle)
source	165439	9.9735E-01	2.1078E+00	escape	137151	8.1110E-01	1.1345E+00
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	3.4798E-03	7.2667E-08	weight cutoff	28291	3.4839E-03	6.9192E-08
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	1.6135E-08	downscattering	0	0.	9.5557E-01
				capture	0	8.7306E-02	1.1732E-02
(n,xn)	6	1.9521E-05	1.9643E-05	loss to (n,xn)	3	9.7605E-06	1.0050E-04
fission	0	0.	0.	loss to fission	0	9.8949E-02	5.8301E-03
total	165445	1.0008E+00	2.1078E+00	total	165445	1.0008E+00	2.1078E+00

number of neutrons banked	3	average lifetime, shakes		cutoffs	
neutron tracks per source particle	1.0000E+00	escape	1.2043E+02	tco	1.0000E+34
neutron collisions per source particle	9.3740E+00	capture	1.1709E+03	eco	0.0000E+00
total neutron collisions	1550826	capture or escape	3.1661E+02	wc1	-5.0000E-01
net multiplication	1.0000E+00 0.0004	any termination	3.3327E+02	wc2	-2.5000E-01

computer time so far in this run	22.81 minutes	maximum number ever in bank	1
computer time in mcrun	22.01 minutes	bank overflows to backup file	0
source particles per minute	7.5151E+03	field length	0
random numbers generated	21361151	most random numbers used was	5051 in history 92343

range of sampled source weights = 7.5529E-01 to 2.2883E+00

-1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	182553	165442	1038565	6.0649E+00	3.4502E-03	1.1861E+00	9.8386E-01	2.4227E+00
2	2	23425	19273	473139	2.0784E+00	2.1133E-04	6.4785E-01	8.3017E-01	1.4973E+00
3	3	149595	140941	39122	2.2538E-01	4.2557E-03	1.2640E+00	9.7375E-01	2.9646E+00
total		355573	325656	1550826	8.3687E+00				

Originator Edwards 9713537.2474 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A33

Job No. 22192 CAL No. 5 REV No. A DATE: 6/15/96 SHEET No. 28
DESC. Optimum MCNP Calculations CAL By. DL APP By.
ikeff results for: title - a Pu soln optimum moderation L-18 Vessel bare, Case R10 probid = 06/14/96 10:53:54

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14307 neutron histories and 150 active cycles with 151132 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 165439 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

the final estimated combined collision/absorption/track-length keff = 0.28675 with an estimated standard deviation of 0.00168

the estimated 68, 95, & 99 percent keff confidence intervals are 0.28507 to 0.28843, 0.28340 to 0.29009, and 0.28231 to 0.29118

the estimated collision/absorption neutron removal lifetime = 3.20E-06 seconds with an estimated standard deviation of 4.02E-08

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.28859	0.00203	0.28655 to 0.29062	0.28454 to 0.29263	0.28322 to 0.29395	
absorption	0.28631	0.00167	0.28464 to 0.28799	0.28298 to 0.28964	0.28189 to 0.29073	
track length	0.28896	0.00212	0.28684 to 0.29108	0.28474 to 0.29317	0.28336 to 0.29455	
col/absorp	0.28669	0.00168	0.28501 to 0.28837	0.28335 to 0.29003	0.28226 to 0.29112	0.7263
abs/trk len	0.28675	0.00167	0.28507 to 0.28842	0.28342 to 0.29008	0.28233 to 0.29117	0.6726
col/trk len	0.28862	0.00204	0.28658 to 0.29066	0.28456 to 0.29268	0.28323 to 0.29401	0.9506
col/abs/trk len	0.28675	0.00168	0.28507 to 0.28843	0.28340 to 0.29009	0.28231 to 0.29118	

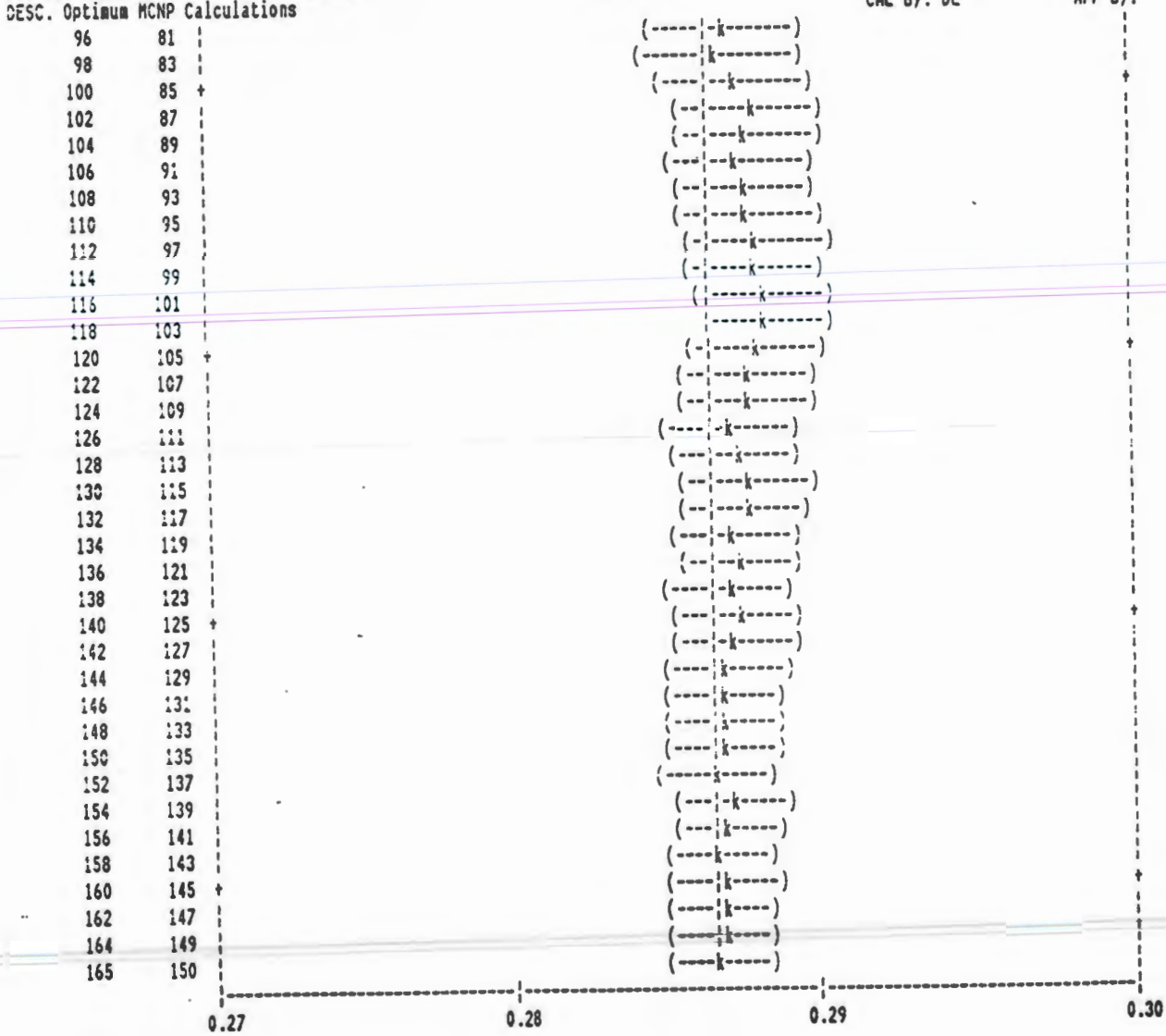
Originator Elwood 9713537.2475 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A34

Job No. 22192 CAL No. 5 REV No. A DATE: 6/15/96 SHEET No. 29
DESC. Optimum MCNP Calculations CAL By. DL APP By.

cycle number	active cycles
22	7
24	9
26	11
28	13
30	15
32	17
34	19
36	21
38	23
40	25
42	27
44	29
46	31
48	33
50	35
52	37
54	39
56	41
58	43
60	45
62	47
64	49
66	51
68	53
70	55
72	57
74	59
76	61
78	63
80	65
82	67
84	69
86	71
88	73
90	75
92	77
94	79

Originator Edward 9713537.2476 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A35

Job No. 22192 CAL No. 5 REV No. A DATE: 6/15/96 SHEET No. 30
DESC. Optimum MCNP Calculations CAL By. DL APP By.



Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CALNO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/17/96	31

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #11 INPUT DESCRIPTION

L-12N COMPONENT CONSISTS OF 1"X6'H TITANIUM PIPE ACCORDING TO MSD96 AND SEG95. HOWEVER, NO DETAILED SPECIFICATION WAS INDICATED SO SCH 40 WAS ASSUMED

GEOMETRY: 1"X6'H SCH 40 TITANIUM

INCORRECT !! THERE ARE 12 OF THESE INSIDE THE 6" SCH 10 PIPE

ACCORDING TO ASTM 79, 1" SCH 40 PIPE HAS A OD = 1.315" WALL THICKNESS = 0.133"

USE PROCESS VESSEL DIMENSIONS

∴ THE GEOMETRICAL SETUP OF THIS RUN IS SAME AS RUN #10, EXCEPT.

NOTE: OUTER VESSEL IS 304LSS

$R_1 = 1.3322$ CM

$R_2 = 1.6701$ CM

$Z_6 = \frac{170G/(0.137G/cc)}{\pi (1.3322)^2} = 222.56$ CM

SINCE THE TOTAL LENGTH OF PIPE IS 182.88CM, SET $Z_6 = 182.5422$CM

$Z_3 = 0.3378$ CM

$Z_1 = 182.88 - 0.3378 = 182.5422$ CM

$Z_2 = 182.88$CM

ESSENTIALLY ELIMINATED CELL 2 OF PREVIOUS RUN.

