DEVELOPMENT OF MURR FLUX TRAP MODEL FOR SIMULATION AND PREDICTION OF SAMPLE LOADING REACTIVITY WORTH AND ISOTOPE PRODUCTION

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DEVELOPMENT OF MURR FLUX TRAP MODEL FOR
SIMULATION AND PREDICTION OF SAMPLE LOADING
REACTIVITY WORTH AND ISOTOPE PRODUCTION

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DEVELOPMENT OF MURR FLUX TRAP MODEL FOR SIMULATION AND PREDICTION OF SAMPLE LOADING REACTIVITY WORTH AND ISOTOPE PRODUCTION

Zhegang Ma

Dr. William H. Miller, Dissertation Supervisor

ABSTRACT

As the highest power university research reactor and the only facility to provide reactor-based radioisotopes besides DOE reactors, the University of Missouri Research Reactor (MURR) has been supplying various radioisotopes for more than 20 years. The flux trap, locating in the center island tube, has the highest flux for sample irradiating with an ability of 6x10^{14} n/cm^2/s. For both safety and economical reasons, it is very important for the MURR to be able to predict the reactivity worth of sample loading in the flux trap, as well as the production of specific isotopes.

The research develops MURR Flux Trap Model (MFTM) which simulates the reactor core and flux trap area, solves the neutron transport equation and calculates the loading worth based on the Monte Carol method, proceeds with burnup and decay calculation, and predicts the requested isotope production. MCNP part of the MFTM model carries out neutron transport calculations and predicts the reactivity worth of sample loading in the flux trap while MonteBurns part of the model calculates isotope production from the target sample irradiated in the flux trap by solving the general nuclide depletion equation. Different sample loadings and their measurement data have been provided by the MURR for benchmarking the model during the developing period. The discrepancy between the model and the corresponding experimental data has been analyzed. Over-prediction of the negative worth of KCl samples was determined to be the cause of most of the deviation between the model and experimentally measured results. The original MCNP model has been refined with the consideration of the self-shielding effect and burnup effect. The modified model has yielded better predictions approaching the experimental values. A later study found that the worth calculation from MCNP model on the loadings with no or one KCl sample had very close results compared with the experimental values, with 10 to 20 percent deviation. The MonteBurns model predicted Ho-166 production with less than 10% error and Lu-177 with approximately 20% error. The MCNP and MonteBurns models were integrated into an automatic analytic tool with Visual Basic language for efficient usage by the MURR. The automated package has been successfully run on MURR MCNP Server.

CHAPTER 1

INTRODUCTION

1.1 Background

The peaceful use of radioisotopes in the United States and other countries has expanded significantly since their introduction in the 1940s. The market for radioisotopes worldwide nowadays is so big as to be a very important component of the economy with the applications ranged from industry to medical therapy. As the highest power university reactor, the University of Missouri Research Reactor (MURR) is one of only a few U.S. reactor facilities that provide reactor-produced isotopes. Specifically, the MURR is one of the few reactors in the world that can supply very high specific activity radiolanthanides such as Lutetium-177, Samarium-153, and Holmium-166.

One design feature of the MURR is the flux trap which can achieve a peak thermal flux as high as 6 x 10^{14} n/(cm^2 sec) for sample irradiation. The flux trap is a highly moderated annulus positioned in the center of the core for irradiating samples. For both safety and economical reasons, it is very important for the MURR to be able to predict the reactivity worth of various sample loadings in the flux trap, as well as the production of specific isotopes.

MURR has used a spreadsheet-based method to predict the reactivity worth of sample loading in the flux trap for many years. For this method, the reactivity worth for individual sample was measured by experiment aforehand while the flux importance function was derived for specific axial positions in the flux trap. Each week before the actual loading is inserted in the flux trap, a simulated loading is set up on the spreadsheet to predict the loading worth which must comply with the limitation of 0.006 δk specified by the Technical Specifications.

This method has been applied to predict the sample loading worth in the MURR for a long time. It works adequately as long as the individual sample worth and flux importance function are well defined from experimental data. However, an analytic tool that can simulate the MURR core and flux trap, and predict sample loading worth and isotopic production accurately is becoming more and more necessary to support the efficiency and accuracy of isotope production for both medical practice and research.

1.2 Objectives of Research

The objective of this research is to develop a MURR Flux Trap Model (MFTM) that will simulate the MURR reactor core and flux trap area, predict the sample loading worth, and calculate isotope production in the flux trap. The calculated loading worth and isotopes produced by the model shall be benchmarked with the corresponding measurement data from the MURR. The model will be integrated into an automated package for easy loading of input data.

The Monte Carlo N-Particle code, MCNP, developed at Los Alamos National Laboratory (LANL) will be used to simulate the neutron behavior in the MURR flux trap and calculate the flux trap sample loading reactivity worth. The MonteBurns code, developed also by LANL, will be applied to predict isotope production in the flux trap by coupling MCNP with ORIGEN, a versatile point-depletion and radioactive-decay computer code developed at the Oak Ridge National Laboratory (ORNL).

After developing and benchmarking of the MCNP and MonteBurns model for the MURR flux trap, the two parts will be integrated using a user-friendly interface. The Visual Basic language will be used for this task.

1.3 Organization

For the rest of this report, Chapter 2 will briefly describe the design features of the MURR core and flux trap. Chapter 3 will introduce the computational method and the computational deck of MCNP-ORIGEN2-MonteBurns that will be used in the research. Chapter 4 will describe the MCNP part of the model as well as its verification and refinement process. Chapter 5 will describe the MonteBurns part of the model. Chapter 6 will briefly introduce the functions of the automated package and its Graphic User Interface (GUI). Chapter 7 will summarize the research results and describe the work that may be done in the future.

CHAPTER 2

MURR REACTOR AND FLUX TRAP

2.1 MURR Reactor

The University of Missouri Research Reactor (MURR) is a 10 MW light-water moderated and cooled flux trap reactor that is the highest-power university research reactor in the country. It has been in operation for 39 years since October 13, 1966. As one of only a few U.S. facilities for producing reactor-based isotopes, the MURR can supply very high specific activity isotopes such as radiolanthanides that are used to make drugs and help diagnose and treat cancer illness. These include Samarium-153, used in Quadramet to alleviate the pain of patients with metastatic bone cancer, Lutetium-177, used in therapeutic cancer treatment drug, and Holmium-166, used to treat bone cancer. Other isotopes for industrial uses are also produced.

The MURR core is a cylindrical annulus located between the inner and outer pressure vessels. It is formed by eight plate-type fuel elements each originally containing 775 grams of U-235 in the fuel zone. Each fuel element contains twenty-four curved fuel plates; each plate is a sandwich of 93 percent enriched uranium aluminide fuel (UAlx) with aluminum cladding. The active height of the core is 60.96 cm (24 inches). The average thermal flux in the core is

4×10^{13} n/(cm^2 sec) at its rated power level. The reactor is controlled by four boral shim blades and one stainless steel regulating blade that form a segmented cylindrical sheath between the outer pressure vessel and the beryllium reflector. The reflector consists of two concentric cylindrical annuli surrounding the control region, a 6.883 cm (2.71 inches) thick inner reflector annulus of beryllium metal and a 22.580 cm (8.89 inches) thick outer reflector of graphite canned in aluminum. The overall height of the reflectors is 76.20 cm (30 inches) which is centered vertically with the core. The reactor core, control and reflector assemblies are centered 25 feet down in a 30-foot deep by 10-foot diameter pool of demineralized light water. Figures 2-1 and 2-2 show the horizontal and vertical views of the MURR reactor core, respectively.

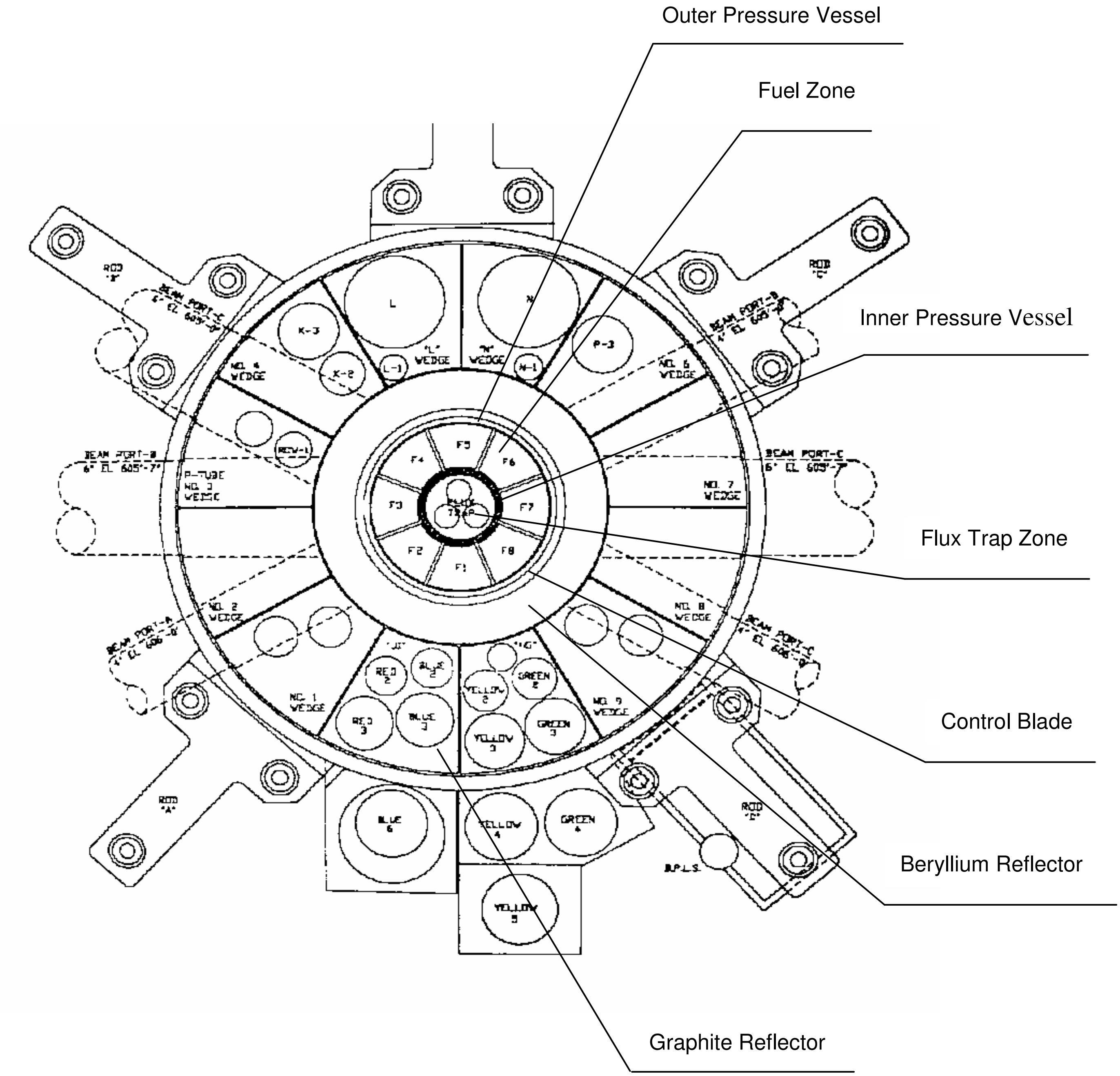


Figure 2-1 Horizontal View of the MURR Core, Flux Trap, and Reflector

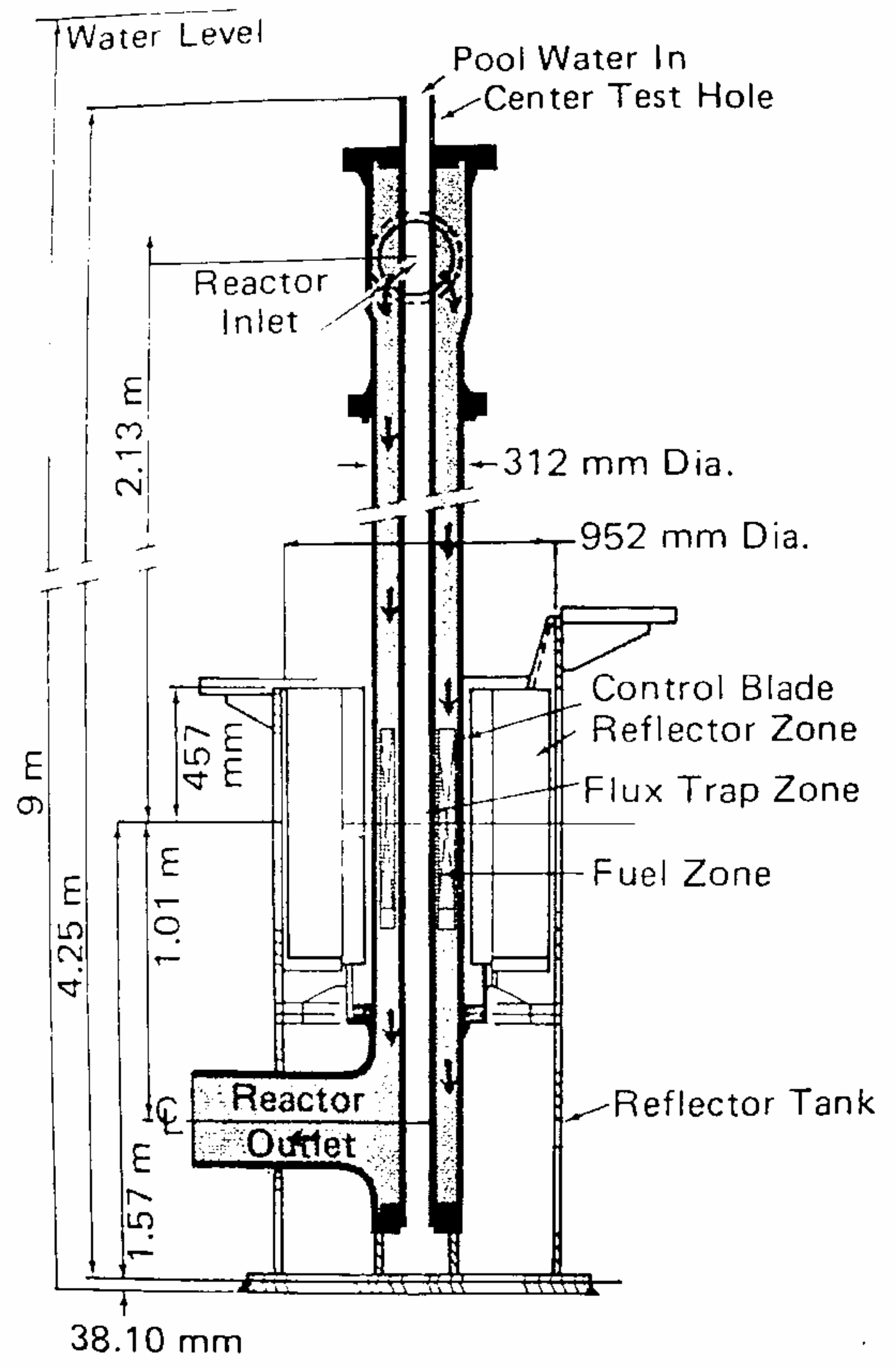


Figure 2-2 Vertical View of the MURR Core, Flux Trap, and Reflector

2.2 Flux Trap

The irradiation facilities that MURR utilizes to irradiate various targets to produce radioisotopes and activated samples include the flux trap, the pneumatic tube system, the neutron beam tube, the graphite reflector region, and the bulk pool facility (see Figure 2-3). The flux trap is located in the center island tube which is a four-inch aluminum tube going through the center of the core inside the inner pressure vessel. It is a three-tube device and is MURR’s highest flux irradiating position with a flux capability of 6 x 10^{14} n/(cm^2 sec). The flux trap is loaded and unloaded once a week. Each tube of the flux trap can be loaded with 30 inches of 1.125-inch diameter samples. The samples are welded aluminum cans containing various materials that are approved for irradiation in the flux trap. The bottom position in the flux trap is approximately 17.5 inches below the core centerline.

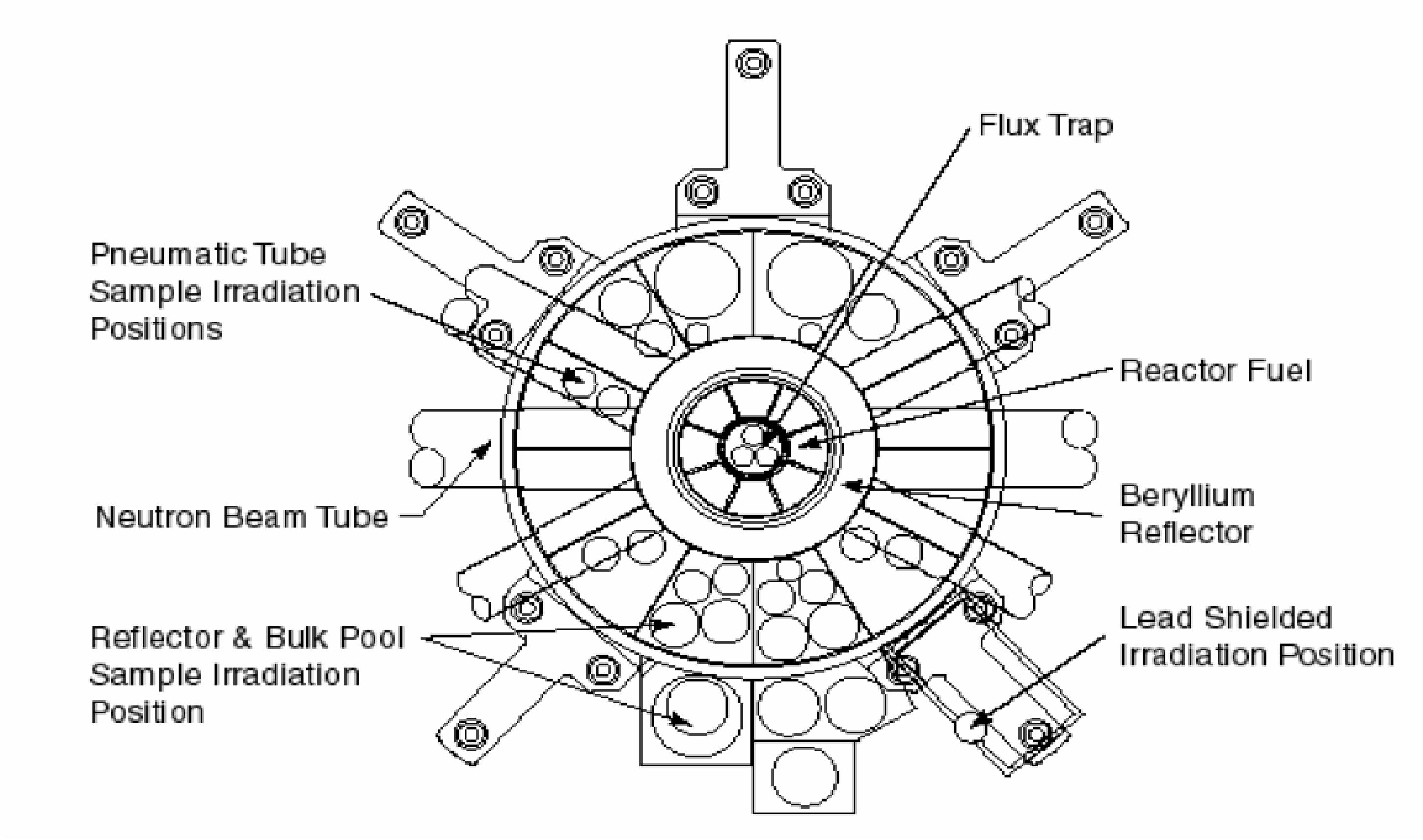


Figure 2-3 Horizontal View of the MURR Irradiation Facilities

2.3 Reactivity Worth of Flux Trap Loading

It is very important for the MURR to be able to accurately predict the loading reactivity worth of the flux trap before it is loaded into the core. From a nuclear safety standpoint, Technical Specification requires that the absolute value of the reactivity worth of all experiments in the center test hole shall not exceed 0.006 δk. Since the aluminum flux trap sample holder alone has a reactivity worth of about 0.004 δk, the absolute worth of all samples in one loading test is limited to less than 0.002 δk. As the various samples of interest for irradiation have different reactivity worths, it is tedious and difficult to figure out a proper loading that meets the reactivity worth limitation, especially when considering the varying reactivity importance of different positions within the core along on the length of the 30-inch length flux trap tubes.

On the other hand, these samples also have different economical value with one isotope product being as much as tens times more profitable than another one. In practice, while most of the samples of interest for irradiation have positive reactivity, a few samples with negative reactivity and much less economical benefit have to be added into the loading to compensate for the positive reactivity samples and be in accordance with the requirement of the Technical Specification.

The MURR is now using a spreadsheet-based method to predict the sample loading worth and assist in the optimization of sample placement before an irradiation is performed. Individual sample worth for those samples that might be loaded and irradiated is measured through the difference in rod worth with and without the sample in the flux trap. A flux importance function is derived for each axial position in the flux trap and reflects the influence of flux spectrum on the samples reactivity effects. Tables 2-1 and 2-2 list the individual sample worth and the flux importance function defined and used in this method, respectively. The effective worth of a sample is calculated by the product of the individual sample worth multiplied by the flux important factor corresponding to its position. The total reactivity worth of the whole flux trap sample loading can then be computed by summing the effective worth of various samples that constitutes the sample loading. An example sheet of such calculations is displayed in Appendix 1.

Table 2-1 List of the MURR Individual Sample Worth

Sample	Reactivity Worth
Al	2.58E-05
Al-4hole	1.90E-05
Cd	-5.37E-05
Cd-5hole	-1.18E-04
Co-60	-9.40E-05
Empty	0.00E+00
Gd	-3.41E-05
H2O	0.00E+00
HgO	7.10E-06
Ir	1.00E-05
Ir-Rts	1.00E-05
KCl-1/3	-1.80E-05
KCl-F	-4.00E-05
Mir	2.00E-05
Moly	-2.27E-05
MUGS	3.23E-05
Os	-1.65E-05
P-33	4.00E-05
P-33 (H2O)	1.00E-05
Pbm-void	3.06E-05
Pbw-void	2.53E-05
Purdue-Dy	1.81E-05
Schup-Os	3.35E-05
Schupp	2.97E-05
Sulfur	1.00E-05
Thulium	-2.56E-05
Tos	-7.80E-05
Ti-Spacer	-3.50E-05

Table 2-2 MURR Flux Trap Flux Importance Function

Position	Importance Factor
29 - 30	0.695002
28 - 29	0.695002
27 - 28	1.257649
26 - 27	1.257649
25 - 26	2.342793
24 - 25	2.342793
23 - 24	3.843365
22 - 23	3.843365
21 - 22	5.713510
20 - 21	5.713510
19 - 20	7.673323
18 - 19	7.673323
17 - 18	9.273694
16 - 17	9.273694
15 - 16	10.024821
14 - 15	10.024821
13 - 14	9.637917
12 - 13	9.637917
11 - 12	8.135472
10 - 11	8.135472
9 - 10	5.855333
8 - 9	5.855333
7 - 8	3.393624
6 - 7	3.393624
5 - 6	1.472149
4 - 5	1.472149
3 - 4	0.458439
2 - 3	0.458439
1 - 2	0.121561
0 - 1	0.121561

This method has been applied to predict sample loading worth in the MURR for a long time. It works adequately as long as the individual sample worth and flux importance function are accurately defined from the experimental data. However, it is not capable of modeling the effect of individual samples on neighboring positions in the flux trap (i.e. the inclusion of a strong absorber on adjacent samples). Table 2-3 shows the reactivity worth results computed with the spreadsheet-based method for several sample loadings performed in the reactor, as well as the corresponding experimental results.

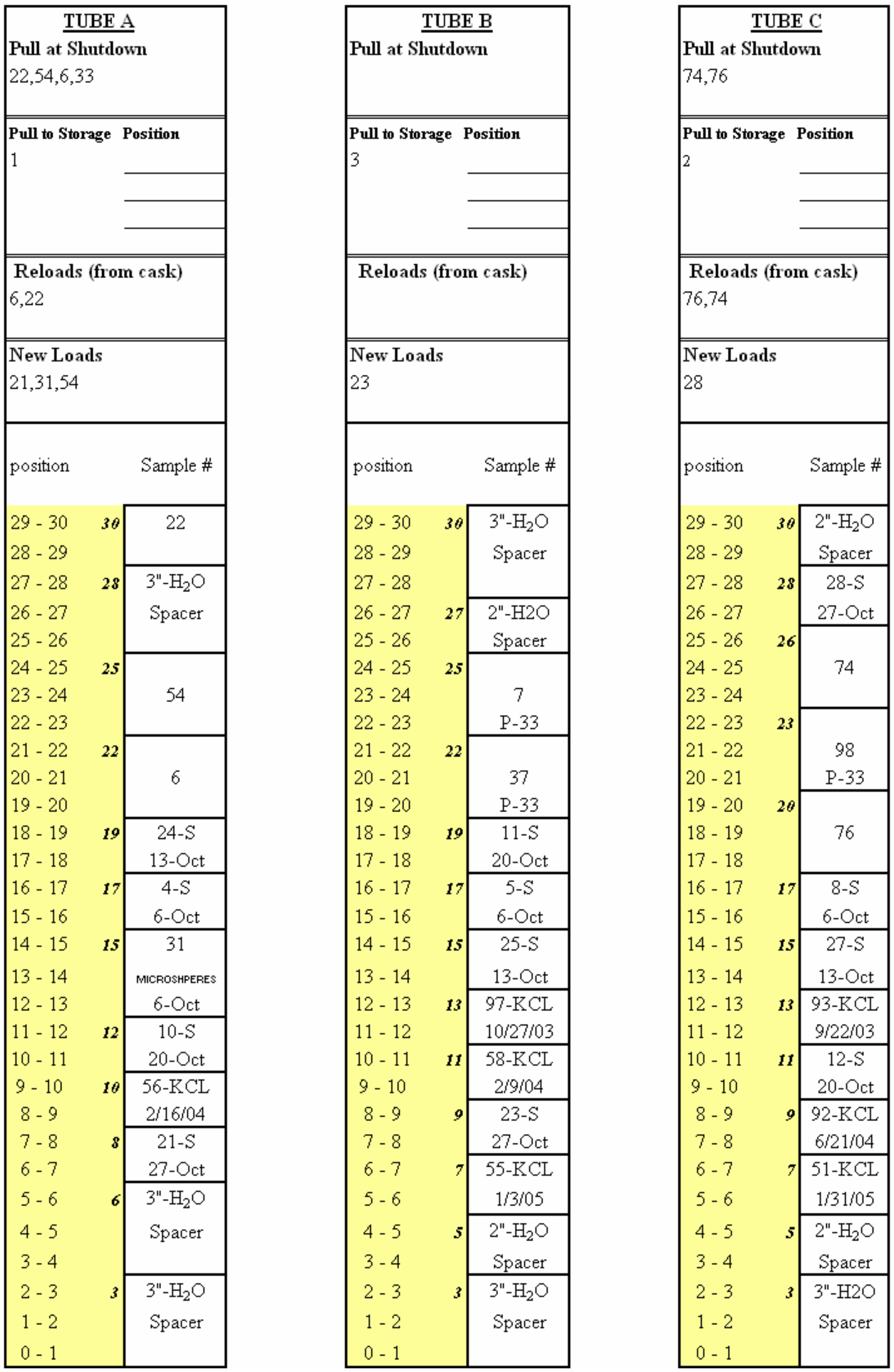
Table 2-3 Flux Trap Loading Worth – MURR Calculation vs. Measurement

Loading	**MURR Worth**		
	Calculation	**Measurement**	Δ
1023	0.004401	0.005300	-17.0%
1024	0.004374	0.005144	-15.0%
1025	0.004499	0.005318	-15.4%

The detailed sample position arrangement for these three loadings are displayed on Tables 2-4 through 2-6.

It can be shown from Table 2-3 that the spreadsheet-based method used by the MURR staff has generally underestimated the loading worth by about fifteen percent.

It would be useful to have an analytic tool that can simulate the MURR flux trap and predict the sample loading worth and isotope production accurately. This need is becoming more and more necessary and would greatly help in the optimal loading of the flux trap on a weekly basis.



TUBE A

Pull at Shutdown
22,54,6,33

Pull to Storage **Position**
1

Reloads (from cask)
6,22

New Loads
21,31,54

position		Sample #
29 - 30	30	22
28 - 29		
27 - 28	28	3"-H_2O Spacer
26 - 27		
25 - 26		
24 - 25	25	54
23 - 24		
22 - 23		
21 - 22	22	6
20 - 21		
19 - 20		
18 - 19	19	24-S 13-Oct
17 - 18		
16 - 17	17	4-S 6-Oct
15 - 16		
14 - 15	15	31 MICROSHPERES 6-Oct
13 - 14		
12 - 13		
11 - 12	12	10-S 20-Oct
10 - 11		
9 - 10	10	56-KCL 2/16/04
8 - 9		
7 - 8	8	21-S 27-Oct
6 - 7		
5 - 6	6	3"-H_2O Spacer
4 - 5		
3 - 4		
2 - 3	3	3"-H_2O Spacer
1 - 2		
0 - 1		

TUBE B

Pull at Shutdown

Pull to Storage **Position**
3

Reloads (from cask)

New Loads
23

position		Sample #
29 - 30	30	3"-H_2O Spacer
28 - 29		
27 - 28		
26 - 27	27	2"-H2O Spacer
25 - 26		
24 - 25	25	7 P-33
23 - 24		
22 - 23		
21 - 22	22	37 P-33
20 - 21		
19 - 20		
18 - 19	19	11-S 20-Oct
17 - 18		
16 - 17	17	5-S 6-Oct
15 - 16		
14 - 15	15	25-S 13-Oct
13 - 14		
12 - 13	13	97-KCL 10/27/03
11 - 12		
10 - 11	11	58-KCL 2/9/04
9 - 10		
8 - 9	9	23-S 27-Oct
7 - 8		
6 - 7	7	55-KCL 1/3/05
5 - 6		
4 - 5	5	2"-H_2O Spacer
3 - 4		
2 - 3	3	3"-H_2O Spacer
1 - 2		
0 - 1		

TUBE C

Pull at Shutdown
74,76

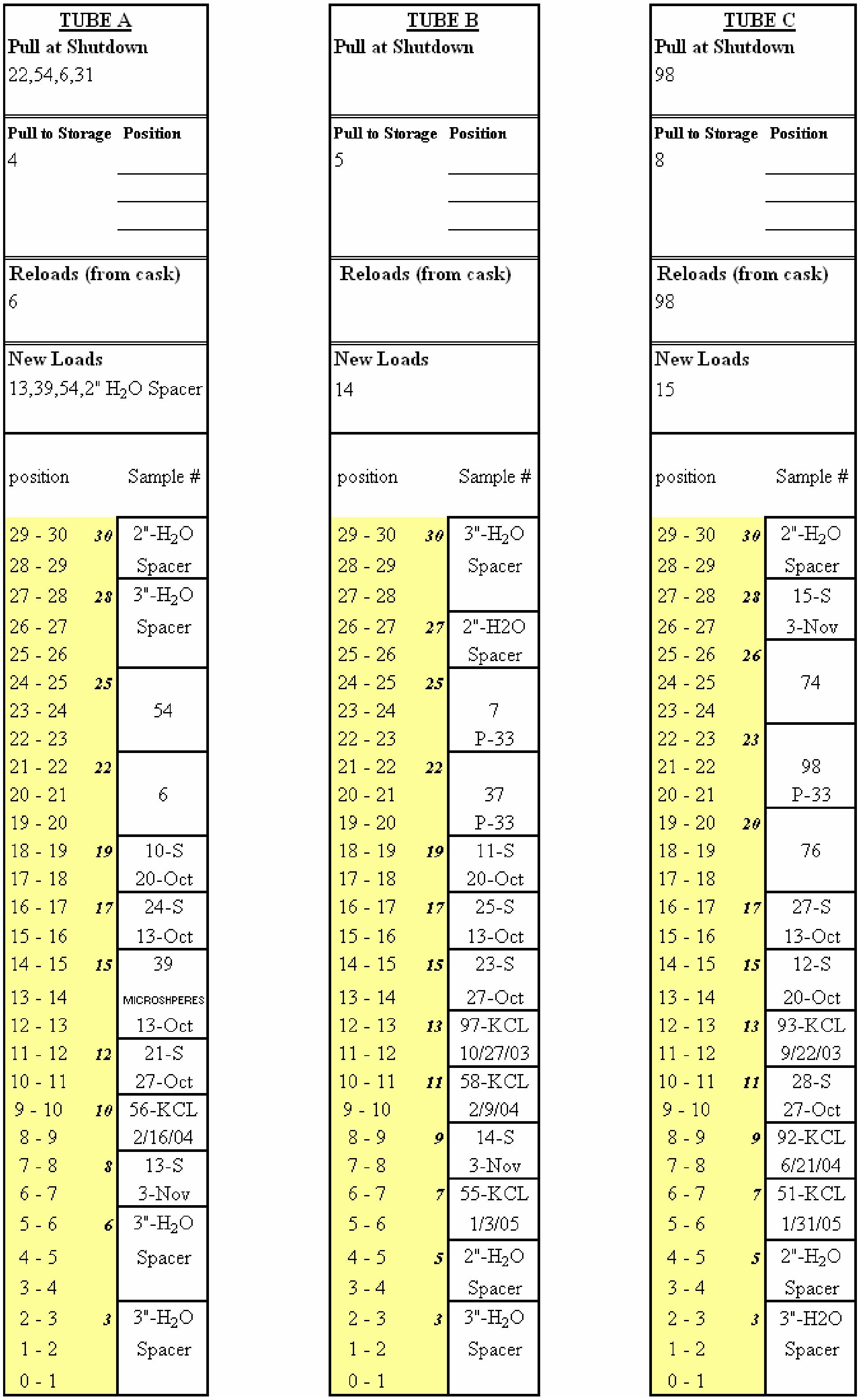
Pull to Storage **Position**
2

Reloads (from cask)
76,74

New Loads
28

position		Sample #
29 - 30	30	2"-H_2O Spacer
28 - 29		
27 - 28	28	28-S 27-Oct
26 - 27		
25 - 26	26	74
24 - 25		
23 - 24		
22 - 23	23	98 P-33
21 - 22		
20 - 21		
19 - 20	20	76
18 - 19		
17 - 18		
16 - 17	17	8-S 6-Oct
15 - 16		
14 - 15	15	27-S 13-Oct
13 - 14		
12 - 13	13	93-KCL 9/22/03
11 - 12		
10 - 11	11	12-S 20-Oct
9 - 10		
8 - 9	9	92-KCL 6/21/04
7 - 8		
6 - 7	7	51-KCL 1/31/05
5 - 6		
4 - 5	5	2"-H_2O Spacer
3 - 4		
2 - 3	3	3"-H2O Spacer
1 - 2		
0 - 1		

Figure 2-4 MURR Flux Trap Loading Sheet #1023



TUBE A

Pull at Shutdown
22,54,6,31

Pull to Storage **Position**
4

Reloads (from cask)
6

New Loads
13,39,54,2" H_2O Spacer

position		Sample #
29 - 30	***30***	2"-H_2O
28 - 29		Spacer
27 - 28	***28***	3"-H_2O
26 - 27		Spacer
25 - 26		
24 - 25	***25***	
23 - 24		54
22 - 23		
21 - 22	***22***	
20 - 21		6
19 - 20		
18 - 19	***19***	10-S
17 - 18		20-Oct
16 - 17	***17***	24-S
15 - 16		13-Oct
14 - 15	***15***	39
13 - 14		MICROSHPERES
12 - 13		13-Oct
11 - 12	***12***	21-S
10 - 11		27-Oct
9 - 10	***10***	56-KCL
8 - 9		2/16/04
7 - 8	***8***	13-S
6 - 7		3-Nov
5 - 6	***6***	3"-H_2O
4 - 5		Spacer
3 - 4		
2 - 3	***3***	3"-H_2O
1 - 2		Spacer
0 - 1		

TUBE B

Pull at Shutdown

Pull to Storage **Position**
5

Reloads (from cask)

New Loads
14

position		Sample #
29 - 30	***30***	3"-H_2O
28 - 29		Spacer
27 - 28		
26 - 27	***27***	2"-H2O
25 - 26		Spacer
24 - 25	***25***	
23 - 24		7
22 - 23		P-33
21 - 22	***22***	
20 - 21		37
19 - 20		P-33
18 - 19	***19***	11-S
17 - 18		20-Oct
16 - 17	***17***	25-S
15 - 16		13-Oct
14 - 15	***15***	23-S
13 - 14		27-Oct
12 - 13	***13***	97-KCL
11 - 12		10/27/03
10 - 11	***11***	58-KCL
9 - 10		2/9/04
8 - 9	***9***	14-S
7 - 8		3-Nov
6 - 7	***7***	55-KCL
5 - 6		1/3/05
4 - 5	***5***	2"-H_2O
3 - 4		Spacer
2 - 3	***3***	3"-H_2O
1 - 2		Spacer
0 - 1		

TUBE C

Pull at Shutdown
98

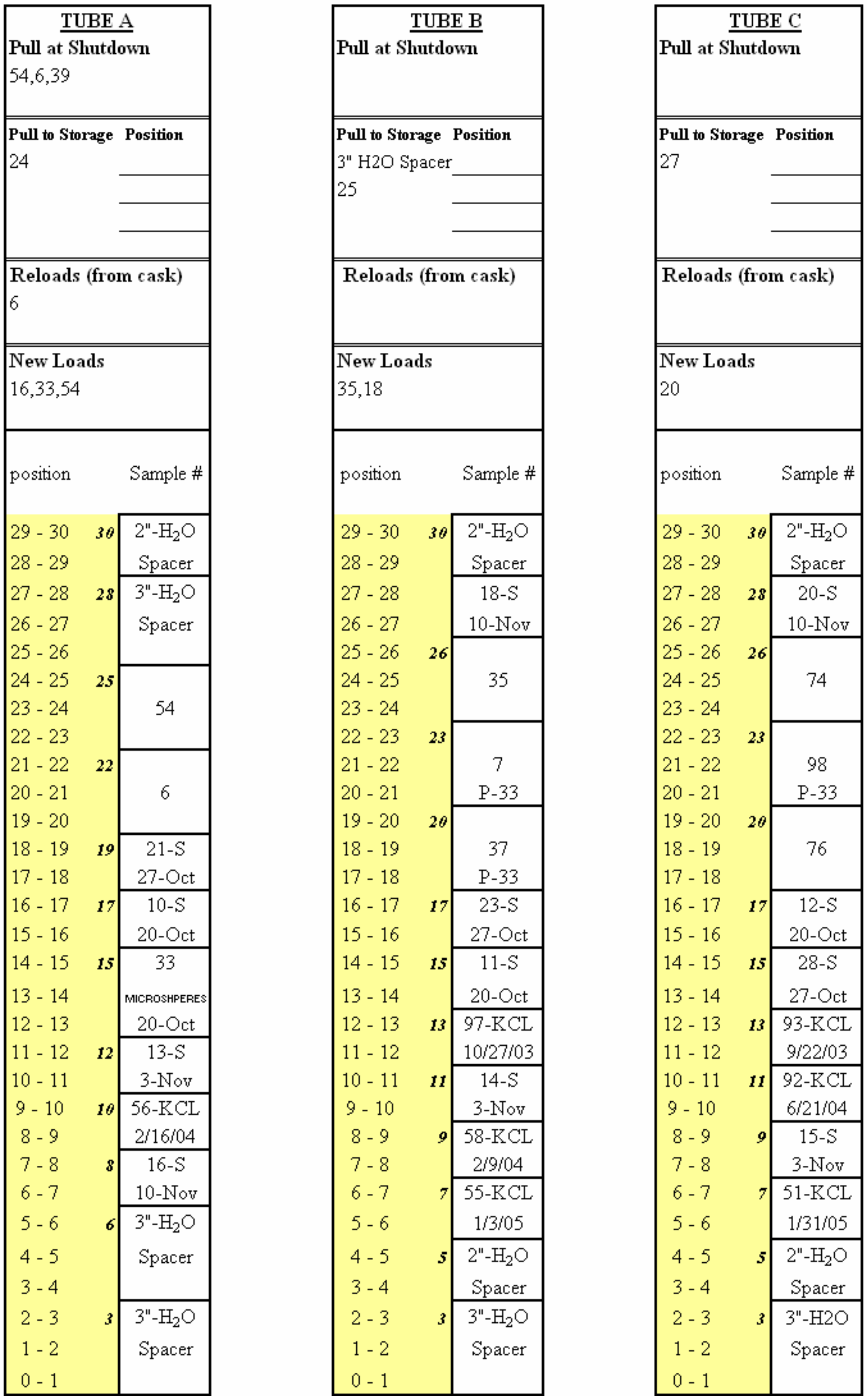
Pull to Storage **Position**
8

Reloads (from cask)
98

New Loads
15

position		Sample #
29 - 30	***30***	2"-H_2O
28 - 29		Spacer
27 - 28	***28***	15-S
26 - 27		3-Nov
25 - 26	***26***	
24 - 25		74
23 - 24		
22 - 23	***23***	
21 - 22		98
20 - 21		P-33
19 - 20	***20***	
18 - 19		76
17 - 18		
16 - 17	***17***	27-S
15 - 16		13-Oct
14 - 15	***15***	12-S
13 - 14		20-Oct
12 - 13	***13***	93-KCL
11 - 12		9/22/03
10 - 11	***11***	28-S
9 - 10		27-Oct
8 - 9	***9***	92-KCL
7 - 8		6/21/04
6 - 7	***7***	51-KCL
5 - 6		1/31/05
4 - 5	***5***	2"-H_2O
3 - 4		Spacer
2 - 3	***3***	3"-H2O
1 - 2		Spacer
0 - 1		

Figure 2-5 MURR Flux Trap Loading Sheet #1024



TUBE A

Pull at Shutdown

54,6,39

Pull to Storage **Position**

24

Reloads (from cask)

6

New Loads

16,33,54

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28	28	3"-H_2O
26 - 27		Spacer
25 - 26		
24 - 25	25	
23 - 24		54
22 - 23		
21 - 22	22	
20 - 21		6
19 - 20		
18 - 19	19	21-S
17 - 18		27-Oct
16 - 17	17	10-S
15 - 16		20-Oct
14 - 15	15	33
13 - 14		MICROSHPERES
12 - 13		20-Oct
11 - 12	12	13-S
10 - 11		3-Nov
9 - 10	10	56-KCL
8 - 9		2/16/04
7 - 8	8	16-S
6 - 7		10-Nov
5 - 6	6	3"-H_2O
4 - 5		Spacer
3 - 4		
2 - 3	3	3"-H_2O
1 - 2		Spacer
0 - 1		

TUBE B

Pull at Shutdown

Pull to Storage **Position**

3" H2O Spacer

25

Reloads (from cask)

New Loads

35,18

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28		18-S
26 - 27		10-Nov
25 - 26	26	
24 - 25		35
23 - 24		
22 - 23	23	
21 - 22		7
20 - 21		P-33
19 - 20	20	
18 - 19		37
17 - 18		P-33
16 - 17	17	23-S
15 - 16		27-Oct
14 - 15	15	11-S
13 - 14		20-Oct
12 - 13	13	97-KCL
11 - 12		10/27/03
10 - 11	11	14-S
9 - 10		3-Nov
8 - 9	9	58-KCL
7 - 8		2/9/04
6 - 7	7	55-KCL
5 - 6		1/3/05
4 - 5	5	2"-H_2O
3 - 4		Spacer
2 - 3	3	3"-H_2O
1 - 2		Spacer
0 - 1		

TUBE C

Pull at Shutdown

Pull to Storage **Position**

27

Reloads (from cask)

New Loads

20

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28	28	20-S
26 - 27		10-Nov
25 - 26	26	
24 - 25		74
23 - 24		
22 - 23	23	
21 - 22		98
20 - 21		P-33
19 - 20	20	
18 - 19		76
17 - 18		
16 - 17	17	12-S
15 - 16		20-Oct
14 - 15	15	28-S
13 - 14		27-Oct
12 - 13	13	93-KCL
11 - 12		9/22/03
10 - 11	11	92-KCL
9 - 10		6/21/04
8 - 9	9	15-S
7 - 8		3-Nov
6 - 7	7	51-KCL
5 - 6		1/31/05
4 - 5	5	2"-H_2O
3 - 4		Spacer
2 - 3	3	3"-H2O
1 - 2		Spacer
0 - 1		

Figure 2-6 MURR Flux Trap Loading Sheet #1025

CHAPTER 3

COMPUTATION METHOD AND COMPUTATION DECK

3.1 Neutron Transport Equation

The neutron transport equation, also called the Boltzmann equation because of its similarity to the expression derived by L. Boltzmann in connection with the kinetic theory of gases, describes the distribution of neutrons in space, energy, and time in a reactor core. When neutrons move and collide with the nuclei of the atoms in a medium, they may be scattered elastically or inelastically, or be absorbed by the nucleus. The absorption may result in a loss of neutrons by such means as radiative capture, or in an increase in the number of neutrons by fission. The rate of change in the number of neutrons is equal to the net difference between the production and the loss of neutrons.

$$\frac{\partial\Phi\left(r,\vec{\Omega},E,t\right)}{\partial t}=\iint\Sigma_t\left(r,E'\right)f\left(r;\vec{\Omega}',E'\rightarrow\vec{\Omega},E\right)\Phi\left(r,\vec{\Omega}',E',t\right)d\vec{\Omega}'dE'$$

$$+S\left(r,\vec{\Omega},E,t\right)-\vec{\Omega}\cdot\nabla\Phi\left(r,\vec{\Omega},E,t\right)-\Sigma_t\left(r,E\right)\Phi\left(r,\vec{\Omega},E,t\right) \qquad (3.1)$$

where

$$\Phi\left(r,\vec{\Omega},E,t\right)\equiv vN\left(r,\vec{\Omega},E,t\right) \qquad (3.2)$$

v ≡ the speed of a neutron with energy *E*

$N\left(r,\vec{\Omega},E,t\right)$ ≡ angular neutron density, the number of neutrons per unit volume at position *r* with energy *E* in dE and moving in the direction $\vec{\Omega}$ in $d\vec{\Omega}$ at time *t*

$\Phi\left(r,\vec{\Omega},E,t\right)$ ≡ neutron angular flux at position *r* with energy *E* in dE and moving in the direction $\vec{\Omega}$ in $d\vec{\Omega}$ at time *t*

$\Phi\left(r,\vec{\Omega}',E',t\right)$ ≡ same as above for neutrons with energy *E'* in dE' moving in the direction $\vec{\Omega}$' in $d\vec{\Omega}'$

$\Sigma_t(r,E)$ ≡ total macroscopic cross section for all interactions of neutrons of energy *E* in dE at position *r*

$\Sigma_t(r,E')$ ≡ same as above for neutrons of energy *E'* in dE'

$f\left(r;\vec{\Omega}',E'\rightarrow\vec{\Omega},E\right)$ ≡ probability that a neutron at *r* with energy *E'* in dE' and direction $\vec{\Omega}'$ in $d\vec{\Omega}'$ will have energy *E* in dE and direction $\vec{\Omega}$ in $d\vec{\Omega}$ after an interaction

$S\left(r,\vec{\Omega},E,t\right)$ ≡ rate of source neutrons appearing at position *r* with energy E in dE and direction $\vec{\Omega}$ in $d\vec{\Omega}$ at time *t*

$\nabla\Phi\left(r,\vec{\Omega},E,t\right)$ ≡ gradient of the angular flux at position *r* with energy *E* in dE and direction $\vec{\Omega}$ in $d\vec{\Omega}$ at time *t*

The first term on the right-hand side of the transport equation represents the rate of gain of specified $\left(\vec{\Omega},E\right)$ neutrons as a result of nuclear interactions of neutrons with all initial energies and directions. The second term on the right-hand side is the gain of neutrons from a source. The third term is the rate of loss of neutrons as a result of leakage. The last term is the rate of loss of neutrons as a result of nuclear interactions of all types. This equation gives a good description of the neutron behavior in a nuclear reactor. It is the most basic in the design of nuclear reactor and fundamental to calculating the conditions for criticality, the spatial distribution of the neutron flux at various energies and other nuclear physics quantities. Yet as an integrodifferential equation, it can only been solved exactly for just a few very simple cases. Various approximation and numerical methods have to be used for practical problems.