MATERIAL : SAME AS THOSE USED IN RUN #10, EXCEPT

MAT2 IS TITANIUM 22000 AS NUCLIDE NO.

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/17/96	32.

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DC	

RUN #11 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN IS PROVIDED IN SHEET NO 33-36.

MCNP PREDICTS:

$$K_{EFF} = 0.00904 \pm 0.00022$$

ALTHOUGH THE MCNP RESULTS SHOWED THE TWO OF THE THREE KEFF ESTIMATORS WERE NOT NORMALLY DISTRIBUTED AT 95%, BECAUSE OF THIS SMALL KEFF, ANY LARGE ERROR WILL NOT AFFECT THE OVERALL SYSTEM (OTHER COMPONENTS HAVE A MUCH HIGHER KEFF THAT COULD INFLUENCE THE RESULTS).

Originator [illegible] Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A38

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/19/96 SHEET No. 33
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1problem summary

run terminated when 165 kcode cycles were done.

+ 06/18/96 09:22:27

title - a Pu soln optimum moderation L-12N Vessel bare, Case R11 probid = 06/18/96 09:14:52

0

neutron creation	tracks	weight (per source particle)	energy	neutron loss	tracks	weight (per source particle)	energy
source	182242	9.0539E-01	2.1159E+00	escape	181667	8.9972E-01	1.7387E+00
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	1.0163E-04	3.2094E-06	weight cutoff	575	1.1778E-04	1.5706E-05
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	9.4892E-11	downscattering	0	0.	3.7042E-01
				capture	0	3.0041E-03	4.6819E-03
(n,xn)	0	0.	0.	loss to (n,xn)	0	0.	0.
fission	0	0.	0.	loss to fission	0	2.6526E-03	2.0562E-03
total	182242	9.0549E-01	2.1159E+00	total	182242	9.0549E-01	2.1159E+00

number of neutrons banked	0		average lifetime, shakes		cutoffs
neutron tracks per source particle	1.0000E+00		escape	1.9634E+00	tco 1.0000E+34
neutron collisions per source particle	1.2665E+00		capture	1.7299E+02	eco 0.0000E+00
total neutron collisions	230801		capture or escape	3.0319E+00	wc1 -5.0000E-01
net multiplication	1.0000E+00	0.0024	any termination	3.0733E+00	wc2 -2.5000E-01

computer time so far in this run	7.57 minutes	maximum number ever in bank	0
computer time in mcrun	7.32 minutes	bank overflows to backup file	0
source particles per minute	2.4882E+04	field length	0
random numbers generated	5192887	most random numbers used was	11217 in history 162661

range of sampled source weights = 3.3014E-01 to 1.2500E+02

1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	193951	182242	176770	8.7233E-01	6.5134E-02	1.7207E+00	9.0030E-01	3.1786E+00
2	2	193403	181932	54031	2.6818E-01	9.0816E-02	1.7061E+00	9.0433E-01	3.3877E+00

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/19/96 SHEET No. 34
DESC. Optimum MCNP Calculations CAL By. DL APP By.
ikeff results for: title - a Pu soln optimum moderation L-12N Vessel bare, Case R11 probid = 06/18/96 09:14:52

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 16179 neutron histories and 150 active cycles with 166063 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 182242 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 99 percent confidence level, but not at 95 percent
the k(absorption) cycle values appear normally distributed at the 99 percent confidence level, but not at 95 percent
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

---

the final estimated combined collision/absorption/track-length keff = 0.00904 with an estimated standard deviation of 0.00022

the estimated 68, 95, & 99 percent keff confidence intervals are 0.00882 to 0.00926, 0.00859 to 0.00948, and 0.00845 to 0.00963

the estimated collision/absorption neutron removal lifetime = 2.95E-08 seconds with an estimated standard deviation of 1.08E-09

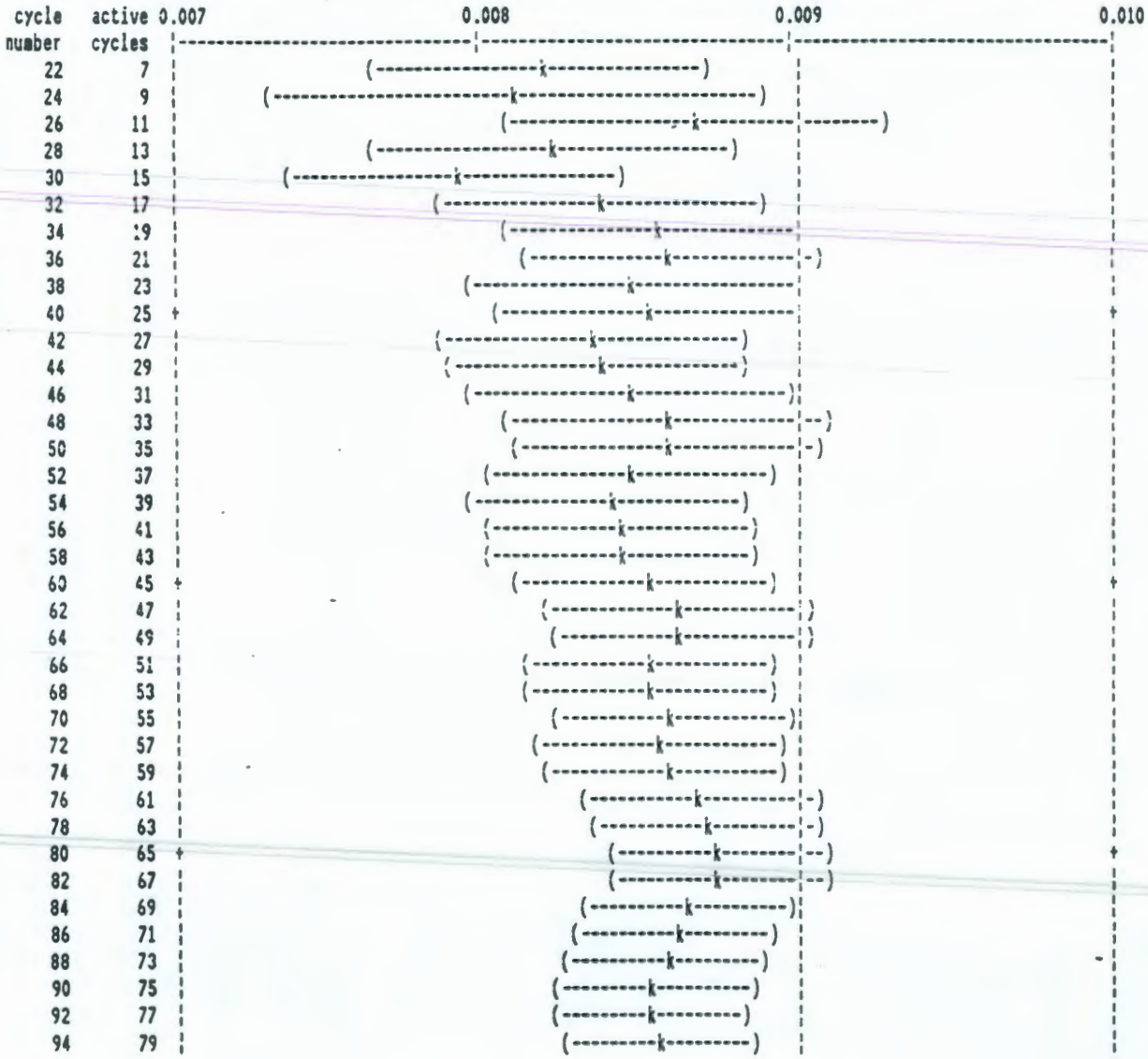
---

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.00919	0.00026	0.00893 to 0.00945	0.00868 to 0.00971	0.00851 to 0.00988	
absorption	0.00891	0.00031	0.00861 to 0.00922	0.00830 to 0.00953	0.00810 to 0.00973	
track length	0.00910	0.00024	0.00887 to 0.00934	0.00863 to 0.00958	0.00848 to 0.00973	
col/absorp	0.00910	0.00024	0.00886 to 0.00933	0.00862 to 0.00957	0.00847 to 0.00973	0.4454
abs/trk len	0.00905	0.00022	0.00883 to 0.00927	0.00861 to 0.00949	0.00846 to 0.00963	0.4014
col/trk len	0.00911	0.00024	0.00887 to 0.00935	0.00863 to 0.00959	0.00848 to 0.00974	0.9065
col/abs/trk len	0.00904	0.00022	0.00882 to 0.00926	0.00859 to 0.00948	0.00845 to 0.00963	