3.2 Monte Carlo Method and MCNP

The neutron transport equation (3.1) can be solved exactly in only a few simple cases. For situations of practical interest, it is necessary to use approximations such as the diffusion theory approximation that assumes the neutron source to be isotropic and applies the Fick’s law of diffusion, or to obtain numerical solutions to the transport equation.

The Monte Carlo method is a numerical procedure based on probability theory that can be used to solve neutron transport problems numerically. In the method, the macroscopic cross section is regarded as the probability of a specific interaction per unit distance traveled by a neutron. Compared to deterministic transport methods that solve the transport equation for the average particle behavior, the Monte Carlo method obtains results by simulating individual particles and recording some aspects of their average behavior. The histories of neutrons can be generated by following individual neutrons through successive collisions with the nuclei of the atoms enroute, which might result in scattering, radiative capture, or fission depending on the neutron energy and the composition of the system. The characteristics of the system are then evaluated from the statistical average of many neutron histories. Since the Monte Carlo technique does not use a space mesh, it can be utilized to determine specific characteristics in problems involving complex geometries for which conventional techniques are prohibitively difficult.

The Monte Carlo method is generally attributed to scientists, including Enrico Fermi, Stan Ulam, and John von Neumann, who were working on the development of nuclear weapons in Los Alamos National Laboratory (LANL) during the World War II, although the roots of the method may go back as farther as about two hundred years. The first Los Alamos general-purpose particle transport Monte Carlo code, MCS, was written in 1963. Since 1977 the code has been known as MCNP after more than ten years of development and improvement. The first MCNP version international distributed through the Radiation Safety Information Computational Center (RSICC), MCNP3, was entirely rewritten in ANSI standard Fortran 77 and released in 1983. The latest version of MCNP is version 5 that was released in April 2003. It is rewritten in ANSI standard Fortran 90 and includes parallel computing enhancements and plotter upgrades.

MCNP is well known as the most popular and most often used code for radiation transport calculations. It is a general-purpose Monte Carlo N-Particle code and can be used for neutron, photon, electron, or coupled particles transport calculations with the ability to model system geometry exactly. In this research a MCNP-based model is being developed to simulate neutron behavior in MURR reactor core and flux trap. The MURR core and flux trap will be described in MCNP feature language with the specific geometry and materials information. The model will calculate the reactivity worth of sample loading inserted into the flux trap of the core.

The general flow of MCNP for setting up a model and executing the model is described below:

- Read the input file and get information such as geometry dimensions, source, and materials specification;
- Load and process cross section libraries;
- For one criticality cycle, track and record neutron histories by starting a number of source neutrons and following the particles throughout their life to death in absorption or escape; calculate the surface, cell, and pulse height tallies as required in the model.
- Process the next criticality cycle and output the results after all computations are done.

3.3 Nuclide Depletion Calculations and ORIGEN2

One of the objectives of this research is to predict the activities of specific product isotopes with the irradiation of the corresponding target samples inserted in the flux trap of the MURR core and the decay with time after removal from the reactor. This task can be accomplished by solving the general nuclide depletion equation in which the rate at which the amount of nuclide *i* changes with time is expressed in a nonhomogeneous first-order ordinary differential equation:

$$\frac{dN_i}{dt} = \sum_{j=1}^{M} l_{j\to i}\lambda_j N_j + \sum f_{k\to i}\sigma_k N_k\phi - \lambda_i N_i - \sigma_i N_i\phi - R_i + F_i \tag{3.3}$$

where

Ni ≡ atom density of nuclide *i*

M ≡ number of nuclides

$l_{j\to i}$ ≡ fraction of radioactive disintegration by nuclide *j* that leads to formation of nuclide *i*

λ_i ≡ radioactive decay constant for nuclide *i*

$f_{k\to i}$ ≡ fraction of neutron absorption by nuclide *k* that leads to formation of nuclide *i*

σ_i ≡ neutron absorption cross section of nuclide *i*

ϕ ≡ neutron flux

R_i ≡ continuous removal rate of nuclide *i* from the system

F_i ≡ continuous feed rate of nuclide *i* from outside

ORIGEN is one of the most widely used computer codes developed to solve the above equation and calculate the buildup, decay, and processing of radioactive materials. It was developed at the Oak Ridge National Laboratory (ORNL) and distributed worldwide in the early 1970s. ORIGEN2 is a revised version of ORIGEN with extensively updating of the decay data, reactor models, cross sections, fission product yields, and photon emission data, as well as the source code itself. The latest and last version of ORIGEN is version 2.2 which was distributed in June 2002 with new libraries for standard and extended-burnup PWR and BWR calculation. ORNL has no plan to further develop ORIGEN2 and suggests a transferring to ORIGEN-ARP which includes a Graphic User Interface (GUI) and a graphics program.

In this research, ORIGEN2 uses one-group cross-section and flux values from MCNP, performs burnup calculations, and supplies the new radionuclide compositions back to MCNP for next calculation step.

3.4 MonteBurns

As discussed in the previous sections, the objective of this research is to calculate the flux trap sample loading reactivity worth and predict isotope production in the flux trap of MURR core. The MCNP code is used to solve the neutron transport equation and get the reactivity for specific system configurations while the ORIGEN2 code is used to calculate material activation and depletion in the system. Since the flux values and one-group cross sections required for ORIGEN2 shall be obtained from MCNP program while the resulting material compositions after burnup from ORIGEN2 need to be fed back to MCNP, a coupling program that links and transmits data between MCNP and ORIGEN2 is necessary for the work. MonteBurns is one such program that can be used to calculate coupled neutronic/isotopic results for nuclear systems.

MonteBurns was developed by Los Alamos National Laboratory in 1999. It is a fully automated Monte Carlo burnup tool that links the Monte Carlo transport code MCNP with the radioactive decay and burnup code ORIGEN2. The first step of running of the program is for the user to develop a MCNP input file that specifies the problem geometry and the initial material compositions, and a MonteBurns input file that describe the material feed and removal specifications and other necessary parameters. The program processes the initial input information, executes MCNP and interacts with ORIGEN2 while manipulating their input and output and transferring the specific intermediate data between the two codes, performs various calculations and outputs the final results.

MonteBurns transfers one-group cross section and flux values from MCNP to ORIGEN2, and then transfers the resulting material compositions from ORIGEN2 back to MCNP in a repeated, cyclic fashion. The MonteBurns version 2.0 package is the latest version of MonteBurns and can run with MCNP4C, MNCP5, or MCNPX.

Besides the principle function of transferring relevant data forth and back between MCNP and ORIGEN2 codes, MONTEBURN also performs a number of calculations as needed. The calculations include the energy per fission, flux normalization, average number of neutrons produced per fission, effective multiplication factor for an “sdef” source definition, power produced by each material, activity of isotopes, and fractional importance of isotopes. Among them, the calculations of the flux tally normalization and activity of isotopes are relevant to this research and will be introduced below.

Since the flux value tallied by MCNP, Φ_m, is normalized per source neutron, the result should be normalized to the system power to get the real flux value, Φ, with a normalization factor, *nf*:

$$\phi = \phi_m * nf \tag{3.4}$$

The normalization factor can be determined with the following equation:

$$nf = \frac{\nu * P * (1\times10^{6} W/MW)}{\left(1.602\times10^{-13} J/MeV\right) * k_{eff} * Q_{ave}} \tag{3.5}$$

where

ν ≡ average number of neutrons produced per fission

P ≡ power for the material, *MW*

k_{eff} ≡ effective multiplication factor obtained from MCNP

Q_{ave} ≡ average recoverable energy per fission for all materials

Another important calculation performed by MonteBurns is of the activity of isotopes in each material as a function of burnup, which can be obtained by solving the following equations:

$$Act_i = m_i * SA_i \tag{3.6}$$

and

$$SA = \frac{\ln 2 * N_a}{A * t_{1/2} / \left(3.7 \times 10^{10}\, Bq / Ci\right)} \tag{3.7}$$

where

Act_i ≡ activity for isotope *i*, *Ci*

m_i ≡ mass of nuclide *i*, *g/mol*

SA_i ≡ specific activity for isotope *i*, *Ci/g*

A ≡ atomic weight of nuclide, *g*

$t_{1/2}$ ≡ half-life of nuclide, *s*

N_a ≡ Avogadro's number ≡ 6.022×10^{23} atoms/mol

3.5 Computation Deck

The computation deck for the MURR Flux Trap Model includes the nuclear codes described above as well as one common computer script language, Perl. All the three nuclear codes were requested from the Radiation Safety Information Computational Center (RSICC) with versions MCNP 5, ORIGEN 2.2, and MonteBurns 2.0. The Perl language, an acronym for Practical Extraction and Report Language which is an interpreted language optimized for string manipulation, can be downloaded free from the website. It combines the familiar syntax of C, C++, grep, sh, and csh into a tool that is more powerful. The Perl language needs to be installed to run the script file in the MonteBurns package that executes MCNP, ORIGEN2, and the FORTRAN77 program.

After the nuclear packages and Perl program were installed on a Pentium 4 PC, Windows XP system, the test cases or sample problems provided with the packages were run to verify that the executables has been installed and operated correctly on the specific operating system and hardware. The results from these tests were compared with those come with the corresponding programs. Following these tests, the MonteBurns-MCNP-ORIGEN2 computational deck is ready for the development of a specific MURR flux trap model to predict flux trap loading reactivity worth and isotope production.

CHAPTER 4

MFTM PART I – MCNP MODEL

4.1 MCNP Model

The MCNP model part of the proposed MURR Flux Trap Model (MFTM) was developed during 2003-2004. The MCNP model is a simplified descriptor of the MURR core combined with a detailed simulation of the flux trap. The MCNP input file R1023 used in the model simulates the sample loading for sheet #1023 (see Table 2-4) and is provided in Appendix 2. The input file has three major sections: cell cards, surface cards, and data cards. A one-line problem title card is the first card in the input file and contains information about the problem being modeled. Blank line delimiter is used to denote separation between the three different sections.

-- Cell cards:

Cell cards are used to define various cells that simulate the shape and material content of physical space. The first fifteen cell cards of the MCNP input file R1023 simulate the regions of flux trap, core, end plate, control rod, beryllium and graphite reflector, and the water gap among and around the regions of the MURR physical reactor in a simplified version. The next ninety-three cards define three aluminum flux trap tubes and thirty one-inch samples for each tube that constitute the flux trap. The last card represents the outside world of the reactor with void and a neutron importance of zero.

-- Surface cards:

Surface cards are used to specify the bounding surfaces that form the cells in the model. The surface cards in the input file R1023 include: (1) cylinders on Z-axis that define the bounding surfaces of flux trap, core, control rod, beryllium and graphite reflectors, and outer boundary of the model; (2) cylinders parallel to Z-axis that define the bounding surfaces of three tubes of the flux trap; (3) vertical plane (normal to Z-axis) that defines the bottom position of control rod, two-end of water gap and fuel end plate, and thirty one-inch sample holder.

-- Data cards:

The remaining information needed for the MCNP model are specified and input in the data cards section. These include the source specification, material specification, tally specification, problem cutoffs, and other necessary parameters. The data cards in the input file R1023 contain following cards:

- neutron importance card (IMP:N)
- F4 flux tally cards (F4:N) and tally energy card (E0)
- energy card (PHYS:N)

- material specification cards (Mn) that specify the composition of the various core component and different samples loaded in sheet #1023 such as KCl, P-32, P-33, the 2-hole host can, and the 4-hole host can. These cards are correspondent with the material numbers that are given in the cell cards.

- the KCODE criticality source card that specifies 8000 neutrons per cycle, an initial guess for keff of 1.20, and 4000 active run cycles,

- and the KSRC card to specify the location of initial source point.

Figures 4-1 and 4-2 show the graphic output of horizontal and vertical views of the MURR core and flux trap from the MCNP model, respectively.

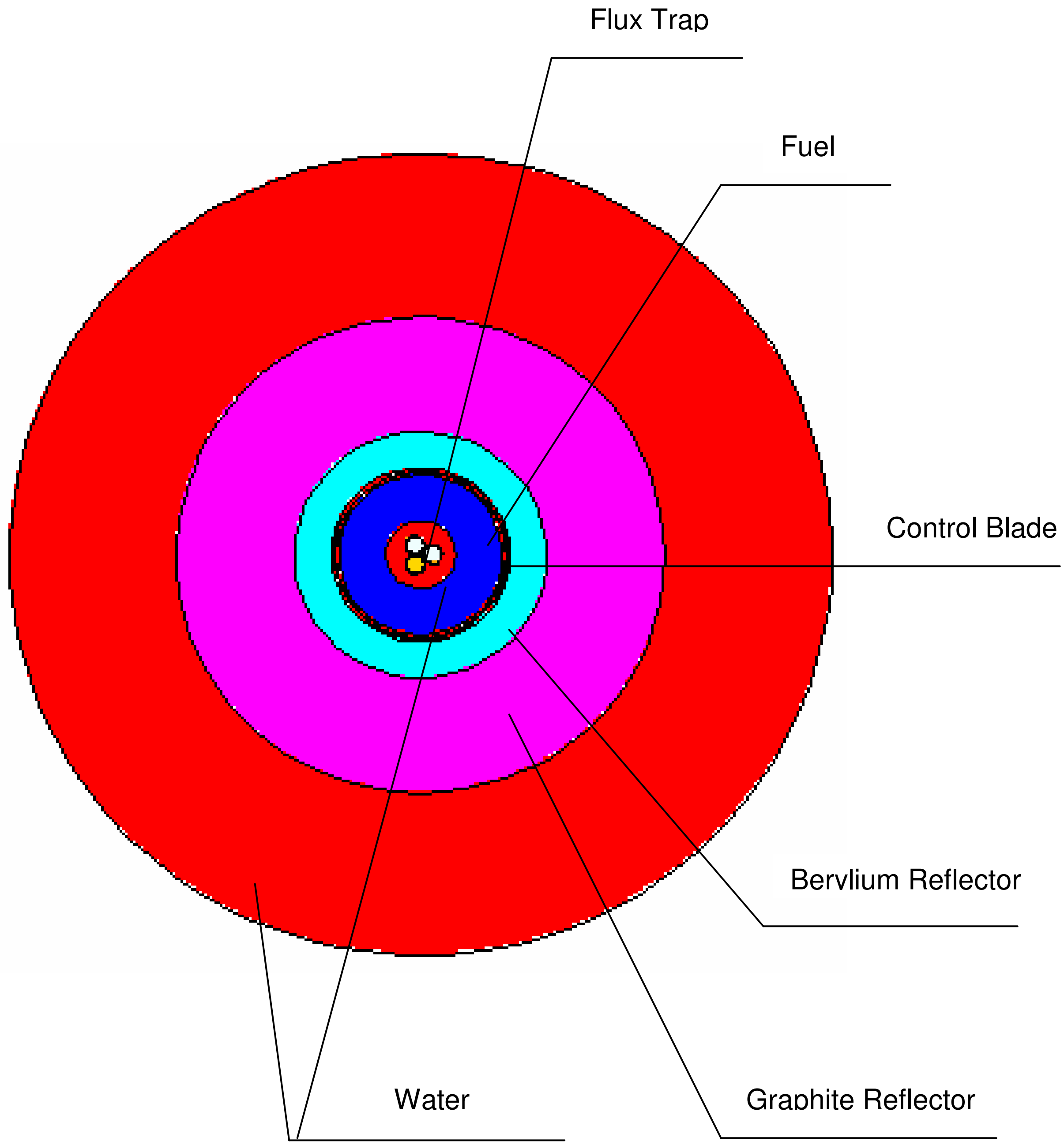


Figure 4-1 Horizontal View of the MURR Flux Trap MCNP Model

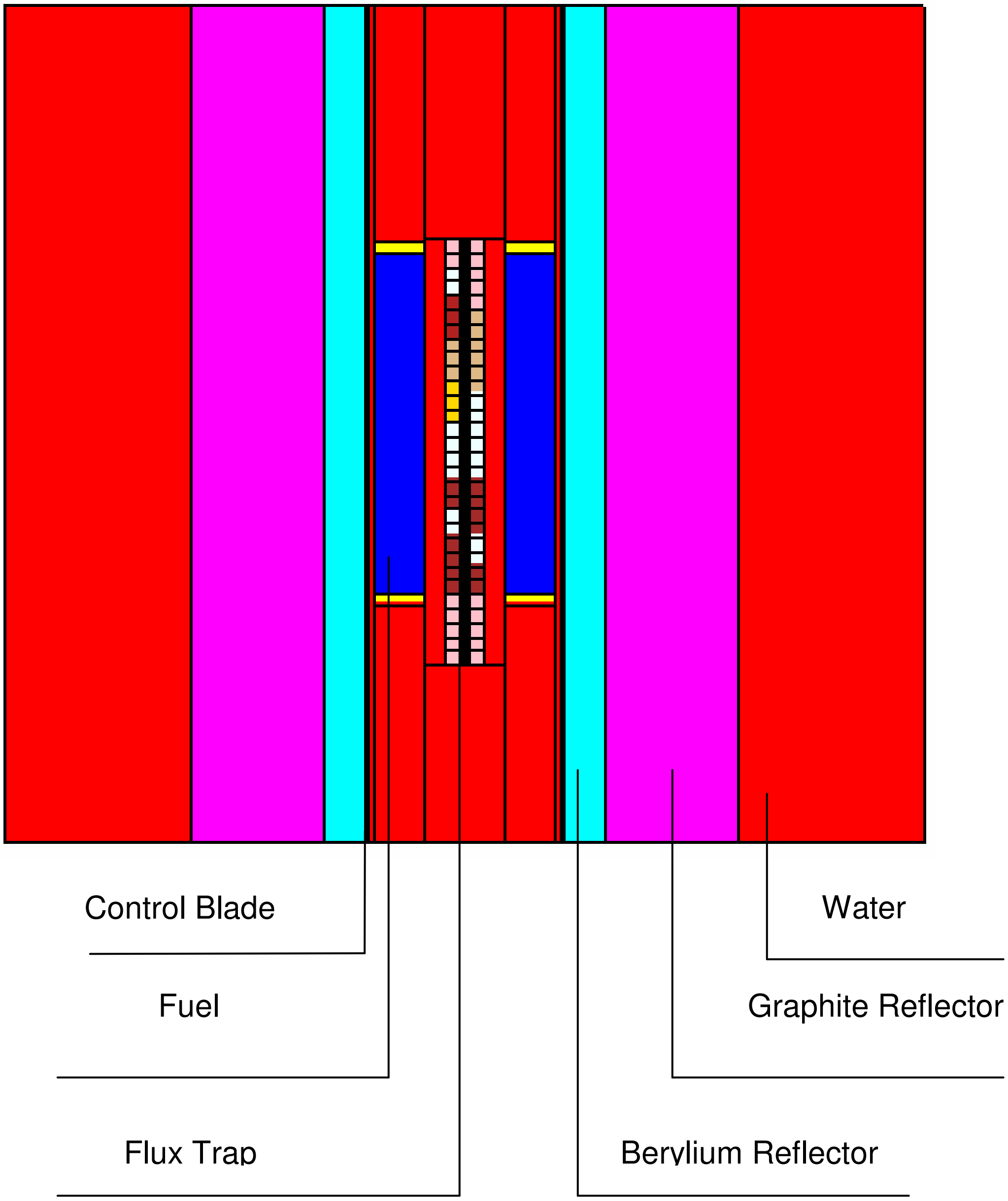


Figure 4-2 Vertical View of the MURR Flux Trap MCNP Model

4.2 Verification of MCNP Model

The developed MCNP Model introduced in the last section has been run for different MURR flux trap loadings. The reactivity worth predicted by the model were compared to the corresponding experimentally measured values. The MCNP input file for a different sample loading is similar with the one for loading *#1023* described above. The main difference is the ninety-three cell cards from card *16* to card *108* that define the three flux trap tubes (FT holder) and the specific samples filled in the tubes for the loading. For example, the MCNP input file for loading sheet *#1024* (see Table 2-5) is provided in Appendix 3 in which the difference between the two inputs are highlighted.

To predict the reactivity worth of sample loading, the MCNP model for the loading is run first to calculate k_{eff} for the loading. A MCNP Base Model is created then by changing the various material of the entire samples cell into water. The Base Model is run and gives the k_{eff} for the base case. The reactivity worth of the sample loading is thus calculated by the difference between the two k_{eff}:

$$\rho_{loading} = k_{eff,loading} - k_{eff,base} \tag{4.1}$$

Table 4-1 displays the predicted reactivity worth for different loadings from the MCNP Model, as well as the comparison with the MURR measured results and spreadsheet calculation results. The table shows that the MCNP model gives good results for some loadings compared with the experimental values. The measured worth for loading *FTLdg1* and *FT Holder Only* are 0.0045 and 0.0036, respectively. The corresponding predicted values by the model are 0.00435 and 0.00389. But the reactivity of the latest three loadings (sheet *#1023*, *#1024*, *#1025*) from MCNP gave negative values of about -0.002 while the experimental values from MURR are positive ones with about 0.005. Thus, the initially developed MCNP model needs to be investigated and refined for better simulation.

Table 4-1 Predictions and Comparison of Loading Worth

Loading	**MURR Worth**		**MCNP Worth**		
	Spreadsheet Calculated	**Measured**	**Loading k_{eff}**	**Base k_{eff}**	**Worth**
1023	0.004401	0.005300	0.98976	0.99142	-0.00166
1024	0.004374	0.005144	0.98971	0.99142	-0.00171
1025	0.004499	0.005318	0.98987	0.99142	-0.00155
FTLdg1		0.004500	0.9964	0.99205	0.00435
FT Holder Only		0.003600	0.99531	0.99142	0.00389

4.3 Refinement of MCNP Model

The preliminary comparisons between the MCNP model and experimental values shows that although the model worked well for some loadings, it gave erroneous results for others. In general, the accuracy of a MCNP model results may be affected by the following: (1) factors related to the modeling of the problem, such as the description of the problem geometry, the physical characteristics of the material in the problem, and the modeling of the radiation source, (2) factors related to the user, such as the possible input errors, misusing of variance reduction techniques, and misunderstanding of the relationship of MCNP tallies to the measured quantities being calculated, (3) factors related to the MCNP code itself, such as the uncertainties in the transport and reaction cross sections data the code used, the quality of the representation of the differential cross sections in energy and angle comparing with the specific physical system. A series of actions have been conducted, varying from file input checking, geometry defining and material specification, to the investigations introduced in the following sub-sections.

4.3.1 Simplified vs. Detailed MCNP Model

As described in section 4.1, the developed MCNP Model is a simplified simulation of the MURR core combined with detailed simulation of the flux trap. One of the concerns is whether or not the model is oversimplified to accurately predict the neutron behaviour in the core. Another MCNP model developed previously by MURR staff to simulate the core in detail was tested to calculate the reactivity worth of sample loadings. The detailed MCNP model has been verified against MURR core before and proven to be effective. To be used in this research, the detailed model was revised to replace the three flux trap irradiation tubes cell cards by ninety inch-by-inch samples cell cards and the corresponding geometry cards. The MCNP input for loading #1023 in detailed model is attached in Appendix 4.

Table 4-2 shows the result of the detailed MCNP model for the loading 1023, as well as the former running result by the simplified model and the measured value. The data shows that the detailed model gave an even more negative loading worth, -0.0049, than the simplified model did. The more detailed simulation of the physical core did not help in predicting experimentally measured results.

Table 4-2 Comparison of Simplified MCNP Model and Detailed Model

Loading	**Detailed Model**			**Simplified Model**			**MURR Worth**
	Loading k_{eff}	**Base k_{eff}**	**Worth**	**Loading k_{eff}**	**Base k_{eff}**	**Worth**	**Measured**
1023	1.04770	1.05262	-0.00492	0.98976	0.99142	-0.00166	0.005300

4.3.2 Flux Spectrum Comparison

The next investigation focused on the accuracy of the flux spectrum computed by the model. Two kinds of reference flux data are available for comparison. One is the MURR Flux Importance Function of the flux trap in Table 2-1. Another one is the radial flux distribution data measured by the MURR, which is shown in Figure 4-1. The flux is divided into four energy regions in the radial flux distribution figure: (1) Flux 1, 0.821-10.0 MeV region; (2) Flux 2, 5.53-821 KeV; (3) Flux 3, 0.625-5530 eV; and (4) Flux 4, thermal region.

The F4 type tally card in MCNP can be used to calculate needed fluxes averaged over a cell while the E0 tally energy card be used to set up the energy bin structure for all tallies. Figure 4-2 displays the flux profile over the thirty-inch long flux trap tube calculated by the developed MCNP model, as well as the profile deduced from the MURR Flux Importance Function of the flux trap listed in Table 2-1. It can be seen from the figure that the axial flux curve predicted by the

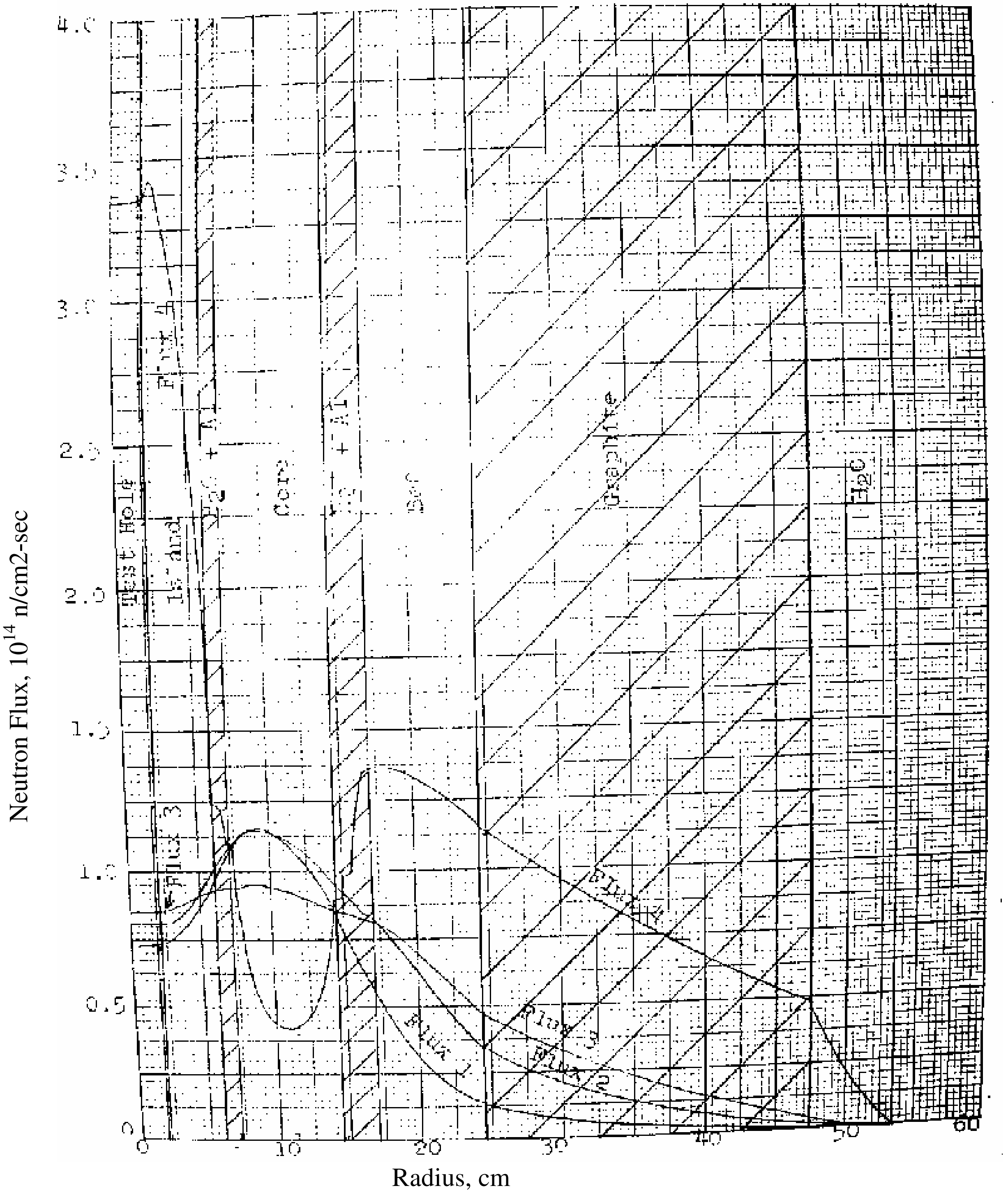


Figure 4-3 MURR Core Radial Flux Distribution –Na in Test Hole; Rods Out; Case W-6; 10 MW

MCNP model is similar with that of MURR used in the spreadsheet method, although the lower part of the flux trap is somewhat over-weighted in the model and so may yield larger flux weighting factor for those samples located in these positions. This axial offset is believed to be affected by the deeper control rod position in the MCNP model computed to the rod position assumed for the MURR spreadsheet method.

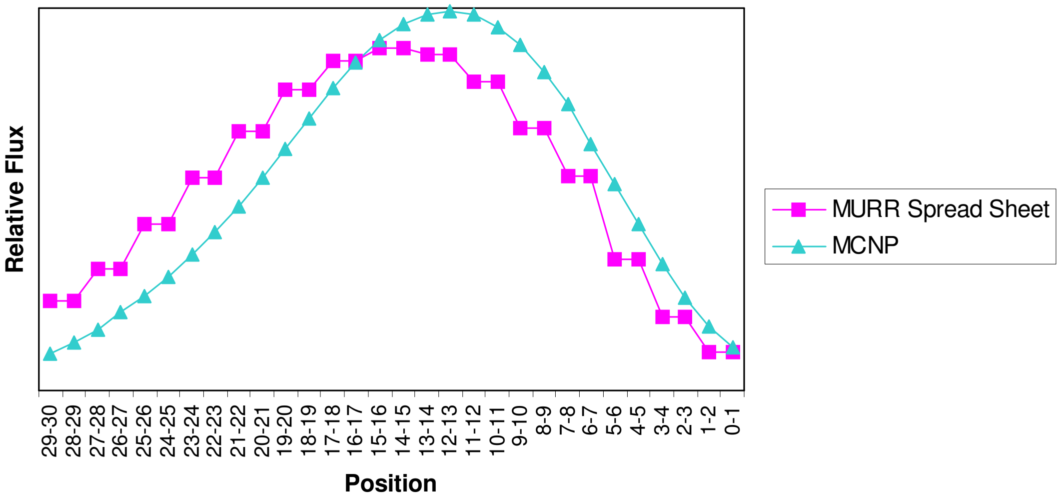


Figure 4-4 Comparison of Flux Profile Over Flux Trap Tube

Next a comparison was carried out for radial flux distribution by running a detailed model since accurate prediction of the radial distribution requires a more complicated model in the MURR core. After analyzing the detailed MCNP model, four radial points in the Figure 4-1 were chosen for comparison with radii of 2.22 cm, 9.1 cm, 11.062 cm, and 14.694 cm. These positions correspondent to the center tube cell inside flux trap tube C, the inner fuel plate cell (plate 1), the middle fuel plate (plate 13), and the outer fuel plate (plate 24), respectively. The tally energy card in the MCNP input file was modified to reflect the same four energy regions as those in Figure 4-1.

The tallied flux results from MCNP are listed in Table 4-3 after being normalized. They are compared with the corresponding data read form Figure 4-1. It is shown that in the region of flux trap tube (2.22 cm radius), the total flux calculated from MCNP is very close to that from MURR data with about a 2% difference, while the low energy flux from MCNP tends to be over-predicted by about 6% and high energy flux under-predicted by 5% to 16%. The MCNP-calculated flux over the fuel region is approximately 10% larger than the total flux assumed from previous MURR models.

The results from the above two comparisons show that the MCNP-predicted flux spectrum is similar with the MURR reference data. The differences between them are acceptable and may not be significant enough to cause the deviation of loading worth prediction. Other factors need to be studied to refine the model.

Table 4-3 Comparison of Radial Flux Over Different Energy Regions

Energy Range	**2.22cm tube**			**7.1cm inner fuel plate**			**11.062cm middle fuel plate**			**14.694cm outer fuel plate**		
	MURR	MCNP	%	MURR	MCNP	%	MURR	MCNP	%	MURR	MCNP	%
Thermal	3.35E+14	3.58E+14	6.98	1.10E+14	9.56E+13	-13.09	4.25E+13	4.25E+13	0.00	9.00E+13	6.71E+13	-25.42
0.625 to 5530.0 ev	8.50E+13	9.03E+13	6.23	9.38E+13	1.01E+14	8.17	9.25E+13	1.01E+14	8.75	8.50E+13	8.68E+13	2.07
5.53 to 821 Kev	8.05E+13	7.61E+13	-5.42	1.10E+14	1.30E+14	18.52	1.11E+14	1.30E+14	16.97	9.35E+13	1.04E+14	10.73
0.821 to 10.0 Mev	7.38E+13	6.13E+13	-16.94	1.10E+14	1.38E+14	25.26	1.10E+14	1.29E+14	18.09	8.00E+13	1.01E+14	26.58
Total	5.74E+14	5.86E+14	2.06	4.24E+14	4.65E+14	9.78	3.56E+14	4.03E+14	13.15	3.49E+14	3.59E+14	2.92

4.3.3 Individual Sample Worth

One possible reason for the model to accurately predict the reactivity worth for some loadings and be in error for others is that some of the samples with large cross section may be biasing the results. When these samples are located at positions with small flux weight, they have small contribution to the whole loading and the model thus gives results close to the experimental values. On the other hand, when they are put in positions with a large flux weight, the whole loading worth will deviate greatly from the real value because of their significant contribution. To study this hypothesis and to determine the effect of sample positioning, a number of tests were performed to get the reactivity worth of individual samples.

There are two different approaches to calculate the worth of individual sample. One is a “sample-inserting” approach which is similar to the approach used to decide the loading worth described in section 4.2. The worth of individual sample is decided by the difference of effective multiplication factor of loading with the single sample and that of base loading (i.e., the sample in the loading is replaced by water):

$$\rho_{sample} = k_{eff,sample} - k_{eff,base} \tag{4.2}$$

in which,

ρ_{sample} Ξ worth of the individual sample

$k_{eff,\ sample}$ Ξ effective multiplication factor for sample loading with only the specified individual sample replacing water

$k_{eff,\ base}$ Ξ effective multiplication factor for base case with the whole flux trap filled with water

Another approach is the sample-removing approach which considers the combining effects of the whole loading. The worth of individual sample is divided by the difference of effective multiplication factor of the whole loading and that of the loading in which the specific single sample is replaced by water:

$$\rho_{sample} = k_{eff,loading} - k_{eff,WaterForSample} \tag{4.3}$$

in which,

$k_{eff,\ loading}$ Ξ effective multiplication factor for the whole loading

$k_{eff,\ WaterForSample}$ Ξ effective multiplication factor for base loading with only the specified individual sample replaced with water

The individual sample worth results calculated by the MCNP model with the two different approaches are listed in Table 4-4 and 4-5, respectively. The corresponding values from MURR spreadsheet method are also listed in the tables. The results from the second approach were reviewed further.

In order to find out which samples are the most significant, the individual sample worth both from the MURR spreadsheet and the second MCNP approach discussed above were plotted in Figure 4-3 according to the sample category.

The MCNP model predicted the worth of the host sample accurately, while over-predicting the positive worth of sulphur and P-33 samples and the negative worth of KCl sample. Since the amount of intrinsic negative worth (from the MURR spreadsheet) of KCl sample is several times of that of positive worth of sulphur and P-33 samples, the predicted worth of whole loading by MCNP model is affected significantly by KCl samples.

To further compare the different prediction results of the model for loadings 1023 to 1025 (in which predicted results are in greatest error) and loading FTLdg1 (in which the results are in good agreement with experimental measurements), the sample position configuration of loading FTLdg1, which is shown in Table 4-6, was compared with the position configurations of loading 1023, 1024, and 1025, which are shown in Table 2-4, Table 2-5, and Table 2-6, respectively. It was found that one of the significant differences among the sample configuration of the loadings is the positions in which KCl samples are located. While KCl samples were located in the most upper part of the flux trap which has small flux weight in loading FTLdg1, they were located in the middle or lower part of the flux trap in all other three loadings that gave out bad prediction results. It is apparent that KCl sample worth as predicted by MCNP is significantly larger than predicted by the MURR spreadsheet method. When they were put in relatively significant flux positions in loadings 1023, 1024, and 1025, they have large contributions, and the whole loading worth became negative, although the real loading worth was positive. When they were put in flux non-significant positions in loading FTLdg1 or were not contained in the loading when computing worth of flux trap holder, the whole loading worth was affected less and the prediction agreed with previous results.

Table 4-4 Individual Samples Worth – Approach I

MCNP vs. MURR

Position	**Worth Factor**	**Tube A**		**Tube B**		**Tube C**	
		MURR	**MCNP**	**MURR**	**MCNP**	**MURR**	**MCNP**
29 - 30	0.695002	0.000013	0.000115	0.000000	0.000142	0.000000	0.000230
28 - 29	0.695002	0.000013	0.000115	0.000000	0.000142	0.000000	0.000230
27 - 28	1.257649	0.000000	0.000166	0.000000	0.000257	0.000013	0.000155
26 - 27	1.257649	0.000000	0.000166	0.000000	0.000154	0.000013	0.000155
25 - 26	2.342793	0.000000	0.000309	0.000000	0.000286	0.000045	0.000170
24 - 25	2.342793	0.000045	0.000196	0.000023	0.000206	0.000045	0.000170
23 - 24	3.843365	0.000073	0.000322	0.000038	0.000337	0.000073	0.000279
22 - 23	3.843365	0.000073	0.000322	0.000038	0.000337	0.000038	0.000184
21 - 22	5.713510	0.000109	0.000242	0.000057	0.000162	0.000057	0.000273
20 - 21	5.713510	0.000109	0.000242	0.000057	0.000162	0.000057	0.000273
19 - 20	7.673323	0.000146	0.000325	0.000077	0.000217	0.000146	0.000280
18 - 19	7.673323	0.000077	0.000263	0.000077	0.000217	0.000146	0.000280
17 - 18	9.273694	0.000093	0.000317	0.000093	0.000263	0.000176	0.000339
16 - 17	9.273694	0.000093	0.000457	0.000093	0.000303	0.000093	0.000442
15 - 16	10.024821	0.000100	0.000493	0.000100	0.000327	0.000100	0.000478
14 - 15	10.024821	0.000190	0.000407	0.000100	0.000367	0.000100	0.000546
13 - 14	9.637917	0.000183	0.000391	0.000096	0.000353	0.000096	0.000524
12 - 13	9.637917	0.000183	0.000391	-0.000386	-0.001215	-0.000386	-0.001193
11 - 12	8.135472	0.000081	0.000415	-0.000325	-0.001025	-0.000325	-0.001007
10 - 11	8.135472	0.000081	0.000415	-0.000325	-0.001082	0.000081	0.000099
9 - 10	5.855333	-0.000234	-0.000705	-0.000234	-0.000778	0.000059	0.000071
8 - 9	5.855333	-0.000234	-0.000705	0.000059	0.000266	-0.000234	-0.000779
7 - 8	3.393624	0.000034	0.000275	0.000034	0.000154	-0.000136	-0.000451
6 - 7	3.393624	0.000034	0.000275	-0.000136	-0.000572	-0.000136	-0.000565
5 - 6	1.472149	0.000000	0.000208	-0.000059	-0.000248	-0.000059	-0.000245
4 - 5	1.472149	0.000000	0.000208	0.000000	0.000450	0.000000	0.000229
3 - 4	0.458439	0.000000	0.000065	0.000000	0.000140	0.000000	0.000071
2 - 3	0.458439	0.000000	0.000261	0.000000	0.000163	0.000000	0.000294
1 - 2	0.121561	0.000000	0.000069	0.000000	0.000043	0.000000	0.000078
0 - 1	0.121561	0.000000	0.000069	0.000000	0.000043	0.000000	0.000078

Table 4-5 Individual Samples Worth – Approach II

MCNP vs. MURR

Position	**Worth Factor**	**Tube A**		**Tube B**		**Tube C**	
		MURR	**MCNP**	**MURR**	**MCNP**	**MURR**	**MCNP**
29 - 30	0.695002	0.000013	0.000090	0.000000	0.000000	0.000000	0.000000
28 - 29	0.695002	0.000013	0.000090	0.000000	0.000000	0.000000	0.000000
27 - 28	1.257649	0.000000	0.000000	0.000000	0.000000	0.000013	0.000305
26 - 27	1.257649	0.000000	0.000000	0.000000	0.000000	0.000013	0.000305
25 - 26	2.342793	0.000000	0.000000	0.000000	0.000000	0.000045	0.000052
24 - 25	2.342793	0.000045	0.000110	0.000023	0.000033	0.000045	0.000052
23 - 24	3.843365	0.000073	0.000180	0.000038	0.000054	0.000073	0.000086
22 - 23	3.843365	0.000073	0.000180	0.000038	0.000054	0.000038	0.000123
21 - 22	5.713510	0.000109	0.000117	0.000057	0.000203	0.000057	0.000183
20 - 21	5.713510	0.000109	0.000117	0.000057	0.000203	0.000057	0.000183
19 - 20	7.673323	0.000146	0.000157	0.000077	0.000273	0.000146	0.000218
18 - 19	7.673323	0.000077	0.000290	0.000077	0.000077	0.000146	0.000218
17 - 18	9.273694	0.000093	0.000350	0.000093	0.000093	0.000176	0.000264
16 - 17	9.273694	0.000093	0.000303	0.000093	0.000274	0.000093	0.000336
15 - 16	10.024821	0.000100	0.000327	0.000100	0.000296	0.000100	0.000364
14 - 15	10.024821	0.000190	0.000380	0.000100	0.000316	0.000100	0.000393
13 - 14	9.637917	0.000183	0.000365	0.000096	0.000304	0.000096	0.000377
12 - 13	9.637917	0.000183	0.000365	-0.000386	-0.000710	-0.000386	-0.000651
11 - 12	8.135472	0.000081	0.000195	-0.000325	-0.000600	-0.000325	-0.000549
10 - 11	8.135472	0.000081	0.000195	-0.000325	-0.000204	0.000081	0.000337
9 - 10	5.855333	-0.000234	-0.000445	-0.000234	-0.000146	0.000059	0.000243
8 - 9	5.855333	-0.000234	-0.000445	0.000059	0.000196	-0.000234	-0.000291
7 - 8	3.393624	0.000034	0.000245	0.000034	0.000114	-0.000136	-0.000169
6 - 7	3.393624	0.000034	0.000245	-0.000136	-0.000628	-0.000136	-0.000244
5 - 6	1.472149	0.000000	0.000000	-0.000059	-0.000272	-0.000059	-0.000106
4 - 5	1.472149	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3 - 4	0.458439	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2 - 3	0.458439	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1 - 2	0.121561	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
0 - 1	0.121561	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

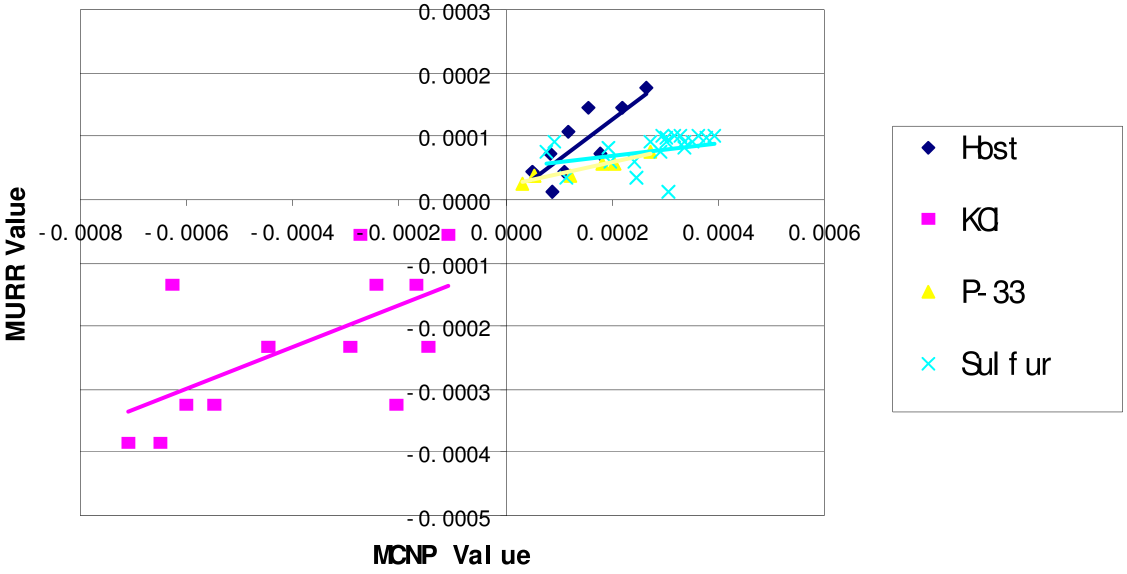
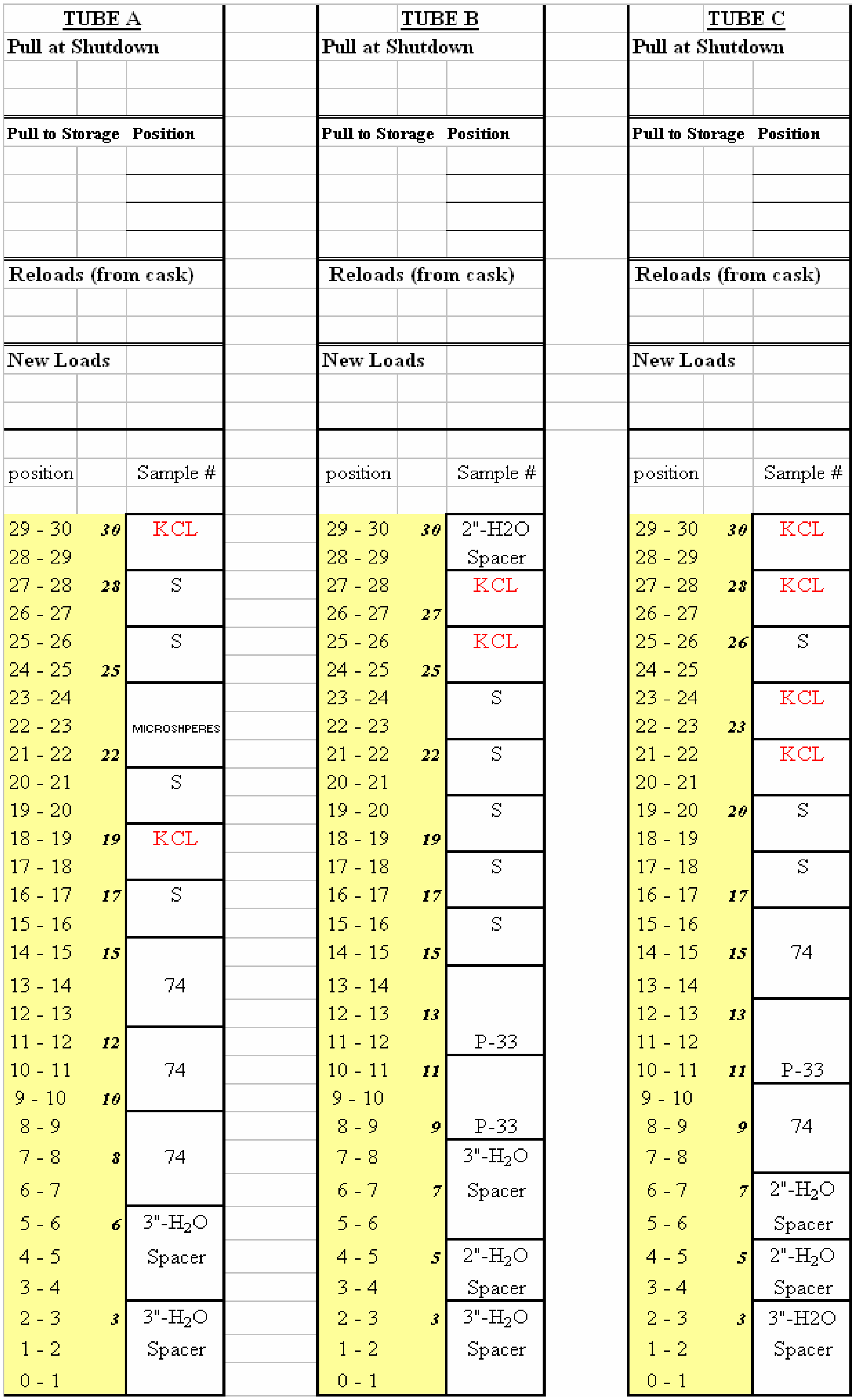


Figure 4-5 Individual Sample Worth – MCNP vs. MURR



TUBE A			TUBE B			TUBE C		
Pull at Shutdown			Pull at Shutdown			Pull at Shutdown		
Pull to Storage		Position	Pull to Storage		Position	Pull to Storage		Position
Reloads (from cask)			Reloads (from cask)			Reloads (from cask)		
New Loads			New Loads			New Loads		
position		Sample #	position		Sample #	position		Sample #
29 - 30	30	KCL	29 - 30	30	2"-H2O Spacer	29 - 30	30	KCL
28 - 29			28 - 29			28 - 29		
27 - 28	28	S	27 - 28		KCL	27 - 28	28	KCL
26 - 27			26 - 27	27		26 - 27		
25 - 26		S	25 - 26		KCL	25 - 26	26	S
24 - 25	25		24 - 25	25		24 - 25		
23 - 24		MICROSHPERES	23 - 24		S	23 - 24		KCL
22 - 23			22 - 23			22 - 23	23	
21 - 22	22		21 - 22	22	S	21 - 22		KCL
20 - 21		S	20 - 21			20 - 21		
19 - 20			19 - 20		S	19 - 20	20	S
18 - 19	19	KCL	18 - 19	19		18 - 19		
17 - 18			17 - 18		S	17 - 18		S
16 - 17	17	S	16 - 17	17		16 - 17	17	
15 - 16			15 - 16		S	15 - 16		74
14 - 15	15	74	14 - 15	15		14 - 15	15	
13 - 14			13 - 14		P-33	13 - 14		
12 - 13			12 - 13	13		12 - 13	13	P-33
11 - 12	12	74	11 - 12			11 - 12		
10 - 11			10 - 11	11	P-33	10 - 11	11	
9 - 10	10		9 - 10			9 - 10		74
8 - 9		74	8 - 9	9		8 - 9	9	
7 - 8	8		7 - 8		3"-H_2O Spacer	7 - 8		
6 - 7			6 - 7	7		6 - 7	7	2"-H_2O Spacer
5 - 6	6	3"-H_2O Spacer	5 - 6			5 - 6		
4 - 5			4 - 5	5	2"-H_2O Spacer	4 - 5	5	2"-H_2O Spacer
3 - 4			3 - 4			3 - 4		
2 - 3	3	3"-H_2O Spacer	2 - 3	3	3"-H_2O Spacer	2 - 3	3	3"-H2O Spacer
1 - 2			1 - 2			1 - 2		
0 - 1			0 - 1			0 - 1		

Figure 4-6 MURR Flux Trap Loading FTLdg1

4.3.4 Analysis of KCl Sample

From the previous results, the high negative worth of KCl sample and its positioning in relatively high flux regions are noticed and believed to be the cause of the deviation of the model in predicting reactivity worth. Several different ways to evaluate the KCl sample worth, as well as some other samples used in the loadings, has been analyzed.

The evaluation of worth for individual sample is similar with that used when considering the effect of a neutron poison:

$$\Delta\rho \approx \frac{\Sigma_{a,sample} * V_{sample}}{\sum(\Sigma_a * V)} \tag{4.4}$$

where $\sum_{a,\ sample}$ is the absorption cross section of the specific sample and V_{sample} is the volume of the sample. The denominator represents the sum of the product of absorption cross-section and corresponding volume for all the reactor constituents. The absorption cross section of sample can be calculated from MCNP by using F4 flux tally card and FM4 tally multiplier card. FM4 tally multiplier card is used to calculate any quantity of the form

$$C\int \Phi(E)\sigma(E)dE$$

where $\Phi(E)$ is the energy-dependent flux calculated by F4 tally card and $\sigma(E)$ is any kind of cross section. The constant C is any quantity that can be used for normalization. By setting the constant C as the atom density of the material and *σ(E)* as absorption cross section, the result from the multiplier card is actually the rate of neutron absorbed by the sample:

$$FM4 = N\int \phi(E)\sigma_a(E)dE = \int \phi(E)\Sigma_a(E)dE \tag{4.5}$$

Then, the average absorption cross section of the sample can be determined by dividing FM4 value by F4.

$$\overline{\Sigma_a} = \frac{\int \phi(E)\Sigma_a(E)dE}{\int \phi(E)dE} = \frac{FM4}{F4} \tag{4.6}$$

Considering flux weighting, the equation 4.4 can be rewritten as:

$$\Delta\rho \approx \frac{(\Sigma_a * \phi)_{sample} * V_{sample}}{\sum(\Sigma_a * \phi * V)} \tag{4.7}$$

where *Φ* is the flux at the position. Here the FM4 tally multiplier card can be used to determine the neutron absorption rate $(\sum_a * \Phi)$ part directly.

The evaluation results of the sample worth are displayed in table 4-6 with the correspondent MURR experimental values. The first two columns are the material number used in the MCNP model and the material compositions. The third column contains the unweighted sample worth determined by equation 4.4 and drawn from the MURR spreadsheet. The fifth column is the weighted sample worth determined by equation 4.5 and from MURR.

Table 4-6 Evaluation of Sample Worth

Material Number of Sample	**Material of Sample**	**Unweighted Worth**		**Weighted Worth**	
		MCNP	**MURR**	**MCNP**	**MURR**
M10	KCl	-4.00E-04	-4.00E-05	-7.19E-04	-2.34E-04
M11	MicroSpheres	5.10E-05	1.90E-05	1.73E-04	1.90E-04
M12	P-32	3.39E-05	1.00E-05	7.39E-05	7.70E-05
M13	P-33	5.67E-05	1.00E-05	6.23E-05	3.80E-05
M14	Host	5.02E-05	1.90E-05	4.35E-05	4.50E-05

From this evaluation of sample worth MCNP predicts that KCl should have about 10 times the worth of other samples instead of the 2 to 4 times which is used in MURR spreadsheet methodology. Further analysis of the effect of the KCl samples is required.

4.3.5 Self-Shielding Effect

One of the refinements made for the MCNP model is to change the homogeneous form of samples with large mass and high cross section into a heterogeneous form to model neutron self-shielding effects.

As found in Section 4.3.3, the MCNP model tends to over-predict the negative reactivity worth of KCl sample. This over-prediction of worth may be caused by the homogeneous modelling method used in the initial model which neglects the neutron self-shielding effects in a heterogeneous system. For samples with large mass and high cross section, neutrons are largely absorbed in the outer regions of the sample. The nuclei in the interior of such sample are thus exposed to a relatively low neutron flux and the amount of absorption is small. The result of this self-shielding effect is that the probability of neutron capture by the sample is less than if the sample has been dispersed uniformly throughout the moderator with the flux trap tube. The neutron escape probability in a heterogeneous system will thus be greater than in a homogeneous system of the same overall composition. The negative reactivity worth of such sample will be over-predicted in a homogeneous system.

The cross section for elements that composed loading samples is listed in Table 4-7. The mass of samples is listed in Table 4-8. With the large cross section, heavy weight, and negative worth, KCl sample is apparently the one that would be over-predicted in worth in a homogeneous system. KCl modelling was thus changed and treated as a heterogeneous sample within the flux trap.

Table 4-7 Sample Cross Section

Element	H	O	Al	S	Cl	K
Cross Section (b)	0.332	0.00027	0.23	0.52	33.2	2.1

Table 4-8 Sample Mass

Sample	Al	H2O	KCl	S	P-33
Weight/in (g/in)	10	6.6	20	20	4.5

The MCNP input file for the loading *#1023* with KCl sample in heterogeneous system is given in Appendix 5. In the heterogeneous system, the KCl sample was treated as two parts: KCl + its aluminum can, and water around the can. Each KCl cell card was thus changed into two cell cards with corresponding new geometry definition and material composition.

The results of running three loadings with KCl sample in heterogeneous form are showed in the last column of Table 4-9. Compared with those of loadings with the KCl sample in homogeneous form, the whole loading worth has been improved from a typical negative value of –0.0016 Δk to zero, demonstrating the neutron self-shielding effect. Yet the effect is not large enough for the model to predict experimentally measured loading worth of a positive 0.005 Δk.

Table 4-9 MCNP Predicted Loading Worth – Homogeneous vs. Heterogeneous

Loading	**MURR Worth**		**MCNP (Homogeneous)**			**MCNP (Heterogeneous)**	
	Calculated	Measured	Loading Value	Base Value	Worth	Loading Value	Worth
1023	0.004401	0.005300	0.98976	0.99142	-0.00166	0.99140	-0.00002
1024	0.004374	0.005144	0.98971	0.99142	-0.00171	0.99141	-0.00001
1025	0.004499	0.005318	0.98987	0.99142	-0.00155	0.99104	-0.00038

4.3.6 Burnup Effect

After the refinements of the original MCNP model were made as discussed in the above sections, the calculated loading reactivity worth from the model still is significantly different from the measurement data. The burnup effect of samples on the loading worth was then analysed.

The material components for the samples in the flux trap loading provided by the MURR were assumed to be unaltered by burnup. The original MCNP model used them directly in the data cards part without modification according to their irradiation time. This simplification ignored the burnup effect which has no significant impact on the material components for samples with small absorption cross-section or short irradiation history. For strong “absorbers” such as KCl sample (Cl: σ_{th}=43.7b, σ_{epi}=17b; K: σ=2.1b), the burnup effect may become large enough to affect the whole loading worth especially when they are put in significant flux position. To evaluate the burnup effect, the following equations were used to calculate Burnup Factor (BF), i.e. the remaining target nuclei after *t* hour's irradiation in the flux trap:

$$BF_{Cl} = e^{-(\sigma_{th}\cdot\phi_{th}+\sigma_{epi}\cdot\phi_{epi})\cdot t\cdot 3600} \tag{4.8}$$

$$BF_{K} = e^{-\sigma_{avg}\cdot\phi_{avg}\cdot t\cdot 3600} \tag{4.9}$$

$$BF_{KCl} = \frac{BF_{Cl}\cdot\sigma_{Cl}\cdot N_{Cl} + BF_{K}\cdot\sigma_{K}\cdot N_{K}}{\sigma_{Cl}\cdot N_{Cl} + \sigma_{K}\cdot N_{K}} \tag{4.10}$$

where N_{Cl} and N_K are the atomic weights of Cl and K, respectively.

By assuming the MURR thermal flux and epithermal flux to be $3x10^{14}$ and $1x10^{14}$ n/cm^3/s for average KCl sample irradiation, the Burnup Factor of KCl sample would be 0.692 after 7500 hrs, or about a 50 week (150 hrs for one week) irradiation, which corresponds to a sample reactivity worth of –2.77E-5, sharply decreased from the original value of –4.0E-5 from the MURR spreadsheet-based method. Figure 4-7 shows the decrease in reactivity worth of KCl sample verses burnup time.

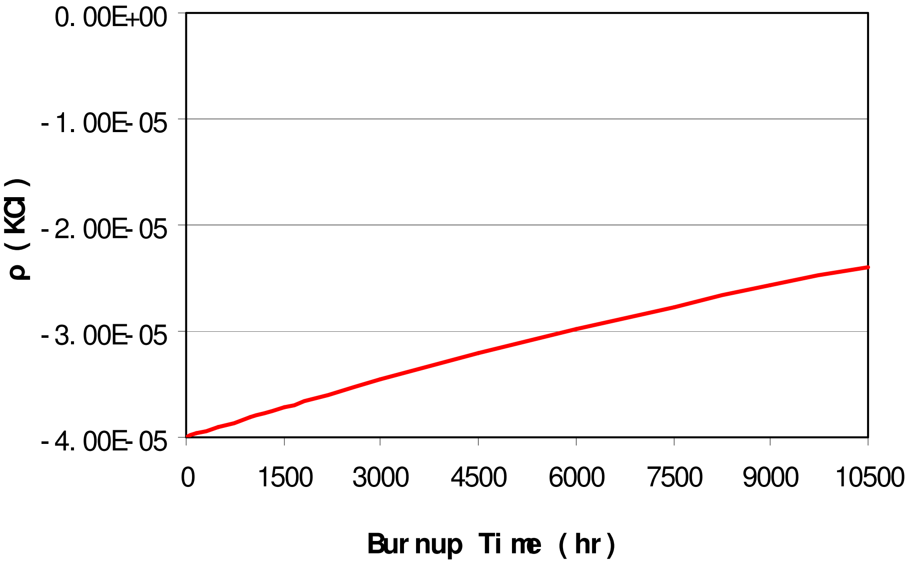


Figure 4-7 ρ(KCl) vs. Burnup Time

Table 4-10 shows the specific ages of KCl samples that had been burned before they were put in the loadings #1023, #1024, and #1025. The Burnup Factor for the samples was calculated according with the method introduced above. The last five KCl samples had only 58% - 78% of their worth remaining. The decreasing worth has a large impact on the loading worth because these samples were put in the positions at or near the highest flux of the flux trap tubes.

Table 4-10 Burnup Time and Burnup Factor of KCl Samples

KCl #		**#51**	**#55**	**#92**	**#56**	**#58**	**#97**	**#93**
Burned Time (hr)	***0***	***313.6***	***927.5***	***4965.7***	***7646.1***	***7952.2***	***10117.7***	***10840.6***
Burnup Factor	1.000	98.4%	95.5%	78.2%	68.7%	67.7%	61.0%	58.9%

The "active" material component of KCl samples were thus input into the data cards and replaced the original "fresh" data in the MCNP model with the above burnup calculations. Table 4-11 displays the new flux trap loading worth calculated from the MCNP model with the consideration of burnup effect. The result shows that the calculated loading worth from MCNP has been improved from about zero to a positive 0.0027 Δk.

Table 4-11 MCNP Loading Worth with Burnup Calculation

Loading	**MURR Measured Worth**	**MCNP Worth**	
		No Burnup	**Burnup**
1023	**0.005300**	-0.00002	**0.00270**
1024	**0.005144**	-0.00001	**0.00228**
1025	**0.005318**	-0.00038	**0.00281**

With the above investigation and modification of the original MCNP model, especially with the consideration of the self-shielding and burnup effects, the reactivity prediction of the model is closer to the expected value, yet they are still not in good agreement and further study is needed. However, it is noted that the discrepancy is consistent for the three loadings above. The difference between the experimental and calculated reactivity worth has a nearly constant value of 0.0027 (the discrepancy above is 0.0026, 0.0029 and 0.0025 for the loadings 1023, 1024 and 1025, respectively, from Table 4-11. Thus, the model appears to be valid for relative reactivity changes although the absolute value is in error.

4.4 Error Estimation

Results of Monte Carlo calculations represent average values of variables determined from many histories sampled during the course of the problem. In order to understand whether or not the method will yield the correct results, it is very important to consider the statistical error or uncertainty associated with the calculation. This error and its behavior versus the number of histories allow the user to gain insight into the quality of the result, as well as determine whether a tally is statistically well behaved. Standard deviation is computed and associated with the effective multiplication factor result in MCNP.

The estimated error associated with the loading reactivity worth calculated by Equation 4.1 can be computed with the standard deviation of effective multiplication factor and the following expression:

$$\sigma_\rho = \sqrt{{\sigma_l}^2 + {\sigma_b}^2} \tag{4.11}$$

where σ_ρ, σ_l, and σ_b are the standard deviation of loading reactivity worth, loading effective multiplication factor, and base effective multiplication factor, respectively.

With the same number of histories set in the MCNP model, the loading effective multiplication factor has approximately a standard deviation of 0.00017 as the base effective multiplication factor. The estimated standard deviation associated with the loading reactivity worth calculated in the above sections can be calculated to be 0.00024 according to Equation 4.11. For example, the

MCNP calculated reactivity worth for loading 1023 in Table 4-11 is thus 0.00270±0.00024. This corresponds to approximately a 10% uncertainty on all calculated results, smaller than the discrepany remaining between experimental and calculated values.

CHAPTER 5

MFTM PART II -- MONTEBURNS MODEL

5.1 MonteBurns Model

To predict isotope production in the flux trap, a MonteBurns model specific to the MURR core needs to be developed. MonteBurns is an automated tool that links code MCNP with the radioactive decay and burnup code ORIGEN2. A MonteBurns model will include the following different input files: (1) a MCNP input file that specifies the system geometry and initial material compositions; (2) a MonteBurns input file that specifies other parameters required for the operation of MonteBurns such as materials to be burned, power of the system, number of days to be burned; (3) a feed input file that specifies the feed/removal information for the system; (4) a cross-section input file, *mbxs.inp*, that contains the default MCNP cross-section identifiers for isotopes that may be produced in the irradiation process and are not specified by the user.

The relationships among MCNP, ORIGEN2, and MonteBurns programs are shown in Figure 5-1. MCNP solves neutron transport equation by using the Monte Carlo technique. It calculates and provides one-group microscopic cross-sections and fluxes to ORIGEN2 through MonteBurns. ORIGEN2 proceeds with radioactive decay and burnup calculations and gets the new material compositions of the system which are transferred back to MCNP by MonteBurns. MonteBurns creates a new MCNP input file with the adjusted compositions and density of each material being analyzed and begin next calculation cycle. The input for ORIGEN2 and interactions between MCNP and ORIGEN2 will be manipulated by MonteBurns.

Of the four needed input files, the previous developed MCNP model mentioned in Chapter 4 can be used as the MCNP input after minor changes being made correspond to the new reactor configuration. The MonteBurns input may be generated according to the specific MURR core configuration and flux trap material irradiation information while the feed input is not needed in this production calculation. The MonteBurns package contains a default input for the cross-section input file *mbxs.in* which can be edited according to user’s needs.

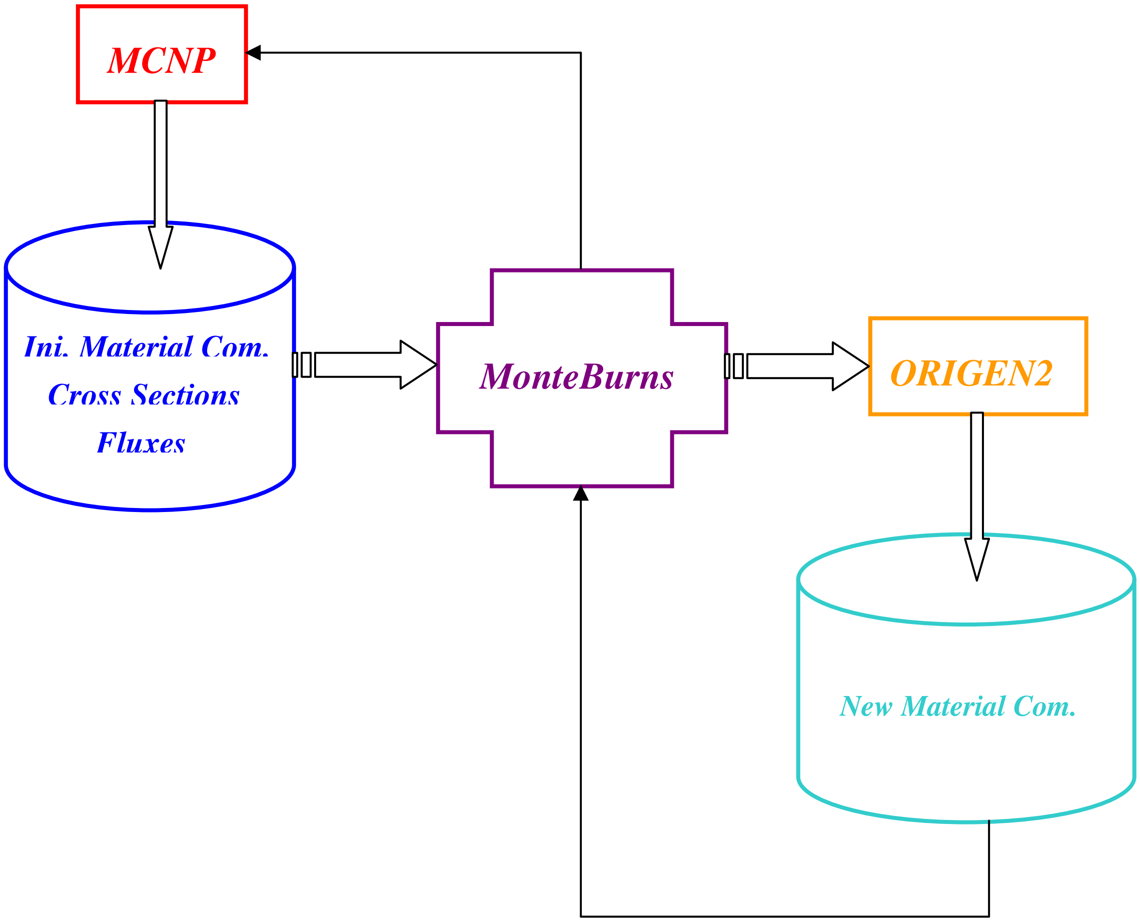


Figure 5-1 Relationships Among MCNP, ORIGEN2, and MonteBurns

5.2 Benchmarking the MonteBurns Model

Two sets of loadings provided by the MURR were used for the MonteBurns model benchmarking purpose: Holmium-166 irradiations and Lutetium-177 irradiations. The following sub-sections describe the benchmark process for these two kinds of irradiations separately.

5.2.1 Ho-166 Irradiation

Holmium-166 (Ho-166) is one of the radiolanthanides that the MURR provides weekly in Curie quantities. It is a promising radioisotope that supports human clinical trials and research with new radiotherapy agents for treating cancer and other diseases. Ho-166 is produced by direct irradiation of Ho-165 with the following reaction:

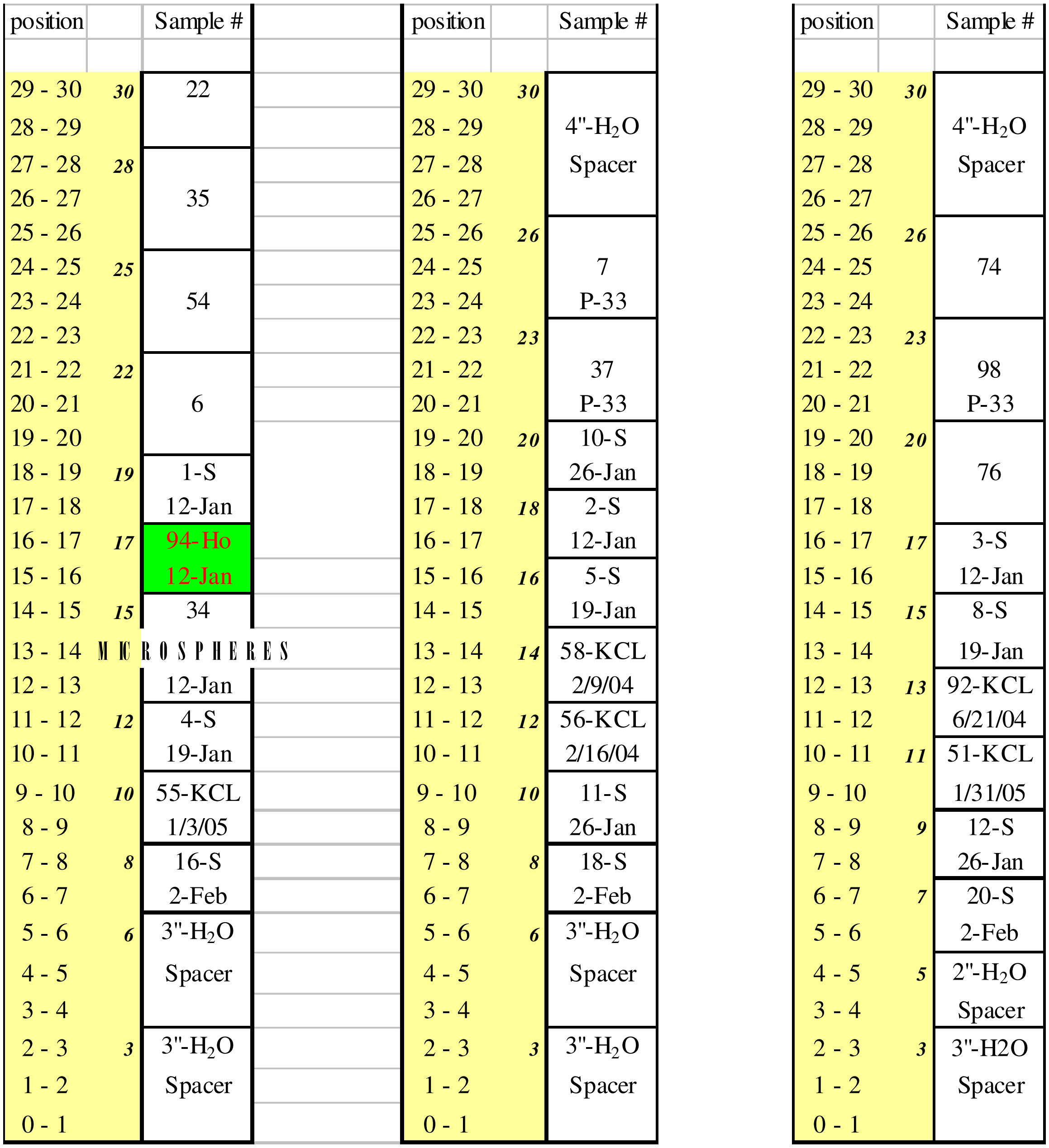
$$\text{Ho-165} + n \rightarrow \text{Ho-166} + \gamma \qquad (5.1)$$

Table 5-1 shows the irradiation length, target size, calculated End Of Irradiation (EOI) activity for the loadings provided by the MURR. Figure 5-2 to 5-5 display the detailed sample position in these loadings with the target sample highlighted.

Table 5-1 MURR Loadings for Ho-166 Production

MURR ID	Loading Sheet #	Irradiation Length (hr)	Size (mg)	Measured EOI Activity (mCi)
17207	1037	156.57	12.00	25878.0
17389	1067	142.03	2.50	48.4
17494	1136	146.57	2.50	60.0

To predict Ho-166 production, a MonteBurns model specific to each of the loadings was developed. A MCNP input file was programmed according to the specific loading information and included the corrections for modelling a heterogeneous sample with burnup effect included in the MCNP model mentioned in the last chapter. The height position of the control rod in the MCNP input was modified from 4.0 cm above the centerline for reactivity worth to 10.6 cm above for isotope production to represent an average control rod position over the week of irradiation. Appendix 6 shows the MCNP input file for the loading # 1037 as part of the MonteBurns model. Another part of the MonteBurns model, the MonteBurns input file, for the same loading is shown in Appendix 7. The MonteBurns input file records the irradiation target material, irradiation length, reactor power, nuclear data library used, and other required parameters of the system required for the calculation.

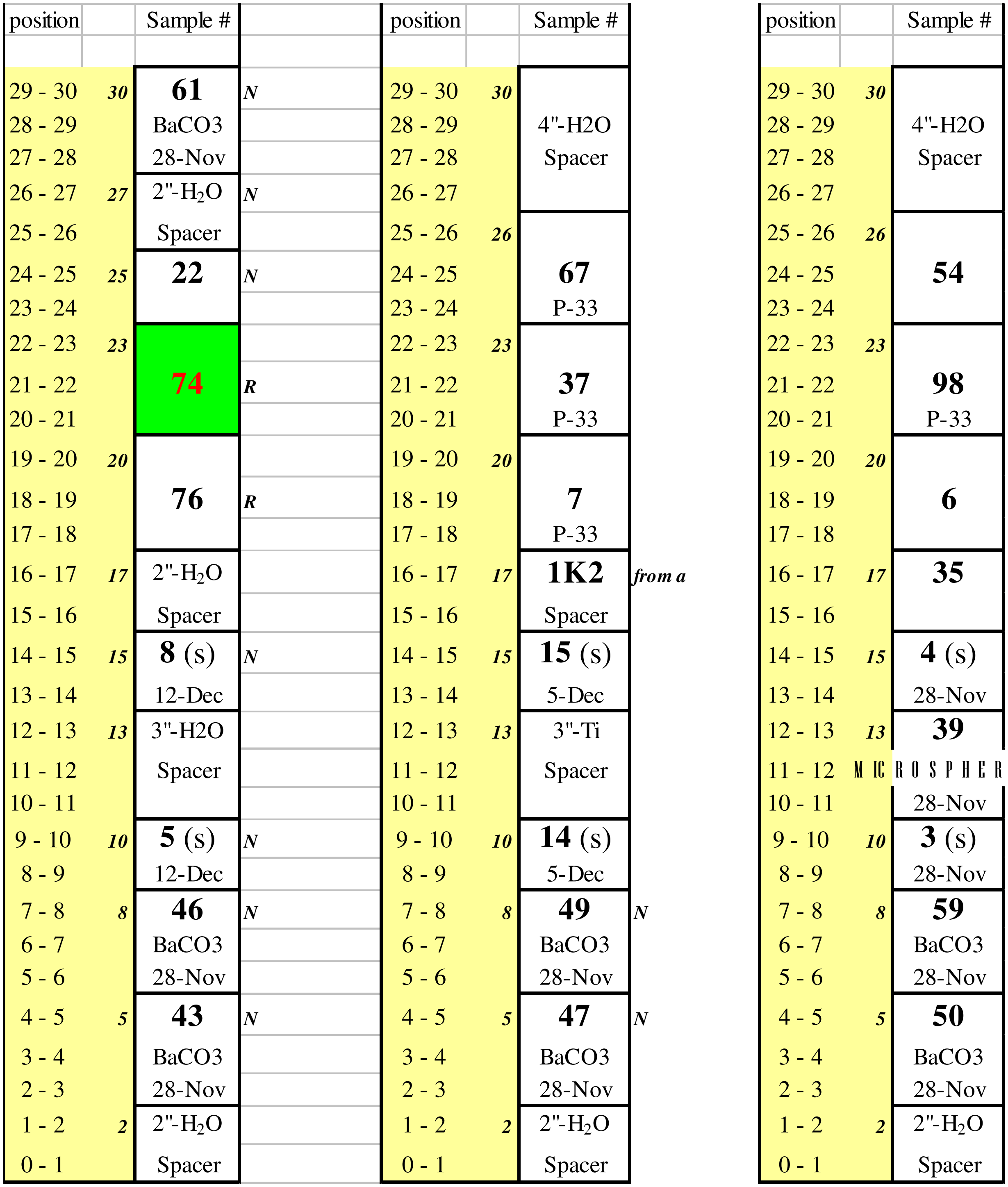


position		Sample #	position		Sample #	position		Sample #
29 - 30	*30*	22	29 - 30	*30*	4"-H_2O Spacer	29 - 30	*30*	4"-H_2O Spacer
28 - 29			28 - 29			28 - 29		
27 - 28	*28*	35	27 - 28			27 - 28		
26 - 27			26 - 27			26 - 27		
25 - 26			25 - 26	*26*	7 P-33	25 - 26	*26*	74
24 - 25	*25*	54	24 - 25			24 - 25		
23 - 24			23 - 24			23 - 24		
22 - 23			22 - 23	*23*	37 P-33	22 - 23	*23*	98 P-33
21 - 22	*22*	6	21 - 22			21 - 22		
20 - 21			20 - 21			20 - 21		
19 - 20			19 - 20	*20*	10-S 26-Jan	19 - 20	*20*	76
18 - 19	*19*	1-S 12-Jan	18 - 19			18 - 19		
17 - 18			17 - 18	*18*	2-S 12-Jan	17 - 18		
16 - 17	*17*	🟩 94-Ho 12-Jan	16 - 17			16 - 17	*17*	3-S 12-Jan
15 - 16			15 - 16	*16*	5-S 19-Jan	15 - 16		
14 - 15	*15*	34 MICROSPHERES 12-Jan	14 - 15			14 - 15	*15*	8-S 19-Jan
13 - 14			13 - 14	*14*	58-KCL 2/9/04	13 - 14		
12 - 13			12 - 13			12 - 13	*13*	92-KCL 6/21/04
11 - 12	*12*	4-S 19-Jan	11 - 12	*12*	56-KCL 2/16/04	11 - 12		
10 - 11			10 - 11			10 - 11	*11*	51-KCL 1/31/05
9 - 10	*10*	55-KCL 1/3/05	9 - 10	*10*	11-S 26-Jan	9 - 10		
8 - 9			8 - 9			8 - 9	*9*	12-S 26-Jan
7 - 8	*8*	16-S 2-Feb	7 - 8	*8*	18-S 2-Feb	7 - 8		
6 - 7			6 - 7			6 - 7	*7*	20-S 2-Feb
5 - 6	*6*	3"-H_2O Spacer	5 - 6	*6*	3"-H_2O Spacer	5 - 6		
4 - 5			4 - 5			4 - 5	*5*	2"-H_2O Spacer
3 - 4			3 - 4			3 - 4		
2 - 3	*3*	3"-H_2O Spacer	2 - 3	*3*	3"-H_2O Spacer	2 - 3	*3*	3"-H2O Spacer
1 - 2			1 - 2			1 - 2		
0 - 1			0 - 1			0 - 1		

Figure 5-2 Ho-166 Irradiation Loading Sheet #1037

position		Sample #		position		Sample #	position		Sample #
29 - 30	*30*	2"-H_2O		29 - 30	*30*		29 - 30	*30*	22
28 - 29		Spacer		28 - 29		4"-H_2O	28 - 29		Spacer
27 - 28	*28*	2"-H_2O		27 - 28		Spacer	27 - 28	*28*	2"-H_2O
26 - 27		Spacer		26 - 27			26 - 27		Spacer
25 - 26	*26*			25 - 26	*26*		25 - 26	*26*	
24 - 25		74		24 - 25		7	24 - 25		54
23 - 24				23 - 24		P-33	23 - 24		
22 - 23	*23*			22 - 23	*23*		22 - 23	*23*	
21 - 22		17		21 - 22		37	21 - 22		98
20 - 21				20 - 21		P-33	20 - 21		P-33
19 - 20	*20*			19 - 20	*20*	10-S	19 - 20	*20*	
18 - 19		76		18 - 19		16-Aug	18 - 19		6
17 - 18				17 - 18	*18*	20-S	17 - 18		
16 - 17	*17*	99-Ho		16 - 17		2-Aug	16 - 17	*17*	23-S
15 - 16		2-Aug		15 - 16	*16*	4-S	15 - 16		2-Aug
14 - 15	*15*	34		14 - 15		9-Aug	14 - 15	*15*	11-S
13 - 14	MICROSPHERES			13 - 14	*14*	14-S	13 - 14		16-Aug
12 - 13		2-Aug		12 - 13		23-Aug	12 - 13	*13*	15-S
11 - 12	*12*	3-S		11 - 12	*12*	55-KCL	11 - 12		23-Aug
10 - 11		9-Aug		10 - 11		1/3/05	10 - 11	*11*	51-KCL
9 - 10	*10*	3K2		9 - 10	*10*	1K2	9 - 10		1/31/05
8 - 9		Spacer		8 - 9		Spacer	8 - 9	*9*	2K2
7 - 8	*8*	5K2		7 - 8	*8*	4K2	7 - 8		Spacer
6 - 7		Spacer		6 - 7		Spacer	6 - 7	*7*	6K2
5 - 6	*6*	2"-H_2O		5 - 6	*6*	80	5 - 6		Spacer
4 - 5		Spacer		4 - 5		BaCO	4 - 5	*5*	3"-H_2O
3 - 4	*4*	2"-H_2O		3 - 4		2-Aug	3 - 4		Spacer
2 - 3		Spacer		2 - 3	*3*	3"-H_2O	2 - 3		
1 - 2	*2*	2"-H_2O		1 - 2		Spacer	1 - 2	*2*	2"-H_2O
0 - 1		Spacer		0 - 1			0 - 1		Spacer

Figure 5-3. Ho-166 Irradiation Loading Sheet # 1067



position		Sample #	
29 - 30	30	**61**	*N*
28 - 29		BaCO3	
27 - 28		28-Nov	
26 - 27	27	2"-H_2O	*N*
25 - 26		Spacer	
24 - 25	25	**22**	*N*
23 - 24			
22 - 23	23		
21 - 22		74	*R*
20 - 21			
19 - 20	20		
18 - 19		**76**	*R*
17 - 18			
16 - 17	17	2"-H_2O	
15 - 16		Spacer	
14 - 15	15	**8** (s)	*N*
13 - 14		12-Dec	
12 - 13	13	3"-H2O	
11 - 12		Spacer	
10 - 11			
9 - 10	10	**5** (s)	*N*
8 - 9		12-Dec	
7 - 8	8	**46**	*N*
6 - 7		BaCO3	
5 - 6		28-Nov	
4 - 5	5	**43**	*N*
3 - 4		BaCO3	
2 - 3		28-Nov	
1 - 2	2	2"-H_2O	
0 - 1		Spacer	

position		Sample #	
29 - 30	30		
28 - 29		4"-H2O	
27 - 28		Spacer	
26 - 27			
25 - 26	26		
24 - 25		**67**	
23 - 24		P-33	
22 - 23	23		
21 - 22		**37**	
20 - 21		P-33	
19 - 20	20		
18 - 19		**7**	
17 - 18		P-33	
16 - 17	17	**1K2**	*from a*
15 - 16		Spacer	
14 - 15	15	**15** (s)	
13 - 14		5-Dec	
12 - 13	13	3"-Ti	
11 - 12		Spacer	
10 - 11			
9 - 10	10	**14** (s)	
8 - 9		5-Dec	
7 - 8	8	**49**	*N*
6 - 7		BaCO3	
5 - 6		28-Nov	
4 - 5	5	**47**	*N*
3 - 4		BaCO3	
2 - 3		28-Nov	
1 - 2	2	2"-H_2O	
0 - 1		Spacer	

position		Sample #
29 - 30	30	
28 - 29		4"-H2O
27 - 28		Spacer
26 - 27		
25 - 26	26	
24 - 25		**54**
23 - 24		
22 - 23	23	
21 - 22		**98**
20 - 21		P-33
19 - 20	20	
18 - 19		**6**
17 - 18		
16 - 17	17	**35**
15 - 16		
14 - 15	15	**4** (s)
13 - 14		28-Nov
12 - 13	13	**39**
11 - 12	MICROSPHER	
10 - 11		28-Nov
9 - 10	10	**3** (s)
8 - 9		28-Nov
7 - 8	8	**59**
6 - 7		BaCO3
5 - 6		28-Nov
4 - 5	5	**50**
3 - 4		BaCO3
2 - 3		28-Nov
1 - 2	2	2"-H_2O
0 - 1		Spacer

Figure 5-4. Ho-166 Irradiation Loading Sheet # 1136

The MonteBurns calculation results for the three loadings are displayed in Table 5-2. It is shown that the MonteBurns predicted Ho-166 production is in very good agreement with the measured values for loading #1037 and 1067 with an error less than 10%, while the model under-estimated the Ho-166 production by about 50% for loading #1136.