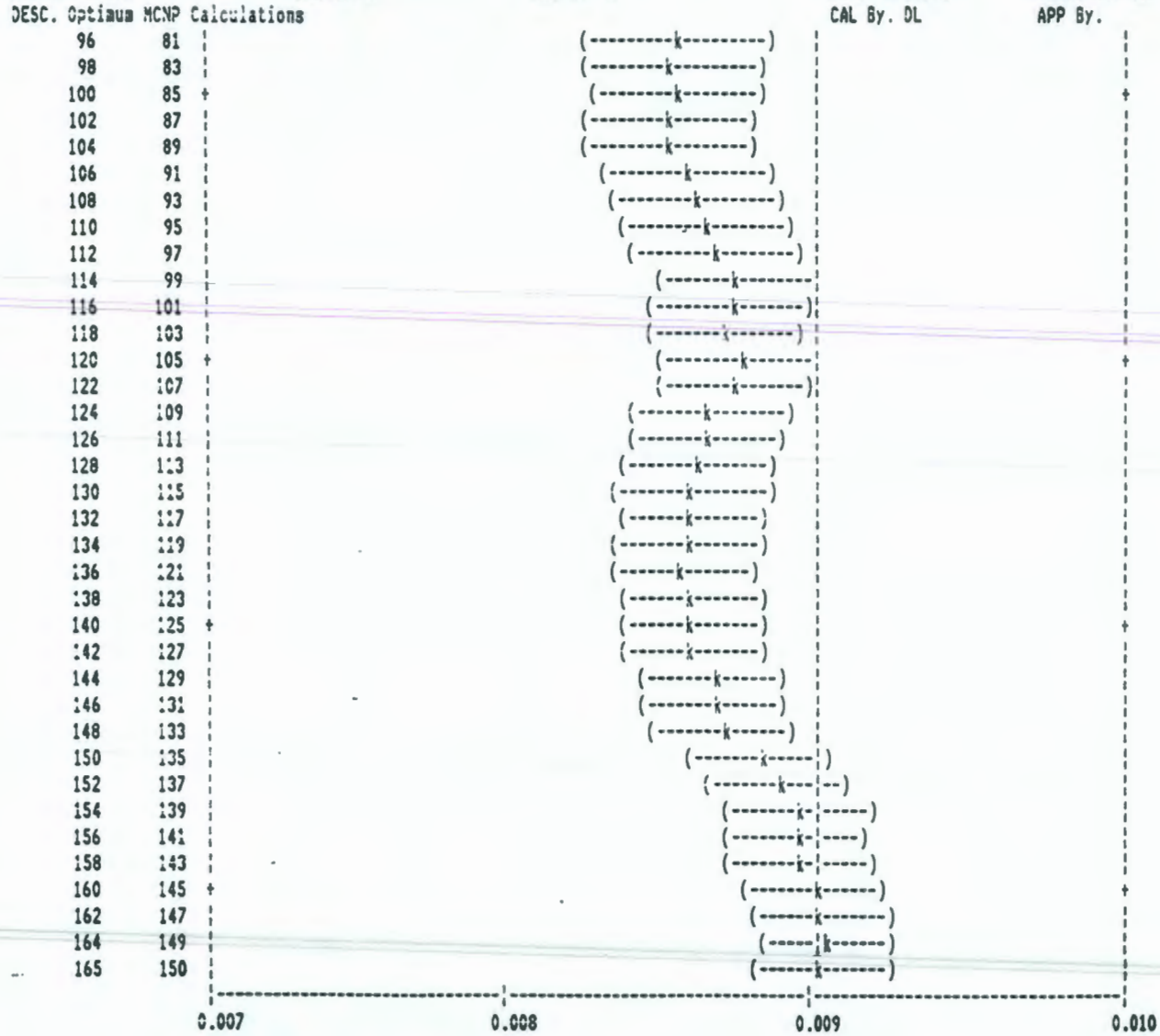
Originator Edwards 9713537.2481 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A40

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/19/96 SHEET No. 35
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (¦ = final keff = 0.00904)



9713537.2482

JOB No. 22192 CAL No. 5 REV No. A DATE: 6/19/96 SHEET No. 36
DESC. Optimum MCNP Calculations CAL By. DL APP By.



Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/17/96	37

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #12 INPUT DESCRIPTION

L-12S COMPONENT CONSISTS OF 6" x 22'H TITANIUM PIPE ACCORDING TO MSD 96 AND SEG 95. HOWEVER, NO DETAILED SPECIFICATION WAS INDICATED SO SCH 40 WAS ASSUMED.

GEOMETRY: 6" x 22'H SCH. 40 TITANIUM

ACCORDING TO ASTM 79, 6" SCH 40 PIPE HAS AN OD = 6.625" WALL THICKNESS = 0.28"

∴ THE GEOMETRICAL SETUP OF THIS RUN IS SAME AS IN RUN #11, EXCEPT.

$R_1 = 7.7026$ CM
$R_2 = 8.4138$ CM
$Z_6 = \dfrac{1906/(0.137\,g/cc)}{\pi(7.7026\,cm)^2}$
$= 7.4406$ CM
$Z_3 = 0.7112$ CM
$Z_1 = 670.5600 - 0.7112 = 669.8488$ CM
$Z_2 = 670.5600$ CM

MATERIALS: SAME AS THOSE IN RUN #11.

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	5	A	6/17/96	38

DESCRIPTION	CALC. BY	APPROVED BY
OPTIMUM MCNP CALCULATIONS	DL	

RUN #12 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN IS PROVIDED IN SHEET No 39-42

MCNP PREDICTS:

$K_{EFF} = 0.35348 \pm 0.00176$ 95%

JOB No. 22192 CAL No. 5 REV No. A DATE 6/18/96 SHEET No. 39
DESC. Optimum MCNP Calculations CAL By. DL APP By.

1problem summary

run terminated when 165 kcode cycles were done.

+ 06/18/96 08:54:11

title - a Pu soln optimum moderation L-12S Vessel bare, Case R12 probid = 06/18/96 08:13:32

0

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron loss	tracks	weight (per source particle)	energy (per source particle)
source	165694	9.9581E-01	2.1134E+00	escape	122678	7.0895E-01	9.4426E-01
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	1.2504E-02	6.1625E-08	weight cutoff	43018	1.2303E-02	6.2231E-08
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	6.3787E-08	downscattering	0	0.	1.1510E+00
				capture	0	1.6470E-01	1.2631E-02
(n,xn)	4	2.1753E-05	1.6817E-05	loss to (n,xn)	2	1.0877E-05	1.1254E-04
fission	0	0.	0.	loss to fission	0	1.2237E-01	5.4526E-03
total	165698	1.0083E+00	2.1134E+00	total	165698	1.0083E+00	2.1134E+00

number of neutrons banked	2	average lifetime, shakes		cutoffs	
neutron tracks per source particle	1.0000E+00	escape	2.9651E+02	tco	1.0000E+34
neutron collisions per source particle	2.3415E+01	capture	3.3374E+03	eco	0.0000E+00
total neutron collisions	3879698	capture or escape	1.1730E+03	wc1	-5.0000E-01
net multiplication	1.0000E+00 0.0003	any termination	1.3697E+03	wc2	-2.5000E-01

computer time so far in this run	40.64 minutes	maximum number ever in bank	1
computer time in mcrun	40.40 minutes	bank overflows to backup file	0
source particles per minute	4.1011E+03	field length	0
random numbers generated	39990967	most random numbers used was	7002 in history 72546

range of sampled source weights = 7.7220E-01 to 1.8587E+00

1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	209410	165695	1136562	6.5122E+00	2.6657E-03	1.1414E+00	9.7744E-01	2.3522E+00
2	2	69850	53305	2633184	1.0356E+01	1.2766E-04	4.8478E-01	7.5004E-01	1.2281E+00
3	3	149909	133310	109952	6.1721E-01	2.8907E-03	1.1497E+00	9.4718E-01	3.0843E+00
total		429169	352310	3879698	1.7485E+01				

Originator Elwarthur 9713537.2486 Date 1-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A45

JOB No. 22192 CAL No. 5 REV No. A DATE 6/18/96 SHEET No. 40
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1keff results for: title - a Pu soln optimum moderation L-125 Vessel bare, Case R12 probid = 06/18/96 08:13:32

the initial fission neutron source distribution used the 1 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 165 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14247 neutron histories and 150 active cycles with 151447 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 165694 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

---

the final estimated combined collision/absorption/track-length keff = 0.35348 with an estimated standard deviation of 0.00176

the estimated 68, 95, & 99 percent keff confidence intervals are 0.35172 to 0.35525, 0.34997 to 0.35699, and 0.34882 to 0.35814

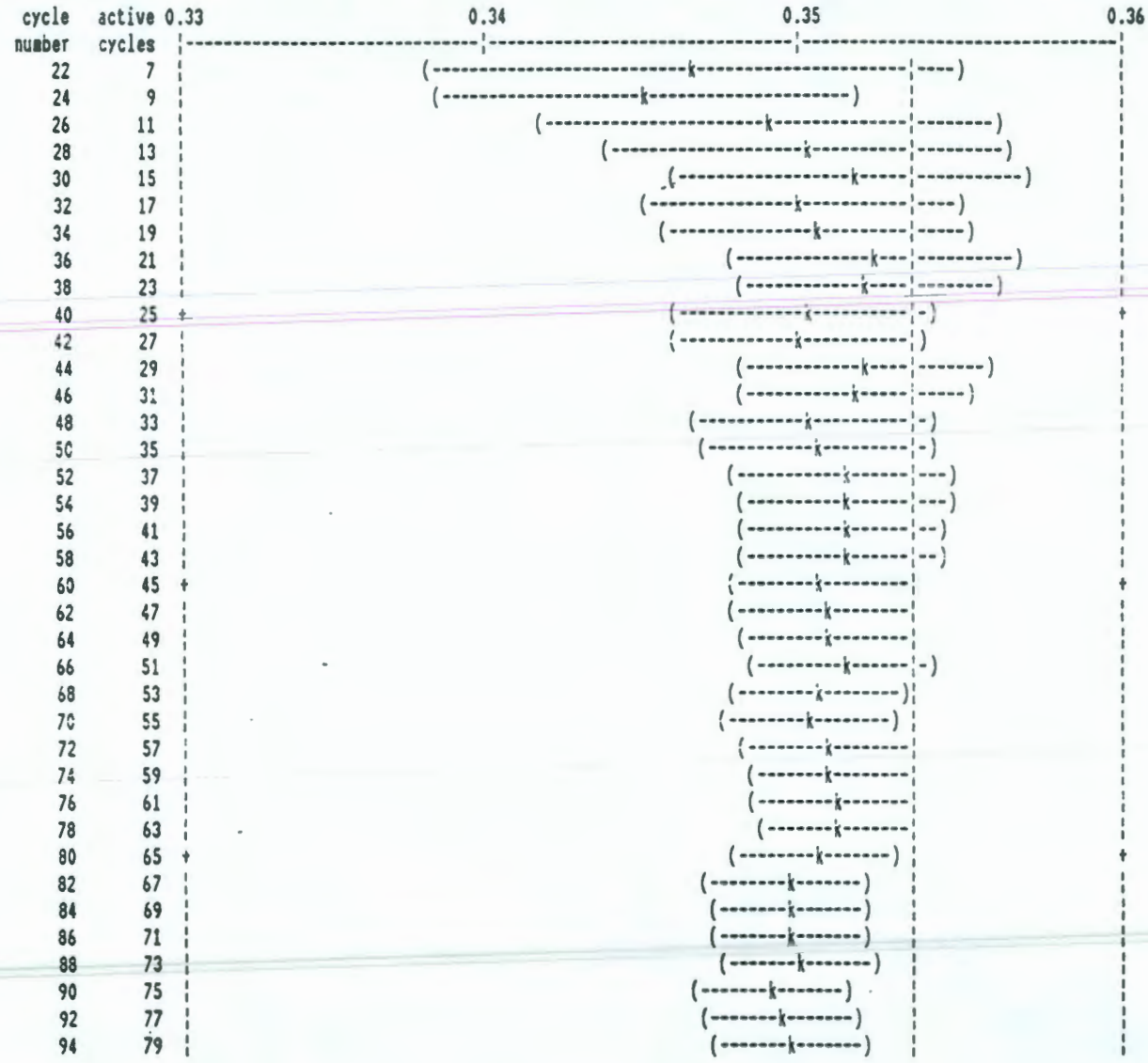
the estimated collision/absorption neutron removal lifetime = 1.17E-05 seconds with an estimated standard deviation of 1.25E-07

---

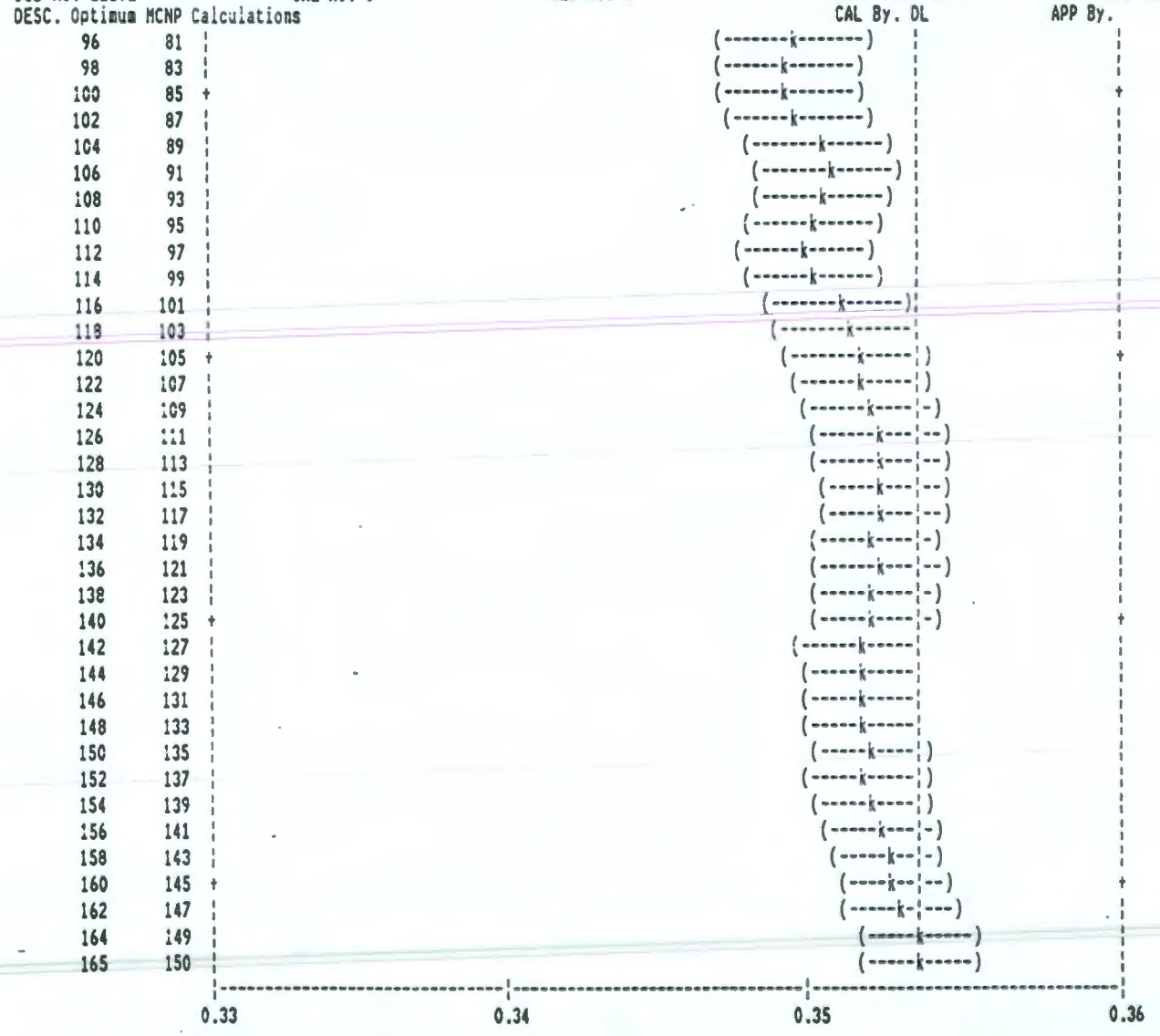
the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	.keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.35091	0.00239	0.34851 to 0.35330	0.34614 to 0.35567	0.34459 to 0.35723	
absorption	0.35404	0.00177	0.35227 to 0.35581	0.35051 to 0.35756	0.34936 to 0.35871	
track length	0.35073	0.00242	0.34830 to 0.35315	0.34590 to 0.35555	0.34432 to 0.35713	
col/absorp	0.35354	0.00176	0.35178 to 0.35531	0.35003 to 0.35705	0.34888 to 0.35820	0.5983
abs/trk len	0.35348	0.00176	0.35172 to 0.35523	0.34998 to 0.35698	0.34884 to 0.35812	0.5659
col/trk len	0.35084	0.00238	0.34846 to 0.35322	0.34610 to 0.35557	0.34455 to 0.35712	0.9409
col/abs/trk len	0.35348	0.00176	0.35172 to 0.35525	0.34997 to 0.35699	0.34882 to 0.35814	

JOB No. 22192 CAL No. 5 REV No. A DATE 6/18/96 SHEET No. 41
DESC. Optimum MCNP Calculations CAL By. DL APP By.
1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (¦ = final keff = 0.35348)



JOB No. 22192 CAL No. 5 REV No. A DATE 6/18/96 SHEET No. 42
DESC. Optimum MCNP Calculations CAL By. DL APP By.



9713537.2489

CALCULATION COVER SHEET

Project Title 0200W-SC-G0013 2335 D&D **Job No.** BH101

Area 200W

Discipline Criticality Analysis **Calc. No.** G

Subject Special MCNP Calculation

Computer Program MCNP **Program No.** 4A

Committed Calculation ☐ **Preliminary** ☑ **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
A	6	D Louie	J. Hinckley			

SUMMARY OF REVISION

Microfilmed:	Rev.	Date	Reel Number	Rev.	Date	Reel Number

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO.	DATE	SHEET NO.
22192	6	A	6/20/96	1

DESCRIPTION	CALC. BY	APPROVED BY
SPECIAL MCNP CALCULATION	DL	

THIS MCNP CALCULATION WAS INTENDED TO PROVIDE SOME INSIGHTS ABOUT BRINGING TWO COMPONENTS CLOSE TOGETHER. TO THE AFFECT OF KEFF

ASSUMPTIONS:

1. APPLY THE SAME MODEL AS IN RUN #2 OF CAL 2 EXEPT, VOID SPACE INSIDE VESSELS FILLED WITH WATER, AND NO REFLECTION IS MODELED OUTSIDE

2. SOLUTION INSIDE THE VESSELS ARE REPLACED WITH Pu METAL WITH OPTIMUM H_2O MIXTURE SO THAT RUN 6S COMPOSITION IS USED. THAT IS H/Pu RATIO OF 197 & ρ_{Pu} OF 0.137 KG/L

3. SPACING BETWEEN THE TWO VESSELS WERE SET TO BE 16.83 CM, SO THAT BOTH VESSELS ARE TOUCHING TO EACH OTHER.

4. BECAUSE OF EXPECTED A SMALL CHANGE IN ΔK, THE NO OF HISTORIES SAMPLE WERE INCREASED.

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	CAL NO.	REV NO	DATE	SHEET NO.
22192	6	A	6/20/96	2

DESCRIPTION	CALC. BY	APPROVED BY
SPECIAL MCNP CALCULATION	DL	

RUN #13 INPUT DESCRIPTION

GEOMETRY: SIMILAR TO THE GEOMETRY SETUP OF RUN #2.

CELL 1 = CELL 4 = Pu RESIDUE
CELL 2 = CELL 5 = WATER INSIDE VESSEL
CELL 3 = CELL 6 = VESSEL

VESSEL #1 VESSEL #2

CELL 7 IS THE ENV.

D = 16.83 CM SO THAT VESSEL #1 & #2 ARE TOUCHING.

NO REFLECTION OUTSIDE THE VESSELS.