Table 5-2 MonteBurns Calculation Results for Ho-166 Production

MURR ID	Sheet #	Irradiation Length (hr)	Size (mg)	Measured Activity (mCi)	MonteBurns Activity (mCi)	Error (%)
17207	1037	156.57	12.00	25878.0	27654.9	6.9
17772	1067	152.71	0.15	341.7	374.4	9.6
19167	1136	146.35	0.10	325.0	169.5	-47.8

To investigate the large error associated with loading #1136, the Specific Activity (SA) for the three loadings has been estimated based upon their size and measured or calculated activity:

$$SA = \frac{Activity(mCi)}{Size(mgHo-165)} \tag{5.2}$$

The average irradiating flux can be calculated according to the relationship between SA and flux:

$$SA = \frac{N_A}{A}\overline{\sigma}\overline{\phi}\left(1-e^{-\lambda t_i}\right) \tag{5.3}$$

where

N_A ≡ Avogadro number, 6.022x10^{23} /mol

A ≡ atomic weight

$\overline{\sigma}$ ≡ average neutron absorption cross section

$\overline{\phi}$ ≡ average neutron flux

λ ≡ radioactive decay constant

t_i ≡ irradiation time

The calculation results for the SA and average irradiation flux of the three loadings are displayed in Table 5-3. The calculated average flux according to the measured activity for loading #1037 and 1067 is about 3.5E14 n/cm2/s. This is reasonable for the sample irradiation position of 16-17 in the flux trap.

Table 5-3 Specific Activity and Average Flux Calculations

MURR ID	Sheet #	Size (mg)	Measured			MonteBurns		
			Activity (mCi)	SA (mCi/mg)	Average Flux	Activity (mCi)	SA (mCi/mg)	Average Flux
17207	1037	12.00	25878.0	2156.5	**3.4E+14**	27654.9	2304.6	**3.6E+14**
17772	1067	0.15	341.7	2278.0	**3.6E+14**	374.4	2496.2	**3.9E+14**
19167	1136	0.10	325.0	3250.0	***5.1E+14***	169.5	1694.9	***2.6E+14***

However, the average flux needed for sample #1136 that corresponds with the measured activity is 5.1E14. This is nearly two times higher than the estimated flux of ~2.8×10^{14} corresponding to the irradiation position of 21-23. This appears to indicate an error in the experimentally measured value. By comparison, the MonteBurns result predicts a flux of 2.6E+14, in good agreement with the expected flux.

5.2.2 Lu-177 Irradiation

Lutetium-177 (Lu-177) is known as a promising therapeutic radioisotope for the treatment of cancer. Lu-177 can be produced by direct (n, gamma) irradiation of Lu-176.

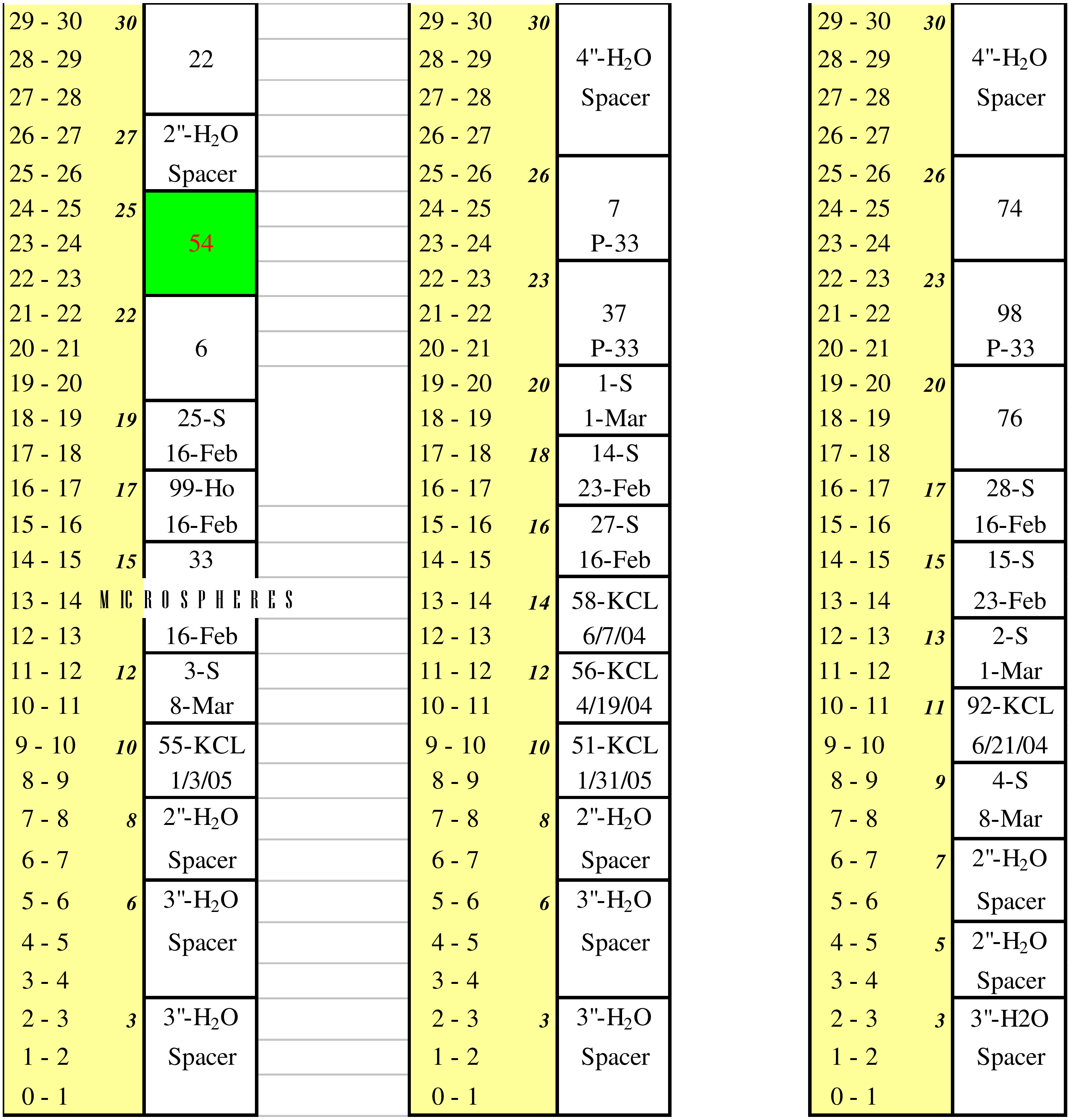
$$\text{Lu-176} + n \rightarrow \text{Lu-177} + \gamma \qquad (5.4)$$

Table 5-4 shows the irradiation length, target size, calculated End Of Irradiation (EOI) activity for the loadings provided by the MURR for benchmarking. Figure 5-5 to 5-8 display the detailed sample position in these loadings with the target sample highlighted.

Table 5-4 MURR Loadings for Lu-177 Production

MURR ID	Loading Sheet #	Irradiation Length (hr)	Size (mg)	Measured EOI Activity (mCi)
17306	1042	155.33	0.250	6526.2
18273	1094	148.89	0.150	3584.4
18675	1113	156.32	0.200	5054.0
16137	9978	142.51	0.128	3444.9

To predict Lu177 production, a MonteBurns model similar with the MonteBurns model shown in Appendix 6 and 7 yet specific to each of the loadings was developed, which included one MCNP input file and one MonteBurns input file.



29 - 30	30		30		30	
28 - 29		22		4"-H_2O		4"-H_2O
27 - 28				Spacer		Spacer
26 - 27	27	2"-H_2O				
25 - 26		Spacer	26		26	
24 - 25	25			7		74
23 - 24		54		P-33		
22 - 23			23		23	
21 - 22	22			37		98
20 - 21		6		P-33		P-33
19 - 20			20	1-S	20	
18 - 19	19	25-S		1-Mar		76
17 - 18		16-Feb	18	14-S		
16 - 17	17	99-Ho		23-Feb	17	28-S
15 - 16		16-Feb	16	27-S		16-Feb
14 - 15	15	33		16-Feb	15	15-S
13 - 14	MICROSPHERES		14	58-KCL		23-Feb
12 - 13		16-Feb		6/7/04	13	2-S
11 - 12	12	3-S	12	56-KCL		1-Mar
10 - 11		8-Mar		4/19/04	11	92-KCL
9 - 10	10	55-KCL	10	51-KCL		6/21/04
8 - 9		1/3/05		1/31/05	9	4-S
7 - 8	8	2"-H_2O	8	2"-H_2O		8-Mar
6 - 7		Spacer		Spacer	7	2"-H_2O
5 - 6	6	3"-H_2O	6	3"-H_2O		Spacer
4 - 5		Spacer		Spacer	5	2"-H_2O
3 - 4						Spacer
2 - 3	3	3"-H_2O	3	3"-H_2O	3	3"-H2O
1 - 2		Spacer		Spacer		Spacer
0 - 1						

Figure 5-5 Lu-177 Irradiation Loading Sheet # 1042

position		Sample #	
29 - 30	*30*	**22**	
28 - 29			*R*
27 - 28			
26 - 27	*27*	2"-H_2O Spacer	
25 - 26			
24 - 25	*25*	**74**	
23 - 24			*N*
22 - 23			
21 - 22	*22*	**76**	
20 - 21			*R*
19 - 20			
18 - 19	*19*	**16**-S 14-Feb	
17 - 18			
16 - 17	*17*	**12**-S 7-Feb	
15 - 16			
14 - 15	*15*	**3**-S 21-Feb	
13 - 14			
12 - 13	*13*	**1K2** Spacer	
11 - 12			
10 - 11	*11*	**2K2** Spacer	
9 - 10			
8 - 9	*9*	**5K2** Spacer	
7 - 8			
6 - 7	*7*	**6K2** Spacer	
5 - 6			
4 - 5	*5*	2"-H_2O Spacer	
3 - 4			
2 - 3	*3*	3"-H_2O Spacer	
1 - 2			
0 - 1			

position		Sample #	
29 - 30	*30*	4"-H_2O Spacer	
28 - 29			
27 - 28			
26 - 27			
25 - 26	*26*	**7** P-33	
24 - 25			*R*
23 - 24			
22 - 23	*23*	**37** P-33	
21 - 22			
20 - 21			
19 - 20	*20*	**4**-S 21-Feb	
18 - 19			
17 - 18	*18*	**13**-S 7-Feb	
16 - 17			
15 - 16	*16*	**18**-S 14-Feb	
14 - 15			
13 - 14	*14*	**10**-S 28-Feb	*N*
12 - 13			
11 - 12	*12*	**3K2** Spacer	
10 - 11			
9 - 10	*10*	**4K2** Spacer	
8 - 9			
7 - 8	*8*	2"-H_2O Spacer	
6 - 7			
5 - 6	*6*	**52** $BaCO_3$ 7-Feb	
4 - 5			*N*
3 - 4			
2 - 3	*3*	3"-H_2O Spacer	
1 - 2			
0 - 1			

position		Sample #
29 - 30	*30*	2"-H_2O Spacer
28 - 29		
27 - 28	*28*	2"-H_2O Spacer
26 - 27		
25 - 26	*26*	**54**
24 - 25		
23 - 24		
22 - 23	*23*	**98** P-33
21 - 22		
20 - 21		
19 - 20	*20*	**6**
18 - 19		
17 - 18		
16 - 17	*17*	**95**-Ho 7-Feb
15 - 16		
14 - 15	*15*	**11**-S 28-Feb
13 - 14		
12 - 13	*13*	**33** MICROSPHE 7-Feb
11 - 12		
10 - 11		
9 - 10	*10*	2"-H_2O Spacer
8 - 9		
7 - 8	*8*	2"-H_2O Spacer
6 - 7		
5 - 6	*6*	**56** $BaCO_3$ 7-Feb
4 - 5		
3 - 4		
2 - 3	*3*	3"-H_2O Spacer
1 - 2		
0 - 1		

Figure 5-6 Lu-177 Irradiation Loading Sheet # 1094

position		Sample #		position		Sample #		position		Sample #
29 - 30	30			29 - 30	30			29 - 30	30	
28 - 29		4"-Ti	N	28 - 29		4"-Ti	N	28 - 29		4"-H2O
27 - 28		Spacer		27 - 28		Spacer		27 - 28		Spacer
26 - 27				26 - 27				26 - 27		
25 - 26	26	2"-H_2O		25 - 26	26			25 - 26	26	
24 - 25		Spacer		24 - 25		**7**		24 - 25		**54**
23 - 24	24			23 - 24		P-33		23 - 24		
22 - 23		**74**	N	22 - 23	22			22 - 23	23	
21 - 22				21 - 22		**37**	R	21 - 22		**98**
20 - 21	21			20 - 21		P-33		20 - 21		P-33
19 - 20		**76**	R	19 - 20	19	**11** (s)		19 - 20	20	
18 - 19				18 - 19		11-Jul	N	18 - 19		**6**
17 - 18	18	**1** (s)		17 - 18	17	**2** (s)		17 - 18		
16 - 17		4-Jul		16 - 17		4-Jul		16 - 17	17	**91** (Lu)
15 - 16	16	**10** (s)		15 - 16	15	**28** (s)		15 - 16		27-Jun
14 - 15		20-Jun	from C	14 - 15		27-Jun		14 - 15	15	**3** (s)
13 - 14	14	**1K2**		13 - 14	13	**27** (s)		13 - 14		20-Jun
12 - 13		Spacer		12 - 13		27-Jun		12 - 13	13	**32**
11 - 12	12	**2K2**		11 - 12	11	**5K2**		11 - 12		MICROSPHER
10 - 11		Spacer		10 - 11		Spacer		10 - 11		20-Jun
9 - 10	10	2" Ti	N	9 - 10	9	**3K2**		9 - 10	10	2"-H_2O
8 - 9		Spacer		8 - 9		Spacer		8 - 9		Spacer
7 - 8	8	**41**	N	7 - 8	8	**45**	N	7 - 8	8	**12** (s)
6 - 7		$BaCO_3$		6 - 7		$BaCO_3$		6 - 7		11-Jul
5 - 6		20-Jun		5 - 6		20-Jun		5 - 6	6	**48**
4 - 5	5	**40**	N	4 - 5	5	**43**	N	4 - 5		$BaCO_3$
3 - 4		$BaCO_3$		3 - 4		$BaCO_3$		3 - 4		20-Jun
2 - 3		20-Jun		2 - 3		20-Jun		2 - 3	3	3"-H2O
1 - 2	2	2"-H_2O		1 - 2	2	2"-H_2O	N	1 - 2		Spacer
0 - 1		Spacer		0 - 1		Spacer		0 - 1		

Figure 5-7 Lu-177 Irradiation Loading Sheet # 1113

position		Sample #
29 - 30	30	56-KCL 02/16/04
28 - 29		
27 - 28	28	5-S 9-Dec
26 - 27		
25 - 26	26	54
24 - 25		
23 - 24		
22 - 23	23	17
21 - 22		
20 - 21		
19 - 20	20	6
18 - 19		
17 - 18		
16 - 17	17	90-Ho 25-Nov
15 - 16		
14 - 15	15	39 MICROSHPERES 25-Nov
13 - 14		
12 - 13		
11 - 12	12	11-S 2-Dec
10 - 11		
9 - 10	10	78-KCL 09/08/03
8 - 9		
7 - 8	8	3-S 9-Dec
6 - 7		
5 - 6	6	22
4 - 5		
3 - 4		
2 - 3	3	"C" Spacer
1 - 2		
0 - 1		

position		Sample #
29 - 30	30	58-KCL 2/9/04
28 - 29		
27 - 28	28	31-KCL 03/03/03
26 - 27		
25 - 26	26	7 P-33
24 - 25		
23 - 24		
22 - 23	23	37 P-33
21 - 22		
20 - 21		
19 - 20	20	1-S 25-Nov
18 - 19		
17 - 18	18	4-S 25-Nov
16 - 17		
15 - 16	16	2-S 25-Nov
14 - 15		
13 - 14	14	26-KCL 09/15/03
12 - 13		
11 - 12	12	97-KCL 10/27/03
10 - 11		
9 - 10	10	18-S 16-Dec
8 - 9		
7 - 8	8	4" Spacer
6 - 7		
5 - 6		
4 - 5		
3 - 4	4	4" Spacer
2 - 3		
1 - 2		
0 - 1		

position		Sample #
29 - 30	30	"C" Spacer
28 - 29		
27 - 28		
26 - 27	27	20-S 16-Dec
25 - 26		
24 - 25	25	21-S 16-Dec
23 - 24		
22 - 23	23	98 P-33
21 - 22		
20 - 21		
19 - 20	20	15-S 2-Dec
18 - 19		
17 - 18	18	8-S 9-Dec
16 - 17		
15 - 16	16	10-S 2-Dec
14 - 15		
13 - 14	14	68-KCL 04/13/03
12 - 13		
11 - 12	12	57-KCL 05/19/03
10 - 11		
9 - 10	10	93-KCL 09/22/03
8 - 9		
7 - 8	8	4" Spacer
6 - 7		
5 - 6		
4 - 5		
3 - 4	4	4" Spacer
2 - 3		
1 - 2		
0 - 1		

Figure 5-8 Lu-177 Irradiation Loading Sheet # 9978

The MonteBurns calculation results for the four loadings are displayed in Table 5-5. It is shown that the MonteBurns model underestimated the production of Lu-177 by 20% to 30% in general.

Table 5-5 MonteBurns Calculation Results for Lu-177 Production

MURR ID	Sheet #	Irradiation Length (hr)	Size (mg)	Measured Activity (mCi)	MonteBurns Activity (mCi)	Error (%)
17306	1042	155.33	0.250	6526.2	5261.7	-19.4
18273	1094	148.89	0.150	3584.4	2667.6	-25.6
18675	1113	156.32	0.200	5054.0	3550.2	-29.8
16137	9978	142.51	0.128	3444.9	2173.8	-36.9

To address this discrepancy, the MonteBurns model was reviewed and the following relevant parameters in the model were modified to investigate their effect on the result:

(1) Increased the outer burn step of MonteBurns from 2 to 10.

(2) Increased the MCNP cycle number from 55 to 2050.

(3) Replaced Lu-176 cross section library from 71176.66c to 71176.75c.

The first two changes brought no improvement on the Lu-177 production while the change of cross section library for Lu-176 increased the Lu-177 production by 2% - 8% (see Table 5-6). Analysis of the cross section data showed that the average (n, gamma) cross section of Lu-176 calculated by

Table 5-6 Effect of Cross Section Data on Production Calculations

Sheet #	**Measured Activity (mCi)**	**MonteBurns Activity (mCi)**			
		71176.66c	**Error (%)**	***71176.65c***	***Error (%)***
1042	6526.2	5261.7	-19.4	*5390.5*	*-17.4*
1094	3584.4	2667.6	-25.6	*2966.8*	*-17.2*
1113	5054.0	3550.2	-29.8	*3846.4*	*-23.9*
9978	3444.9	2173.8	-36.9	*2281.6*	*-33.8*

MonteBurns is about 1730 barns when using the 71176.66c library. This is lower than the data from the CRC Handbook, 2100 b, by about 20%. By using the 71176.65c library, the average (n, gamma) cross section of Lu-176 calculated by the MonteBurns is about 1800 barns, a 3% increase from the one in 71176.66c. This cross section still results in about a 20% difference between the model calculation and measurement, but is in better overall agreement.

CHAPTER 6

FURTHER STUDY OF THE MFTM MODEL

After completing the previous work on developing and benchmarking the MFTM model, the model was compared with routine production runs to assess its accuracy. More flux trap sample loading sheets as well as their measurement data were provided by MURR. The MCNP model and MonteBurns model were used to simulate the loadings and calculate their reactivity worth or isotope productions, respectively. The results were compared and analyzed with their corresponding measurement values.

6.1 MCNP Reactivity Comparisons

Four loading sheets were provided with their associated measured loading reactivity worth. Three of them, loadings 1162, 1172, and 1176, have only one KCl sample for each loading while another one, loading 1148, has no KCl at all. Table 6-1 displays the loading worth values from measurement, MURR Spreadsheet calculation, and MCNP calculation.

Table 6-1 Reactivity Comparisons with Few KCl Samples

Loading Sheet #	MURR Measured Worth	MURR Spreadsheet		MCNP	
		Worth	Error	Worth	Error
1148	0.0049	0.00436	-11%	0.00544	11%
1162	0.0055	0.004761	-13%	0.00432	-21%
1172	0.00559	0.0045678	-18%	0.00427	-24%
1176	0.00536	0.00467	-13%	0.00451	-16%

It can be shown that the error between MCNP results and measurement data is only about 10 to 20 percent. The results from the model are comparable with those from MURR Spreadsheet method and are capable to be used in MURR routine prediction of reactivity worth for flux trap loading process.

The much improved calculation results from MCNP model for these loadings compared to the loadings in the previous comparisions is believed to be due to the number of KCl samples presented in the loadings. Three of the loadings being studied this time have only one KCl sample. The other one has no KCl sample. Previously studied loadings had seven KCl samples. It is suspected that the assumed burnup of the KCl samples in previous loadings may not be sufficient to correct for the the value of their negative reactivity in the model and a higher assumed flux creating additional burnup should be included. Independent of this,however, it is obvioius that something remains in error concerning the worth of KCl samples, and the model works quite well if little or no KCl is present.

6.2 MonteBurns Production Comparisons

Ten loading sheets were provided by MURR with Lu-177 production data. These were analyzed using the MonteBurns model developed before. The calculated results from the model are listed in Table 6-2. The model underestimated the production from 11% to 33%, similar to the results in the last section.

Table 6-2 Additional Lu-177 Production Comparisons

Loading Sheet #	Irradiation Length (hr)	Size (mg) Lu-176	Measured Activity (mCi)	MonteBurns Activity (mCi)	Error (%)
1182	148.31	0.200	5205.0	3567.3	-31.5
1158	153.06	0.200	4957.0	3680.3	-25.8
1141	151.63	0.200	5195.0	3728.4	-28.2
1130	148.11	0.200	5016.0	3515.8	-29.9
1107	156.03	0.150	4309.0	2944.0	-31.7
1090	155.37	0.150	3926.0	2924.0	-25.5
1077	140.86	0.150	4156.0	2752.4	-33.8
1053	148.89	0.150	4049.0	2826.9	-30.2
1041	147.48	0.250	5923.0	5263.1	-11.1
1034	153.83	0.128	3607.0	2750.9	-23.7

CHAPTER 7

AUTOMATED PACKAGE

After developing and benchmarking the MCNP model part and MonteBurns model part, the final step to fully accomplish the objectives of the research is to integrate the two parts into an automated package for MURR to use. The automated package will start by selecting and placing various kinds of samples into the three irradiation tubes of flux trap according to the specific necessity. Then the user inputs the burnup history of KCl samples if available, and the irradiation target isotope information for production calculation. After the input of loading and samples information, the user can choose to run the MCNP for a loading reactivity worth calculation or MonteBurns for isotope production calculation. At the end of the run, the package will search and sort out the needed information from the running results of MCNP and MonteBurns. The loading reactivity worth or isotopes productions will be delivered in the output file of the automated package.

Figure 7-1 shows the flow discussed above.

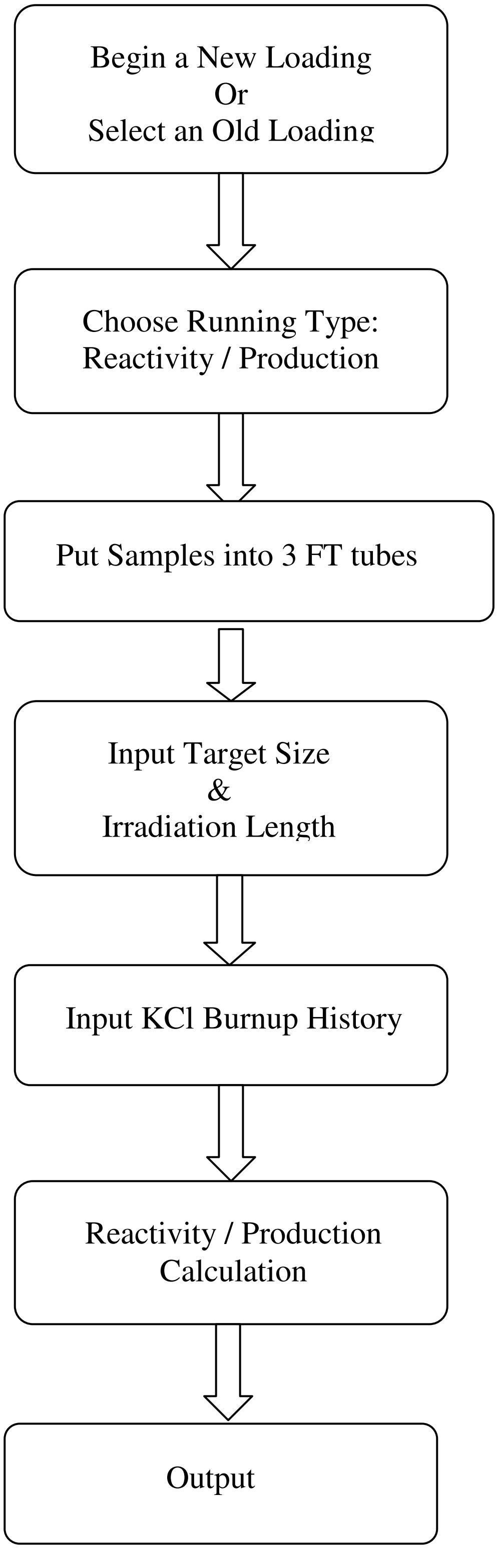


Figure 7-1 Flow Process of MFTM Package

Visual Basic 6.0 has been chosen to develop the User Interface of the package because of its flexibility and easy use. Visual Basic is a powerful, integrated development environment that allows user to create professional Windows applications. It has an intuitive user interface for even a new learner to write professional applications successfully, as well as an extensive set of controls and excellent debugging facilities.

To use the MFTM package successfully on the MCNP Server in MURR, the package should be installed in the user's local working directory in the Server. The package includes the following files:

- MURR_Flux_Trap_v1.EXE – execute file;
- MonteBurns.pl – edited MonteBurns perl file so that it could be executed from VB without entering base file name;
- Origen2.exe -- a copy from ORIGEN package to avoid the pop-up window during the execution;
- mbxs.inp -- required by Monteburns, can be edited by user if needed;
- R1162.ldg -- a sample FT loading for testing.

The package has been successfully tested with the provided sample loading, R1162.ldg, on the MCNP Server for both MCNP part (input file named as R1162W and output was R1162W.out) and MonteBurns part (input file named as R1162P and output as R1162P.out). The running results are as following:

Loading Sheet #: 1162

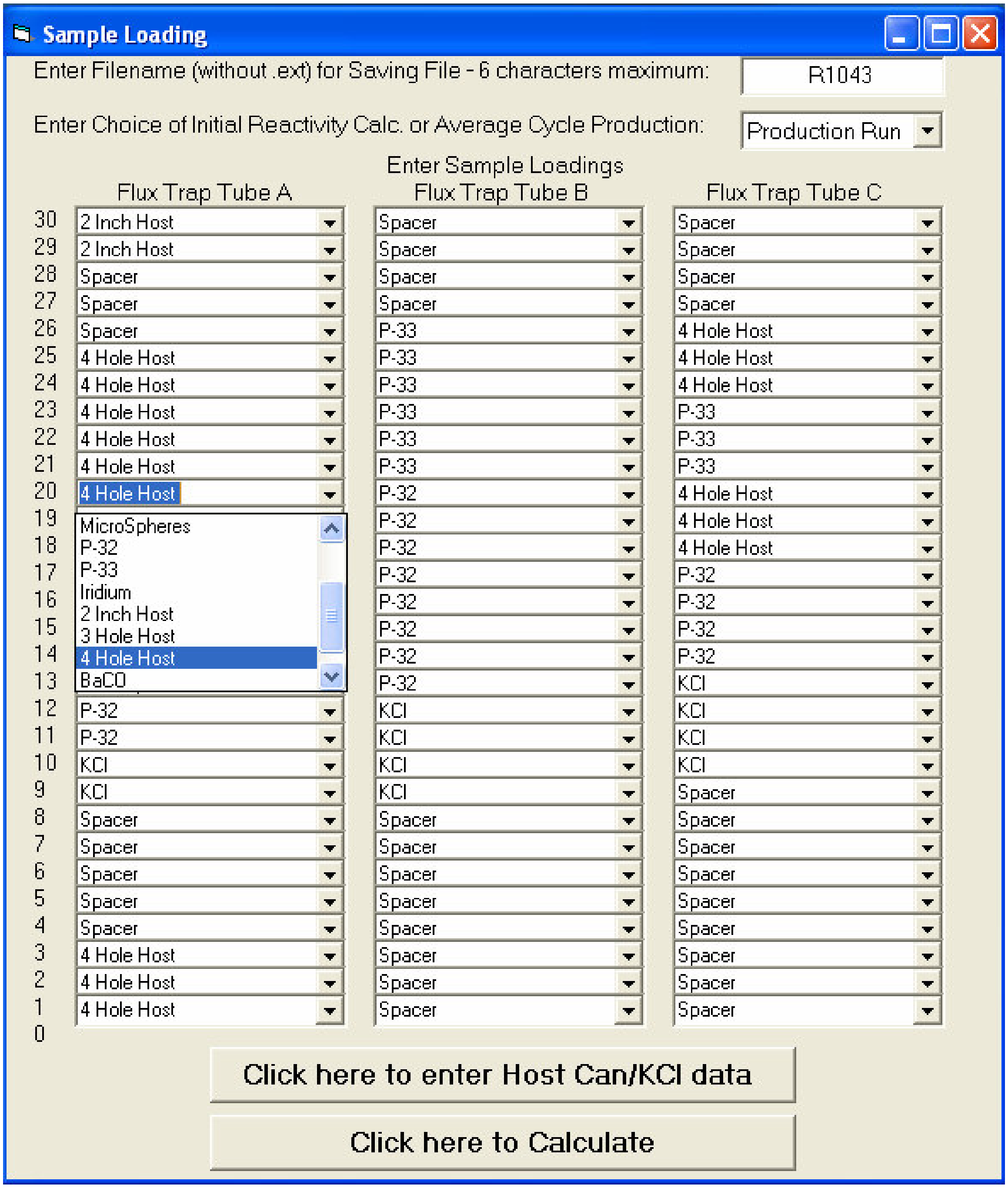
Loading Worth from VB Script: 0.00472

Loading Worth from MURR Spreadsheet Method: 0.004761

Loading Worth from measurement: 0.0055

Assuming that 2mg Ho165 sample in Host Can 54 (Tube C, loc 24-26) been irradiated for 150 hours, the Ho166 production calculated from the script is 2675.042 mCi. There was no measurement data for this loading and it was only for test purpose, though the result was comparable with those acquired in previous study.

The following figures show representative screens of this package.



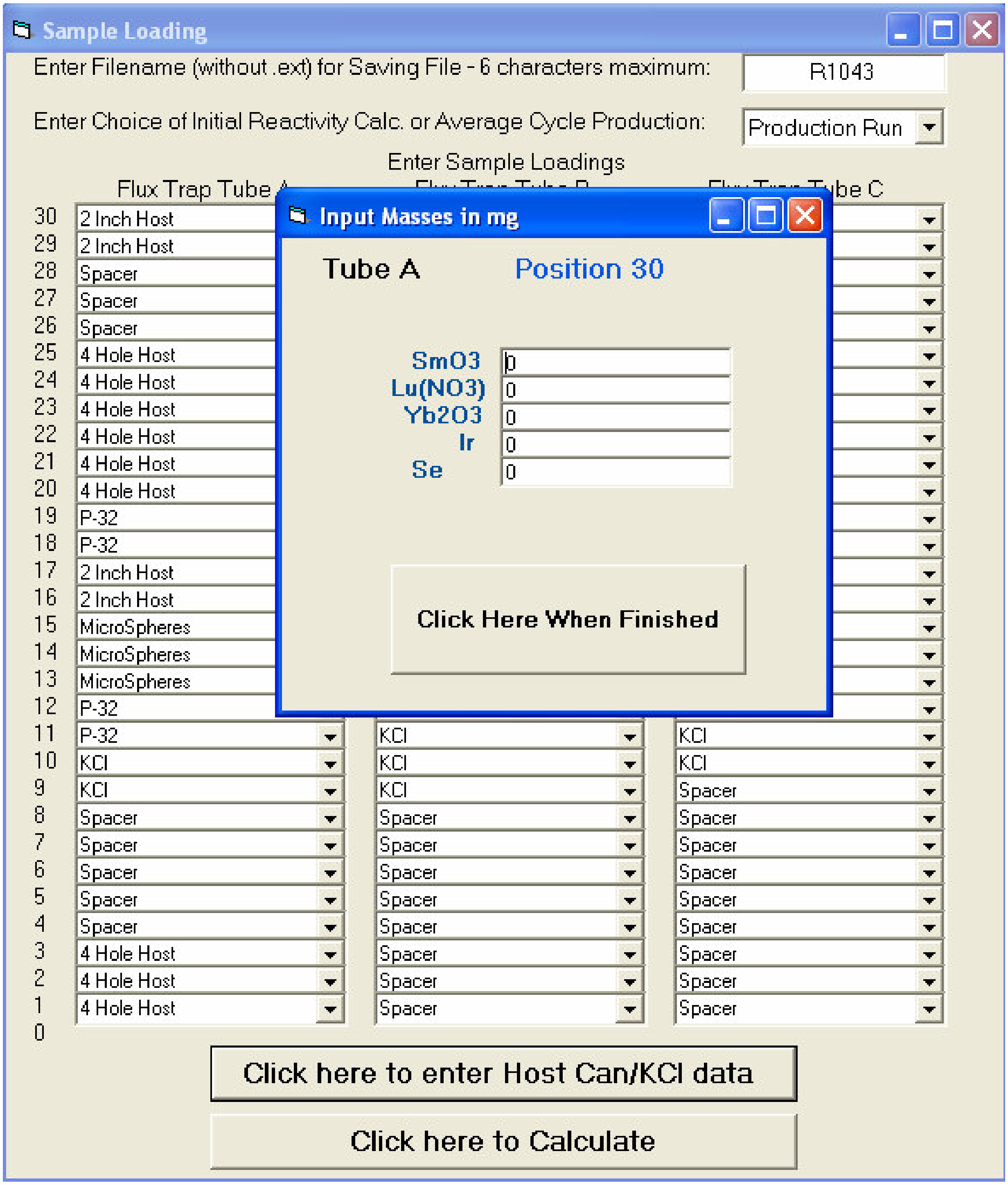
Enter Filename (without .ext) for Saving File - 6 characters maximum: R1043

Enter Choice of Initial Reactivity Calc. or Average Cycle Production: Production Run

Enter Sample Loadings

	Flux Trap Tube A	Flux Trap Tube B	Flux Trap Tube C
30	2 Inch Host	Spacer	Spacer
29	2 Inch Host	Spacer	Spacer
28	Spacer	Spacer	Spacer
27	Spacer	Spacer	Spacer
26	Spacer	P-33	4 Hole Host
25	4 Hole Host	P-33	4 Hole Host
24	4 Hole Host	P-33	4 Hole Host
23	4 Hole Host	P-33	P-33
22	4 Hole Host	P-33	P-33
21	4 Hole Host	P-33	P-33
20	4 Hole Host	P-32	4 Hole Host
19		P-32	4 Hole Host
18		P-32	4 Hole Host
17		P-32	P-32
16		P-32	P-32
15		P-32	P-32
14		P-32	P-32
13		P-32	KCl
12	P-32	KCl	KCl
11	P-32	KCl	KCl
10	KCl	KCl	KCl
9	KCl	KCl	Spacer
8	Spacer	Spacer	Spacer
7	Spacer	Spacer	Spacer
6	Spacer	Spacer	Spacer
5	Spacer	Spacer	Spacer
4	Spacer	Spacer	Spacer
3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Figure 7-2 MFTM Package GUI – Loading Input



Enter Filename (without .ext) for Saving File - 6 characters maximum: R1043

Enter Choice of Initial Reactivity Calc. or Average Cycle Production: Production Run

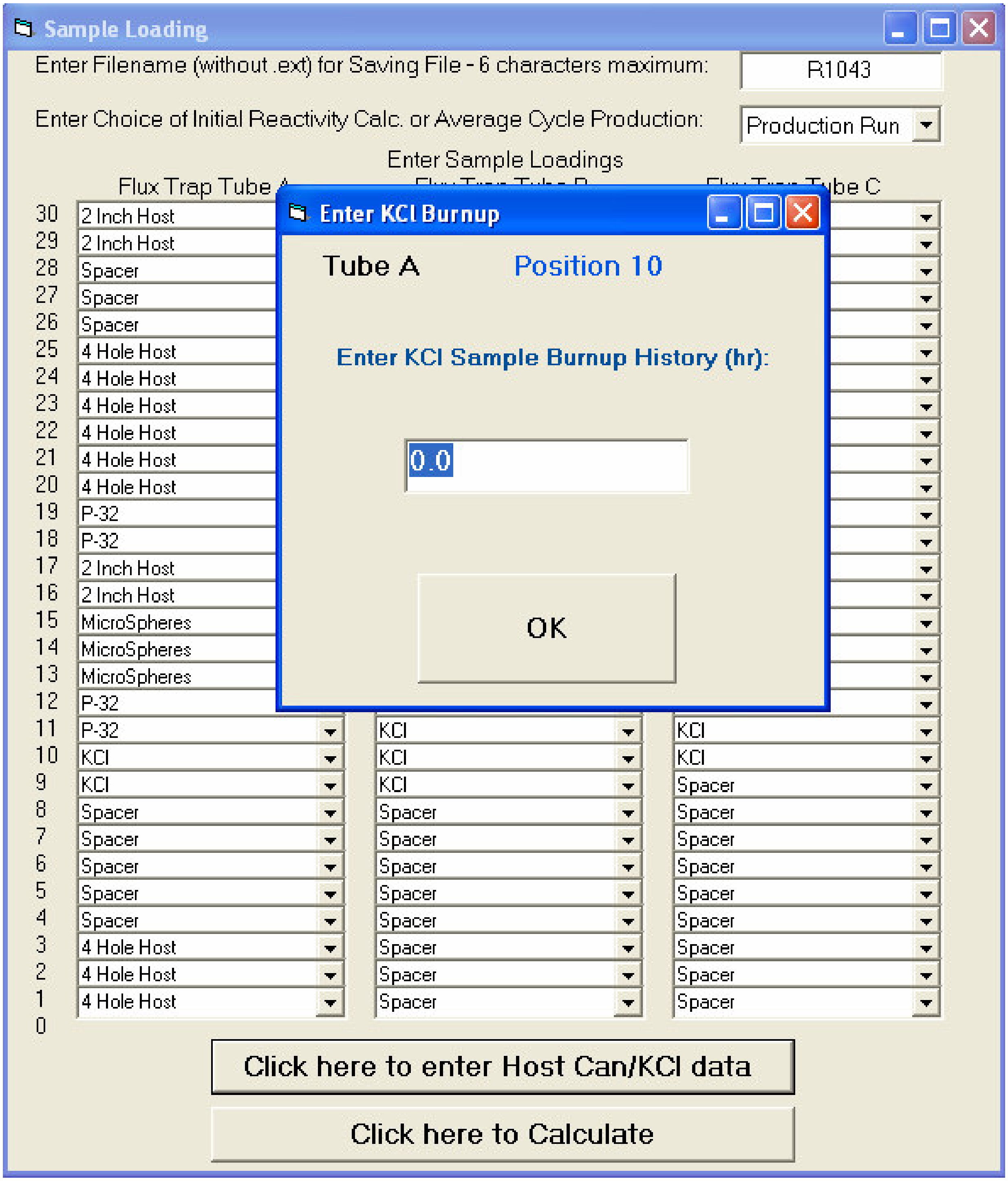
Enter Sample Loadings

	Flux Trap Tube A	Flux Trap Tube B	Flux Trap Tube C
30	2 Inch Host		
29	2 Inch Host		
28	Spacer		
27	Spacer		
26	Spacer		
25	4 Hole Host		
24	4 Hole Host		
23	4 Hole Host		
22	4 Hole Host		
21	4 Hole Host		
20	4 Hole Host		
19	P-32		
18	P-32		
17	2 Inch Host		
16	2 Inch Host		
15	MicroSpheres		
14	MicroSpheres		
13	MicroSpheres		
12	P-32		
11	P-32	KCl	KCl
10	KCl	KCl	KCl
9	KCl	KCl	Spacer
8	Spacer	Spacer	Spacer
7	Spacer	Spacer	Spacer
6	Spacer	Spacer	Spacer
5	Spacer	Spacer	Spacer
4	Spacer	Spacer	Spacer
3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Tube A Position 30

SmO3: 0
Lu(NO3): 0
Yb2O3: 0
Ir: 0
Se: 0

Figure 7-3 MFTM Package GUI – Target Sample Data Input



Enter Filename (without .ext) for Saving File - 6 characters maximum: R1043

Enter Choice of Initial Reactivity Calc. or Average Cycle Production: Production Run

Enter Sample Loadings

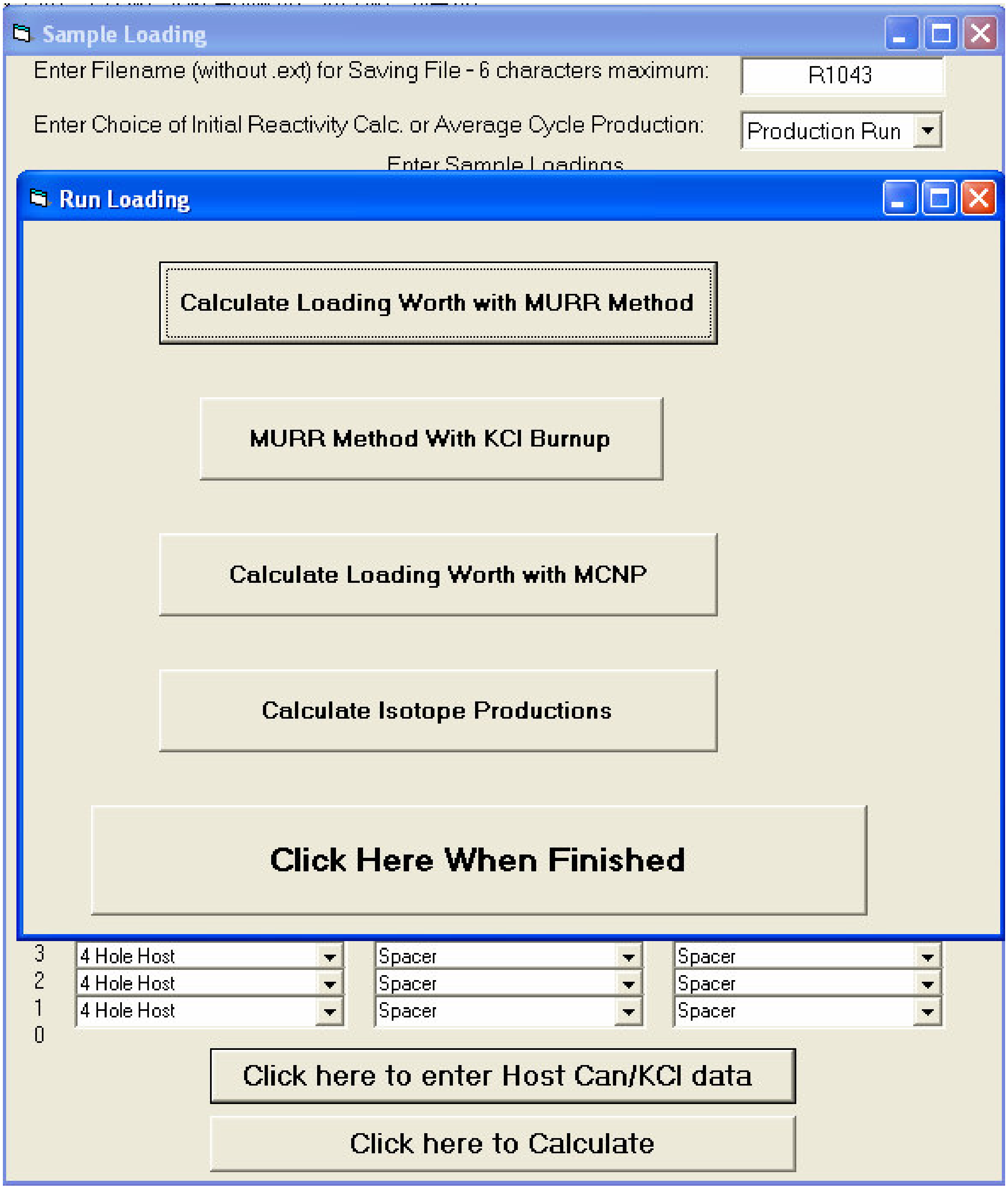
	Flux Trap Tube A	Flux Trap Tube B	Flux Trap Tube C
30	2 Inch Host		
29	2 Inch Host		
28	Spacer		
27	Spacer		
26	Spacer		
25	4 Hole Host		
24	4 Hole Host		
23	4 Hole Host		
22	4 Hole Host		
21	4 Hole Host		
20	4 Hole Host		
19	P-32		
18	P-32		
17	2 Inch Host		
16	2 Inch Host		
15	MicroSpheres		
14	MicroSpheres		
13	MicroSpheres		
12	P-32		
11	P-32	KCl	KCl
10	KCl	KCl	KCl
9	KCl	KCl	Spacer
8	Spacer	Spacer	Spacer
7	Spacer	Spacer	Spacer
6	Spacer	Spacer	Spacer
5	Spacer	Spacer	Spacer
4	Spacer	Spacer	Spacer
3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Tube A Position 10

Enter KCl Sample Burnup History (hr):

0.0

Figure 7-4 MFTM Package GUI – KCl Burnup Time Input

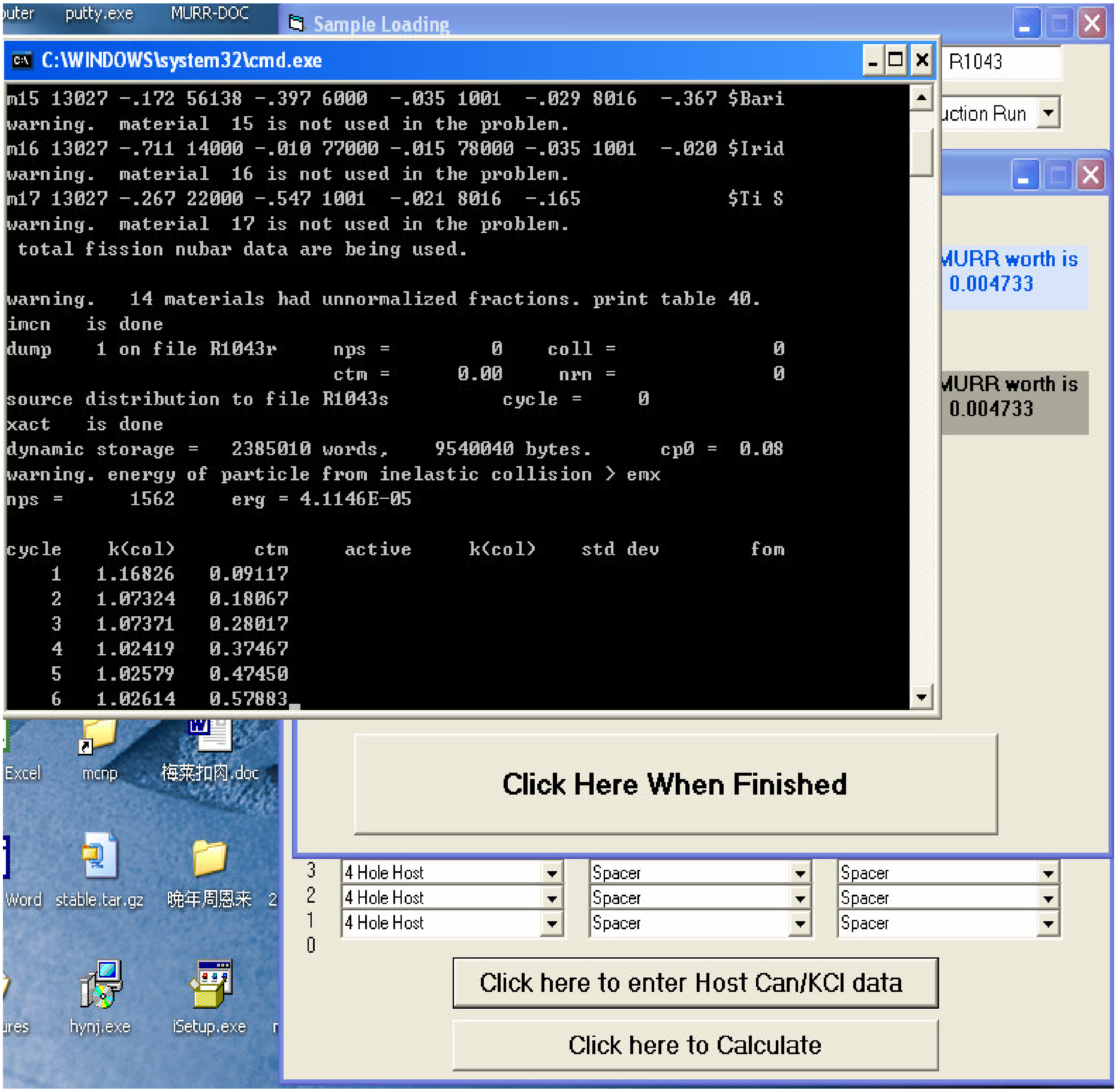


Enter Filename (without .ext) for Saving File - 6 characters maximum: R1043

Enter Choice of Initial Reactivity Calc. or Average Cycle Production: Production Run

3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Figure 7-5 MFTM Package GUI – Run Program



```
m15 13027 -.172 56138 -.397 6000  -.035 1001  -.029 8016  -.367 $Bari
warning.  material  15 is not used in the problem.
m16 13027 -.711 14000 -.010 77000 -.015 78000 -.035 1001  -.020 $Irid
warning.  material  16 is not used in the problem.
m17 13027 -.267 22000 -.547 1001  -.021 8016  -.165            $Ti $
warning.  material  17 is not used in the problem.
 total fission nubar data are being used.

warning.   14 materials had unnormalized fractions. print table 40.
imcn   is done
dump    1 on file R1043r     nps =         0    coll =              0
                             ctm =      0.00     nrn =              0
source distribution to file R1043s          cycle =     0
xact   is done
dynamic storage =    2385010 words,    9540040 bytes.      cp0 =  0.08
warning. energy of particle from inelastic collision > emx
nps =      1562      erg = 4.1146E-05

cycle    k(col)       ctm      active     k(col)    std dev        fom
    1    1.16826    0.09117
    2    1.07324    0.18067
    3    1.07371    0.28017
    4    1.02419    0.37467
    5    1.02579    0.47450
    6    1.02614    0.57883
```

R1043

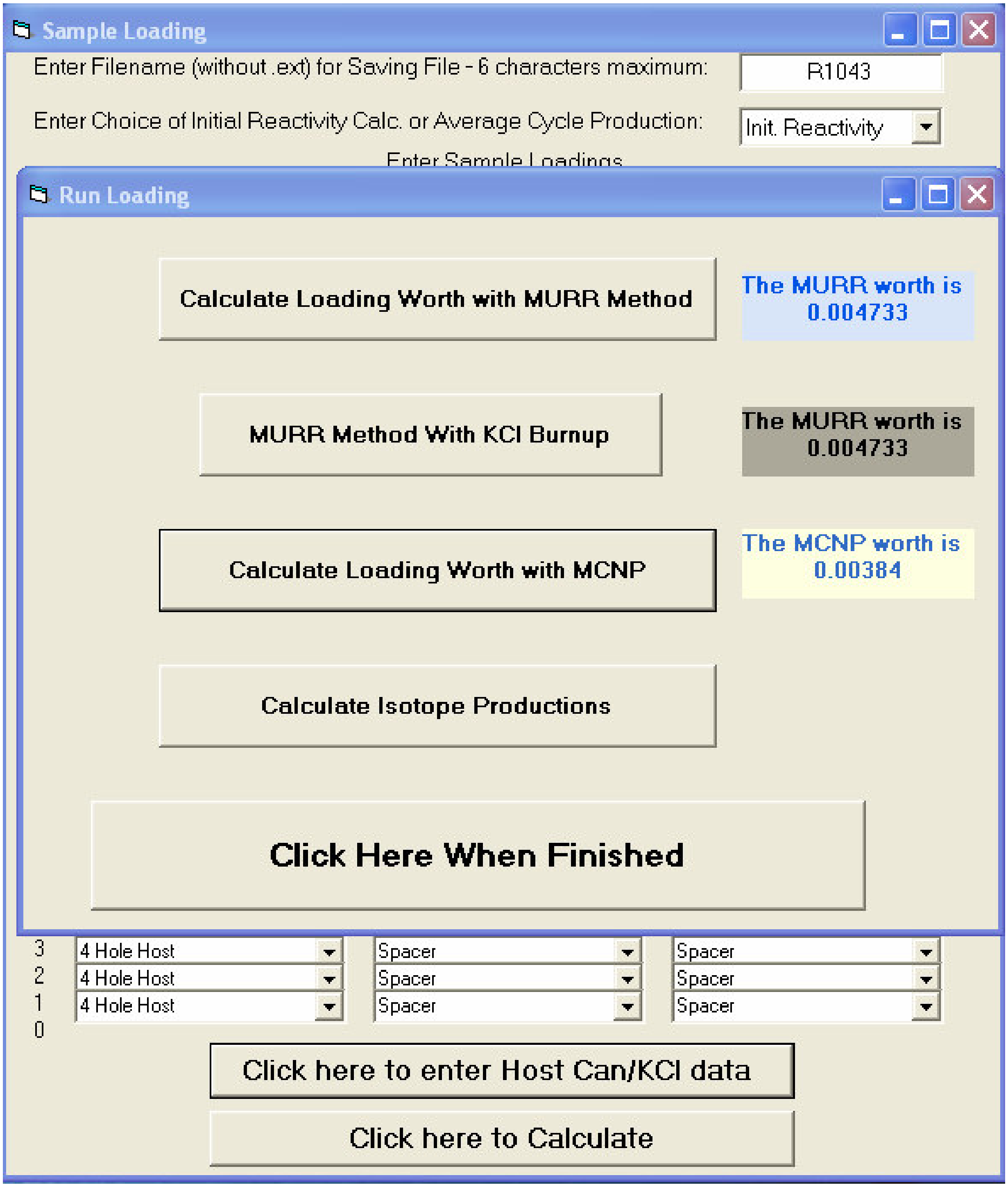
uction Run

MURR worth is
0.004733

MURR worth is
0.004733

3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Figure 7-6 MFTM Package GUI – Program Running



Enter Filename (without .ext) for Saving File - 6 characters maximum: R1043

Enter Choice of Initial Reactivity Calc. or Average Cycle Production: Init. Reactivity

The MURR worth is 0.004733

The MURR worth is 0.004733

The MCNP worth is 0.00384

3	4 Hole Host	Spacer	Spacer
2	4 Hole Host	Spacer	Spacer
1	4 Hole Host	Spacer	Spacer
0			

Figure 7-7 MFTM Package GUI – Output

CHAPTER 8

SUMMARY

MURR Flux Trap Model (MFTM) has been developed and benchmarked in this research to simulate the University of Missouri Research Reactor (MURR) reactor core and flux trap. The MURR is the highest power university research reactor and one of the few facilities for producing reactor-produced isotopes in the country. The MURR can supply high specific activity radioisotopes that are used for clinic trials and medical research. Located in the center island tube of the reactor core, the flux trap is MURR's highest flux irradiating position with flux capability of $6x10^{14}$ n/(cm^2 sec).

To satisfy reactivity safety requirement and to optimize loadings for economical consideration, it is important for the MURR to predict the reactivity worth of flux trap loadings and the isotopes products. The function of the MFTM model is to provide such an analytical tool to calculate the loading reactivity worth and isotopes production.

The MFTM model consists of two parts: MCNP and MonteBurns. The MCNP model carries out neutron transport calculations and predicts the reactivity worth of sample loading in the flux trap by using MCNP code which bases on the Monte Carol method. The model was benchmarked with the experimental data provided by the MURR. The results showed that the model worked well for some loadings while it gave different results for others. The original model was intensively analyzed for possible problems. Over-prediction of the negative worth of KCl samples was determined to be the cause of most of the deviation between the model and experimentally measured results. The original model was refined with the consideration of the self-shielding effect and burnup effect. The modified MCNP model has predicted the loading reactivity worth closer to the expected value, but the results appear to have a nearly constant bias relative to the experimental results. Further study on the model with loadings which have no or one KCl sample yielded very good prediction on loading worth with 10 to 20 percent deviation from measurement data. Smaller average flux assumption made in burnup effect analysis is believed to the reason for different prediction accuracy of MCNP model for loadings with different numbers of KCl samples.

The MonteBurns model predicts isotope production from the target sample irradiated in the flux trap by solving the general nuclide depletion equation. It includes MCNP input and MonteBurns input for a specific irradiated loading. Seventeen loadings has been provided for the benchmarking purpose for two different isotope productions, Holmium-166 and Lutetium-177. The model predicted the Holmium-166 production very well, with less than 10% error from the measured activity in general. The prediction of Lutetium-177 production by the model shows a consistent underestimation of approximately 20% compared to measurement.

An automated package was programmed to integrate the MCNP model and MonteBurns model with Visual Basic language for efficient use. After the user inputs the sample loading arrangement, target sample information, and KCl burnup history, the package will automatically create the MCNP input and/or MonteBurns input specific for the loading and then proceed with reactivity worth or isotopes production calculations according to the user's requirements. The package has been successfully run both on a Intel Pentium PC and the MURR MCNP Server.

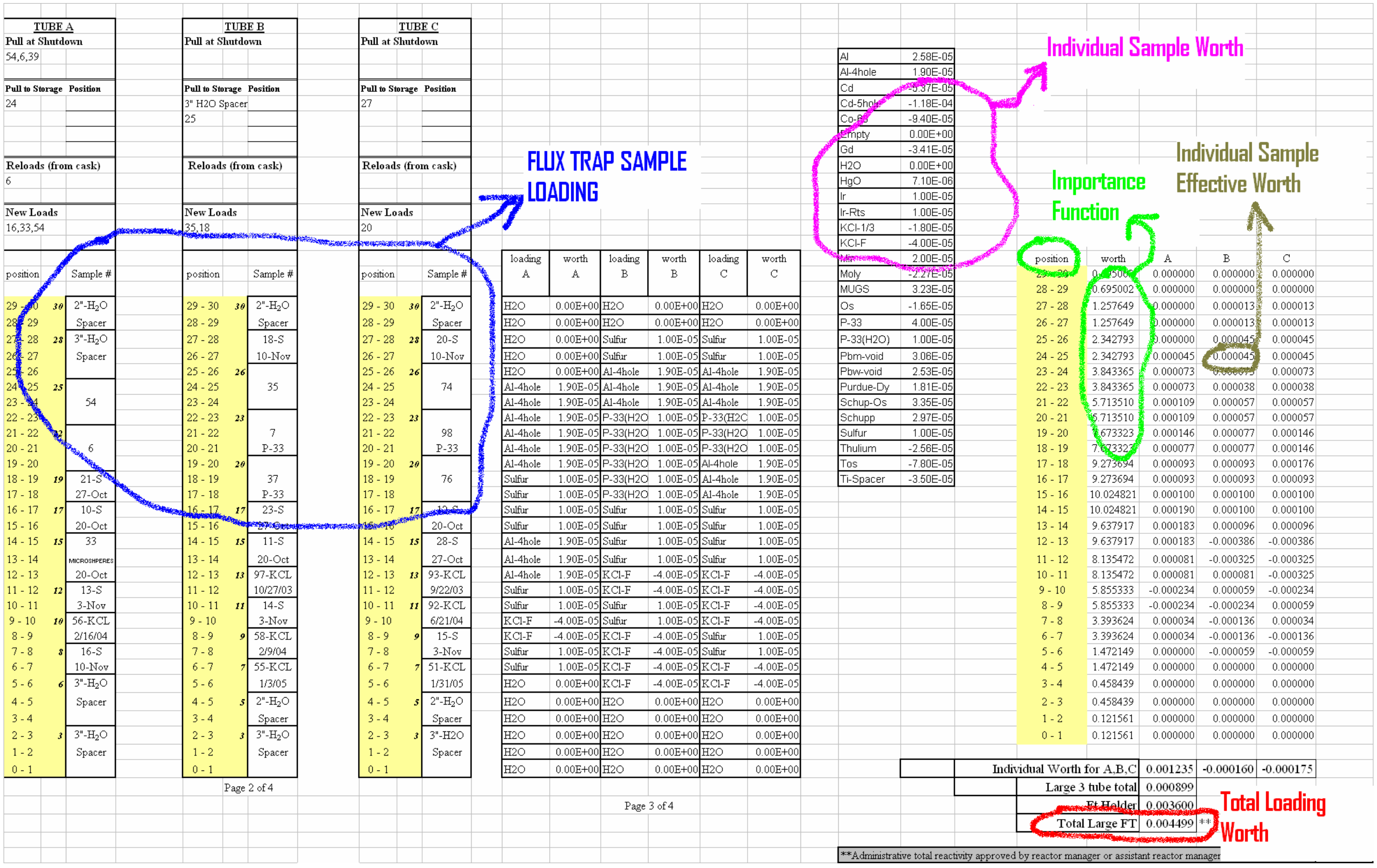
Future studies are suggested to make necessary improvements on the MFTM model. First, reevaluate the assumed average flux used in KCl burnup calculation and the change on loading worth prediction. With a higher average flux in burnup analysis, effective KCl contents contributed to the negative reactivity worth will decrease and the overall loading worth will be more positive. This will be more significant if there are more numbers of KCl sample in the loading.

Second, MonteBurns parameters for specific isotope irradiation should be optimized. This may include the selection of general ORIGEN2 cross-section libraries for the MURR reactor and specific MCNP cross-section library for irradiated isotope. The ORIGEN2 package contains a list of over fifty different cross-section libraries for different types of systems from which the user can choose. About ten of these libraries are for pressurized water reactors (PWR). The *PWRU* library is for a typical PWR of ^{235}U-enriched UO_2 with a burnup of 33,000 MWd/MTU and was chosen in the MFTM model. Other kinds of libraries may be used in the model in the future to see whether there is one more proper to represent the MURR reactor system. The effect of using different MCNP cross-section library for irradiated isotope has been shown in Section 5.2.2 on Lutetium-177 production. For other isotope production calculations, it may be worth trying different MCNP library in the model for better prediction.

Third, develop a full-sized, menu-driven program to fulfill the entire requirement for flux trap loading irradiation. The new program may include a database of old loadings and irradiated samples, enable the user to easily setup and optimize new loading that meets the requirement, and output the loading sheet that has similar format to the one the MURR is using now.

APPENDIX 1

A TYPICAL SPREAD SHEET FOR MURR METHOD



TUBE A

Pull at Shutdown
54,6,39

Pull to Storage Position
24

Reloads (from cask)
6

New Loads
16,33,54

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28	28	3"-H_2O
26 - 27		Spacer
25 - 26		
24 - 25	25	
23 - 24		54
22 - 23		
21 - 22	22	
20 - 21		6
19 - 20		
18 - 19	19	21-S
17 - 18		27-Oct
16 - 17	17	10-S
15 - 16		20-Oct
14 - 15	15	33
13 - 14		MICROSHPERES
12 - 13		20-Oct
11 - 12	12	13-S
10 - 11		3-Nov
9 - 10	10	56-KCL
8 - 9		2/16/04
7 - 8	8	16-S
6 - 7		10-Nov
5 - 6	6	3"-H_2O
4 - 5		Spacer
3 - 4		
2 - 3	3	3"-H_2O
1 - 2		Spacer
0 - 1		

TUBE B

Pull at Shutdown

Pull to Storage Position
3" H2O Spacer
25

Reloads (from cask)

New Loads
35,18

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28		18-S
26 - 27		10-Nov
25 - 26	26	
24 - 25		35
23 - 24		
22 - 23	23	
21 - 22		7
20 - 21		P-33
19 - 20	20	
18 - 19		37
17 - 18		P-33
16 - 17	17	23-S
15 - 16		27-Oct
14 - 15	15	11-S
13 - 14		20-Oct
12 - 13	13	97-KCL
11 - 12		10/27/03
10 - 11	11	14-S
9 - 10		3-Nov
8 - 9	9	58-KCL
7 - 8		2/9/04
6 - 7	7	55-KCL
5 - 6		1/3/05
4 - 5	5	2"-H_2O
3 - 4		Spacer
2 - 3	3	3"-H_2O
1 - 2		Spacer
0 - 1		

Page 2 of 4

TUBE C

Pull at Shutdown

Pull to Storage Position
27

Reloads (from cask)

New Loads
20

position		Sample #
29 - 30	30	2"-H_2O
28 - 29		Spacer
27 - 28	28	20-S
26 - 27		10-Nov
25 - 26	26	
24 - 25		74
23 - 24		
22 - 23	23	
21 - 22		98
20 - 21		P-33
19 - 20	20	
18 - 19		76
17 - 18		
16 - 17	17	12-S
15 - 16		20-Oct
14 - 15	15	28-S
13 - 14		27-Oct
12 - 13	13	93-KCL
11 - 12		9/22/03
10 - 11	11	92-KCL
9 - 10		6/21/04
8 - 9	9	15-S
7 - 8		3-Nov
6 - 7	7	51-KCL
5 - 6		1/31/05
4 - 5	5	2"-H_2O
3 - 4		Spacer
2 - 3	3	3"-H2O
1 - 2		Spacer
0 - 1		

loading A	worth A	loading B	worth B	loading C	worth C
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	Sulfur	1.00E-05	Sulfur	1.00E-05
H2O	0.00E+00	Sulfur	1.00E-05	Sulfur	1.00E-05
H2O	0.00E+00	Al-4hole	1.90E-05	Al-4hole	1.90E-05
Al-4hole	1.90E-05	Al-4hole	1.90E-05	Al-4hole	1.90E-05
Al-4hole	1.90E-05	Al-4hole	1.90E-05	Al-4hole	1.90E-05
Al-4hole	1.90E-05	P-33(H2O	1.00E-05	P-33(H2C	1.00E-05
Al-4hole	1.90E-05	P-33(H2O	1.00E-05	P-33(H2O	1.00E-05
Al-4hole	1.90E-05	P-33(H2O	1.00E-05	P-33(H2O	1.00E-05
Al-4hole	1.90E-05	P-33(H2O	1.00E-05	Al-4hole	1.90E-05
Sulfur	1.00E-05	P-33(H2O	1.00E-05	Al-4hole	1.90E-05
Sulfur	1.00E-05	P-33(H2O	1.00E-05	Al-4hole	1.90E-05
Sulfur	1.00E-05	Sulfur	1.00E-05	Sulfur	1.00E-05
Sulfur	1.00E-05	Sulfur	1.00E-05	Sulfur	1.00E-05
Al-4hole	1.90E-05	Sulfur	1.00E-05	Sulfur	1.00E-05
Al-4hole	1.90E-05	Sulfur	1.00E-05	Sulfur	1.00E-05
Al-4hole	1.90E-05	KCl-F	-4.00E-05	KCl-F	-4.00E-05
Sulfur	1.00E-05	KCl-F	-4.00E-05	KCl-F	-4.00E-05
Sulfur	1.00E-05	Sulfur	1.00E-05	KCl-F	-4.00E-05
KCl-F	-4.00E-05	Sulfur	1.00E-05	KCl-F	-4.00E-05
KCl-F	-4.00E-05	KCl-F	-4.00E-05	Sulfur	1.00E-05
Sulfur	1.00E-05	KCl-F	-4.00E-05	Sulfur	1.00E-05
Sulfur	1.00E-05	KCl-F	-4.00E-05	KCl-F	-4.00E-05
H2O	0.00E+00	KCl-F	-4.00E-05	KCl-F	-4.00E-05
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00
H2O	0.00E+00	H2O	0.00E+00	H2O	0.00E+00

Page 3 of 4

Al	2.58E-05
Al-4hole	1.90E-05
Cd	-5.37E-05
Cd-5hole	-1.18E-04
Co-60	-9.40E-05
Empty	0.00E+00
Gd	-3.41E-05
H2O	0.00E+00
HgO	7.10E-06
Ir	1.00E-05
Ir-Rts	1.00E-05
KCl-1/3	-1.80E-05
KCl-F	-4.00E-05
Mir	2.00E-05
Moly	-2.27E-05
MUGS	3.23E-05
Os	-1.65E-05
P-33	4.00E-05
P-33(H2O)	1.00E-05
Pbm-void	3.06E-05
Pbw-void	2.53E-05
Purdue-Dy	1.81E-05
Schup-Os	3.35E-05
Schupp	2.97E-05
Sulfur	1.00E-05
Thulium	-2.56E-05
Tos	-7.80E-05
Ti-Spacer	-3.50E-05

position	worth	A	B	C
29 - 30	0.695002	0.000000	0.000000	0.000000
28 - 29	0.695002	0.000000	0.000000	0.000000
27 - 28	1.257649	0.000000	0.000013	0.000013
26 - 27	1.257649	0.000000	0.000013	0.000013
25 - 26	2.342793	0.000000	0.000045	0.000045
24 - 25	2.342793	0.000045	0.000045	0.000045
23 - 24	3.843365	0.000073	0.000073	0.000073
22 - 23	3.843365	0.000073	0.000038	0.000038
21 - 22	5.713510	0.000109	0.000057	0.000057
20 - 21	5.713510	0.000109	0.000057	0.000057
19 - 20	7.673323	0.000146	0.000077	0.000146
18 - 19	7.673323	0.000077	0.000077	0.000146
17 - 18	9.273694	0.000093	0.000093	0.000176
16 - 17	9.273694	0.000093	0.000093	0.000093
15 - 16	10.024821	0.000100	0.000100	0.000100
14 - 15	10.024821	0.000190	0.000100	0.000100
13 - 14	9.637917	0.000183	0.000096	0.000096
12 - 13	9.637917	0.000183	-0.000386	-0.000386
11 - 12	8.135472	0.000081	-0.000325	-0.000325
10 - 11	8.135472	0.000081	0.000081	-0.000325
9 - 10	5.855333	-0.000234	0.000059	-0.000234
8 - 9	5.855333	-0.000234	-0.000234	0.000059
7 - 8	3.393624	0.000034	-0.000136	0.000034
6 - 7	3.393624	0.000034	-0.000136	-0.000136
5 - 6	1.472149	0.000000	-0.000059	-0.000059
4 - 5	1.472149	0.000000	0.000000	0.000000
3 - 4	0.458439	0.000000	0.000000	0.000000
2 - 3	0.458439	0.000000	0.000000	0.000000
1 - 2	0.121561	0.000000	0.000000	0.000000
0 - 1	0.121561	0.000000	0.000000	0.000000

Individual Worth for A,B,C	0.001235	-0.000160	-0.000175
Large 3 tube total	0.000899		
Ft Holder	0.003600		
Total Large FT	0.004499 **		

**Administrative total reactivity approved by reactor manager or assistant reactor manager

APPENDIX 2

MCNP MODEL FOR LOADING #1023 – HOMOGENEOUS

```
MURR Criticality Sample w/ FLux Trap for #1023
C  Cell cards
1  1  -1.0      -1      50 -20  11  13  15    $Flux trap
2  1  -1.0      -1      20 -16              $Water above samples
3  1  -1.0      -1      19 -50              $Water below samples
4  2  0.08256    1  -2  45 -21             $Core
5  3  -1.5       1  -2  21 -17              $Top core end plate
6  3  -1.5       1  -2  18 -45              $Bottom end plate
7  1  -1.0       1  -2  17 -16              $Water above core
8  1  -1.0       1  -2  19 -18              $Water below core
9  1  -1.0       2  -3  19 -16              $Water channel
10 4  0.0797     3  -4   9 -16             $Control Rod
11 1  -1.0       3  -4  19  -9              $Water below CR
12 1  -1.0       4  -5  19 -16               $Water gap
13 5  -1.85      5  -6  19 -16               $Be
14 6  -1.6       6  -7  19 -16               $Graphite
15 1  -1.0       7  -8  19 -16               $Water outside graphite
16 7  -2.7     -11  10  50 -20                $1st tube Al
17 7  -2.7     -13  12  50 -20                $2nd tube Al
18 7  -2.7     -15  14  50 -20                $3rd tube Al
19 14 -1.352  -10  21 -20     $Tube A loc 30
20 14 -1.352  -10  22 -21     $Tube A loc 29
21  8 -1.121  -10  23 -22    $Tube A loc 28
22  8 -1.121  -10  24 -23    $Tube A loc 27
23  8 -1.121  -10  25 -24    $Tube A loc 26
24 15 -1.352  -10  26 -25     $Tube A loc 25
25 15 -1.352  -10  27 -26     $Tube A loc 24
26 15 -1.352  -10  28 -27     $Tube A loc 23
27 16 -1.352  -10  29 -28     $Tube A loc 22
28 16 -1.352  -10  30 -29     $Tube A loc 21
29 16 -1.352  -10  31 -30     $Tube A loc 20
30 12 -1.599  -10  32 -31     $Tube A loc 19
31 12 -1.599  -10  33 -32     $Tube A loc 18
32 12 -1.599  -10  34 -33     $Tube A loc 17
33 12 -1.599  -10  35 -34     $Tube A loc 16
34 11 -1.566  -10  36 -35     $Tube A loc 15
35 11 -1.566  -10  37 -36     $Tube A loc 14
36 11 -1.566  -10  38 -37     $Tube A loc 13
37 12 -1.599  -10  39 -38     $Tube A loc 12
38 12 -1.599  -10  40 -39     $Tube A loc 11
39 10 -1.551  -10  41 -40     $Tube A loc 10
40 10 -1.551  -10  42 -41     $Tube A loc 9
41 12 -1.599  -10  43 -42     $Tube A loc 8
42 12 -1.599  -10  44 -43     $Tube A loc 7
43  8 -1.121  -10  45 -44    $Tube A loc 6
44  8 -1.121  -10  46 -45    $Tube A loc 5
45  8 -1.121  -10  47 -46    $Tube A loc 4
46  8 -1.121  -10  48 -47    $Tube A loc 3
47  8 -1.121  -10  49 -48    $Tube A loc 2
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48  8 -1.121  -10  50 -49     $Tube A loc 1
49  8 -1.121  -12  21 -20     $Tube B loc 30
50  8 -1.121  -12  22 -21     $Tube B loc 29
51  8 -1.121  -12  23 -22     $Tube B loc 28
52  8 -1.121  -12  24 -23     $Tube B loc 27
53  8 -1.121  -12  25 -24     $Tube B loc 26
54 13 -0.682  -12  26 -25     $Tube B loc 25
55 13 -0.682  -12  27 -26     $Tube B loc 24
56 13 -0.682  -12  28 -27     $Tube B loc 23
57 13 -0.682  -12  29 -28     $Tube B loc 22
58 13 -0.682  -12  30 -29     $Tube B loc 21
59 13 -0.682  -12  31 -30     $Tube B loc 20
60 12 -1.599  -12  32 -31     $Tube B loc 19
61 12 -1.599  -12  33 -32     $Tube B loc 18
62 12 -1.599  -12  34 -33     $Tube B loc 17
63 12 -1.599  -12  35 -34     $Tube B loc 16
64 12 -1.599  -12  36 -35     $Tube B loc 15
65 12 -1.599  -12  37 -36     $Tube B loc 14
66 10 -1.551  -12  38 -37     $Tube B loc 13
67 10 -1.551  -12  39 -38     $Tube B loc 12
68 10 -1.551  -12  40 -39     $Tube B loc 11
69 10 -1.551  -12  41 -40     $Tube B loc 10
70 12 -1.599  -12  42 -41     $Tube B loc 9
71 12 -1.599  -12  43 -42     $Tube B loc 8
72 10 -1.551  -12  44 -43     $Tube B loc 7
73 10 -1.551  -12  45 -44     $Tube B loc 6
74  8 -1.121  -12  46 -45     $Tube B loc 5
75  8 -1.121  -12  47 -46     $Tube B loc 4
76  8 -1.121  -12  48 -47     $Tube B loc 3
77  8 -1.121  -12  49 -48     $Tube B loc 2
78  8 -1.121  -12  50 -49     $Tube B loc 1
79  8 -1.121  -14  21 -20     $Tube C loc 30
80  8 -1.121  -14  22 -21     $Tube C loc 29
81 12 -1.599  -14  23 -22     $Tube C loc 28
82 12 -1.599  -14  24 -23     $Tube C loc 27
83 17 -1.352  -14  25 -24     $Tube C loc 26
84 17 -1.352  -14  26 -25     $Tube C loc 25
85 17 -1.352  -14  27 -26     $Tube C loc 24
86 13 -0.682  -14  28 -27     $Tube C loc 23
87 13 -0.682  -14  29 -28     $Tube C loc 22
88 13 -0.682  -14  30 -29     $Tube C loc 21
89 18 -1.352  -14  31 -30     $Tube C loc 20
90 18 -1.352  -14  32 -31     $Tube C loc 19
91 18 -1.352  -14  33 -32     $Tube C loc 18
92 12 -1.599  -14  34 -33     $Tube C loc 17
93 12 -1.599  -14  35 -34     $Tube C loc 16
94 12 -1.599  -14  36 -35     $Tube C loc 15
95 12 -1.599  -14  37 -36     $Tube C loc 14
96 10 -1.551  -14  38 -37     $Tube C loc 13
97 10 -1.551  -14  39 -38     $Tube C loc 12
98 12 -1.599  -14  40 -39     $Tube C loc 11
99 12 -1.599  -14  41 -40     $Tube C loc 10
100 10 -1.551  -14  42 -41     $Tube C loc 9
101 10 -1.551  -14  43 -42     $Tube C loc 8
102 10 -1.551  -14  44 -43     $Tube C loc 7
103 10 -1.551  -14  45 -44     $Tube C loc 6
```

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104  8 -1.121  -14  46 -45     $Tube C loc 5
105  8 -1.121  -14  47 -46     $Tube C loc 4
106  8 -1.121  -14  48 -47     $Tube C loc 3
107  8 -1.121  -14  49 -48     $Tube C loc 2
108  8 -1.121  -14  50 -49     $Tube C loc 1
109 0           16:    -19:  8              $Outside

C Surface Cards - Cylinderical
1  CZ  6.8072                           $ID of flux trap
2  CZ  15.946                           $OD of core
3  CZ  16.529                           $ID of control rod meat
4  CZ  16.785                           $OD of control rod meat
5  CZ  17.367                           $ID of Be
6  CZ  24.567                           $OD of Be
7  CZ  47.625                           $OD of Graphite
8  CZ  80.165                           $Outer edge of problem
C Surface Cards - bottom position of control rod
9  PZ  4.0
C Surface Cards - flux tap tubes
10 C/Z  0.00  2.22 1.694                   $1st Tube I.D.
11 C/Z  0.00  2.22 1.905                   $1st Tube O.D.
12 C/Z  1.92 -1.11 1.694                   $2nd Tube I.D.
13 C/Z  1.92 -1.11 1.905                   $2nd Tube O.D.
14 C/Z -1.92 -1.11 1.694                   $3rd Tube I.D.
15 C/Z -1.92 -1.11 1.905                   $3rd Tube O.D.
C Surface Cards - Verticle care parts
16 PZ  75.00                              $Top of water
17 PZ  32.38                              $Top of fuel end plate
18 PZ -32.38                              $Bottom of fuel plate
19 PZ -75.00                              $Bottom of water
C Surface Cards - Sample holder spacing
20 PZ  33.02      $Sample border #30
21 PZ  30.48      $Sample border #29, top of core
22 PZ  27.94      $Sample border #28
23 PZ  25.40      $Sample border #27
24 PZ  22.86      $Sample border #26
25 PZ  20.32      $Sample border #25
26 PZ  17.78      $Sample border #24
27 PZ  15.24      $Sample border #23
28 PZ  12.70      $Sample border #22
29 PZ  10.16      $Sample border #21
30 PZ   7.62     $Sample border #20
31 PZ   5.08     $Sample border #19
32 PZ   2.54     $Sample border #18
33 PZ   0.00     $Sample border #17
34 PZ  -2.54     $Sample border #16
35 PZ  -5.08     $Sample border #15
36 PZ  -7.62     $Sample border #14
37 PZ -10.16      $Sample border #13
38 PZ -12.70      $Sample border #12
39 PZ -15.24      $Sample border #11
40 PZ -17.78      $Sample border #10
41 PZ -20.32      $Sample border # 9
42 PZ -22.86      $Sample border # 8
43 PZ -25.40      $Sample border # 7
44 PZ -27.94      $Sample border # 6
```

```
45 PZ -30.48      $Sample border # 5, bottom of core
46 PZ -33.02      $Sample border # 4
47 PZ -35.56      $Sample border # 3
48 PZ -38.10      $Sample border # 2
49 PZ -40.64      $Sample border # 1
50 PZ -43.18      $Sample border # 0

C Data Cards
IMP:N 1 107r 0
E0 1.0E-7 10
PHYS:N 10. 10. 3E-6
M1  1001 0.6667 8016 0.3333                              $H2O
M2  92235 4.E-3  92238 3.22E-4 1001 .4566
           54135 1.8E-7  8016 .2277   13027 .310698       $CORE
M3  13027 .4 1001 .4 8016 .2                             $End plate
M4  13027 0.3074 5010 0.1230 5011 0.5094 6000 0.0602    $CR
M5  4009 1.0                                        $Be
M6  6000 1.0                                        $Graphite
M7  13027 1.0                                        $Al
M8  13027 -.171 1001  -.092 8016  -.736          $Spacer
M9  13027 -.710 14000 -.014 67165 -.001 1001  -.023 8016  -.252 $Holmium
M10 13027 -.266 19000 -.290 17000 -.257 1001  -.021 8016  -.165 $KCl
M11 13027 -.713 14000 -.018 39089 -.007 1001  -.020 8016  -.242 $MicroSpheres
M12 13027 -.294 16000 -.526 1001  -.020 8016  -.160           $P-32
M13 13027 -.282 16032 -.295 1001  -.047 8016  -.376           $P-33
M14 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $2 Hole Host
M15 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M16 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M17 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M18 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
KCODE 8000 1.20 50 4050
KSRC 10.0 0.0 0.0
```

APPENDIX 3

MCNP MODEL FOR LOADING #1024 – HOMOGENEOUS

```
MURR Criticality Sample w/ FLux Trap for #1024
C  Cell cards
1  1  -1.0      -1      50 -20  11  13  15    $Flux trap
2  1  -1.0      -1      20 -16               $Water above samples
3  1  -1.0      -1      19 -50               $Water below samples
4  2  0.08256    1  -2  45 -21                 $Core
5  3  -1.5       1  -2  21 -17               $Top core end plate
6  3  -1.5       1  -2  18 -45               $Bottom end plate
7  1  -1.0       1  -2  17 -16               $Water above core
8  1  -1.0       1  -2  19 -18               $Water below core
9  1  -1.0       2  -3  19 -16               $Water channel
10 4  0.0797     3  -4   9 -16                 $Control Rod
11 1  -1.0       3  -4  19  -9               $Water below CR
12 1  -1.0       4  -5  19 -16                $Water gap
13 5  -1.85      5  -6  19 -16                 $Be
14 6  -1.6       6  -7  19 -16                $Graphite
15 1  -1.0       7  -8  19 -16                $Water outside graphite
16 7  -2.7     -11  10  50 -20                 $1st tube Al
17 7  -2.7     -13  12  50 -20                 $2nd tube Al
18 7  -2.7     -15  14  50 -20                 $3rd tube Al
19  8 -1.121  -10  21 -20    $Tube A loc 30
20  8 -1.121  -10  22 -21    $Tube A loc 29
21  8 -1.121  -10  23 -22    $Tube A loc 28
22  8 -1.121  -10  24 -23    $Tube A loc 27
23  8 -1.121  -10  25 -24    $Tube A loc 26
24 15 -1.352  -10  26 -25    $Tube A loc 25
25 15 -1.352  -10  27 -26    $Tube A loc 24
26 15 -1.352  -10  28 -27    $Tube A loc 23
27 16 -1.352  -10  29 -28    $Tube A loc 22
28 16 -1.352  -10  30 -29    $Tube A loc 21
29 16 -1.352  -10  31 -30    $Tube A loc 20
30 12 -1.599  -10  32 -31    $Tube A loc 19
31 12 -1.599  -10  33 -32    $Tube A loc 18
32 12 -1.599  -10  34 -33    $Tube A loc 17
33 12 -1.599  -10  35 -34    $Tube A loc 16
34 11 -1.566  -10  36 -35    $Tube A loc 15
35 11 -1.566  -10  37 -36    $Tube A loc 14
36 11 -1.566  -10  38 -37    $Tube A loc 13
37 12 -1.599  -10  39 -38    $Tube A loc 12
38 12 -1.599  -10  40 -39    $Tube A loc 11
39 10 -1.551  -10  41 -40    $Tube A loc 10
40 10 -1.551  -10  42 -41    $Tube A loc 9
41 12 -1.599  -10  43 -42    $Tube A loc 8
42 12 -1.599  -10  44 -43    $Tube A loc 7
43  8 -1.121  -10  45 -44    $Tube A loc 6
44  8 -1.121  -10  46 -45    $Tube A loc 5
45  8 -1.121  -10  47 -46    $Tube A loc 4
46  8 -1.121  -10  48 -47    $Tube A loc 3
47  8 -1.121  -10  49 -48    $Tube A loc 2
48  8 -1.121  -10  50 -49    $Tube A loc 1
```