MATERIALS: Pu RESIDUE SAME AS IN RUN #6S.
OTHER MATERIALS SAME AS IN RUN #2.

RUN #13 OUTPUT SUMMARY

THE OUTPUT SUMMARY OF THIS RUN ARE PROVIDED IN THE SUBSEQUENT SHEETS.

THE MCNP PREDICTS

$$\boxed{K_{EFF} = 0.58471 \pm 0.00208 \quad 95\%}$$

COMPARED TO THE SINGLE VESSEL CASE OF RUN #6S, THIS TWO-VESSEL CASE ONLY INCREASE REACTIVITY BY:

$$\Delta K = 5.66\,mK \pm 5.02\,mK$$

WHICH IS VERY SMALL.

Originator [illegible] 9713537.2492 Date 1-30-96 Calc. No. 0200W-CA-V0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A51

JOB No. 22192 CAL No. 6 REV No. A DATE: 6/20/96 SHEET No. 3
DESC. Special MCNP Calculation CAL By. DL APP By.
1problem summary

run terminated when 185 kcode cycles were done.

+ 06/19/96 13:46:20

title - two Pu metal/H2O L-16 Vessels in water, Case R13 probid = 06/19/96 13:07:29

0

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron loss	tracks	weight (per source particle)	energy (per source particle)
source	185030	9.9984E-01	2.1138E+00	escape	119304	6.2839E-01	8.5499E-01
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
cell importance	0	0.	0.	cell importance	0	0.	0.
weight cutoff	0	7.2220E-03	1.1000E-07	weight cutoff	65730	7.3546E-03	1.1619E-07
energy importance	0	0.	0.	energy importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	2.4903E-08	downscattering	0	0.	1.2379E+00
				capture	0	1.6801E-01	1.3267E-02
(n,xn)	8	3.1390E-05	2.1576E-05	loss to (n,xn)	4	1.5695E-05	1.5058E-04
fission	0	0.	0.	loss to fission	0	2.0332E-01	7.5306E-03
total	185038	1.0071E+00	2.1138E+00	total	185038	1.0071E+00	2.1138E+00

number of neutrons banked	4	average lifetime, shakes		cutoffs	
neutron tracks per source particle	1.0000E+00	escape	1.2532E+02	tco	1.0000E+34
neutron collisions per source particle	1.4472E+01	capture	1.1366E+03	ecc	0.0000E+00
total neutron collisions	2677770	capture or escape	5.0096E+02	wc1	-5.0000E-01
net multiplication	1.0000E+00 0.0002	any termination	5.4362E+02	wc2	-2.5000E-01

computer time so far in this run	38.83 minutes	maximum number ever in bank	1
computer time in mcrun	38.15 minutes	bank overflows to backup file	0
source particles per minute	4.8505E+03	field length	0
random numbers generated	35759159	most random numbers used was	7287 in history 41423

range of sampled source weights = 7.8064E-01 to 1.2563E+00

1neutron activity in each cell print table 126

	cell	tracks entering	population	collisions	collisions x weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	1	185063	160401	1673404	8.6789E+00	2.2369E-03	1.0605E+00	9.8034E-01	2.2895E+00
2	2	15375	11261	568612	1.9926E+00	1.2297E-04	4.8570E-01	7.4559E-01	1.2175E+00
3	3	124859	112596	82213	4.1599E-01	3.4254E-03	1.1457E+00	9.6450E-01	2.8935E+00
4	4	28363	24632	260434	1.3650E+00	2.1875E-03	1.0510E+00	9.9073E-01	2.2731E+00
5	5	2202	1609	80473	2.8277E-01	1.2278E-04	4.8585E-01	7.4653E-01	1.2221E+00
6	6	19077	17204	12634	6.4873E-02	3.4986E-03	1.1419E+00	9.7496E-01	2.9011E+00
total		374939	327703	2677770	1.2800E+01				

JOB No. 22192 CAL No. 6 REV No. A DATE: 6/20/96 SHEET No. 4
DESC. Special MCNP Calculation CAL By. DL APP By.
keff results for: title - two Pu metal/H2O L-16 Vessels in water, Case R13 probid = 06/19/96 13:07:29

the initial fission neutron source distribution used the 2 source points that were input on the ksrc card.
the criticality problem was scheduled to skip 15 cycles and run a total of 185 cycles with nominally 1000 neutrons per cycle.
this problem has run 15 inactive cycles with 14433 neutron histories and 170 active cycles with 170597 neutron histories.

this calculation has completed the requested number of keff cycles using a total of 185030 fission neutron source histories.
all cells with fissionable material were sampled and had fission neutron source points.

the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

the k(collision) cycle values appear normally distributed at the 95 percent confidence level
the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
the k(trk length) cycle values appear normally distributed at the 95 percent confidence level

the final estimated combined collision/absorption/track-length keff = 0.58471 with an estimated standard deviation of 0.00208

the estimated 68, 95, & 99 percent keff confidence intervals are 0.58263 to 0.58679, 0.58057 to 0.58885, and 0.57922 to 0.59020

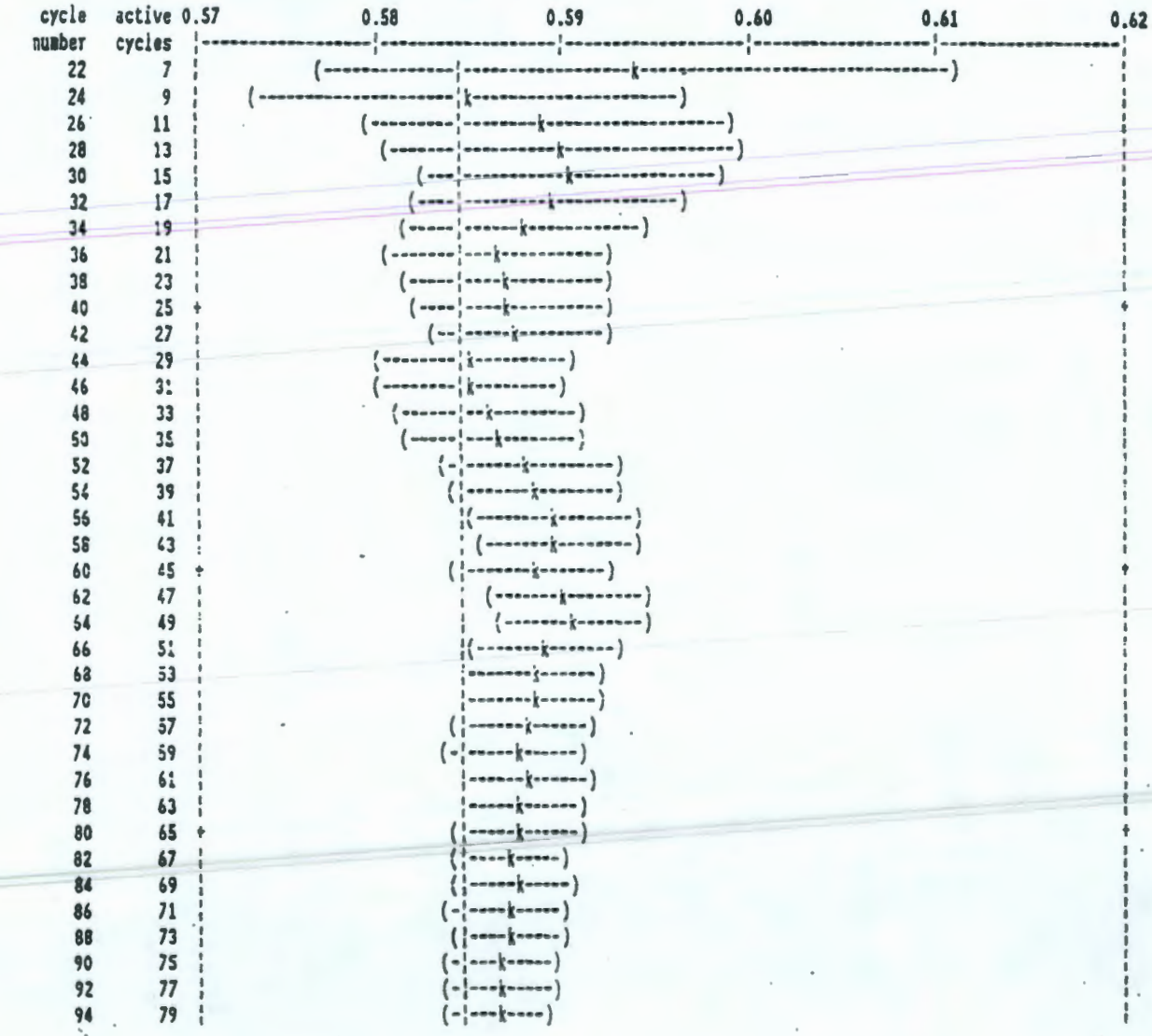
the estimated collision/absorption neutron removal lifetime = 5.01E-06 seconds with an estimated standard deviation of 6.03E-08

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.58442	0.00289	0.58153 to 0.58731	0.57867 to 0.59017	0.57679 to 0.59205	
absorption	0.58530	0.00207	0.58323 to 0.58737	0.58118 to 0.58942	0.57983 to 0.59077	
track length	0.58258	0.00295	0.57963 to 0.58554	0.57670 to 0.58847	0.57478 to 0.59039	
col/absorp	0.58521	0.00206	0.58315 to 0.58728	0.58110 to 0.58932	0.57976 to 0.59066	0.6309
abs/trk len	0.58496	0.00206	0.58290 to 0.58702	0.58086 to 0.58906	0.57952 to 0.59040	0.5778
col/trk len	0.58392	0.00292	0.58100 to 0.58684	0.57810 to 0.58973	0.57621 to 0.59163	0.9501
col/abs/trk len	0.58471	0.00208	0.58263 to 0.58679	0.58057 to 0.58885	0.57922 to 0.59020	

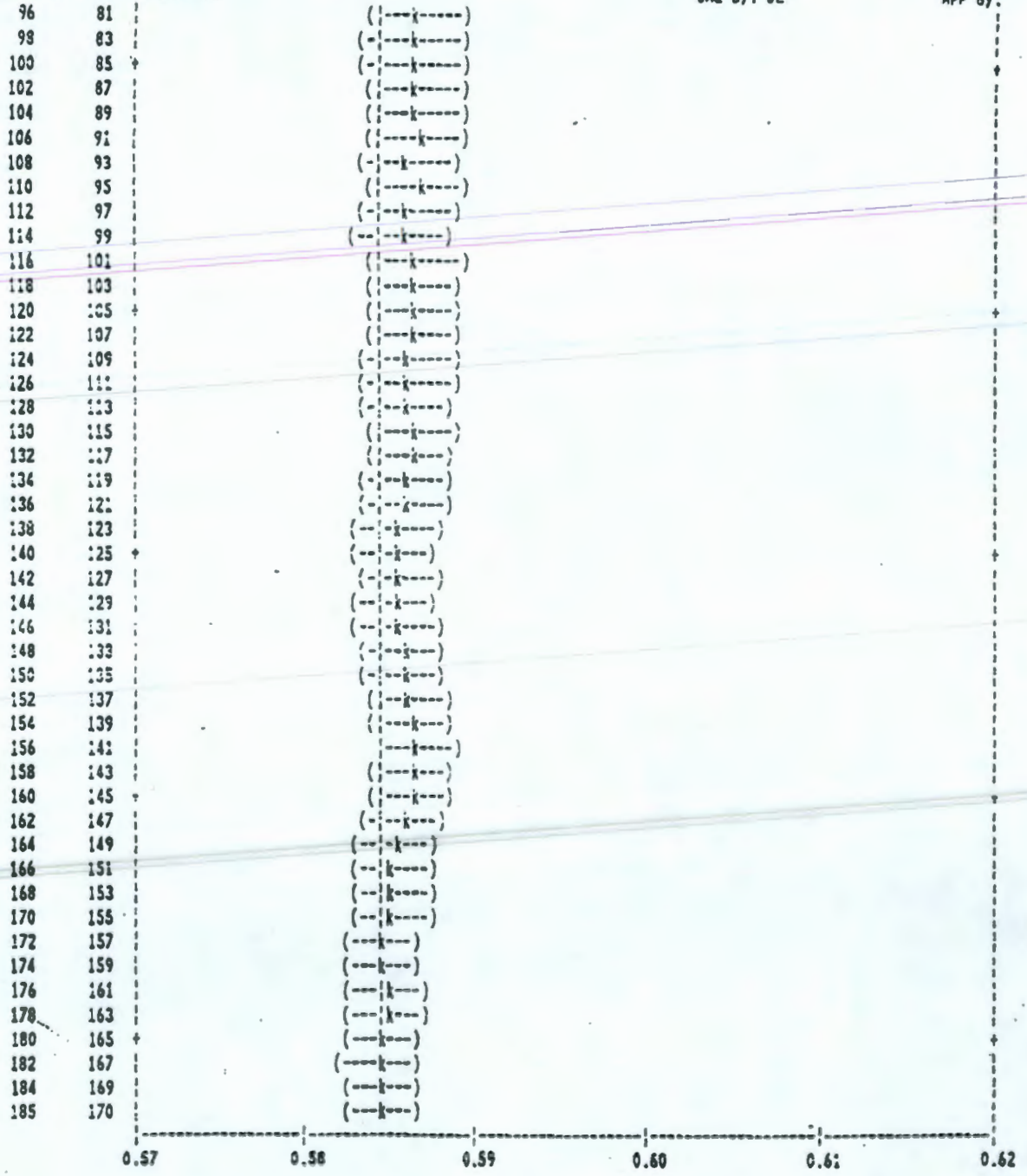
Originator Edwards Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A53

JOB No. 22192 CAL No. 6 REV No. A DATE: 6/20/96 SHEET No. 5
DESC. Special MCNP Calculation CAL By. DL APP By.
1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (¦ = final keff = 0.58471)



Originator [illegible] Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A54

JOB No. 22192 CAL No. 6 REV No. A DATE: 6/20/96 SHEET No. 6
DESC. Special MCNP Calculation CAL By. CL APP By.



Originator Edwards 9713537.2496 Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 233S D&D Job No. 22192 Checked R.J. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A55

CALCULATION COVER SHEET

Project Title 233-S D&D **Job No.** 0200W-SC-G0018

Area 200W

Discipline Engineering **Calc. No.** 7

Subject Criticality Analysis

Computer Program _____ **Program No.** _____

Committed Calculation ☐ **Preliminary** ☒ **Superseded** ☐

Rev.	Sheet Numbers	Originator	Checker	Reviewer	Approval	Date
0	5	JP Hinckley	DL Louie			

SUMMARY OF REVISION

Microfilmed:	Rev.	Date	Reel Number	Rev.	Date	Reel Number

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	calc	rev	DATE	SHEET NO
0200W-SC-G0018	7	0	6-17-96	1/5

DESCRIPTION	CALC. BY	APPROVED BY
Solid angle of 233-S process vessel array with respect to tank L-16 in its normal position	[illegible]	

Reference:

1. Knief - 1986
2. Hanford drawing H-2-18029 rn
3. Calculations

Assumptions:

1. All vessels are vertical cylinders with the center of the fissile volumes on the same plane

Data:

Distance from L-16 to:

L-4	6'9"	(81 in)	L-14	2'3"	(27 in)
L-12S	6'0"	(72 in)	L-6	3'0"	(36 in)
L-12N	6'9"	(81 in)	L-18	5'2"	(62 in)

Tank Parameters:

	D (cm/inches) =		H (cm/inches) =		K_{eff}
L-4	14.2	(5.6)	10.1	(4.0)	0.39
L-6	11.4	(4.5)	19.2	(7.6)	0.36
L-12S	15.4	(6.1)	7.4	(2.9)	0.35
L-12N	2.6	(1.0)	182.5	(72.0)	0.0002
L-14	14.2	(5.6)	19.1	(7.5)	0.50
L-16	15.4	(6.8)	30.5	(12.0)	0.58
L-18	10.8	(4.25)	15.8	(6.2)	0.29

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	Calc	Rev	DATE	SHEET NO
0200W-SC-G0012	7	0	6-17-96	2/5

DESCRIPTION	CALC. BY	APPROVED BY
from Knief figure 8-5 and Appendix C	JPH	

$$\Omega = 4\sin^{-1}\left[\frac{(D/2)(H/2)}{\left(\sqrt{(D/2)^2+L^2}\right)\left(\sqrt{(H/2)^2+L^2}\right)}\right]$$

$$\Omega_{L4} = 4\sin^{-1}\left[\frac{(2.8)(2.0)}{\left(\sqrt{(2.8)^2+81^2}\right)\left(\sqrt{2.0^2+31^2}\right)}\right] = \frac{5.6}{(81)(81)} = \boxed{.0031}$$

$$\Omega_{L6} = 4\sin^{-1}\left[\frac{(2.25)(3.8)}{\left(\sqrt{2.25^2+36^2}\right)\left(\sqrt{3.8^2+36^2}\right)}\right] = \frac{8.6}{(36.1)(36.2)} = \boxed{.026}$$

$$\Omega_{L12S} = 4\sin^{-1}\left[\frac{(3.05)(1.45)}{\left(\sqrt{(3.05)^2+72^2}\right)\left(\sqrt{1.45^2+72^2}\right)}\right] = \frac{4.42}{(72.1)(72)} = \boxed{.003}$$

$$\Omega_{L12N} = 4\sin^{-1}\left[\frac{(.5)(36)}{\left(\sqrt{.5^2+81^2}\right)\left(\sqrt{36^2+81^2}\right)}\right] = \frac{18}{(81)(88.6)} = \boxed{.01}$$

$$\Omega_{L14} = 4\sin^{-1}\left[\frac{(2.8)(3.75)}{\left(\sqrt{2.8^2+27^2}\right)\left(\sqrt{3.75^2+27^2}\right)}\right] = \frac{10.5}{(27.1)(27.3)} = \boxed{.06}$$

$$\Omega_{L18} = 4\sin^{-1}\left[\frac{(2.13)(3.1)}{\left(\sqrt{2.13^2+62^2}\right)\left(\sqrt{3.1^2+62^2}\right)}\right] = \frac{6.59}{(62)(62)} = \boxed{.007}$$

$$\Omega_T = .003+.026+.003+.01+.06+.007 = \underline{0.11}$$

since $0.11 \ll 9-(10)(.6)(.6)$ the array is extremely subcritical w/r to L-16

1.9

USING RELATIONSHIP WRONG!