```
49  8 -1.121  -12  21 -20     $Tube B loc 30
50  8 -1.121  -12  22 -21     $Tube B loc 29
51  8 -1.121  -12  23 -22     $Tube B loc 28
52  8 -1.121  -12  24 -23     $Tube B loc 27
53  8 -1.121  -12  25 -24     $Tube B loc 26
54 13 -0.682  -12  26 -25     $Tube B loc 25
55 13 -0.682  -12  27 -26     $Tube B loc 24
56 13 -0.682  -12  28 -27     $Tube B loc 23
57 13 -0.682  -12  29 -28     $Tube B loc 22
58 13 -0.682  -12  30 -29     $Tube B loc 21
59 13 -0.682  -12  31 -30     $Tube B loc 20
60 12 -1.599  -12  32 -31     $Tube B loc 19
61 12 -1.599  -12  33 -32     $Tube B loc 18
62 12 -1.599  -12  34 -33     $Tube B loc 17
63 12 -1.599  -12  35 -34     $Tube B loc 16
64 12 -1.599  -12  36 -35     $Tube B loc 15
65 12 -1.599  -12  37 -36     $Tube B loc 14
66 10 -1.551  -12  38 -37     $Tube B loc 13
67 10 -1.551  -12  39 -38     $Tube B loc 12
68 10 -1.551  -12  40 -39     $Tube B loc 11
69 10 -1.551  -12  41 -40     $Tube B loc 10
70 12 -1.599  -12  42 -41     $Tube B loc 9
71 12 -1.599  -12  43 -42     $Tube B loc 8
72 10 -1.551  -12  44 -43     $Tube B loc 7
73 10 -1.551  -12  45 -44     $Tube B loc 6
74  8 -1.121  -12  46 -45     $Tube B loc 5
75  8 -1.121  -12  47 -46     $Tube B loc 4
76  8 -1.121  -12  48 -47     $Tube B loc 3
77  8 -1.121  -12  49 -48     $Tube B loc 2
78  8 -1.121  -12  50 -49     $Tube B loc 1
79  8 -1.121  -14  21 -20     $Tube C loc 30
80  8 -1.121  -14  22 -21     $Tube C loc 29
81 12 -1.599  -14  23 -22     $Tube C loc 28
82 12 -1.599  -14  24 -23     $Tube C loc 27
83 17 -1.352  -14  25 -24     $Tube C loc 26
84 17 -1.352  -14  26 -25     $Tube C loc 25
85 17 -1.352  -14  27 -26     $Tube C loc 24
86 13 -0.682  -14  28 -27     $Tube C loc 23
87 13 -0.682  -14  29 -28     $Tube C loc 22
88 13 -0.682  -14  30 -29     $Tube C loc 21
89 18 -1.352  -14  31 -30     $Tube C loc 20
90 18 -1.352  -14  32 -31     $Tube C loc 19
91 18 -1.352  -14  33 -32     $Tube C loc 18
92 12 -1.599  -14  34 -33     $Tube C loc 17
93 12 -1.599  -14  35 -34     $Tube C loc 16
94 12 -1.599  -14  36 -35     $Tube C loc 15
95 12 -1.599  -14  37 -36     $Tube C loc 14
96 10 -1.551  -14  38 -37     $Tube C loc 13
97 10 -1.551  -14  39 -38     $Tube C loc 12
98 12 -1.599  -14  40 -39     $Tube C loc 11
99 12 -1.599  -14  41 -40     $Tube C loc 10
100 10 -1.551  -14  42 -41     $Tube C loc 9
101 10 -1.551  -14  43 -42     $Tube C loc 8
102 10 -1.551  -14  44 -43     $Tube C loc 7
103 10 -1.551  -14  45 -44     $Tube C loc 6
104  8 -1.121  -14  46 -45     $Tube C loc 5
```

```
105  8 -1.121  -14  47 -46     $Tube C loc 4
106  8 -1.121  -14  48 -47     $Tube C loc 3
107  8 -1.121  -14  49 -48     $Tube C loc 2
108  8 -1.121  -14  50 -49     $Tube C loc 1
109 0           16:    -19:  8             $Outside

C Surface Cards - Cylinderical
1  CZ  6.8072                          $ID of flux trap
2  CZ  15.946                          $OD of core
3  CZ  16.529                          $ID of control rod meat
4  CZ  16.785                          $OD of control rod meat
5  CZ  17.367                          $ID of Be
6  CZ  24.567                          $OD of Be
7  CZ  47.625                          $OD of Graphite
8  CZ  80.165                          $Outer edge of problem
C Surface Cards - bottom position of control rod
9  PZ  4.0
C Surface Cards - flux tap tubes
10 C/Z  0.00  2.22 1.694                   $1st Tube I.D.
11 C/Z  0.00  2.22 1.905                   $1st Tube O.D.
12 C/Z  1.92 -1.11 1.694                   $2nd Tube I.D.
13 C/Z  1.92 -1.11 1.905                   $2nd Tube O.D.
14 C/Z -1.92 -1.11 1.694                   $3rd Tube I.D.
15 C/Z -1.92 -1.11 1.905                   $3rd Tube O.D.
C Surface Cards - Verticle care parts
16 PZ  75.00                            $Top of water
17 PZ  32.38                            $Top of fuel end plate
18 PZ -32.38                            $Bottom of fuel plate
19 PZ -75.00                            $Bottom of water
C Surface Cards - Sample holder spacing
20 PZ  33.02      $Sample border #30
21 PZ  30.48      $Sample border #29, top of core
22 PZ  27.94      $Sample border #28
23 PZ  25.40      $Sample border #27
24 PZ  22.86      $Sample border #26
25 PZ  20.32      $Sample border #25
26 PZ  17.78      $Sample border #24
27 PZ  15.24      $Sample border #23
28 PZ  12.70      $Sample border #22
29 PZ  10.16      $Sample border #21
30 PZ   7.62     $Sample border #20
31 PZ   5.08     $Sample border #19
32 PZ   2.54     $Sample border #18
33 PZ   0.00     $Sample border #17
34 PZ  -2.54     $Sample border #16
35 PZ  -5.08     $Sample border #15
36 PZ  -7.62     $Sample border #14
37 PZ -10.16      $Sample border #13
38 PZ -12.70      $Sample border #12
39 PZ -15.24      $Sample border #11
40 PZ -17.78      $Sample border #10
41 PZ -20.32      $Sample border # 9
42 PZ -22.86      $Sample border # 8
43 PZ -25.40      $Sample border # 7
44 PZ -27.94      $Sample border # 6
45 PZ -30.48      $Sample border # 5, bottom of core
```

```
46 PZ -33.02     $Sample border # 4
47 PZ -35.56     $Sample border # 3
48 PZ -38.10     $Sample border # 2
49 PZ -40.64     $Sample border # 1
50 PZ -43.18     $Sample border # 0

C Data Cards
IMP:N 1 107r 0
E0 1.0E-7 10
PHYS:N 10. 10. 3E-6
M1  1001 0.6667 8016 0.3333                                 $H2O
M2  92235 4.E-3  92238 3.22E-4 1001 .4566
            54135 1.8E-7  8016 .2277   13027 .310698      $CORE
M3  13027 .4 1001 .4 8016 .2                               $End plate
M4  13027 0.3074 5010 0.1230 5011 0.5094 6000 0.0602          $CR
M5  4009 1.0                                      $Be
M6  6000 1.0                                      $Graphite
M7  13027 1.0                                      $Al
M8  13027 -.171 1001  -.092 8016  -.736                     $Spacer
M9  13027 -.710 14000 -.014 67165 -.001 1001  -.023 8016  -.252 $Holmium
M10 13027 -.266 19000 -.290 17000 -.257 1001  -.021 8016  -.165 $KCl
M11 13027 -.713 14000 -.018 39089 -.007 1001  -.020 8016  -.242 $MicroSpheres
M12 13027 -.294 16000 -.526 1001  -.020 8016  -.160           $P-32
M13 13027 -.282 16032 -.295 1001  -.047 8016  -.376           $P-33
M14 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $2 Hole Host
M15 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M16 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M17 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M18 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
KCODE 8000 1.20 50 4050
KSRC 10.0 0.0 0.0
```

APPENDIX 4

MCNP DETAILED MODEL FOR LOADING #1023

```
current fuel - full core - reactivity effects of flux trap tubes
c
c     this begins the second set of runs made to find the effect of
c     moving small samples from the flux trap irradiation positions. if
c     the reactivity effects are within allowable limits for
c     "movable" experiments, then it will allow us to move samples in
c     and out of the flux trap while the reactor is operating.
c
c     this is the fifth run. in this case also two tubes are filled
c     completely with water. in the middle of the third tube a thin al
c     rod is inserted. the diameter of this al rod is the same as the
c     proposed diameter of the new small tubes (0.75" o.d). walt wanted
c     this case since it is easy to measure the reactivity of this
c     case during startup. note: new surfaces had to be designed to
c     accomplish the above task
c
c     control rods are kept at 4" above the core centerline (17"
c     withdrawn). this is done because in order to benchmark the mcnp
c     calculations, we can compare the measured reactivity worths
c     with mcnp results. to do this we have to simulate the conditions
c     present during actual measurements. all the reactivity worth
c     measurements (such as the worth of the 3 tubes in the flux trap)
c     are made under clean core conditions (i.e., before any xenon
c     buildup). hence they are made at low power and with all rods almost
c     fully inserted).
c
c     *** control rods are kept at 4" above core centerline ***
c     *** histories tracked = 3,50,000 (70 cycles) for this case ***
c
c
1     1  -1.0   -1       196 -120   181  183  185    $flux trap(with tubes)
2     2  -2.7   -2   1   196 -120               $inner pressure vessel
c
c
c    right side core description starts from here
c
C Cell Cards
3     1  -1.00  -99  2   193 -118 -122  170  128      $water gap
4     1  -1.00  -99  2   193 -118 -134  135  128 121  $water gap
5     1  -1.00  -99  2   193 -118 -127  129      121  $water gap
6     1  -1.00  -99  2   193 -118 -140  141 -128 121  $water gap
7     1  -1.00  -99  2   193 -118 -122  170 -128      $water gap
8     2  -2.7   -99  2   193 -118  122 -123  128 121  $aluminum side plate
9     2  -2.7   -99  2   193 -118 -133  134  128 121  $aluminum side plate
10     2  -2.7   -99  2   193 -118 -135  136  128 121  $aluminum side plate
11     2  -2.7   -99  2   193 -118 -126  127  128 121  $aluminum side plate
12     2  -2.7   -99  2   193 -118 -129  130 -128 121  $aluminum side plate
13     2  -2.7   -99  2   193 -118 -139  140 -128 121  $aluminum side plate
14     2  -2.7   -99  2   193 -118 -141  142 -128 121  $aluminum side plate
15     2  -2.7   -99  2   193 -118  122 -123 -128 121  $aluminum side plate
```

```
16    1  -1.0   -3   2   193 -118  123  133  128  121  $pl 1 wg
17    2  -2.7   -4   3   190 -115  123  133  128  121  $pl 1 clad
18    2  -2.7   -5   4   190 -115  123 -124  128  121  $pl 1 clad
19    2  -2.7   -5   4   190 -115 -132  133  128  121  $pl 1 clad
20    2  -2.7   -6   3   115 -116  123  133  128  121  $pl 1 clad on top
21    2  -2.7   -6   3   191 -190  123  133  128  121  $pl 1 clad on bot
22    3  -3.88  -5   4    190 -115  124  132  128  121  $pl 1 fuel
23    2  -2.7   -6   5   190 -115  123  133  128  121  $pl 1 clad
24    1  -1.00  -7   6    191 -116  123  133  128  121  $pl 2 wg
25    2  -2.7   -8   7   190 -115  123  133  128  121  $pl 2 clad
26    2  -2.7   -9   8   190 -115  123 -124  128  121  $pl 2 clad
27    2  -2.7   -9   8   190 -115 -132  133  128  121  $pl 2 clad
28    2  -2.7   -10  7    115 -116  123  133  128  121  $pl 2 clad on top
29    2  -2.7   -10  7    191 -190  123  133  128  121  $pl 2 clad on bot
30    3  -3.88  -9   8    190 -115  124  132  128  121  $pl 2 fuel
31    2  -2.7   -10  9    190 -115  123  133  128  121  $pl 2 clad
32    1  -1.00  -11  10  191 -116  123  133  128  121  $pl 3 wg
33    2  -2.7   -12  11  190 -115  123  133  128  121  $pl 3 clad
34    2  -2.7   -13  12  190 -115  123 -124  128  121  $pl 3 clad
35    2  -2.7   -13  12  190 -115 -132  133  128  121  $pl 3 clad
36    2  -2.7   -14  11  115 -116  123  133  128  121  $pl 3 clad on top
37    2  -2.7   -14  11  191 -190  123  133  128  121  $pl 3 clad on bot
38    3  -3.88  -13  12  190 -115  124  132  128  121  $pl 3 fuel
39    2  -2.7   -14  13  190 -115  123  133  128  121  $pl 3 clad
40    1  -1.00  -15  14  191 -116  123  133  128  121  $pl 4 wg
41    2  -2.7   -16  15  190 -115  123  133  128  121  $pl 4 clad
42    2  -2.7   -17  16  190 -115  123 -124  128  121  $pl 4 clad
43    2  -2.7   -17  16  190 -115 -132  133  128  121  $pl 4 clad
44    2  -2.7   -18  15  115 -116  123  133  128  121  $pl 4 clad on top
45    2  -2.7   -18  15  191 -190  123  133  128  121  $pl 4 clad on bot
46    3  -3.88  -17  16  190 -115  124  132  128  121  $pl 4 fuel
47    2  -2.7   -18  17  190 -115  123  133  128  121  $pl 4 clad
48    1  -1.00  -19  18  191 -116  123  133  128  121  $pl 5 wg
49    2  -2.7   -20  19  190 -115  123  133  128  121  $pl 5 clad
50    2  -2.7   -21  20  190 -115  123 -124  128  121  $pl 5 clad
51    2  -2.7   -21  20  190 -115 -132  133  128  121  $pl 5 clad
52    2  -2.7   -22  19  115 -116  123  133  128  121  $pl 5 clad on top
53    2  -2.7   -22  19  191 -190  123  133  128  121  $pl 5 clad on bot
54    3  -3.88  -21  20  190 -115  124  132  128  121  $pl 5 fuel
55    2  -2.7   -22  21  190 -115  123  133  128  121  $pl 5 clad
56    1  -1.00  -23  22  191 -116  123  133  128  121  $pl 6 wg
57    2  -2.7   -24  23  190 -115  123  133  128  121  $pl 6 clad
58    2  -2.7   -25  24  190 -115  123 -124  128  121  $pl 6 clad
59    2  -2.7   -25  24  190 -115 -132  133  128  121  $pl 6 clad
60    2  -2.7   -26  23  115 -116  123  133  128  121  $pl 6 clad on top
61    2  -2.7   -26  23  191 -190  123  133  128  121  $pl 6 clad on bot
62    3  -3.88  -25  24  190 -115  124  132  128  121  $pl 6 fuel
63    2  -2.7   -26  25  190 -115  123  133  128  121  $pl 6 clad
64    1  -1.00  -27  26  191 -116  123  133  128  121  $pl 7 wg
65    2  -2.7   -28  27  190 -115  123  133  128  121  $pl 7 clad
66    2  -2.7   -29  28  190 -115  123 -124  128  121  $pl 7 clad
67    2  -2.7   -29  28  190 -115 -132  133  128  121  $pl 7 clad
68    2  -2.7   -30  27  115 -116  123  133  128  121  $pl 7 clad on top
69    2  -2.7   -30  27  191 -190  123  133  128  121  $pl 7 clad on bot
70    3  -3.88  -29  28  190 -115  124  132  128  121  $pl 7 fuel
71    2  -2.7   -30  29  190 -115  123  133  128  121  $pl 7 clad
```

```
72    1  -1.00  -31  30  191 -116  123  133  128  121  $pl 8 wg
73    2  -2.7   -32  31  190 -115  123  133  128  121  $pl 8 clad
74    2  -2.7   -33  32  190 -115  123 -124  128  121  $pl 8 clad
75    2  -2.7   -33  32  190 -115 -132  133  128  121  $pl 8 clad
76    2  -2.7   -34  31  115 -116  123  133  128  121  $pl 8 clad on top
77    2  -2.7   -34  31  191 -190  123  133  128  121  $pl 8 clad on bot
78    3  -3.88  -33  32  190 -115  124  132  128  121  $pl 8 fuel
79    2  -2.7   -34  33  190 -115  123  133  128  121  $pl 8 clad
80    1  -1.00  -35  34  191 -116  123  133  128  121  $pl 9 wg
81    2  -2.7   -36  35  190 -115  123  133  128  121  $pl 9 clad
82    2  -2.7   -37  36  190 -115  123 -124  128  121  $pl 9 clad
83    2  -2.7   -37  36  190 -115 -132  133  128  121  $pl 9 clad
84    2  -2.7   -38  35  115 -116  123  133  128  121  $pl 9 clad on top
85    2  -2.7   -38  35  191 -190  123  133  128  121  $pl 9 clad on bot
86    3  -3.88  -37  36  190 -115  124  132  128  121  $pl 9 fuel
87    2  -2.7   -38  37  190 -115  123  133  128  121  $pl 9 clad
88    1  -1.00  -39  38  191 -116  123  133  128  121  $pl 10 wg
89    2  -2.7   -40  39  190 -115  123  133  128  121  $pl 10 clad
90    2  -2.7   -41  40  190 -115  123 -124  128  121  $pl 10 clad
91    2  -2.7   -41  40  190 -115 -132  133  128  121  $pl 10 clad
92    2  -2.7   -42  39  115 -116  123  133  128  121  $pl 10 clad on top
93    2  -2.7   -42  39  191 -190  123  133  128  121  $pl 10 clad on bot
94    3  -3.88  -41  40  190 -115  124  132  128  121  $pl 10 fuel
95    2  -2.7   -42  41  190 -115  123  133  128  121  $pl 10 clad
96    1  -1.00  -43  42  191 -116  123  133  128  121  $pl 11 wg
97    2  -2.7   -44  43  190 -115  123  133  128  121  $pl 11 clad
98    2  -2.7   -45  44  190 -115  123 -124  128  121  $pl 11 clad
99    2  -2.7   -45  44  190 -115 -132  133  128  121  $pl 11 clad
100    2  -2.7   -46  43  115 -116  123  133  128  121  $pl 11 clad on top
101    2  -2.7   -46  43  191 -190  123  133  128  121  $pl 11 clad on bot
102    3  -3.88  -45  44  190 -115  124  132  128  121  $pl 11 fuel
103    2  -2.7   -46  45  190 -115  123  133  128  121  $pl 11 clad
104    1  -1.00  -47  46  191 -116  123  133  128  121  $pl 12 wg
105    2  -2.7   -48  47  190 -115  123  133  128  121  $pl 12 clad
106    2  -2.7   -49  48  190 -115  123 -124  128  121  $pl 12 clad
107    2  -2.7   -49  48  190 -115 -132  133  128  121  $pl 12 clad
108    2  -2.7   -50  47  115 -116  123  133  128  121  $pl 12 clad on top
109    2  -2.7   -50  47  191 -190  123  133  128  121  $pl 12 clad on bot
110    3  -3.88  -49  48  190 -115  124  132  128  121  $pl 12 fuel
111    2  -2.7   -50  49  190 -115  123  133  128  121  $pl 12 clad
112    1  -1.00  -51  50  191 -116  123  133  128  121  $pl 13 wg
113    2  -2.7   -52  51  190 -115  123  133  128  121  $pl 13 clad
114    2  -2.7   -53  52  190 -115  123 -124  128  121  $pl 13 clad
115    2  -2.7   -53  52  190 -115 -132  133  128  121  $pl 13 clad
116    2  -2.7   -54  51  115 -116  123  133  128  121  $pl 13 clad on top
117    2  -2.7   -54  51  191 -190  123  133  128  121  $pl 13 clad on bot
118    3  -3.88  -53  52  190 -115  124  132  128  121  $pl 13 fuel
119    2  -2.7   -54  53  190 -115  123  133  128  121  $pl 13 clad
120    1  -1.00  -55  54  191 -116  123  133  128  121  $pl 14 wg
121    2  -2.7   -56  55  190 -115  123  133  128  121  $pl 14 clad
122    2  -2.7   -57  56  190 -115  123 -124  128  121  $pl 14 clad
123    2  -2.7   -57  56  190 -115 -132  133  128  121  $pl 14 clad
124    2  -2.7   -58  55  115 -116  123  133  128  121  $pl 14 clad on top
125    2  -2.7   -58  55  191 -190  123  133  128  121  $pl 14 clad on bot
126    3  -3.88  -57  56  190 -115  124  132  128  121  $pl 14 fuel
127    2  -2.7   -58  57  190 -115  123  133  128  121  $pl 14 clad
```

```
128    1  -1.00  -59  58  191 -116  123  133  128  121  $pl 15 wg
129    2  -2.7   -60  59  190 -115  123  133  128  121  $pl 15 clad
130    2  -2.7   -61  60  190 -115  123 -124  128  121  $pl 15 clad
131    2  -2.7   -61  60  190 -115 -132  133  128  121  $pl 15 clad
132    2  -2.7   -62  59  115 -116  123  133  128  121  $pl 15 clad on top
133    2  -2.7   -62  59  191 -190  123  133  128  121  $pl 15 clad on bot
134    3  -3.88  -61  60  190 -115  124  132  128  121  $pl 15 fuel
135    2  -2.7   -62  61  190 -115  123  133  128  121  $pl 15 clad
136    1  -1.00  -63  62  191 -116  123  133  128  121  $pl 16 wg
137    2  -2.7   -64  63  190 -115  123  133  128  121  $pl 16 clad
138    2  -2.7   -65  64  190 -115  123 -124  128  121  $pl 16 clad
139    2  -2.7   -65  64  190 -115 -132  133  128  121  $pl 16 clad
140    2  -2.7   -66  63  115 -116  123  133  128  121  $pl 16 clad on top
141    2  -2.7   -66  63  191 -190  123  133  128  121  $pl 16 clad on bot
142    3  -3.88  -65  64  190 -115  124  132  128  121  $pl 16 fuel
143    2  -2.7   -66  65  190 -115  123  133  128  121  $pl 16 clad
144    1  -1.00  -67  66  191 -116  123  133  128  121  $pl 17 wg
145    2  -2.7   -68  67  190 -115  123  133  128  121  $pl 17 clad
146    2  -2.7   -69  68  190 -115  123 -124  128  121  $pl 17 clad
147    2  -2.7   -69  68  190 -115 -132  133  128  121  $pl 17 clad
148    2  -2.7   -70  67  115 -116  123  133  128  121  $pl 17 clad on top
149    2  -2.7   -70  67  191 -190  123  133  128  121  $pl 17 clad on bot
150    3  -3.88  -69  68  190 -115  124  132  128  121  $pl 17 fuel
151    2  -2.7   -70  69  190 -115  123  133  128  121  $pl 17 clad
152    1  -1.00  -71  70  191 -116  123  133  128  121  $pl 18 wg
153    2  -2.7   -72  71  190 -115  123  133  128  121  $pl 18 clad
154    2  -2.7   -73  72  190 -115  123 -124  128  121  $pl 18 clad
155    2  -2.7   -73  72  190 -115 -132  133  128  121  $pl 18 clad
156    2  -2.7   -74  71  115 -116  123  133  128  121  $pl 18 clad on top
157    2  -2.7   -74  71  191 -190  123  133  128  121  $pl 18 clad on bot
158    3  -3.88  -73  72  190 -115  124  132  128  121  $pl 18 fuel
159    2  -2.7   -74  73  190 -115  123  133  128  121  $pl 18 clad
160    1  -1.00  -75  74  191 -116  123  133  128  121  $pl 19 wg
161    2  -2.7   -76  75  190 -115  123  133  128  121  $pl 19 clad
162    2  -2.7   -77  76  190 -115  123 -124  128  121  $pl 19 clad
163    2  -2.7   -77  76  190 -115 -132  133  128  121  $pl 19 clad
164    2  -2.7   -78  75  115 -116  123  133  128  121  $pl 19 clad on top
165    2  -2.7   -78  75  191 -190  123  133  128  121  $pl 19 clad on bot
166    3  -3.88  -77  76  190 -115  124  132  128  121  $pl 19 fuel
167    2  -2.7   -78  77  190 -115  123  133  128  121  $pl 19 clad
168    1  -1.00  -79  78  191 -116  123  133  128  121  $pl 20 wg
169    2  -2.7   -80  79  190 -115  123  133  128  121  $pl 20 clad
170    2  -2.7   -81  80  190 -115  123 -124  128  121  $pl 20 clad
171    2  -2.7   -81  80  190 -115 -132  133  128  121  $pl 20 clad
172    2  -2.7   -82  79  115 -116  123  133  128  121  $pl 20 clad on top
173    2  -2.7   -82  79  191 -190  123  133  128  121  $pl 20 clad on bot
174    3  -3.88  -81  80  190 -115  124  132  128  121  $pl 20 fuel
175    2  -2.7   -82  81  190 -115  123  133  128  121  $pl 20 clad
176    1  -1.00  -83  82  191 -116  123  133  128  121  $pl 21 wg
177    2  -2.7   -84  83  190 -115  123  133  128  121  $pl 21 clad
178    2  -2.7   -85  84  190 -115  123 -124  128  121  $pl 21 clad
179    2  -2.7   -85  84  190 -115 -132  133  128  121  $pl 21 clad
180    2  -2.7   -86  83  115 -116  123  133  128  121  $pl 21 clad on top
181    2  -2.7   -86  83  191 -190  123  133  128  121  $pl 21 clad on bot
182    3  -3.88  -85  84  190 -115  124  132  128  121  $pl 21 fuel
183    2  -2.7   -86  85  190 -115  123  133  128  121  $pl 21 clad
```