AS STATED $\Omega_{ALL} = 5.4$

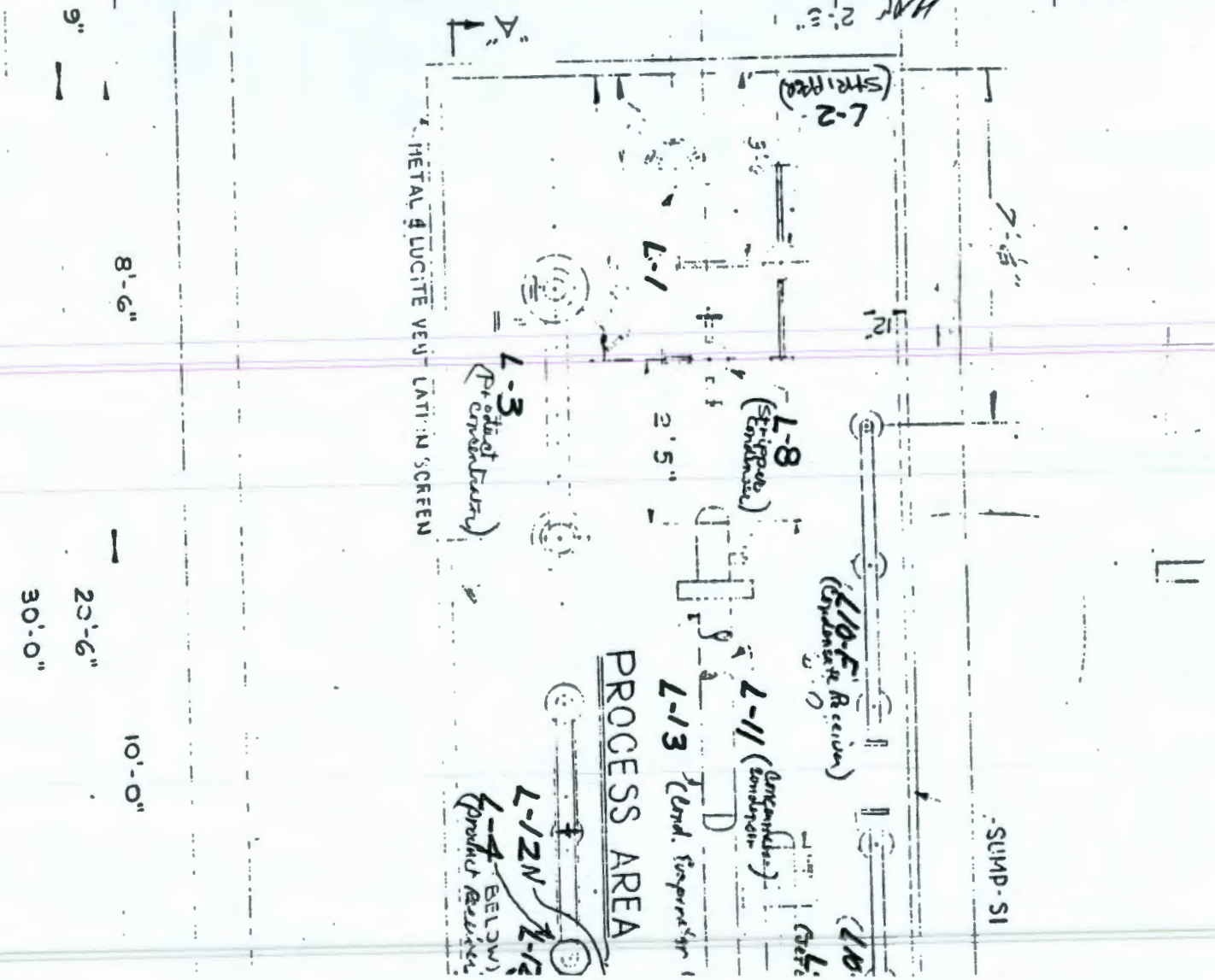
$$\Omega_{ALL} = (1-0.4)[9-10\,k_{eff}]$$
$$= 1.80$$

9713537.2499

Originator Z/Warner Date 7-30-96 Calc. No. 0200W-CA-N0001 Rev. No. 0
Project BLDG 2335 D&D Job No. 22192 Checked R.I. SMITH Date 10/23/96
Subject Pu CONCENTRATION SYSTEM REMOVAL CRITICALITY REVIEW Sheet No. A58

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB			DATE	SHEET NO
0200W-SC-G0018	calc 7	Rev 0	6-17-96	3/5
DESCRIPTION			CALC. BY NDH	APPROVED BY



Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	calc	Rev	DATE	SHEET NO.
0200W-SC-G0019	Y	0	6-17-96	4/5

DESCRIPTION	CALC. BY	APPROVED BY
Solid angle of 233-S process vessel/array with tank L-16 moved near L-4, L-12S, L-12N, and L-18	SM	

Data and assumptions are the same as for calc. SA-1, except:

Distance from L-16 to:

L-4	12 inches	L-12N	12 inches
L-6	82 inches	L-14	72 inches
L-12S	12 inches	L-18	31 inches

$$\Omega_{L-4} = 4\sin^{-1}\left[\frac{5.6}{(\sqrt{12.8^2+12^2})(\sqrt{12.5^2+12^2})}\right] = 4\sin^{-1}\frac{5.6}{(12.3)(12.2)} = \boxed{.15}$$

$$\Omega_{L6} = 4\sin^{-1}\left[\frac{8.6}{(\sqrt{12.25^2+82^2})(\sqrt{3.8^2+82^2})}\right] = 4\sin^{-1}\frac{8.6}{(82)(82)} = \boxed{.01}$$

$$\Omega_{L12S} = 4\sin^{-1}\left[\frac{4.42}{(\sqrt{3.05^2+12^2})(\sqrt{11.45^2+12^2})}\right] = 4\sin^{-1}\frac{4.42}{(12.4)(12.1)} = \boxed{.12}$$

$$\Omega_{L12N} = 4\sin^{-1}\left[\frac{18}{(\sqrt{1.5^2+12^2})(\sqrt{36^2+12^2})}\right] = 4\sin^{-1}\frac{18}{(12)(37.9)} = \boxed{.16}$$

$$\Omega_{L14} = 4\sin^{-1}\left[\frac{10.5}{(\sqrt{2.8^2+72^2})(\sqrt{3.75^2+72^2})}\right] = 4\sin^{-1}\frac{10.5}{(72)(72.1)} = \boxed{.01}$$

$$\Omega_{L18} = 4\sin^{-1}\left[\frac{6.59}{(\sqrt{2.13^2+31^2})(\sqrt{3.1^2+31^2})}\right] = 4\sin^{-1}\frac{6.59}{(31.1)(31.2)} = \boxed{.03}$$

$$\Omega_T = .15 + .01 + .12 + .16 + .01 + .03 = \underline{0.48}$$

Los Alamos Technical Associates, Inc.
ENGINEERING CALCULATIONS

JOB	calc	Rev	DATE	SHEET NO
0200W-SC-G 0018	7	0	6-17-96	5/5

DESCRIPTION	CALC. BY	APPROVED BY
Solid angle of 233-S vessel array, arranged such that all vessels are 12" from each other. This will yield the largest possible solid angle.	[illegible]	

from sheet 1:

$\Omega_{L4} = .15$ $\Omega_{L12D} = .16$

$\Omega_{L12S} = .12$

$$\Omega_{L6} = 4\sin^{-1}\left[\frac{8.6}{(\sqrt{2.25^2+12^2})(\sqrt{3.8^2+12^2})}\right] = 4\sin^{-1}\frac{8.6}{(12.2)(12.6)} = \boxed{.22}$$

$$\Omega_{L14} = 4\sin^{-1}\left[\frac{10.5}{(\sqrt{2.8^2+12^2})(\sqrt{3.75^2+12^2})}\right] = 4\sin^{-1}\frac{10.5}{(12.3)(12.6)} = \boxed{.27}$$

$$\Omega_{L16} = 4\sin^{-1}\left[\frac{(3.4)(6.0)}{(\sqrt{3.4^2+12^2})(\sqrt{16^2+12^2})}\right] = 4\sin^{-1}\frac{20.4}{(12.5)(13.4)} = \boxed{.49}$$

$$\Omega_{L18} = 4\sin^{-1}\left[\frac{6.59}{(\sqrt{2.13^2+12^2})(\sqrt{3.1^2+12^2})}\right] = 4\sin^{-1}\frac{6.59}{(12.2)(12.4)} = \boxed{.18}$$

The largest possible solid angle is w/r to L12S, and so

$\Omega_T = .15 + .16 + .22 + .27 + .49 + .18 = \underline{1.47}$

The smallest allowable solid angle is $9 - 10(.58) = 3.2$ which should be reduced by 40% to account for reflection from concrete walls and workers.

$\Rightarrow$ Since $1.47 < 1.9$, the array is subcritical

ATTACHMENT B

SOLID ANGLE METHOD FOR EVALUATING ARRAY CRITICALITY

FROM NUREG/CR-0095

"NUCLEAR SAFETY GUIDE", TID-7016, REV 2

JUNE, 1978

4.26. It is informative to contrast the surface density and density analogue models applied to a large number of units. Consider 20,000 units as described in 4.24. The administrative control limiting the number of units in one direction to only two would permit a center spacing of ~0.7 m, by Eq. 4.6. On the other hand, no comparable administrative control would be required by the density analogue method and any arrangement of the 20,000 units would be allowed, but would necessitate a spacing of ~1.3 m.

4.27. The safety limits for water-reflected arrays may be extended to individual arrays reflected by concrete of any thickness by the following:

- The surface density, σ, of Eq. 4.5, for water-reflected *planar* arrays is reduced to 60% for similar concrete-reflected *planar* arrays to determine the allowed spacing.
- The average fissile material density for concrete-reflected arrays of any shape is 50% of the average fissile material density for similar water-reflected arrays.
- The number of units for concrete-reflected arrays of any shape is 1/4 the number of units for similar water-reflected arrays.

4.28. Experimentally determined unreflected spherical masses or values calculated by a validated method may be used in Eqs. 4.5 through 4.8. Table 4.4 lists some useful calculated data for the materials of Table 4.1.