```
184    1  -1.00  -87  86  191 -116  123  133  128  121  $pl 22 wg
185    2  -2.7   -88  87  190 -115  123  133  128  121  $pl 22 clad
186    2  -2.7   -89  88  190 -115  123 -124  128  121  $pl 22 clad
187    2  -2.7   -89  88  190 -115 -132  133  128  121  $pl 22 clad
188    2  -2.7   -90  87  115 -116  123  133  128  121  $pl 22 clad on top
189    2  -2.7   -90  87  191 -190  123  133  128  121  $pl 22 clad on bot
190    3  -3.88  -89  88  190 -115  124  132  128  121  $pl 22 fuel
191    2  -2.7   -90  89  190 -115  123  133  128  121  $pl 22 clad
192    1  -1.00  -91  90  191 -116  123  133  128  121  $pl 23 wg
193    2  -2.7   -92  91  190 -115  123  133  128  121  $pl 23 clad
194    2  -2.7   -93  92  190 -115  123 -124  128  121  $pl 23 clad
195    2  -2.7   -93  92  190 -115 -132  133  128  121  $pl 23 clad
196    2  -2.7   -94  91  115 -116  123  133  128  121  $pl 23 clad on top
197    2  -2.7   -94  91  191 -190  123  133  128  121  $pl 23 clad on bot
198    3  -3.88  -93  92  190 -115  124  132  128  121  $pl 23 fuel
199    2  -2.7   -94  93  190 -115  123  133  128  121  $pl 23 clad
200    1  -1.00  -95  94  191 -116  123  133  128  121  $pl 24 wg
201    2  -2.7   -96  95  190 -115  123  133  128  121  $pl 24 clad
202    2  -2.7   -97  96  190 -115  123 -124  128  121  $pl 24 clad
203    2  -2.7   -97  96  190 -115 -132  133  128  121  $pl 24 clad
204    2  -2.7   -98  95  115 -116  123  133  128  121  $pl 24 clad on top
205    2  -2.7   -98  95  191 -190  123  133  128  121  $pl 24 clad on bot
206    3  -3.88  -97  96  190 -115  124  132  128  121  $pl 24 fuel
207    2  -2.7   -98  97  190 -115  123  133  128  121  $pl 24 clad
208    1  -1.0   -99  98  193 -118  123  133  128  121  $outer water gap
209    1  -1.0   -98  3   116 -117  123  133  128  121  $fuel top water
210    1  -1.0   -98  3   192 -191  123  133  128  121  $fuel bot water
211    6  +0.0803 -98  3   117 -118  123  133  128 121   $fuel top hanger
212    6  +0.0803 -98  3   193 -192  123  133  128 121   $fuel bot hanger
c
c
213     1  -1.0   -3   2   193 -118 -142  123  -128  121  $pl 1 wg
214     2  -2.7   -4   3   190 -115 -142  123  -128  121  $pl 1 clad
215     2  -2.7   -5   4   190 -115 -142  143  -128  121  $pl 1 clad
216     2  -2.7   -5   4   190 -115 -124  123  -128  121  $pl 1 clad
217     2  -2.7   -6   3   115 -116 -142  123  -128  121  $pl 1 clad on top
218     2  -2.7   -6   3   191 -190 -142  123  -128  121  $pl 1 clad on bot
219     3  -3.88  -5   4   190 -115 -143  124  -128  121  $pl 1 fuel
220     2  -2.7   -6   5   190 -115 -142  123  -128  121  $pl 1 clad
221     1  -1.00  -7   6   191 -116 -142  123  -128  121  $pl 2 wg
222     2  -2.7   -8   7   190 -115 -142  123  -128  121  $pl 2 clad
223     2  -2.7   -9   8   190 -115 -142  143  -128  121  $pl 2 clad
224     2  -2.7   -9   8   190 -115 -124  123  -128  121  $pl 2 clad
225     2  -2.7   -10  7   115 -116 -142  123  -128  121  $pl 2 clad on top
226     2  -2.7   -10  7   191 -190 -142  123  -128  121  $pl 2 clad on bot
227     3  -3.88  -9   8   190 -115 -143  124  -128  121  $pl 2 fuel
228     2  -2.7   -10  9   190 -115 -142  123  -128  121  $pl 2 clad
229     1  -1.00  -11  10  191 -116 -142  123  -128  121  $pl 3 wg
230     2  -2.7   -12  11  190 -115 -142  123  -128  121  $pl 3 clad
231     2  -2.7   -13  12  190 -115 -142  143  -128  121  $pl 3 clad
232     2  -2.7   -13  12  190 -115 -124  123  -128  121  $pl 3 clad
233     2  -2.7   -14  11  115 -116 -142  123  -128  121  $pl 3 clad on top
234     2  -2.7   -14  11  191 -190 -142  123  -128  121  $pl 3 clad on bot
235     3  -3.88  -13  12  190 -115 -143  124  -128  121  $pl 3 fuel
236     2  -2.7   -14  13  190 -115 -142  123  -128  121  $pl 3 clad
237     1  -1.00  -15  14  191 -116 -142  123  -128  121  $pl 4 wg
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238    2  -2.7   -16  15  190 -115 -142  123  -128  121  $pl 4 clad
239    2  -2.7   -17  16  190 -115 -142  143  -128  121  $pl 4 clad
240    2  -2.7   -17  16  190 -115 -124  123  -128  121  $pl 4 clad
241    2  -2.7   -18  15  115 -116 -142  123  -128  121  $pl 4 clad on top
242    2  -2.7   -18  15  191 -190 -142  123  -128  121  $pl 4 clad on bot
243    3  -3.88  -17  16  190 -115 -143  124  -128  121  $pl 4 fuel
244    2  -2.7   -18  17  190 -115 -142  123  -128  121  $pl 4 clad
245    1  -1.00  -19  18  191 -116 -142  123  -128  121  $pl 5 wg
246    2  -2.7   -20  19  190 -115 -142  123  -128  121  $pl 5 clad
247    2  -2.7   -21  20  190 -115 -142  143  -128  121  $pl 5 clad
248    2  -2.7   -21  20  190 -115 -124  123  -128  121  $pl 5 clad
249    2  -2.7   -22  19  115 -116 -142  123  -128  121  $pl 5 clad on top
250    2  -2.7   -22  19  191 -190 -142  123  -128  121  $pl 5 clad on bot
251    3  -3.88  -21  20  190 -115 -143  124  -128  121  $pl 5 fuel
252    2  -2.7   -22  21  190 -115 -142  123  -128  121  $pl 5 clad
253    1  -1.00  -23  22  191 -116 -142  123  -128  121  $pl 6 wg
254    2  -2.7   -24  23  190 -115 -142  123  -128  121  $pl 6 clad
255    2  -2.7   -25  24  190 -115 -142  143  -128  121  $pl 6 clad
256    2  -2.7   -25  24  190 -115 -124  123  -128  121  $pl 6 clad
257    2  -2.7   -26  23  115 -116 -142  123  -128  121  $pl 6 clad on top
258    2  -2.7   -26  23  191 -190 -142  123  -128  121  $pl 6 clad on bot
259    3  -3.88  -25  24  190 -115 -143  124  -128  121  $pl 6 fuel
260    2  -2.7   -26  25  190 -115 -142  123  -128  121  $pl 6 clad
261    1  -1.00  -27  26  191 -116 -142  123  -128  121  $pl 7 wg
262    2  -2.7   -28  27  190 -115 -142  123  -128  121  $pl 7 clad
263    2  -2.7   -29  28  190 -115 -142  143  -128  121  $pl 7 clad
264    2  -2.7   -29  28  190 -115 -124  123  -128  121  $pl 7 clad
265    2  -2.7   -30  27  115 -116 -142  123  -128  121  $pl 7 clad on top
266    2  -2.7   -30  27  191 -190 -142  123  -128  121  $pl 7 clad on bot
267    3  -3.88  -29  28  190 -115 -143  124  -128  121  $pl 7 fuel
268    2  -2.7   -30  29  190 -115 -142  123  -128  121  $pl 7 clad
269    1  -1.00  -31  30  191 -116 -142  123  -128  121  $pl 8 wg
270    2  -2.7   -32  31  190 -115 -142  123  -128  121  $pl 8 clad
271    2  -2.7   -33  32  190 -115 -142  143  -128  121  $pl 8 clad
272    2  -2.7   -33  32  190 -115 -124  123  -128  121  $pl 8 clad
273    2  -2.7   -34  31  115 -116 -142  123  -128  121  $pl 8 clad on top
274    2  -2.7   -34  31  191 -190 -142  123  -128  121  $pl 8 clad on bot
275    3  -3.88  -33  32  190 -115 -143  124  -128  121  $pl 8 fuel
276    2  -2.7   -34  33  190 -115 -142  123  -128  121  $pl 8 clad
277    1  -1.00  -35  34  191 -116 -142  123  -128  121  $pl 9 wg
278    2  -2.7   -36  35  190 -115 -142  123  -128  121  $pl 9 clad
279    2  -2.7   -37  36  190 -115 -142  143  -128  121  $pl 9 clad
280    2  -2.7   -37  36  190 -115 -124  123  -128  121  $pl 9 clad
281    2  -2.7   -38  35  115 -116 -142  123  -128  121  $pl 9 clad on top
282    2  -2.7   -38  35  191 -190 -142  123  -128  121  $pl 9 clad on bot
283    3  -3.88  -37  36  190 -115 -143  124  -128  121  $pl 9 fuel
284    2  -2.7   -38  37  190 -115 -142  123  -128  121  $pl 9 clad
285    1  -1.00  -39  38  191 -116 -142  123  -128  121  $pl 10 wg
286    2  -2.7   -40  39  190 -115 -142  123  -128  121  $pl 10 clad
287    2  -2.7   -41  40  190 -115 -142  143  -128  121  $pl 10 clad
288    2  -2.7   -41  40  190 -115 -124  123  -128  121  $pl 10 clad
289    2  -2.7   -42  39  115 -116 -142  123  -128  121  $pl 10 clad on top
290    2  -2.7   -42  39  191 -190 -142  123  -128  121  $pl 10 clad on bot
291    3  -3.88  -41  40  190 -115 -143  124  -128  121  $pl 10 fuel
292    2  -2.7   -42  41  190 -115 -142  123  -128  121  $pl 10 clad
293    1  -1.00  -43  42  191 -116 -142  123  -128  121  $pl 11 wg
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294     2  -2.7    -44  43  190 -115 -142  123  -128  121  $pl 11 clad
295     2  -2.7    -45  44  190 -115 -142  143  -128  121  $pl 11 clad
296     2  -2.7    -45  44  190 -115 -124  123  -128  121  $pl 11 clad
297     2  -2.7    -46  43  115 -116 -142  123  -128  121  $pl 11 clad on top
298     2  -2.7    -46  43  191 -190 -142  123  -128  121  $pl 11 clad on bot
299     3  -3.88  -45  44  190 -115 -143  124  -128  121  $pl 11 fuel
300     2  -2.7    -46  45  190 -115 -142  123  -128  121  $pl 11 clad
301     1  -1.00  -47  46  191 -116 -142  123  -128  121  $pl 12 wg
302     2  -2.7    -48  47  190 -115 -142  123  -128  121  $pl 12 clad
303     2  -2.7    -49  48  190 -115 -142  143  -128  121  $pl 12 clad
304     2  -2.7    -49  48  190 -115 -124  123  -128  121  $pl 12 clad
305     2  -2.7    -50  47  115 -116 -142  123  -128  121  $pl 12 clad on top
306     2  -2.7    -50  47  191 -190 -142  123  -128  121  $pl 12 clad on bot
307     3  -3.88  -49  48  190 -115 -143  124  -128  121  $pl 12 fuel
308     2  -2.7    -50  49  190 -115 -142  123  -128  121  $pl 12 clad
309     1  -1.00  -51  50  191 -116 -142  123  -128  121  $pl 13 wg
310     2  -2.7    -52  51  190 -115 -142  123  -128  121  $pl 13 clad
311     2  -2.7    -53  52  190 -115 -142  143  -128  121  $pl 13 clad
312     2  -2.7    -53  52  190 -115 -124  123  -128  121  $pl 13 clad
313     2  -2.7    -54  51  115 -116 -142  123  -128  121  $pl 13 clad on top
314     2  -2.7    -54  51  191 -190 -142  123  -128  121  $pl 13 clad on bot
315     3  -3.88  -53  52  190 -115 -143  124  -128  121  $pl 13 fuel
316     2  -2.7    -54  53  190 -115 -142  123  -128  121  $pl 13 clad
317     1  -1.00  -55  54  191 -116 -142  123  -128  121  $pl 14 wg
318     2  -2.7    -56  55  190 -115 -142  123  -128  121  $pl 14 clad
319     2  -2.7    -57  56  190 -115 -142  143  -128  121  $pl 14 clad
320     2  -2.7    -57  56  190 -115 -124  123  -128  121  $pl 14 clad
321     2  -2.7    -58  55  115 -116 -142  123  -128  121  $pl 14 clad on top
322     2  -2.7    -58  55  191 -190 -142  123  -128  121  $pl 14 clad on bot
323     3  -3.88  -57  56  190 -115 -143  124  -128  121  $pl 14 fuel
324     2  -2.7    -58  57  190 -115 -142  123  -128  121  $pl 14 clad
325     1  -1.00  -59  58  191 -116 -142  123  -128  121  $pl 15 wg
326     2  -2.7    -60  59  190 -115 -142  123  -128  121  $pl 15 clad
327     2  -2.7    -61  60  190 -115 -142  143  -128  121  $pl 15 clad
328     2  -2.7    -61  60  190 -115 -124  123  -128  121  $pl 15 clad
329     2  -2.7    -62  59  115 -116 -142  123  -128  121  $pl 15 clad on top
330     2  -2.7    -62  59  191 -190 -142  123  -128  121  $pl 15 clad on bot
331     3  -3.88  -61  60  190 -115 -143  124  -128  121  $pl 15 fuel
332     2  -2.7    -62  61  190 -115 -142  123  -128  121  $pl 15 clad
333     1  -1.00  -63  62  191 -116 -142  123  -128  121  $pl 16 wg
334     2  -2.7    -64  63  190 -115 -142  123  -128  121  $pl 16 clad
335     2  -2.7    -65  64  190 -115 -142  143  -128  121  $pl 16 clad
336     2  -2.7    -65  64  190 -115 -124  123  -128  121  $pl 16 clad
337     2  -2.7    -66  63  115 -116 -142  123  -128  121  $pl 16 clad on top
338     2  -2.7    -66  63  191 -190 -142  123  -128  121  $pl 16 clad on bot
339     3  -3.88  -65  64  190 -115 -143  124  -128  121  $pl 16 fuel
340     2  -2.7    -66  65  190 -115 -142  123  -128  121  $pl 16 clad
341     1  -1.00  -67  66  191 -116 -142  123  -128  121  $pl 17 wg
342     2  -2.7    -68  67  190 -115 -142  123  -128  121  $pl 17 clad
343     2  -2.7    -69  68  190 -115 -142  143  -128  121  $pl 17 clad
344     2  -2.7    -69  68  190 -115 -124  123  -128  121  $pl 17 clad
345     2  -2.7    -70  67  115 -116 -142  123  -128  121  $pl 17 clad on top
346     2  -2.7    -70  67  191 -190 -142  123  -128  121  $pl 17 clad on bot
347     3  -3.88  -69  68  190 -115 -143  124  -128  121  $pl 17 fuel
348     2  -2.7    -70  69  190 -115 -142  123  -128  121  $pl 17 clad
349     1  -1.00  -71  70  191 -116 -142  123  -128  121  $pl 18 wg
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350    2  -2.7   -72  71  190 -115 -142  123  -128  121  $pl 18 clad
351    2  -2.7   -73  72  190 -115 -142  143  -128  121  $pl 18 clad
352    2  -2.7   -73  72  190 -115 -124  123  -128  121  $pl 18 clad
353    2  -2.7   -74  71  115 -116 -142  123  -128  121  $pl 18 clad on top
354    2  -2.7   -74  71  191 -190 -142  123  -128  121  $pl 18 clad on bot
355    3  -3.88  -73  72  190 -115 -143  124  -128  121  $pl 18 fuel
356    2  -2.7   -74  73  190 -115 -142  123  -128  121  $pl 18 clad
357    1  -1.00  -75  74  191 -116 -142  123  -128  121  $pl 19 wg
358    2  -2.7   -76  75  190 -115 -142  123  -128  121  $pl 19 clad
359    2  -2.7   -77  76  190 -115 -142  143  -128  121  $pl 19 clad
360    2  -2.7   -77  76  190 -115 -124  123  -128  121  $pl 19 clad
361    2  -2.7   -78  75  115 -116 -142  123  -128  121  $pl 19 clad on top
362    2  -2.7   -78  75  191 -190 -142  123  -128  121  $pl 19 clad on bot
363    3  -3.88  -77  76  190 -115 -143  124  -128  121  $pl 19 fuel
364    2  -2.7   -78  77  190 -115 -142  123  -128  121  $pl 19 clad
365    1  -1.00  -79  78  191 -116 -142  123  -128  121  $pl 20 wg
366    2  -2.7   -80  79  190 -115 -142  123  -128  121  $pl 20 clad
367    2  -2.7   -81  80  190 -115 -142  143  -128  121  $pl 20 clad
368    2  -2.7   -81  80  190 -115 -124  123  -128  121  $pl 20 clad
369    2  -2.7   -82  79  115 -116 -142  123  -128  121  $pl 20 clad on top
370    2  -2.7   -82  79  191 -190 -142  123  -128  121  $pl 20 clad on bot
371    3  -3.88  -81  80  190 -115 -143  124  -128  121  $pl 20 fuel
372    2  -2.7   -82  81  190 -115 -142  123  -128  121  $pl 20 clad
373    1  -1.00  -83  82  191 -116 -142  123  -128  121  $pl 21 wg
374    2  -2.7   -84  83  190 -115 -142  123  -128  121  $pl 21 clad
375    2  -2.7   -85  84  190 -115 -142  143  -128  121  $pl 21 clad
376    2  -2.7   -85  84  190 -115 -124  123  -128  121  $pl 21 clad
377    2  -2.7   -86  83  115 -116 -142  123  -128  121  $pl 21 clad on top
378    2  -2.7   -86  83  191 -190 -142  123  -128  121  $pl 21 clad on bot
379    3  -3.88  -85  84  190 -115 -143  124  -128  121  $pl 21 fuel
380    2  -2.7   -86  85  190 -115 -142  123  -128  121  $pl 21 clad
381    1  -1.00  -87  86  191 -116 -142  123  -128  121  $pl 22 wg
382    2  -2.7   -88  87  190 -115 -142  123  -128  121  $pl 22 clad
383    2  -2.7   -89  88  190 -115 -142  143  -128  121  $pl 22 clad
384    2  -2.7   -89  88  190 -115 -124  123  -128  121  $pl 22 clad
385    2  -2.7   -90  87  115 -116 -142  123  -128  121  $pl 22 clad on top
386    2  -2.7   -90  87  191 -190 -142  123  -128  121  $pl 22 clad on bot
387    3  -3.88  -89  88  190 -115 -143  124  -128  121  $pl 22 fuel
388    2  -2.7   -90  89  190 -115 -142  123  -128  121  $pl 22 clad
389    1  -1.00  -91  90  191 -116 -142  123  -128  121  $pl 23 wg
390    2  -2.7   -92  91  190 -115 -142  123  -128  121  $pl 23 clad
391    2  -2.7   -93  92  190 -115 -142  143  -128  121  $pl 23 clad
392    2  -2.7   -93  92  190 -115 -124  123  -128  121  $pl 23 clad
393    2  -2.7   -94  91  115 -116 -142  123  -128  121  $pl 23 clad on top
394    2  -2.7   -94  91  191 -190 -142  123  -128  121  $pl 23 clad on bot
395    3  -3.88  -93  92  190 -115 -143  124  -128  121  $pl 23 fuel
396    2  -2.7   -94  93  190 -115 -142  123  -128  121  $pl 23 clad
397    1  -1.00  -95  94  191 -116 -142  123  -128  121  $pl 24 wg
398    2  -2.7   -96  95  190 -115 -142  123  -128  121  $pl 24 clad
399    2  -2.7   -97  96  190 -115 -142  143  -128  121  $pl 24 clad
400    2  -2.7   -97  96  190 -115 -124  123  -128  121  $pl 24 clad
401    2  -2.7   -98  95  115 -116 -142  123  -128  121  $pl 24 clad on top
402    2  -2.7   -98  95  191 -190 -142  123  -128  121  $pl 24 clad on bot
403    3  -3.88  -97  96  190 -115 -143  124  -128  121  $pl 24 fuel
404    2  -2.7   -98  97  190 -115 -142  123  -128  121  $pl 24 clad
405    1  -1.0   -99  98  193 -118 -142  123  -128  121  $outer water gap
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406     1  -1.0    -98  3    116 -117 -142  123  -128  121  $fuel top water
407     1  -1.0    -98  3    192 -191 -142  123  -128  121  $fuel bot water
408     6  +0.0803 -98  3    117 -118 -142  123  -128 121   $fuel top hanger
409     6  +0.0803 -98  3    193 -192 -142  123  -128 121   $fuel bot hanger
c
c
410    1  -1.0    -3   2   193 -118 -130  139  -128  121  $pl 1 wg
411    2  -2.7    -4   3   190 -115 -130  139  -128  121  $pl 1 clad
412    2  -2.7    -5   4   190 -115 -130  131  -128  121  $pl 1 clad
413    2  -2.7    -5   4   190 -115 -138  139  -128  121  $pl 1 clad
414    2  -2.7    -6   3   115 -116 -130  139  -128  121  $pl 1 clad on top
415    2  -2.7    -6   3   191 -190 -130  139  -128  121  $pl 1 clad on bot
416    3  -3.88  -5   4   190 -115 -131  138  -128  121  $pl 1 fuel
417    2  -2.7    -6   5   190 -115 -130  139  -128  121  $pl 1 clad
418    1  -1.00  -7   6   191 -116 -130  139  -128  121  $pl 2 wg
419    2  -2.7    -8   7   190 -115 -130  139  -128  121  $pl 2 clad
420    2  -2.7    -9   8   190 -115 -130  131  -128  121  $pl 2 clad
421    2  -2.7    -9   8   190 -115 -138  139  -128  121  $pl 2 clad
422    2  -2.7    -10  7   115 -116 -130  139  -128  121  $pl 2 clad on top
423    2  -2.7    -10  7   191 -190 -130  139  -128  121  $pl 2 clad on bot
424    3  -3.88  -9   8   190 -115 -131  138  -128  121  $pl 2 fuel
425    2  -2.7    -10  9   190 -115 -130  139  -128  121  $pl 2 clad
426    1  -1.00  -11  10  191 -116 -130  139  -128  121  $pl 3 wg
427    2  -2.7    -12  11  190 -115 -130  139  -128  121  $pl 3 clad
428    2  -2.7    -13  12  190 -115 -130  131  -128  121  $pl 3 clad
429    2  -2.7    -13  12  190 -115 -138  139  -128  121  $pl 3 clad
430    2  -2.7    -14  11  115 -116 -130  139  -128  121  $pl 3 clad on top
431    2  -2.7    -14  11  191 -190 -130  139  -128  121  $pl 3 clad on bot
432    3  -3.88  -13  12  190 -115 -131  138  -128  121  $pl 3 fuel
433    2  -2.7    -14  13  190 -115 -130  139  -128  121  $pl 3 clad
434    1  -1.00  -15  14  191 -116 -130  139  -128  121  $pl 4 wg
435    2  -2.7    -16  15  190 -115 -130  139  -128  121  $pl 4 clad
436    2  -2.7    -17  16  190 -115 -130  131  -128  121  $pl 4 clad
437    2  -2.7    -17  16  190 -115 -138  139  -128  121  $pl 4 clad
438    2  -2.7    -18  15  115 -116 -130  139  -128  121  $pl 4 clad on top
439    2  -2.7    -18  15  191 -190 -130  139  -128  121  $pl 4 clad on bot
440    3  -3.88  -17  16  190 -115 -131  138  -128  121  $pl 4 fuel
441    2  -2.7    -18  17  190 -115 -130  139  -128  121  $pl 4 clad
442    1  -1.00  -19  18  191 -116 -130  139  -128  121  $pl 5 wg
443    2  -2.7    -20  19  190 -115 -130  139  -128  121  $pl 5 clad
444    2  -2.7    -21  20  190 -115 -130  131  -128  121  $pl 5 clad
445    2  -2.7    -21  20  190 -115 -138  139  -128  121  $pl 5 clad
446    2  -2.7    -22  19  115 -116 -130  139  -128  121  $pl 5 clad on top
447    2  -2.7    -22  19  191 -190 -130  139  -128  121  $pl 5 clad on bot
448    3  -3.88  -21  20  190 -115 -131  138  -128  121  $pl 5 fuel
449    2  -2.7    -22  21  190 -115 -130  139  -128  121  $pl 5 clad
450    1  -1.00  -23  22  191 -116 -130  139  -128  121  $pl 6 wg
451    2  -2.7    -24  23  190 -115 -130  139  -128  121  $pl 6 clad
452    2  -2.7    -25  24  190 -115 -130  131  -128  121  $pl 6 clad
453    2  -2.7    -25  24  190 -115 -138  139  -128  121  $pl 6 clad
454    2  -2.7    -26  23  115 -116 -130  139  -128  121  $pl 6 clad on top
455    2  -2.7    -26  23  191 -190 -130  139  -128  121  $pl 6 clad on bot
456    3  -3.88  -25  24  190 -115 -131  138  -128  121  $pl 6 fuel
457    2  -2.7    -26  25  190 -115 -130  139  -128  121  $pl 6 clad
458    1  -1.00  -27  26  191 -116 -130  139  -128  121  $pl 7 wg
459    2  -2.7    -28  27  190 -115 -130  139  -128  121  $pl 7 clad
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460   2  -2.7   -29  28  190 -115 -130  131  -128  121  $pl 7 clad
461   2  -2.7   -29  28  190 -115 -138  139  -128  121  $pl 7 clad
462   2  -2.7   -30  27  115 -116 -130  139  -128  121  $pl 7 clad on top
463   2  -2.7   -30  27  191 -190 -130  139  -128  121  $pl 7 clad on bot
464   3  -3.88  -29  28  190 -115 -131  138  -128  121  $pl 7 fuel
465   2  -2.7   -30  29  190 -115 -130  139  -128  121  $pl 7 clad
466   1  -1.00  -31  30  191 -116 -130  139  -128  121  $pl 8 wg
467   2  -2.7   -32  31  190 -115 -130  139  -128  121  $pl 8 clad
468   2  -2.7   -33  32  190 -115 -130  131  -128  121  $pl 8 clad
469   2  -2.7   -33  32  190 -115 -138  139  -128  121  $pl 8 clad
470   2  -2.7   -34  31  115 -116 -130  139  -128  121  $pl 8 clad on top
471   2  -2.7   -34  31  191 -190 -130  139  -128  121  $pl 8 clad on bot
472   3  -3.88  -33  32  190 -115 -131  138  -128  121  $pl 8 fuel
473   2  -2.7   -34  33  190 -115 -130  139  -128  121  $pl 8 clad
474   1  -1.00  -35  34  191 -116 -130  139  -128  121  $pl 9 wg
475   2  -2.7   -36  35  190 -115 -130  139  -128  121  $pl 9 clad
476   2  -2.7   -37  36  190 -115 -130  131  -128  121  $pl 9 clad
477   2  -2.7   -37  36  190 -115 -138  139  -128  121  $pl 9 clad
478   2  -2.7   -38  35  115 -116 -130  139  -128  121  $pl 9 clad on top
479   2  -2.7   -38  35  191 -190 -130  139  -128  121  $pl 9 clad on bot
480   3  -3.88  -37  36  190 -115 -131  138  -128  121  $pl 9 fuel
481   2  -2.7   -38  37  190 -115 -130  139  -128  121  $pl 9 clad
482   1  -1.00  -39  38  191 -116 -130  139  -128  121  $pl 10 wg
483   2  -2.7   -40  39  190 -115 -130  139  -128  121  $pl 10 clad
484   2  -2.7   -41  40  190 -115 -130  131  -128  121  $pl 10 clad
485   2  -2.7   -41  40  190 -115 -138  139  -128  121  $pl 10 clad
486   2  -2.7   -42  39  115 -116 -130  139  -128  121  $pl 10 clad on top
487   2  -2.7   -42  39  191 -190 -130  139  -128  121  $pl 10 clad on bot
488   3  -3.88  -41  40  190 -115 -131  138  -128  121  $pl 10 fuel
489   2  -2.7   -42  41  190 -115 -130  139  -128  121  $pl 10 clad
490   1  -1.00  -43  42  191 -116 -130  139  -128  121  $pl 11 wg
491   2  -2.7   -44  43  190 -115 -130  139  -128  121  $pl 11 clad
492   2  -2.7   -45  44  190 -115 -130  131  -128  121  $pl 11 clad
493   2  -2.7   -45  44  190 -115 -138  139  -128  121  $pl 11 clad
494   2  -2.7   -46  43  115 -116 -130  139  -128  121  $pl 11 clad on top
495   2  -2.7   -46  43  191 -190 -130  139  -128  121  $pl 11 clad on bot
496   3  -3.88  -45  44  190 -115 -131  138  -128  121  $pl 11 fuel
497   2  -2.7   -46  45  190 -115 -130  139  -128  121  $pl 11 clad
498   1  -1.00  -47  46  191 -116 -130  139  -128  121  $pl 12 wg
499   2  -2.7   -48  47  190 -115 -130  139  -128  121  $pl 12 clad
500   2  -2.7   -49  48  190 -115 -130  131  -128  121  $pl 12 clad
501   2  -2.7   -49  48  190 -115 -138  139  -128  121  $pl 12 clad
502   2  -2.7   -50  47  115 -116 -130  139  -128  121  $pl 12 clad on top
503   2  -2.7   -50  47  191 -190 -130  139  -128  121  $pl 12 clad on bot
504   3  -3.88  -49  48  190 -115 -131  138  -128  121  $pl 12 fuel
505   2  -2.7   -50  49  190 -115 -130  139  -128  121  $pl 12 clad
506   1  -1.00  -51  50  191 -116 -130  139  -128  121  $pl 13 wg
507   2  -2.7   -52  51  190 -115 -130  139  -128  121  $pl 13 clad
508   2  -2.7   -53  52  190 -115 -130  131  -128  121  $pl 13 clad
509   2  -2.7   -53  52  190 -115 -138  139  -128  121  $pl 13 clad
510   2  -2.7   -54  51  115 -116 -130  139  -128  121  $pl 13 clad on top
511   2  -2.7   -54  51  191 -190 -130  139  -128  121  $pl 13 clad on bot
512   3  -3.88  -53  52  190 -115 -131  138  -128  121  $pl 13 fuel
513   2  -2.7   -54  53  190 -115 -130  139  -128  121  $pl 13 clad
514   1  -1.00  -55  54  191 -116 -130  139  -128  121  $pl 14 wg
515   2  -2.7   -56  55  190 -115 -130  139  -128  121  $pl 14 clad
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516    2  -2.7   -57  56  190 -115 -130  131  -128  121  $pl 14 clad
517    2  -2.7   -57  56  190 -115 -138  139  -128  121  $pl 14 clad
518    2  -2.7   -58  55  115 -116 -130  139  -128  121  $pl 14 clad on top
519    2  -2.7   -58  55  191 -190 -130  139  -128  121  $pl 14 clad on bot
520    3  -3.88  -57  56  190 -115 -131  138  -128  121  $pl 14 fuel
521    2  -2.7   -58  57  190 -115 -130  139  -128  121  $pl 14 clad
522    1  -1.00  -59  58  191 -116 -130  139  -128  121  $pl 15 wg
523    2  -2.7   -60  59  190 -115 -130  139  -128  121  $pl 15 clad
524    2  -2.7   -61  60  190 -115 -130  131  -128  121  $pl 15 clad
525    2  -2.7   -61  60  190 -115 -138  139  -128  121  $pl 15 clad
526    2  -2.7   -62  59  115 -116 -130  139  -128  121  $pl 15 clad on top
527    2  -2.7   -62  59  191 -190 -130  139  -128  121  $pl 15 clad on bot
528    3  -3.88  -61  60  190 -115 -131  138  -128  121  $pl 15 fuel
529    2  -2.7   -62  61  190 -115 -130  139  -128  121  $pl 15 clad
530    1  -1.00  -63  62  191 -116 -130  139  -128  121  $pl 16 wg
531    2  -2.7   -64  63  190 -115 -130  139  -128  121  $pl 16 clad
532    2  -2.7   -65  64  190 -115 -130  131  -128  121  $pl 16 clad
533    2  -2.7   -65  64  190 -115 -138  139  -128  121  $pl 16 clad
534    2  -2.7   -66  63  115 -116 -130  139  -128  121  $pl 16 clad on top
535    2  -2.7   -66  63  191 -190 -130  139  -128  121  $pl 16 clad on bot
536    3  -3.88  -65  64  190 -115 -131  138  -128  121  $pl 16 fuel
537    2  -2.7   -66  65  190 -115 -130  139  -128  121  $pl 16 clad
538    1  -1.00  -67  66  191 -116 -130  139  -128  121  $pl 17 wg
539    2  -2.7   -68  67  190 -115 -130  139  -128  121  $pl 17 clad
540    2  -2.7   -69  68  190 -115 -130  131  -128  121  $pl 17 clad
541    2  -2.7   -69  68  190 -115 -138  139  -128  121  $pl 17 clad
542    2  -2.7   -70  67  115 -116 -130  139  -128  121  $pl 17 clad on top
543    2  -2.7   -70  67  191 -190 -130  139  -128  121  $pl 17 clad on bot
544    3  -3.88  -69  68  190 -115 -131  138  -128  121  $pl 17 fuel
545    2  -2.7   -70  69  190 -115 -130  139  -128  121  $pl 17 clad
546    1  -1.00  -71  70  191 -116 -130  139  -128  121  $pl 18 wg
547    2  -2.7   -72  71  190 -115 -130  139  -128  121  $pl 18 clad
548    2  -2.7   -73  72  190 -115 -130  131  -128  121  $pl 18 clad
549    2  -2.7   -73  72  190 -115 -138  139  -128  121  $pl 18 clad
550    2  -2.7   -74  71  115 -116 -130  139  -128  121  $pl 18 clad on top
551    2  -2.7   -74  71  191 -190 -130  139  -128  121  $pl 18 clad on bot
552    3  -3.88  -73  72  190 -115 -131  138  -128  121  $pl 18 fuel
553    2  -2.7   -74  73  190 -115 -130  139  -128  121  $pl 18 clad
554    1  -1.00  -75  74  191 -116 -130  139  -128  121  $pl 19 wg
555    2  -2.7   -76  75  190 -115 -130  139  -128  121  $pl 19 clad
556    2  -2.7   -77  76  190 -115 -130  131  -128  121  $pl 19 clad
557    2  -2.7   -77  76  190 -115 -138  139  -128  121  $pl 19 clad
558    2  -2.7   -78  75  115 -116 -130  139  -128  121  $pl 19 clad on top
559    2  -2.7   -78  75  191 -190 -130  139  -128  121  $pl 19 clad on bot
560    3  -3.88  -77  76  190 -115 -131  138  -128  121  $pl 19 fuel
561    2  -2.7   -78  77  190 -115 -130  139  -128  121  $pl 19 clad
562    1  -1.00  -79  78  191 -116 -130  139  -128  121  $pl 20 wg
563    2  -2.7   -80  79  190 -115 -130  139  -128  121  $pl 20 clad
564    2  -2.7   -81  80  190 -115 -130  131  -128  121  $pl 20 clad
565    2  -2.7   -81  80  190 -115 -138  139  -128  121  $pl 20 clad
566    2  -2.7   -82  79  115 -116 -130  139  -128  121  $pl 20 clad on top
567    2  -2.7   -82  79  191 -190 -130  139  -128  121  $pl 20 clad on bot
568    3  -3.88  -81  80  190 -115 -131  138  -128  121  $pl 20 fuel
569    2  -2.7   -82  81  190 -115 -130  139  -128  121  $pl 20 clad
570    1  -1.00  -83  82  191 -116 -130  139  -128  121  $pl 21 wg
571    2  -2.7   -84  83  190 -115 -130  139  -128  121  $pl 21 clad
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572    2  -2.7    -85  84  190 -115 -130  131  -128  121  $pl 21 clad
573    2  -2.7    -85  84  190 -115 -138  139  -128  121  $pl 21 clad
574    2  -2.7    -86  83  115 -116 -130  139  -128  121  $pl 21 clad on top
575    2  -2.7    -86  83  191 -190 -130  139  -128  121  $pl 21 clad on bot
576    3  -3.88  -85  84  190 -115 -131  138  -128  121  $pl 21 fuel
577    2  -2.7    -86  85  190 -115 -130  139  -128  121  $pl 21 clad
578    1  -1.00  -87  86  191 -116 -130  139  -128  121  $pl 22 wg
579    2  -2.7    -88  87  190 -115 -130  139  -128  121  $pl 22 clad
580    2  -2.7    -89  88  190 -115 -130  131  -128  121  $pl 22 clad
581    2  -2.7    -89  88  190 -115 -138  139  -128  121  $pl 22 clad
582    2  -2.7    -90  87  115 -116 -130  139  -128  121  $pl 22 clad on top
583    2  -2.7    -90  87  191 -190 -130  139  -128  121  $pl 22 clad on bot
584    3  -3.88  -89  88  190 -115 -131  138  -128  121  $pl 22 fuel
585    2  -2.7    -90  89  190 -115 -130  139  -128  121  $pl 22 clad
586    1  -1.00  -91  90  191 -116 -130  139  -128  121  $pl 23 wg
587    2  -2.7    -92  91  190 -115 -130  139  -128  121  $pl 23 clad
588    2  -2.7    -93  92  190 -115 -130  131  -128  121  $pl 23 clad
589    2  -2.7    -93  92  190 -115 -138  139  -128  121  $pl 23 clad
590    2  -2.7    -94  91  115 -116 -130  139  -128  121  $pl 23 clad on top
591    2  -2.7    -94  91  191 -190 -130  139  -128  121  $pl 23 clad on bot
592    3  -3.88  -93  92  190 -115 -131  138  -128  121  $pl 23 fuel
593    2  -2.7    -94  93  190 -115 -130  139  -128  121  $pl 23 clad
594    1  -1.00  -95  94  191 -116 -130  139  -128  121  $pl 24 wg
595    2  -2.7    -96  95  190 -115 -130  139  -128  121  $pl 24 clad
596    2  -2.7    -97  96  190 -115 -130  131  -128  121  $pl 24 clad
597    2  -2.7    -97  96  190 -115 -138  139  -128  121  $pl 24 clad
598    2  -2.7    -98  95  115 -116 -130  139  -128  121  $pl 24 clad on top
599    2  -2.7    -98  95  191 -190 -130  139  -128  121  $pl 24 clad on bot
600    3  -3.88  -97  96  190 -115 -131  138  -128  121  $pl 24 fuel
601    2  -2.7    -98  97  190 -115 -130  139  -128  121  $pl 24 clad
602    1  -1.0    -99  98  193 -118 -130  139  -128  121  $outer water gap
603    1  -1.0    -98  3   116 -117 -130  139  -128  121  $fuel top water
604    1  -1.0    -98  3   192 -191 -130  139  -128  121  $fuel bot water
605    6  +0.0803 -98  3   117 -118 -130  139  -128 121  $fuel top hanger
606    6  +0.0803 -98  3   193 -192 -130  139  -128 121  $fuel bot hanger
c
c
607     1  -1.0    -3   2   193 -118 -136  126  128  121  $pl 1 wg
608     2  -2.7    -4   3   190 -115 -136  126  128  121  $pl 1 clad
609     2  -2.7    -5   4   190 -115 -136  137  128  121  $pl 1 clad
610     2  -2.7    -5   4   190 -115 -125  126  128  121  $pl 1 clad
611     2  -2.7    -6   3   115 -116 -136  126  128  121  $pl 1 clad on top
612     2  -2.7    -6   3   191 -190 -136  126  128  121  $pl 1 clad on bot
613     3  -3.88  -5   4   190 -115 -137  125  128  121  $pl 1 fuel
614     2  -2.7    -6   5   190 -115 -136  126  128  121  $pl 1 clad
615     1  -1.00  -7   6   191 -116 -136  126  128  121  $pl 2 wg
616     2  -2.7    -8   7   190 -115 -136  126  128  121  $pl 2 clad
617     2  -2.7    -9   8   190 -115 -136  137  128  121  $pl 2 clad
618     2  -2.7    -9   8   190 -115 -125  126  128  121  $pl 2 clad
619     2  -2.7    -10  7   115 -116 -136  126  128  121  $pl 2 clad on top
620     2  -2.7    -10  7   191 -190 -136  126  128  121  $pl 2 clad on bot
621     3  -3.88  -9   8   190 -115 -137  125  128  121  $pl 2 fuel
622     2  -2.7    -10  9   190 -115 -136  126  128  121  $pl 2 clad
623     1  -1.00  -11  10  191 -116 -136  126  128  121  $pl 3 wg
624     2  -2.7    -12  11  190 -115 -136  126  128  121  $pl 3 clad
625     2  -2.7    -13  12  190 -115 -136  137  128  121  $pl 3 clad
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626    2  -2.7    -13  12  190 -115 -125  126  128  121  $pl 3 clad
627    2  -2.7    -14  11  115 -116 -136  126  128  121  $pl 3 clad on top
628    2  -2.7    -14  11  191 -190 -136  126  128  121  $pl 3 clad on bot
629    3  -3.88  -13  12  190 -115 -137  125  128  121  $pl 3 fuel
630    2  -2.7    -14  13  190 -115 -136  126  128  121  $pl 3 clad
631    1  -1.00  -15  14  191 -116 -136  126  128  121  $pl 4 wg
632    2  -2.7    -16  15  190 -115 -136  126  128  121  $pl 4 clad
633    2  -2.7    -17  16  190 -115 -136  137  128  121  $pl 4 clad
634    2  -2.7    -17  16  190 -115 -125  126  128  121  $pl 4 clad
635    2  -2.7    -18  15  115 -116 -136  126  128  121  $pl 4 clad on top
636    2  -2.7    -18  15  191 -190 -136  126  128  121  $pl 4 clad on bot
637    3  -3.88  -17  16  190 -115 -137  125  128  121  $pl 4 fuel
638    2  -2.7    -18  17  190 -115 -136  126  128  121  $pl 4 clad
639    1  -1.00  -19  18  191 -116 -136  126  128  121  $pl 5 wg
640    2  -2.7    -20  19  190 -115 -136  126  128  121  $pl 5 clad
641    2  -2.7    -21  20  190 -115 -136  137  128  121  $pl 5 clad
642    2  -2.7    -21  20  190 -115 -125  126  128  121  $pl 5 clad
643    2  -2.7    -22  19  115 -116 -136  126  128  121  $pl 5 clad on top
644    2  -2.7    -22  19  191 -190 -136  126  128  121  $pl 5 clad on bot
645    3  -3.88  -21  20  190 -115 -137  125  128  121  $pl 5 fuel
646    2  -2.7    -22  21  190 -115 -136  126  128  121  $pl 5 clad
647    1  -1.00  -23  22  191 -116 -136  126  128  121  $pl 6 wg
648    2  -2.7    -24  23  190 -115 -136  126  128  121  $pl 6 clad
649    2  -2.7    -25  24  190 -115 -136  137  128  121  $pl 6 clad
650    2  -2.7    -25  24  190 -115 -125  126  128  121  $pl 6 clad
651    2  -2.7    -26  23  115 -116 -136  126  128  121  $pl 6 clad on top
652    2  -2.7    -26  23  191 -190 -136  126  128  121  $pl 6 clad on bot
653    3  -3.88  -25  24  190 -115 -137  125  128  121  $pl 6 fuel
654    2  -2.7    -26  25  190 -115 -136  126  128  121  $pl 6 clad
655    1  -1.00  -27  26  191 -116 -136  126  128  121  $pl 7 wg
656    2  -2.7    -28  27  190 -115 -136  126  128  121  $pl 7 clad
657    2  -2.7    -29  28  190 -115 -136  137  128  121  $pl 7 clad
658    2  -2.7    -29  28  190 -115 -125  126  128  121  $pl 7 clad
659    2  -2.7    -30  27  115 -116 -136  126  128  121  $pl 7 clad on top
660    2  -2.7    -30  27  191 -190 -136  126  128  121  $pl 7 clad on bot
661    3  -3.88  -29  28  190 -115 -137  125  128  121  $pl 7 fuel
662    2  -2.7    -30  29  190 -115 -136  126  128  121  $pl 7 clad
663    1  -1.00  -31  30  191 -116 -136  126  128  121  $pl 8 wg
664    2  -2.7    -32  31  190 -115 -136  126  128  121  $pl 8 clad
665    2  -2.7    -33  32  190 -115 -136  137  128  121  $pl 8 clad
666    2  -2.7    -33  32  190 -115 -125  126  128  121  $pl 8 clad
667    2  -2.7    -34  31  115 -116 -136  126  128  121  $pl 8 clad on top
668    2  -2.7    -34  31  191 -190 -136  126  128  121  $pl 8 clad on bot
669    3  -3.88  -33  32  190 -115 -137  125  128  121  $pl 8 fuel
670    2  -2.7    -34  33  190 -115 -136  126  128  121  $pl 8 clad
671    1  -1.00  -35  34  191 -116 -136  126  128  121  $pl 9 wg
672    2  -2.7    -36  35  190 -115 -136  126  128  121  $pl 9 clad
673    2  -2.7    -37  36  190 -115 -136  137  128  121  $pl 9 clad
674    2  -2.7    -37  36  190 -115 -125  126  128  121  $pl 9 clad
675    2  -2.7    -38  35  115 -116 -136  126  128  121  $pl 9 clad on top
676    2  -2.7    -38  35  191 -190 -136  126  128  121  $pl 9 clad on bot
677    3  -3.88  -37  36  190 -115 -137  125  128  121  $pl 9 fuel
678    2  -2.7    -38  37  190 -115 -136  126  128  121  $pl 9 clad
679    1  -1.00  -39  38  191 -116 -136  126  128  121  $pl 10 wg
680    2  -2.7    -40  39  190 -115 -136  126  128  121  $pl 10 clad
681    2  -2.7    -41  40  190 -115 -136  137  128  121  $pl 10 clad
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682    2  -2.7   -41  40  190 -115 -125  126  128  121  $pl 10 clad
683    2  -2.7   -42  39  115 -116 -136  126  128  121  $pl 10 clad on top
684    2  -2.7   -42  39  191 -190 -136  126  128  121  $pl 10 clad on bot
685    3  -3.88  -41  40  190 -115 -137  125  128  121  $pl 10 fuel
686    2  -2.7   -42  41  190 -115 -136  126  128  121  $pl 10 clad
687    1  -1.00  -43  42  191 -116 -136  126  128  121  $pl 11 wg
688    2  -2.7   -44  43  190 -115 -136  126  128  121  $pl 11 clad
689    2  -2.7   -45  44  190 -115 -136  137  128  121  $pl 11 clad
690    2  -2.7   -45  44  190 -115 -125  126  128  121  $pl 11 clad
691    2  -2.7   -46  43  115 -116 -136  126  128  121  $pl 11 clad on top
692    2  -2.7   -46  43  191 -190 -136  126  128  121  $pl 11 clad on bot
693    3  -3.88  -45  44  190 -115 -137  125  128  121  $pl 11 fuel
694    2  -2.7   -46  45  190 -115 -136  126  128  121  $pl 11 clad
695    1  -1.00  -47  46  191 -116 -136  126  128  121  $pl 12 wg
696    2  -2.7   -48  47  190 -115 -136  126  128  121  $pl 12 clad
697    2  -2.7   -49  48  190 -115 -136  137  128  121  $pl 12 clad
698    2  -2.7   -49  48  190 -115 -125  126  128  121  $pl 12 clad
699    2  -2.7   -50  47  115 -116 -136  126  128  121  $pl 12 clad on top
700    2  -2.7   -50  47  191 -190 -136  126  128  121  $pl 12 clad on bot
701    3  -3.88  -49  48  190 -115 -137  125  128  121  $pl 12 fuel
702    2  -2.7   -50  49  190 -115 -136  126  128  121  $pl 12 clad
703    1  -1.00  -51  50  191 -116 -136  126  128  121  $pl 13 wg
704    2  -2.7   -52  51  190 -115 -136  126  128  121  $pl 13 clad
705    2  -2.7   -53  52  190 -115 -136  137  128  121  $pl 13 clad
706    2  -2.7   -53  52  190 -115 -125  126  128  121  $pl 13 clad
707    2  -2.7   -54  51  115 -116 -136  126  128  121  $pl 13 clad on top
708    2  -2.7   -54  51  191 -190 -136  126  128  121  $pl 13 clad on bot
709    3  -3.88  -53  52  190 -115 -137  125  128  121  $pl 13 fuel
710    2  -2.7   -54  53  190 -115 -136  126  128  121  $pl 13 clad
711    1  -1.00  -55  54  191 -116 -136  126  128  121  $pl 14 wg
712    2  -2.7   -56  55  190 -115 -136  126  128  121  $pl 14 clad
713    2  -2.7   -57  56  190 -115 -136  137  128  121  $pl 14 clad
714    2  -2.7   -57  56  190 -115 -125  126  128  121  $pl 14 clad
715    2  -2.7   -58  55  115 -116 -136  126  128  121  $pl 14 clad on top
716    2  -2.7   -58  55  191 -190 -136  126  128  121  $pl 14 clad on bot
717    3  -3.88  -57  56  190 -115 -137  125  128  121  $pl 14 fuel
718    2  -2.7   -58  57  190 -115 -136  126  128  121  $pl 14 clad
719    1  -1.00  -59  58  191 -116 -136  126  128  121  $pl 15 wg
720    2  -2.7   -60  59  190 -115 -136  126  128  121  $pl 15 clad
721    2  -2.7   -61  60  190 -115 -136  137  128  121  $pl 15 clad
722    2  -2.7   -61  60  190 -115 -125  126  128  121  $pl 15 clad
723    2  -2.7   -62  59  115 -116 -136  126  128  121  $pl 15 clad on top
724    2  -2.7   -62  59  191 -190 -136  126  128  121  $pl 15 clad on bot
725    3  -3.88  -61  60  190 -115 -137  125  128  121  $pl 15 fuel
726    2  -2.7   -62  61  190 -115 -136  126  128  121  $pl 15 clad
727    1  -1.00  -63  62  191 -116 -136  126  128  121  $pl 16 wg
728    2  -2.7   -64  63  190 -115 -136  126  128  121  $pl 16 clad
729    2  -2.7   -65  64  190 -115 -136  137  128  121  $pl 16 clad
730    2  -2.7   -65  64  190 -115 -125  126  128  121  $pl 16 clad
731    2  -2.7   -66  63  115 -116 -136  126  128  121  $pl 16 clad on top
732    2  -2.7   -66  63  191 -190 -136  126  128  121  $pl 16 clad on bot
733    3  -3.88  -65  64  190 -115 -137  125  128  121  $pl 16 fuel
734    2  -2.7   -66  65  190 -115 -136  126  128  121  $pl 16 clad
735    1  -1.00  -67  66  191 -116 -136  126  128  121  $pl 17 wg
736    2  -2.7   -68  67  190 -115 -136  126  128  121  $pl 17 clad
737    2  -2.7   -69  68  190 -115 -136  137  128  121  $pl 17 clad
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738     2  -2.7    -69  68  190 -115 -125  126  128  121  $pl 17 clad
739     2  -2.7    -70  67  115 -116 -136  126  128  121  $pl 17 clad on top
740     2  -2.7    -70  67  191 -190 -136  126  128  121  $pl 17 clad on bot
741     3  -3.88  -69  68  190 -115 -137  125  128  121  $pl 17 fuel
742     2  -2.7    -70  69  190 -115 -136  126  128  121  $pl 17 clad
743     1  -1.00  -71  70  191 -116 -136  126  128  121  $pl 18 wg
744     2  -2.7    -72  71  190 -115 -136  126  128  121  $pl 18 clad
745     2  -2.7    -73  72  190 -115 -136  137  128  121  $pl 18 clad
746     2  -2.7    -73  72  190 -115 -125  126  128  121  $pl 18 clad
747     2  -2.7    -74  71  115 -116 -136  126  128  121  $pl 18 clad on top
748     2  -2.7    -74  71  191 -190 -136  126  128  121  $pl 18 clad on bot
749     3  -3.88  -73  72  190 -115 -137  125  128  121  $pl 18 fuel
750     2  -2.7    -74  73  190 -115 -136  126  128  121  $pl 18 clad
751     1  -1.00  -75  74  191 -116 -136  126  128  121  $pl 19 wg
752     2  -2.7    -76  75  190 -115 -136  126  128  121  $pl 19 clad
753     2  -2.7    -77  76  190 -115 -136  137  128  121  $pl 19 clad