Solid Angle

4.29. This method was developed[67] as a quick, empirical means of evaluating interaction between small numbers of moderated fissile units. The technique has been extended in practice to arrays containing large numbers of units. Application of the method, which is based on experiments with aqueous solutions, to small numbers of closely spaced units characterized by a fast neutron spectrum can result in nonconservative spacing.[50,68] Specifically, direct application of the relationship between k_{eff} and the maximum allowable solid angle could lead to critical configurations were there not a required minimum spacing of 0.3 m between units. Guidance for the storage of these units can best be obtained from American National Standard N16.5-1975.

4.30. The solid angle method specifies a maximum allowable solid angle subtended at any unit, with a neutron multiplication factor k_{eff}, by all other units in the array. A given array is then judged to be subcritical if the actual solid angle is equal to or less than the allowed solid angle given by

$$\Omega_{allowed} = 9 - 10k_{eff} \tag{4.9}$$

where

$\Omega_{allowed}$ = the allowed solid angle in steradians (sr) subtended at the center of any unit by the remainder of the units in the array

k_{eff} = the neutron multiplication factor of the given unit.

Table 4.4. Some Calculated Unreflected Spherical Critical Masses

Material form	Atomic ratio,[a] H:U or H:Pu	Density, (kg U/l or kg Pu/l)	Mass,[a] (kg)
U(100)Metal	0.0	18.7	45.6
U(100)O_2	0.4	8.3	81.7
U(100)O_2	3.0	4.5	57.8
U(93.2)Metal	0.0	18.7	52.1
U(93.2)O_2	0.4	8.3	90.2
U(93.2)O_2	3.0	4.5	63.5
U(80)Metal	0.0	18.7	69.8
U(80)O_2	0.4	8.3	111.3
U(80)O_2	3.0	4.5	74.0
U(70)Metal	0.0	18.7	89.1
U(70)O_2	0.4	8.3	133.3
U(70)O_2	3.0	4.5	83.4
U(50)Metal	0.0	18.7	159.6
U(50)O_2	0.4	8.3	207.7
U(50)O_2	3.0	4.5	112.8
U(40)Metal	0.0	18.7	228.0
U(30)Metal	0.0	18.7	379.7
U(30)O_2	0.4	8.3	409.6
U(30)O_2	3.0	4.5	150.0
U(5)O_2	3.0	4.6	494.6
Pu(100)Metal	0.0	19.7	9.9
Pu(100)O_2	0.4	8.7	26.6
Pu(100)O_2	3.0	4.7	28.6
Pu(94.8)Metal	0.0	19.7	10.3
Pu(94.8)O_2	0.4	8.7	27.9
Pu(94.8)O_2	3.0	4.7	32.7
Pu(80)Metal	0.0	19.7	11.6
Pu(80)O_2	0.4	8.7	32.1
Pu(80)O_2	3.0	4.7	42.4
^{233}U Metal	0.0	18.4	15.7
$^{233}UO_2$	0.4	8.2	34.4
$^{233}UO_2$	3.0	4.5	31.6

[a]Total uranium or total plutonium.

The neutron multiplication factor of each unreflected unit by itself is estimated by a validated calculational technique. The following conditions must be satisfied in order to apply the method:

a. The k_{eff} of any unit shall not exceed 0.80,

b. Each unit shall be subcritical when completely reflected by water,

c. The minimum separation between units shall be 0.3 m, and ~ 12 in

d. The allowed solid angle shall not exceed 6 sr.

4.31. The actual solid angle between units is calculated by the methods illustrated in Figs. 4.1 and 4.2. The contribution of a unit to the solid angle at a point P is a function of its surface area and its minimum distance H to the point P. For arrays of simple identical units at uniform spacing, the interpretations of H and P are straightforward. For these arrays, P is chosen as the center of the "centermost" unit. The total solid angle subtended at this point is, then, the sum of the contributions due to all other units in the array.

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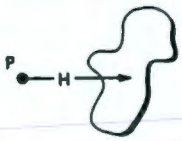
POINT–TO–ARBITRARY SHAPE

$$\Omega = \frac{\text{Cross Sectional Area}}{(\text{Separation})^2}$$



POINT–TO–CYLINDER

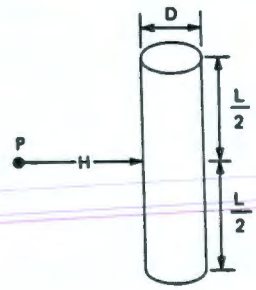
$$\Omega = \frac{LD}{H\sqrt{(L/2)^2 + H^2}}$$

where

L = Length of the cylinder

D = Diameter of the cylinder

H = Distance from the point to the surface of the cylinder



POINT–TO–DISK

$$\Omega = 2\pi\left(1 - \frac{1}{\sqrt{1 + (R/H)^2}}\right) < \frac{\pi R^2}{H^2}$$

where

R = Radius of the disk

H = Distance from the point P to the surface of the disk

POINT–TO–SPHERE

$$\Omega = 2\pi\left(1 - \frac{1}{\sqrt{1 + (R/H)^2}}\right)$$

where

R = Radius of the sphere

H = Distance from the point to the surface of the sphere

POINT–TO–PLANE

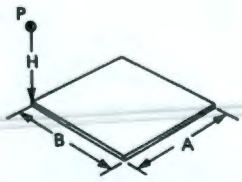
$$\Omega = \sin^{-1}\left[\frac{AB}{\sqrt{A^2 + H^2}\,\sqrt{B^2 + H^2}}\right]$$

where

A = Length of one side of the plane

B = Length of the other side of the plane

H = Perpendicular distance from the point to the plane



If the point is directly above the center of a plane with dimensions 2A X 2B (rather than over a corner as shown above), multiply Ω by 4 to obtain the solid angle.

Fig. 4.1. Solid angle approximate formulas.

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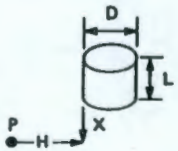
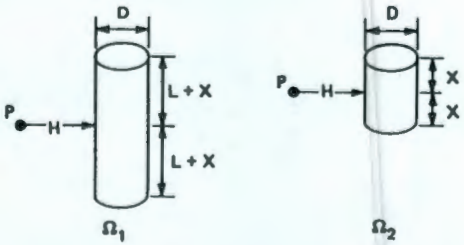
OFFSET CYLINDERS

The solid angle subtended at point P by the curved surface of the offset cylinder shown below



can be evaluated by superposition. To do this, the solid angles subtended by cylinders with lengths 2 (L + X) and 2 X are calculated as shown below. The desired solid angle is $(\Omega_1 - \Omega_2)/_2$ where Ω_1 and Ω_2 are as shown.



Thus

$$\Omega = \frac{(\Omega_1 - \Omega_2)}{2} = \frac{D(L+X)}{H\sqrt{(L+X)^2 + H^2}} - \frac{D}{H\sqrt{X^2 + H^2}} + \text{contribution from disk.}$$

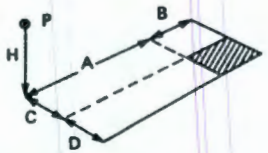
The solid angle subtended by the bottom of the cylinder can be evaluated as an offset disk.

OFFSET PLANES

For plane S, shown below the solid angle Ω_s is given by

$$\Omega_S = \Omega_{(A+B)\times(C+D)} - \Omega_{(A+B)\times C}$$

$$-\left[\Omega_{A\times(C+D)} - \Omega_{A\times C}\right]$$



Using the point to plane formula from Fig. 4.1

$$\Omega_S = \sin^{-1}\left[\frac{(A+B)(C+D)}{\sqrt{(A+B)^2 + H^2}\sqrt{(C+D)^2 + H^2}}\right] - \sin^{-1}\left[\frac{(A+B)C}{\sqrt{(A+B)^2 + H^2}\sqrt{C^2 + H^2}}\right]$$

$$-\sin^{-1}\left[\frac{A(C+D)}{\sqrt{A^2 + H^2}\sqrt{(C+D)^2 + H^2}}\right] + \sin^{-1}\left[\frac{AC}{\sqrt{A^2 + H^2}\sqrt{C^2 + H^2}}\right]$$

OFFSET DISKS

Rather complex expressions for the solid angle result when the point P is not directly above the center of the disk. A conservative approximation for this offset case is to apply the point-to-disk formula in Fig. 4.1 with the distance H defined as the perpendicular distance from the point P to the plane of the disk.

Fig. 4.2. Superposition application of solid angle formulas.

4.32. For other arrays the procedure is similar, but the solid angle at each unit must be calculated and compared to the $\Omega_{allowed}$ for that unit. Care must be exercised in selecting the point P for a unit of complex shape. If each total subtended solid angle is less than its respective allowed value, the array is judged subcritical.

4.33. Application of the method to other than solutions should be approached with caution. More detailed analyses[50,68] indicate that some large arrays of metal units spaced by the solid angle method may not have an adequate margin of subcriticality.

4.34. The solid angle method should not be applied unless the following array reflector condition is satisfied:

> The effectiveness of the reflector is no greater than that of a thick water reflector located at the boundary of the array. This boundary is no closer to the peripheral units than half the separation between unit surfaces.

Concrete reflection on three sides of the array can be shown to meet this criterion. For full reflection by concrete thicker than 12 cm, the allowable solid angle shall be reduced by 40%.

Other Methods

4.35. Models and methods shown to satisfy the requirements of American National Standard N16.9 may be used to establish nuclear criticality safety limits. It is emphasized that the concept of the method, its parameter dependence, its uncertainty in biases, and its area of applicability must be clearly understood. Appropriately, a user should document, for himself and for others, his ability to apply the method.

A method, well described and extensively correlated with the results of critical experiments, is Clark's albedo method.[69] Various tables and graphs of parameters have been published[70,71] which facilitate these hand calculations.