754     2  -2.7    -77  76  190 -115 -125  126  128  121  $pl 19 clad
755     2  -2.7    -78  75  115 -116 -136  126  128  121  $pl 19 clad on top
756     2  -2.7    -78  75  191 -190 -136  126  128  121  $pl 19 clad on bot
757     3  -3.88  -77  76  190 -115 -137  125  128  121  $pl 19 fuel
758     2  -2.7    -78  77  190 -115 -136  126  128  121  $pl 19 clad
759     1  -1.00  -79  78  191 -116 -136  126  128  121  $pl 20 wg
760     2  -2.7    -80  79  190 -115 -136  126  128  121  $pl 20 clad
761     2  -2.7    -81  80  190 -115 -136  137  128  121  $pl 20 clad
762     2  -2.7    -81  80  190 -115 -125  126  128  121  $pl 20 clad
763     2  -2.7    -82  79  115 -116 -136  126  128  121  $pl 20 clad on top
764     2  -2.7    -82  79  191 -190 -136  126  128  121  $pl 20 clad on bot
765     3  -3.88  -81  80  190 -115 -137  125  128  121  $pl 20 fuel
766     2  -2.7    -82  81  190 -115 -136  126  128  121  $pl 20 clad
767     1  -1.00  -83  82  191 -116 -136  126  128  121  $pl 21 wg
768     2  -2.7    -84  83  190 -115 -136  126  128  121  $pl 21 clad
769     2  -2.7    -85  84  190 -115 -136  137  128  121  $pl 21 clad
770     2  -2.7    -85  84  190 -115 -125  126  128  121  $pl 21 clad
771     2  -2.7    -86  83  115 -116 -136  126  128  121  $pl 21 clad on top
772     2  -2.7    -86  83  191 -190 -136  126  128  121  $pl 21 clad on bot
773     3  -3.88  -85  84  190 -115 -137  125  128  121  $pl 21 fuel
774     2  -2.7    -86  85  190 -115 -136  126  128  121  $pl 21 clad
775     1  -1.00  -87  86  191 -116 -136  126  128  121  $pl 22 wg
776     2  -2.7    -88  87  190 -115 -136  126  128  121  $pl 22 clad
777     2  -2.7    -89  88  190 -115 -136  137  128  121  $pl 22 clad
778     2  -2.7    -89  88  190 -115 -125  126  128  121  $pl 22 clad
779     2  -2.7    -90  87  115 -116 -136  126  128  121  $pl 22 clad on top
780     2  -2.7    -90  87  191 -190 -136  126  128  121  $pl 22 clad on bot
781     3  -3.88  -89  88  190 -115 -137  125  128  121  $pl 22 fuel
782     2  -2.7    -90  89  190 -115 -136  126  128  121  $pl 22 clad
783     1  -1.00  -91  90  191 -116 -136  126  128  121  $pl 23 wg
784     2  -2.7    -92  91  190 -115 -136  126  128  121  $pl 23 clad
785     2  -2.7    -93  92  190 -115 -136  137  128  121  $pl 23 clad
786     2  -2.7    -93  92  190 -115 -125  126  128  121  $pl 23 clad
787     2  -2.7    -94  91  115 -116 -136  126  128  121  $pl 23 clad on top
788     2  -2.7    -94  91  191 -190 -136  126  128  121  $pl 23 clad on bot
789     3  -3.88  -93  92  190 -115 -137  125  128  121  $pl 23 fuel
790     2  -2.7    -94  93  190 -115 -136  126  128  121  $pl 23 clad
791     1  -1.00  -95  94  191 -116 -136  126  128  121  $pl 24 wg
792     2  -2.7    -96  95  190 -115 -136  126  128  121  $pl 24 clad
793     2  -2.7    -97  96  190 -115 -136  137  128  121  $pl 24 clad
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794     2  -2.7   -97  96  190 -115 -125  126  128  121  $pl 24 clad
795     2  -2.7   -98  95  115 -116 -136  126  128  121  $pl 24 clad on top
796     2  -2.7   -98  95  191 -190 -136  126  128  121  $pl 24 clad on bot
797     3  -3.88  -97  96  190 -115 -137  125  128  121  $pl 24 fuel
798     2  -2.7   -98  97  190 -115 -136  126  128  121  $pl 24 clad
799     1  -1.0   -99  98  193 -118 -136  126  128  121  $outer water gap
800     1  -1.0   -98  3   116 -117 -136  126  128  121  $fuel top water
801     1  -1.0   -98  3   192 -191 -136  126  128  121  $fuel bot water
802     6  +0.0803 -98 3   117 -118 -136  126  128  121  $fuel top hanger
803     6  +0.0803 -98 3   193 -192 -136  126  128  121  $fuel bot hanger
c
804      1  -1.0   -99  2     118 -120             $top pool water
805      1  -1.0   -99  2     196 -193             $bot pool water
806      2  -2.7   -100 99    196 -120          121      $outer pr. vessel
807      1  -1.0   -160 100   196 -120          121      $control rod ch.
808      1  -1.0   -163 160   196 -164          121      $control rod ch.
809      1  -1.0   -101 163   196 -120          121      $control rod ch.
810      2  -2.7   -161 160   164 -120          121      $al clad of rod
811      7  +0.0797 -162 161  164 -120          121      $control rod meat
812      2  -2.7   -163 162   164 -120          121      $al clad of rod
c
813      4  -1.85  -102 101   194 -119          121      $be
814      1  -1.0   -103 102   194 -119          121      $be-gr h20
815      2  -2.7   -104 103   194 -119          121      $inner al case
816     12   2.38e-5   -105   104  194  -119    121      $inner he layer
c
817      5  -1.65  -108  105  194 -119   144  121   128   $homo graphite
818      5  -1.65  -108  105  194 -119  -144  128   121   $homo graphite
819      5  -1.65  -108  105  194 -119  -128  145   121   $homo graphite
820      5  -1.65  -108  105  194 -119  -145  121  -128   $homo graphite
821      2  -2.7   -108  101  195 -194   121     $graphite bottom support
c
c
822      1  -1.0   -109 108   195 -119     121       $h2o
823      2  -2.7   -110 109   195 -119     121       $al
824      1  -1.0   -111 110   195 -119     121       $h2o
825      1  -1.0   -111 101   119 -120     121       $top h2o
826      1  -1.0   -111 101   196 -195     121       $bot h2o
c
c      core left side description starts from here
c
827     1  -1.00  -99  2   193 -118 -134  135  -128 -121  $water gap
828     1  -1.00  -99  2   193 -118 -127  129       -121  $water gap
829     1  -1.00  -99  2   193 -118 -140  141   128 -121  $water gap
830     2  -2.7   -99  2   193 -118  171 -170  -128 -121  $aluminum side plate
831     2  -2.7   -99  2   193 -118 -135  136  -128 -121  $aluminum side plate
832     2  -2.7   -99  2   193 -118 -133  134  -128 -121  $aluminum side plate
833     2  -2.7   -99  2   193 -118 -129  130  -128 -121  $aluminum side plate
834     2  -2.7   -99  2   193 -118 -126  127   128 -121  $aluminum side plate
835     2  -2.7   -99  2   193 -118 -141  142   128 -121  $aluminum side plate
836     2  -2.7   -99  2   193 -118 -139  140   128 -121  $aluminum side plate
837     2  -2.7   -99  2   193 -118  171 -170   128 -121  $aluminum side plate
c
c
838     1  -1.0   -3   2   193 -118 -171 -136  -128  -121  $pl 1 wg
839     2  -2.7   -4   3   190 -115 -171 -136  -128  -121  $pl 1 clad
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840     2  -2.7   -5   4   190 -115 -171  172  -128  -121  $pl 1 clad
841     2  -2.7   -5   4   190 -115  137 -136  -128  -121  $pl 1 clad
842     2  -2.7   -6   3   115 -116 -171 -136  -128  -121  $pl 1 clad on top
843     2  -2.7   -6   3   191 -190 -171 -136  -128  -121  $pl 1 clad on bot
844     3  -3.88  -5   4   190 -115 -172 -137  -128  -121  $pl 1 fuel
845     2  -2.7   -6   5   190 -115 -171 -136  -128  -121  $pl 1 clad
846     1  -1.00  -7   6   191 -116 -171 -136  -128  -121  $pl 2 wg
847     2  -2.7   -8   7   190 -115 -171 -136  -128  -121  $pl 2 clad
848     2  -2.7   -9   8   190 -115 -171  172  -128  -121  $pl 2 clad
849     2  -2.7   -9   8   190 -115  137 -136  -128  -121  $pl 2 clad
850     2  -2.7   -10  7   115 -116 -171 -136  -128  -121  $pl 2 clad on top
851     2  -2.7   -10  7   191 -190 -171 -136  -128  -121  $pl 2 clad on bot
852     3  -3.88  -9   8   190 -115 -172 -137  -128  -121  $pl 2 fuel
853     2  -2.7   -10  9   190 -115 -171 -136  -128  -121  $pl 2 clad
854     1  -1.00  -11  10  191 -116 -171 -136  -128  -121  $pl 3 wg
855     2  -2.7   -12  11  190 -115 -171 -136  -128  -121  $pl 3 clad
856     2  -2.7   -13  12  190 -115 -171  172  -128  -121  $pl 3 clad
857     2  -2.7   -13  12  190 -115  137 -136  -128  -121  $pl 3 clad
858     2  -2.7   -14  11  115 -116 -171 -136  -128  -121  $pl 3 clad on top
859     2  -2.7   -14  11  191 -190 -171 -136  -128  -121  $pl 3 clad on bot
860     3  -3.88  -13  12  190 -115 -172 -137  -128  -121  $pl 3 fuel
861     2  -2.7   -14  13  190 -115 -171 -136  -128  -121  $pl 3 clad
862     1  -1.00  -15  14  191 -116 -171 -136  -128  -121  $pl 4 wg
863     2  -2.7   -16  15  190 -115 -171 -136  -128  -121  $pl 4 clad
864     2  -2.7   -17  16  190 -115 -171  172  -128  -121  $pl 4 clad
865     2  -2.7   -17  16  190 -115  137 -136  -128  -121  $pl 4 clad
866     2  -2.7   -18  15  115 -116 -171 -136  -128  -121  $pl 4 clad on top
867     2  -2.7   -18  15  191 -190 -171 -136  -128  -121  $pl 4 clad on bot
868     3  -3.88  -17  16  190 -115 -172 -137  -128  -121  $pl 4 fuel
869     2  -2.7   -18  17  190 -115 -171 -136  -128  -121  $pl 4 clad
870     1  -1.00  -19  18  191 -116 -171 -136  -128  -121  $pl 5 wg
871     2  -2.7   -20  19  190 -115 -171 -136  -128  -121  $pl 5 clad
872     2  -2.7   -21  20  190 -115 -171  172  -128  -121  $pl 5 clad
873     2  -2.7   -21  20  190 -115  137 -136  -128  -121  $pl 5 clad
874     2  -2.7   -22  19  115 -116 -171 -136  -128  -121  $pl 5 clad on top
875     2  -2.7   -22  19  191 -190 -171 -136  -128  -121  $pl 5 clad on bot
876     3  -3.88  -21  20  190 -115 -172 -137  -128  -121  $pl 5 fuel
877     2  -2.7   -22  21  190 -115 -171 -136  -128  -121  $pl 5 clad
878     1  -1.00  -23  22  191 -116 -171 -136  -128  -121  $pl 6 wg
879     2  -2.7   -24  23  190 -115 -171 -136  -128  -121  $pl 6 clad
880     2  -2.7   -25  24  190 -115 -171  172  -128  -121  $pl 6 clad
881     2  -2.7   -25  24  190 -115  137 -136  -128  -121  $pl 6 clad
882     2  -2.7   -26  23  115 -116 -171 -136  -128  -121  $pl 6 clad on top
883     2  -2.7   -26  23  191 -190 -171 -136  -128  -121  $pl 6 clad on bot
884     3  -3.88  -25  24  190 -115 -172 -137  -128  -121  $pl 6 fuel
885     2  -2.7   -26  25  190 -115 -171 -136  -128  -121  $pl 6 clad
886     1  -1.00  -27  26  191 -116 -171 -136  -128  -121  $pl 7 wg
887     2  -2.7   -28  27  190 -115 -171 -136  -128  -121  $pl 7 clad
888     2  -2.7   -29  28  190 -115 -171  172  -128  -121  $pl 7 clad
889     2  -2.7   -29  28  190 -115  137 -136  -128  -121  $pl 7 clad
890     2  -2.7   -30  27  115 -116 -171 -136  -128  -121  $pl 7 clad on top
891     2  -2.7   -30  27  191 -190 -171 -136  -128  -121  $pl 7 clad on bot
892     3  -3.88  -29  28  190 -115 -172 -137  -128  -121  $pl 7 fuel
893     2  -2.7   -30  29  190 -115 -171 -136  -128  -121  $pl 7 clad
894     1  -1.00  -31  30  191 -116 -171 -136  -128  -121  $pl 8 wg
895     2  -2.7   -32  31  190 -115 -171 -136  -128  -121  $pl 8 clad
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896    2  -2.7   -33  32  190 -115 -171  172  -128  -121  $pl 8 clad
897    2  -2.7   -33  32  190 -115  137 -136  -128  -121  $pl 8 clad
898    2  -2.7   -34  31  115 -116 -171 -136  -128  -121  $pl 8 clad on top
899    2  -2.7   -34  31  191 -190 -171 -136  -128  -121  $pl 8 clad on bot
900    3  -3.88  -33  32  190 -115 -172 -137  -128  -121  $pl 8 fuel
901    2  -2.7   -34  33  190 -115 -171 -136  -128  -121  $pl 8 clad
902    1  -1.00  -35  34  191 -116 -171 -136  -128  -121  $pl 9 wg
903    2  -2.7   -36  35  190 -115 -171 -136  -128  -121  $pl 9 clad
904    2  -2.7   -37  36  190 -115 -171  172  -128  -121  $pl 9 clad
905    2  -2.7   -37  36  190 -115  137 -136  -128  -121  $pl 9 clad
906    2  -2.7   -38  35  115 -116 -171 -136  -128  -121  $pl 9 clad on top
907    2  -2.7   -38  35  191 -190 -171 -136  -128  -121  $pl 9 clad on bot
908    3  -3.88  -37  36  190 -115 -172 -137  -128  -121  $pl 9 fuel
909    2  -2.7   -38  37  190 -115 -171 -136  -128  -121  $pl 9 clad
910    1  -1.00  -39  38  191 -116 -171 -136  -128  -121  $pl 10 wg
911    2  -2.7   -40  39  190 -115 -171 -136  -128  -121  $pl 10 clad
912    2  -2.7   -41  40  190 -115 -171  172  -128  -121  $pl 10 clad
913    2  -2.7   -41  40  190 -115  137 -136  -128  -121  $pl 10 clad
914    2  -2.7   -42  39  115 -116 -171 -136  -128  -121  $pl 10 clad on top
915    2  -2.7   -42  39  191 -190 -171 -136  -128  -121  $pl 10 clad on bot
916    3  -3.88  -41  40  190 -115 -172 -137  -128  -121  $pl 10 fuel
917    2  -2.7   -42  41  190 -115 -171 -136  -128  -121  $pl 10 clad
918    1  -1.00  -43  42  191 -116 -171 -136  -128  -121  $pl 11 wg
919    2  -2.7   -44  43  190 -115 -171 -136  -128  -121  $pl 11 clad
920    2  -2.7   -45  44  190 -115 -171  172  -128  -121  $pl 11 clad
921    2  -2.7   -45  44  190 -115  137 -136  -128  -121  $pl 11 clad
922    2  -2.7   -46  43  115 -116 -171 -136  -128  -121  $pl 11 clad on top
923    2  -2.7   -46  43  191 -190 -171 -136  -128  -121  $pl 11 clad on bot
924    3  -3.88  -45  44  190 -115 -172 -137  -128  -121  $pl 11 fuel
925    2  -2.7   -46  45  190 -115 -171 -136  -128  -121  $pl 11 clad
926    1  -1.00  -47  46  191 -116 -171 -136  -128  -121  $pl 12 wg
927    2  -2.7   -48  47  190 -115 -171 -136  -128  -121  $pl 12 clad
928    2  -2.7   -49  48  190 -115 -171  172  -128  -121  $pl 12 clad
929    2  -2.7   -49  48  190 -115  137 -136  -128  -121  $pl 12 clad
930    2  -2.7   -50  47  115 -116 -171 -136  -128  -121  $pl 12 clad on top
931    2  -2.7   -50  47  191 -190 -171 -136  -128  -121  $pl 12 clad on bot
932    3  -3.88  -49  48  190 -115 -172 -137  -128  -121  $pl 12 fuel
933    2  -2.7   -50  49  190 -115 -171 -136  -128  -121  $pl 12 clad
934    1  -1.00  -51  50  191 -116 -171 -136  -128  -121  $pl 13 wg
935    2  -2.7   -52  51  190 -115 -171 -136  -128  -121  $pl 13 clad
936    2  -2.7   -53  52  190 -115 -171  172  -128  -121  $pl 13 clad
937    2  -2.7   -53  52  190 -115  137 -136  -128  -121  $pl 13 clad
938    2  -2.7   -54  51  115 -116 -171 -136  -128  -121  $pl 13 clad on top
939    2  -2.7   -54  51  191 -190 -171 -136  -128  -121  $pl 13 clad on bot
940    3  -3.88  -53  52  190 -115 -172 -137  -128  -121  $pl 13 fuel
941    2  -2.7   -54  53  190 -115 -171 -136  -128  -121  $pl 13 clad
942    1  -1.00  -55  54  191 -116 -171 -136  -128  -121  $pl 14 wg
943    2  -2.7   -56  55  190 -115 -171 -136  -128  -121  $pl 14 clad
944    2  -2.7   -57  56  190 -115 -171  172  -128  -121  $pl 14 clad
945    2  -2.7   -57  56  190 -115  137 -136  -128  -121  $pl 14 clad
946    2  -2.7   -58  55  115 -116 -171 -136  -128  -121  $pl 14 clad on top
947    2  -2.7   -58  55  191 -190 -171 -136  -128  -121  $pl 14 clad on bot
948    3  -3.88  -57  56  190 -115 -172 -137  -128  -121  $pl 14 fuel
949    2  -2.7   -58  57  190 -115 -171 -136  -128  -121  $pl 14 clad
950    1  -1.00  -59  58  191 -116 -171 -136  -128  -121  $pl 15 wg
951   2  -2.7   -60  59  190 -115 -171 -136  -128  -121  $pl 15 clad
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952    2  -2.7   -61  60  190 -115 -171  172  -128  -121  $pl 15 clad
953    2  -2.7   -61  60  190 -115  137 -136  -128  -121  $pl 15 clad
954    2  -2.7   -62  59  115 -116 -171 -136  -128  -121  $pl 15 clad on top
955    2  -2.7   -62  59  191 -190 -171 -136  -128  -121  $pl 15 clad on bot
956    3  -3.88  -61  60  190 -115 -172 -137  -128  -121  $pl 15 fuel
957    2  -2.7   -62  61  190 -115 -171 -136  -128  -121  $pl 15 clad
958    1  -1.00  -63  62  191 -116 -171 -136  -128  -121  $pl 16 wg
959    2  -2.7   -64  63  190 -115 -171 -136  -128  -121  $pl 16 clad
960    2  -2.7   -65  64  190 -115 -171  172  -128  -121  $pl 16 clad
961    2  -2.7   -65  64  190 -115  137 -136  -128  -121  $pl 16 clad
962    2  -2.7   -66  63  115 -116 -171 -136  -128  -121  $pl 16 clad on top
963    2  -2.7   -66  63  191 -190 -171 -136  -128  -121  $pl 16 clad on bot
964    3  -3.88  -65  64  190 -115 -172 -137  -128  -121  $pl 16 fuel
965    2  -2.7   -66  65  190 -115 -171 -136  -128  -121  $pl 16 clad
966    1  -1.00  -67  66  191 -116 -171 -136  -128  -121  $pl 17 wg
967    2  -2.7   -68  67  190 -115 -171 -136  -128  -121  $pl 17 clad
968    2  -2.7   -69  68  190 -115 -171  172  -128  -121  $pl 17 clad
969    2  -2.7   -69  68  190 -115  137 -136  -128  -121  $pl 17 clad
970    2  -2.7   -70  67  115 -116 -171 -136  -128  -121  $pl 17 clad on top
971    2  -2.7   -70  67  191 -190 -171 -136  -128  -121  $pl 17 clad on bot
972    3  -3.88  -69  68  190 -115 -172 -137  -128  -121  $pl 17 fuel
973    2  -2.7   -70  69  190 -115 -171 -136  -128  -121  $pl 17 clad
974    1  -1.00  -71  70  191 -116 -171 -136  -128  -121  $pl 18 wg
975    2  -2.7   -72  71  190 -115 -171 -136  -128  -121  $pl 18 clad
976    2  -2.7   -73  72  190 -115 -171  172  -128  -121  $pl 18 clad
977    2  -2.7   -73  72  190 -115  137 -136  -128  -121  $pl 18 clad
978    2  -2.7   -74  71  115 -116 -171 -136  -128  -121  $pl 18 clad on top
979    2  -2.7   -74  71  191 -190 -171 -136  -128  -121  $pl 18 clad on bot
980    3  -3.88  -73  72  190 -115 -172 -137  -128  -121  $pl 18 fuel
981    2  -2.7   -74  73  190 -115 -171 -136  -128  -121  $pl 18 clad
982    1  -1.00  -75  74  191 -116 -171 -136  -128  -121  $pl 19 wg
983    2  -2.7   -76  75  190 -115 -171 -136  -128  -121  $pl 19 clad
984    2  -2.7   -77  76  190 -115 -171  172  -128  -121  $pl 19 clad
985    2  -2.7   -77  76  190 -115  137 -136  -128  -121  $pl 19 clad
986    2  -2.7   -78  75  115 -116 -171 -136  -128  -121  $pl 19 clad on top
987    2  -2.7   -78  75  191 -190 -171 -136  -128  -121  $pl 19 clad on bot
988    3  -3.88  -77  76  190 -115 -172 -137  -128  -121  $pl 19 fuel
989    2  -2.7   -78  77  190 -115 -171 -136  -128  -121  $pl 19 clad
990    1  -1.00  -79  78  191 -116 -171 -136  -128  -121  $pl 20 wg
991    2  -2.7   -80  79  190 -115 -171 -136  -128  -121  $pl 20 clad
992    2  -2.7   -81  80  190 -115 -171  172  -128  -121  $pl 20 clad
993    2  -2.7   -81  80  190 -115  137 -136  -128  -121  $pl 20 clad
994    2  -2.7   -82  79  115 -116 -171 -136  -128  -121  $pl 20 clad on top
995    2  -2.7   -82  79  191 -190 -171 -136  -128  -121  $pl 20 clad on bot
996    3  -3.88  -81  80  190 -115 -172 -137  -128  -121  $pl 20 fuel
997    2  -2.7   -82  81  190 -115 -171 -136  -128  -121  $pl 20 clad
998    1  -1.00  -83  82  191 -116 -171 -136  -128  -121  $pl 21 wg
999    2  -2.7   -84  83  190 -115 -171 -136  -128  -121  $pl 21 clad
1000   2  -2.7   -85  84  190 -115 -171  172  -128  -121  $pl 21 clad
1001   2  -2.7   -85  84  190 -115  137 -136  -128  -121  $pl 21 clad
1002   2  -2.7   -86  83  115 -116 -171 -136  -128  -121  $pl 21 clad on top
1003   2  -2.7   -86  83  191 -190 -171 -136  -128  -121  $pl 21 clad on bot
1004   3  -3.88  -85  84  190 -115 -172 -137  -128  -121  $pl 21 fuel
1005   2  -2.7   -86  85  190 -115 -171 -136  -128  -121  $pl 21 clad
1006   1  -1.00  -87  86  191 -116 -171 -136  -128  -121  $pl 22 wg
1007   2  -2.7   -88  87  190 -115 -171 -136  -128  -121  $pl 22 clad
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1008   2  -2.7   -89  88  190 -115 -171  172  -128  -121  $pl 22 clad
1009   2  -2.7   -89  88  190 -115  137 -136  -128  -121  $pl 22 clad
1010   2  -2.7   -90  87  115 -116 -171 -136  -128  -121  $pl 22 clad on top
1011   2  -2.7   -90  87  191 -190 -171 -136  -128  -121  $pl 22 clad on bot
1012   3  -3.88  -89  88  190 -115 -172 -137  -128  -121  $pl 22 fuel
1013   2  -2.7   -90  89  190 -115 -171 -136  -128  -121  $pl 22 clad
1014   1  -1.00  -91  90  191 -116 -171 -136  -128  -121  $pl 23 wg
1015   2  -2.7   -92  91  190 -115 -171 -136  -128  -121  $pl 23 clad
1016   2  -2.7   -93  92  190 -115 -171  172  -128  -121  $pl 23 clad
1017   2  -2.7   -93  92  190 -115  137 -136  -128  -121  $pl 23 clad
1018   2  -2.7   -94  91  115 -116 -171 -136  -128  -121  $pl 23 clad on top
1019   2  -2.7   -94  91  191 -190 -171 -136  -128  -121  $pl 23 clad on bot
1020   3  -3.88  -93  92  190 -115 -172 -137  -128  -121  $pl 23 fuel
1021   2  -2.7   -94  93  190 -115 -171 -136  -128  -121  $pl 23 clad
1022   1  -1.00  -95  94  191 -116 -171 -136  -128  -121  $pl 24 wg
1023   2  -2.7   -96  95  190 -115 -171 -136  -128  -121  $pl 24 clad
1024   2  -2.7   -97  96  190 -115 -171  172  -128  -121  $pl 24 clad
1025   2  -2.7   -97  96  190 -115  137 -136  -128  -121  $pl 24 clad
1026   2  -2.7   -98  95  115 -116 -171 -136  -128  -121  $pl 24 clad on top
1027   2  -2.7   -98  95  191 -190 -171 -136  -128  -121  $pl 24 clad on bot
1028   3  -3.88  -97  96  190 -115 -172 -137  -128  -121  $pl 24 fuel
1029   2  -2.7   -98  97  190 -115 -171 -136  -128  -121  $pl 24 clad
1030   1  -1.0   -99  98  193 -118 -171 -136  -128  -121  $outer water gap
1031   1  -1.0   -98  3   116 -117 -171 -136  -128  -121  $fuel top water
1032   1  -1.0   -98  3   192 -191 -171 -136  -128  -121  $fuel bot water
1033   6  +0.0803 -98  3  117 -118 -171 -136  -128  -121  $fuel top hanger
1034   6  +0.0803 -98  3  193 -192 -171 -136  -128  -121  $fuel bot hanger
c
c
c
1035    1  -1.0   -3   2   193 -118  139 -171    128 -121  $pl 1 wg
1036    2  -2.7   -4   3   190 -115  139 -171    128 -121  $pl 1 clad
1037    2  -2.7   -5   4   190 -115  139 -138    128 -121  $pl 1 clad
1038    2  -2.7   -5   4   190 -115  172 -171    128 -121  $pl 1 clad
1039    2  -2.7   -6   3   115 -116  139 -171    128 -121  $pl 1 clad on top
1040    2  -2.7   -6   3   191 -190  139 -171    128 -121  $pl 1 clad on bot
1041    3  -3.88  -5   4   190 -115  138 -172    128 -121  $pl 1 fuel
1042    2  -2.7   -6   5   190 -115  139 -171    128 -121  $pl 1 clad
1043    1  -1.00  -7   6   191 -116  139 -171    128 -121  $pl 2 wg
1044    2  -2.7   -8   7   190 -115  139 -171    128 -121  $pl 2 clad
1045    2  -2.7   -9   8   190 -115  139 -138    128 -121  $pl 2 clad
1046    2  -2.7   -9   8   190 -115  172 -171    128 -121  $pl 2 clad
1047    2  -2.7   -10  7   115 -116  139 -171    128 -121  $pl 2 clad on top
1048    2  -2.7   -10  7   191 -190  139 -171    128 -121  $pl 2 clad on bot
1049    3  -3.88  -9   8   190 -115  138 -172    128 -121  $pl 2 fuel
1050    2  -2.7   -10  9   190 -115  139 -171    128 -121  $pl 2 clad
1051    1  -1.00  -11  10  191 -116  139 -171    128 -121  $pl 3 wg
1052    2  -2.7   -12  11  190 -115  139 -171    128 -121  $pl 3 clad
1053    2  -2.7   -13  12  190 -115  139 -138    128 -121  $pl 3 clad
1054    2  -2.7   -13  12  190 -115  172 -171    128 -121  $pl 3 clad
1055    2  -2.7   -14  11  115 -116  139 -171    128 -121  $pl 3 clad on top
1056    2  -2.7   -14  11  191 -190  139 -171    128 -121  $pl 3 clad on bot
1057    3  -3.88  -13  12  190 -115  138 -172    128 -121  $pl 3 fuel
1058    2  -2.7   -14  13  190 -115  139 -171    128 -121  $pl 3 clad
1059    1  -1.00  -15  14  191 -116  139 -171    128 -121  $pl 4 wg
1060    2  -2.7   -16  15  190 -115  139 -171    128 -121  $pl 4 clad
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1061    2  -2.7   -17  16  190 -115  139 -138   128 -121  $pl 4 clad
1062    2  -2.7   -17  16  190 -115  172 -171   128 -121  $pl 4 clad
1063    2  -2.7   -18  15  115 -116  139 -171   128 -121  $pl 4 clad on top
1064    2  -2.7   -18  15  191 -190  139 -171   128 -121  $pl 4 clad on bot
1065    3  -3.88  -17  16  190 -115  138 -172   128 -121  $pl 4 fuel
1066    2  -2.7   -18  17  190 -115  139 -171   128 -121  $pl 4 clad
1067    1  -1.00  -19  18  191 -116  139 -171   128 -121  $pl 5 wg
1068    2  -2.7   -20  19  190 -115  139 -171   128 -121  $pl 5 clad
1069    2  -2.7   -21  20  190 -115  139 -138   128 -121  $pl 5 clad
1070    2  -2.7   -21  20  190 -115  172 -171   128 -121  $pl 5 clad
1071    2  -2.7   -22  19  115 -116  139 -171   128 -121  $pl 5 clad on top
1072    2  -2.7   -22  19  191 -190  139 -171   128 -121  $pl 5 clad on bot
1073    3  -3.88  -21  20  190 -115  138 -172   128 -121  $pl 5 fuel
1074    2  -2.7   -22  21  190 -115  139 -171   128 -121  $pl 5 clad
1075    1  -1.00  -23  22  191 -116  139 -171   128 -121  $pl 6 wg
1076    2  -2.7   -24  23  190 -115  139 -171   128 -121  $pl 6 clad
1077    2  -2.7   -25  24  190 -115  139 -138   128 -121  $pl 6 clad
1078    2  -2.7   -25  24  190 -115  172 -171   128 -121  $pl 6 clad
1079    2  -2.7   -26  23  115 -116  139 -171   128 -121  $pl 6 clad on top
1080    2  -2.7   -26  23  191 -190  139 -171   128 -121  $pl 6 clad on bot
1081    3  -3.88  -25  24  190 -115  138 -172   128 -121  $pl 6 fuel
1082    2  -2.7   -26  25  190 -115  139 -171   128 -121  $pl 6 clad
1083    1  -1.00  -27  26  191 -116  139 -171   128 -121  $pl 7 wg
1084    2  -2.7   -28  27  190 -115  139 -171   128 -121  $pl 7 clad
1085    2  -2.7   -29  28  190 -115  139 -138   128 -121  $pl 7 clad
1086    2  -2.7   -29  28  190 -115  172 -171   128 -121  $pl 7 clad
1087    2  -2.7   -30  27  115 -116  139 -171   128 -121  $pl 7 clad on top
1088    2  -2.7   -30  27  191 -190  139 -171   128 -121  $pl 7 clad on bot
1089    3  -3.88  -29  28  190 -115  138 -172   128 -121  $pl 7 fuel
1090    2  -2.7   -30  29  190 -115  139 -171   128 -121  $pl 7 clad
1091    1  -1.00  -31  30  191 -116  139 -171   128 -121  $pl 8 wg
1092    2  -2.7   -32  31  190 -115  139 -171   128 -121  $pl 8 clad
1093    2  -2.7   -33  32  190 -115  139 -138   128 -121  $pl 8 clad
1094    2  -2.7   -33  32  190 -115  172 -171   128 -121  $pl 8 clad
1095    2  -2.7   -34  31  115 -116  139 -171   128 -121  $pl 8 clad on top
1096    2  -2.7   -34  31  191 -190  139 -171   128 -121  $pl 8 clad on bot
1097    3  -3.88  -33  32  190 -115  138 -172   128 -121  $pl 8 fuel
1098    2  -2.7   -34  33  190 -115  139 -171   128 -121  $pl 8 clad
1099    1  -1.00  -35  34  191 -116  139 -171   128 -121  $pl 9 wg
1100    2  -2.7   -36  35  190 -115  139 -171   128 -121  $pl 9 clad
1101     2  -2.7   -37  36  190 -115  139 -138   128 -121  $pl 9 clad
1102    2  -2.7   -37  36  190 -115  172 -171   128 -121  $pl 9 clad
1103    2  -2.7   -38  35  115 -116  139 -171   128 -121  $pl 9 clad on top
1104    2  -2.7   -38  35  191 -190  139 -171   128 -121  $pl 9 clad on bot
1105    3  -3.88  -37  36  190 -115  138 -172   128 -121  $pl 9 fuel
1106    2  -2.7   -38  37  190 -115  139 -171   128 -121  $pl 9 clad
1107    1  -1.00  -39  38  191 -116  139 -171   128 -121  $pl 10 wg
1108    2  -2.7   -40  39  190 -115  139 -171   128 -121  $pl 10 clad
1109    2  -2.7   -41  40  190 -115  139 -138   128 -121  $pl 10 clad
1110    2  -2.7   -41  40  190 -115  172 -171   128 -121  $pl 10 clad
1111    2  -2.7   -42  39  115 -116  139 -171   128 -121  $pl 10 clad on top
1112    2  -2.7   -42  39  191 -190  139 -171   128 -121  $pl 10 clad on bot
1113    3  -3.88  -41  40  190 -115  138 -172   128 -121  $pl 10 fuel
1114    2  -2.7   -42  41  190 -115  139 -171   128 -121  $pl 10 clad
1115    1  -1.00  -43  42  191 -116  139 -171   128 -121  $pl 11 wg
1116    2  -2.7   -44  43  190 -115  139 -171   128 -121  $pl 11 clad
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1117   2  -2.7   -45  44  190 -115  139 -138   128 -121  $pl 11 clad
1118   2  -2.7   -45  44  190 -115  172 -171   128 -121  $pl 11 clad
1119   2  -2.7   -46  43  115 -116  139 -171   128 -121  $pl 11 clad on top
1120   2  -2.7   -46  43  191 -190  139 -171   128 -121  $pl 11 clad on bot
1121   3  -3.88  -45  44  190 -115  138 -172   128 -121  $pl 11 fuel
1122   2  -2.7   -46  45  190 -115  139 -171   128 -121  $pl 11 clad
1123   1  -1.00  -47  46  191 -116  139 -171   128 -121  $pl 12 wg
1124   2  -2.7   -48  47  190 -115  139 -171   128 -121  $pl 12 clad
1125   2  -2.7   -49  48  190 -115  139 -138   128 -121  $pl 12 clad
1126   2  -2.7   -49  48  190 -115  172 -171   128 -121  $pl 12 clad
1127   2  -2.7   -50  47  115 -116  139 -171   128 -121  $pl 12 clad on top
1128   2  -2.7   -50  47  191 -190  139 -171   128 -121  $pl 12 clad on bot
1129   3  -3.88  -49  48  190 -115  138 -172   128 -121  $pl 12 fuel
1130   2  -2.7   -50  49  190 -115  139 -171   128 -121  $pl 12 clad
1131   1  -1.00  -51  50  191 -116  139 -171   128 -121  $pl 13 wg
1132   2  -2.7   -52  51  190 -115  139 -171   128 -121  $pl 13 clad
1133   2  -2.7   -53  52  190 -115  139 -138   128 -121  $pl 13 clad
1134   2  -2.7   -53  52  190 -115  172 -171   128 -121  $pl 13 clad
1135   2  -2.7   -54  51  115 -116  139 -171   128 -121  $pl 13 clad on top
1136   2  -2.7   -54  51  191 -190  139 -171   128 -121  $pl 13 clad on bot
1137   3  -3.88  -53  52  190 -115  138 -172   128 -121  $pl 13 fuel
1138   2  -2.7   -54  53  190 -115  139 -171   128 -121  $pl 13 clad
1139   1  -1.00  -55  54  191 -116  139 -171   128 -121  $pl 14 wg
1140   2  -2.7   -56  55  190 -115  139 -171   128 -121  $pl 14 clad
1141   2  -2.7   -57  56  190 -115  139 -138   128 -121  $pl 14 clad
1142   2  -2.7   -57  56  190 -115  172 -171   128 -121  $pl 14 clad
1143   2  -2.7   -58  55  115 -116  139 -171   128 -121  $pl 14 clad on top
1144   2  -2.7   -58  55  191 -190  139 -171   128 -121  $pl 14 clad on bot
1145   3  -3.88  -57  56  190 -115  138 -172   128 -121  $pl 14 fuel
1146   2  -2.7   -58  57  190 -115  139 -171   128 -121  $pl 14 clad
1147   1  -1.00  -59  58  191 -116  139 -171   128 -121  $pl 15 wg
1148   2  -2.7   -60  59  190 -115  139 -171   128 -121  $pl 15 clad
1149   2  -2.7   -61  60  190 -115  139 -138   128 -121  $pl 15 clad
1150   2  -2.7   -61  60  190 -115  172 -171   128 -121  $pl 15 clad
1151   2  -2.7   -62  59  115 -116  139 -171   128 -121  $pl 15 clad on top
1152   2  -2.7   -62  59  191 -190  139 -171   128 -121  $pl 15 clad on bot
1153   3  -3.88  -61  60  190 -115  138 -172   128 -121  $pl 15 fuel
1154   2  -2.7   -62  61  190 -115  139 -171   128 -121  $pl 15 clad
1155   1  -1.00  -63  62  191 -116  139 -171   128 -121  $pl 16 wg
1156   2  -2.7   -64  63  190 -115  139 -171   128 -121  $pl 16 clad
1157   2  -2.7   -65  64  190 -115  139 -138   128 -121  $pl 16 clad
1158   2  -2.7   -65  64  190 -115  172 -171   128 -121  $pl 16 clad
1159   2  -2.7   -66  63  115 -116  139 -171   128 -121  $pl 16 clad on top
1160   2  -2.7   -66  63  191 -190  139 -171   128 -121  $pl 16 clad on bot
1161   3  -3.88  -65  64  190 -115  138 -172   128 -121  $pl 16 fuel
1162   2  -2.7   -66  65  190 -115  139 -171   128 -121  $pl 16 clad
1163   1  -1.00  -67  66  191 -116  139 -171   128 -121  $pl 17 wg
1164   2  -2.7   -68  67  190 -115  139 -171   128 -121  $pl 17 clad
1165   2  -2.7   -69  68  190 -115  139 -138   128 -121  $pl 17 clad
1166   2  -2.7   -69  68  190 -115  172 -171   128 -121  $pl 17 clad
1167   2  -2.7   -70  67  115 -116  139 -171   128 -121  $pl 17 clad on top
1168   2  -2.7   -70  67  191 -190  139 -171   128 -121  $pl 17 clad on bot
1169   3  -3.88  -69  68  190 -115  138 -172   128 -121  $pl 17 fuel
1170   2  -2.7   -70  69  190 -115  139 -171   128 -121  $pl 17 clad
1171   1  -1.00  -71  70  191 -116  139 -171   128 -121  $pl 18 wg
1172   2  -2.7   -72  71  190 -115  139 -171   128 -121  $pl 18 clad
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1173   2  -2.7   -73  72  190 -115  139 -138   128 -121  $pl 18 clad
1174   2  -2.7   -73  72  190 -115  172 -171   128 -121  $pl 18 clad
1175   2  -2.7   -74  71  115 -116  139 -171   128 -121  $pl 18 clad on top
1176   2  -2.7   -74  71  191 -190  139 -171   128 -121  $pl 18 clad on bot
1177   3  -3.88  -73  72  190 -115  138 -172   128 -121  $pl 18 fuel
1178   2  -2.7   -74  73  190 -115  139 -171   128 -121  $pl 18 clad
1179   1  -1.00  -75  74  191 -116  139 -171   128 -121  $pl 19 wg
1180   2  -2.7   -76  75  190 -115  139 -171   128 -121  $pl 19 clad
1181   2  -2.7   -77  76  190 -115  139 -138   128 -121  $pl 19 clad
1182   2  -2.7   -77  76  190 -115  172 -171   128 -121  $pl 19 clad
1183   2  -2.7   -78  75  115 -116  139 -171   128 -121  $pl 19 clad on top
1184   2  -2.7   -78  75  191 -190  139 -171   128 -121  $pl 19 clad on bot
1185   3  -3.88  -77  76  190 -115  138 -172   128 -121  $pl 19 fuel
1186   2  -2.7   -78  77  190 -115  139 -171   128 -121  $pl 19 clad
1187   1  -1.00  -79  78  191 -116  139 -171   128 -121  $pl 20 wg
1188   2  -2.7   -80  79  190 -115  139 -171   128 -121  $pl 20 clad
1189   2  -2.7   -81  80  190 -115  139 -138   128 -121  $pl 20 clad
1190   2  -2.7   -81  80  190 -115  172 -171   128 -121  $pl 20 clad
1191   2  -2.7   -82  79  115 -116  139 -171   128 -121  $pl 20 clad on top
1192   2  -2.7   -82  79  191 -190  139 -171   128 -121  $pl 20 clad on bot
1193   3  -3.88  -81  80  190 -115  138 -172   128 -121  $pl 20 fuel
1194   2  -2.7   -82  81  190 -115  139 -171   128 -121  $pl 20 clad
1195   1  -1.00  -83  82  191 -116  139 -171   128 -121  $pl 21 wg
1196   2  -2.7   -84  83  190 -115  139 -171   128 -121  $pl 21 clad
1197   2  -2.7   -85  84  190 -115  139 -138   128 -121  $pl 21 clad
1198   2  -2.7   -85  84  190 -115  172 -171   128 -121  $pl 21 clad
1199   2  -2.7   -86  83  115 -116  139 -171   128 -121  $pl 21 clad on top
1200   2  -2.7   -86  83  191 -190  139 -171   128 -121  $pl 21 clad on bot
1201   3  -3.88  -85  84  190 -115  138 -172   128 -121  $pl 21 fuel
1202   2  -2.7   -86  85  190 -115  139 -171   128 -121  $pl 21 clad
1203   1  -1.00  -87  86  191 -116  139 -171   128 -121  $pl 22 wg
1204   2  -2.7   -88  87  190 -115  139 -171   128 -121  $pl 22 clad
1205   2  -2.7   -89  88  190 -115  139 -138   128 -121  $pl 22 clad
1206   2  -2.7   -89  88  190 -115  172 -171   128 -121  $pl 22 clad
1207   2  -2.7   -90  87  115 -116  139 -171   128 -121  $pl 22 clad on top
1208   2  -2.7   -90  87  191 -190  139 -171   128 -121  $pl 22 clad on bot
1209   3  -3.88  -89  88  190 -115  138 -172   128 -121  $pl 22 fuel
1210   2  -2.7   -90  89  190 -115  139 -171   128 -121  $pl 22 clad
1211   1  -1.00  -91  90  191 -116  139 -171   128 -121  $pl 23 wg
1212   2  -2.7   -92  91  190 -115  139 -171   128 -121  $pl 23 clad
1213   2  -2.7   -93  92  190 -115  139 -138   128 -121  $pl 23 clad
1214   2  -2.7   -93  92  190 -115  172 -171   128 -121  $pl 23 clad
1215   2  -2.7   -94  91  115 -116  139 -171   128 -121  $pl 23 clad on top
1216   2  -2.7   -94  91  191 -190  139 -171   128 -121  $pl 23 clad on bot
1217   3  -3.88  -93  92  190 -115  138 -172   128 -121  $pl 23 fuel
1218   2  -2.7   -94  93  190 -115  139 -171   128 -121  $pl 23 clad
1219   1  -1.00  -95  94  191 -116  139 -171   128 -121  $pl 24 wg
1220   2  -2.7   -96  95  190 -115  139 -171   128 -121  $pl 24 clad
1221   2  -2.7   -97  96  190 -115  139 -138   128 -121  $pl 24 clad
1222   2  -2.7   -97  96  190 -115  172 -171   128 -121  $pl 24 clad
1223   2  -2.7   -98  95  115 -116  139 -171   128 -121  $pl 24 clad on top
1224   2  -2.7   -98  95  191 -190  139 -171   128 -121  $pl 24 clad on bot
1225   3  -3.88  -97  96  190 -115  138 -172   128 -121  $pl 24 fuel
1226   2  -2.7   -98  97  190 -115  139 -171   128 -121  $pl 24 clad
1227   1  -1.0   -99  98  193 -118  139 -171   128 -121  $outer water gap
1228   1  -1.0   -98  3   116 -117  139 -171   128 -121  $fuel top water
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1229    1  -1.0   -98  3   192 -191  139 -171   128 -121  $fuel bot water
1230    6  +0.0803 -98  3   117 -118  139 -171  128 -121  $fuel top hanger
1231    6  +0.0803 -98  3   193 -192  139 -171  128 -121  $fuel bot hanger
c
c
c
1232   1  -1.0   -3   2   193 -118 -130  133  -128 -121  $pl 1 wg
1233   2  -2.7   -4   3   190 -115 -130  133  -128 -121  $pl 1 clad
1234   2  -2.7   -5   4   190 -115 -130  131  -128 -121  $pl 1 clad
1235   2  -2.7   -5   4   190 -115 -132  133  -128 -121  $pl 1 clad
1236   2  -2.7   -6   3   115 -116 -130  133  -128 -121  $pl 1 clad on top
1237   2  -2.7   -6   3   191 -190 -130  133  -128 -121  $pl 1 clad on bot
1238   3  -3.88  -5   4   190 -115 -131  132  -128 -121  $pl 1 fuel
1239   2  -2.7   -6   5   190 -115 -130  133  -128 -121  $pl 1 clad
1240   1  -1.00  -7   6   191 -116 -130  133  -128 -121  $pl 2 wg
1241   2  -2.7   -8   7   190 -115 -130  133  -128 -121  $pl 2 clad
1242   2  -2.7   -9   8   190 -115 -130  131  -128 -121  $pl 2 clad
1243   2  -2.7   -9   8   190 -115 -132  133  -128 -121  $pl 2 clad
1244   2  -2.7   -10  7   115 -116 -130  133  -128 -121  $pl 2 clad on top
1245   2  -2.7   -10  7   191 -190 -130  133  -128 -121  $pl 2 clad on bot
1246   3  -3.88  -9   8   190 -115 -131  132  -128 -121  $pl 2 fuel
1247   2  -2.7   -10  9   190 -115 -130  133  -128 -121  $pl 2 clad
1248   1  -1.00  -11  10  191 -116 -130  133  -128 -121  $pl 3 wg
1249   2  -2.7   -12  11  190 -115 -130  133  -128 -121  $pl 3 clad
1250   2  -2.7   -13  12  190 -115 -130  131  -128 -121  $pl 3 clad
1251   2  -2.7   -13  12  190 -115 -132  133  -128 -121  $pl 3 clad
1252   2  -2.7   -14  11  115 -116 -130  133  -128 -121  $pl 3 clad on top
1253   2  -2.7   -14  11  191 -190 -130  133  -128 -121  $pl 3 clad on bot
1254   3  -3.88  -13  12  190 -115 -131  132  -128 -121  $pl 3 fuel
1255   2  -2.7   -14  13  190 -115 -130  133  -128 -121  $pl 3 clad
1256   1  -1.00  -15  14  191 -116 -130  133  -128 -121  $pl 4 wg
1257   2  -2.7   -16  15  190 -115 -130  133  -128 -121  $pl 4 clad
1258   2  -2.7   -17  16  190 -115 -130  131  -128 -121  $pl 4 clad
1259   2  -2.7   -17  16  190 -115 -132  133  -128 -121  $pl 4 clad
1260   2  -2.7   -18  15  115 -116 -130  133  -128 -121  $pl 4 clad on top
1261   2  -2.7   -18  15  191 -190 -130  133  -128 -121  $pl 4 clad on bot
1262   3  -3.88  -17  16  190 -115 -131  132  -128 -121  $pl 4 fuel
1263   2  -2.7   -18  17  190 -115 -130  133  -128 -121  $pl 4 clad
1264   1  -1.00  -19  18  191 -116 -130  133  -128 -121  $pl 5 wg
1265   2  -2.7   -20  19  190 -115 -130  133  -128 -121  $pl 5 clad
1266   2  -2.7   -21  20  190 -115 -130  131  -128 -121  $pl 5 clad
1267   2  -2.7   -21  20  190 -115 -132  133  -128 -121  $pl 5 clad
1268   2  -2.7   -22  19  115 -116 -130  133  -128 -121  $pl 5 clad on top
1269   2  -2.7   -22  19  191 -190 -130  133  -128 -121  $pl 5 clad on bot
1270   3  -3.88  -21  20  190 -115 -131  132  -128 -121  $pl 5 fuel
1271   2  -2.7   -22  21  190 -115 -130  133  -128 -121  $pl 5 clad
1272   1  -1.00  -23  22  191 -116 -130  133  -128 -121  $pl 6 wg
1273   2  -2.7   -24  23  190 -115 -130  133  -128 -121  $pl 6 clad
1274   2  -2.7   -25  24  190 -115 -130  131  -128 -121  $pl 6 clad
1275   2  -2.7   -25  24  190 -115 -132  133  -128 -121  $pl 6 clad
1276   2  -2.7   -26  23  115 -116 -130  133  -128 -121  $pl 6 clad on top
1277   2  -2.7   -26  23  191 -190 -130  133  -128 -121  $pl 6 clad on bot
1278   3  -3.88  -25  24  190 -115 -131  132  -128 -121  $pl 6 fuel
1279   2  -2.7   -26  25  190 -115 -130  133  -128 -121  $pl 6 clad
1280   1  -1.00  -27  26  191 -116 -130  133  -128 -121  $pl 7 wg
1281   2  -2.7   -28  27  190 -115 -130  133  -128 -121  $pl 7 clad
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1282  2  -2.7   -29  28  190 -115 -130  131  -128 -121  $pl 7 clad
1283  2  -2.7   -29  28  190 -115 -132  133  -128 -121  $pl 7 clad
1284  2  -2.7   -30  27  115 -116 -130  133  -128 -121  $pl 7 clad on top
1285  2  -2.7   -30  27  191 -190 -130  133  -128 -121  $pl 7 clad on bot
1286  3  -3.88  -29  28  190 -115 -131  132  -128 -121  $pl 7 fuel
1287  2  -2.7   -30  29  190 -115 -130  133  -128 -121  $pl 7 clad
1288  1  -1.00  -31  30  191 -116 -130  133  -128 -121  $pl 8 wg
1289  2  -2.7   -32  31  190 -115 -130  133  -128 -121  $pl 8 clad
1290  2  -2.7   -33  32  190 -115 -130  131  -128 -121  $pl 8 clad
1291  2  -2.7   -33  32  190 -115 -132  133  -128 -121  $pl 8 clad
1292  2  -2.7   -34  31  115 -116 -130  133  -128 -121  $pl 8 clad on top
1293  2  -2.7   -34  31  191 -190 -130  133  -128 -121  $pl 8 clad on bot
1294  3  -3.88  -33  32  190 -115 -131  132  -128 -121  $pl 8 fuel
1295  2  -2.7   -34  33  190 -115 -130  133  -128 -121  $pl 8 clad
1296  1  -1.00  -35  34  191 -116 -130  133  -128 -121  $pl 9 wg
1297  2  -2.7   -36  35  190 -115 -130  133  -128 -121  $pl 9 clad
1298  2  -2.7   -37  36  190 -115 -130  131  -128 -121  $pl 9 clad
1299  2  -2.7   -37  36  190 -115 -132  133  -128 -121  $pl 9 clad
1300  2  -2.7   -38  35  115 -116 -130  133  -128 -121  $pl 9 clad on top
1301  2  -2.7   -38  35  191 -190 -130  133  -128 -121  $pl 9 clad on bot
1302  3  -3.88  -37  36  190 -115 -131  132  -128 -121  $pl 9 fuel
1303  2  -2.7   -38  37  190 -115 -130  133  -128 -121  $pl 9 clad
1304  1  -1.00  -39  38  191 -116 -130  133  -128 -121  $pl 10 wg
1305  2  -2.7   -40  39  190 -115 -130  133  -128 -121  $pl 10 clad
1306  2  -2.7   -41  40  190 -115 -130  131  -128 -121  $pl 10 clad
1307  2  -2.7   -41  40  190 -115 -132  133  -128 -121  $pl 10 clad
1308  2  -2.7   -42  39  115 -116 -130  133  -128 -121  $pl 10 clad on top
1309  2  -2.7   -42  39  191 -190 -130  133  -128 -121  $pl 10 clad on bot
1310  3  -3.88  -41  40  190 -115 -131  132  -128 -121  $pl 10 fuel
1311  2  -2.7   -42  41  190 -115 -130  133  -128 -121  $pl 10 clad
1312  1  -1.00  -43  42  191 -116 -130  133  -128 -121  $pl 11 wg
1313  2  -2.7   -44  43  190 -115 -130  133  -128 -121  $pl 11 clad
1314  2  -2.7   -45  44  190 -115 -130  131  -128 -121  $pl 11 clad
1315  2  -2.7   -45  44  190 -115 -132  133  -128 -121  $pl 11 clad
1316  2  -2.7   -46  43  115 -116 -130  133  -128 -121  $pl 11 clad on top
1317  2  -2.7   -46  43  191 -190 -130  133  -128 -121  $pl 11 clad on bot
1318  3  -3.88  -45  44  190 -115 -131  132  -128 -121  $pl 11 fuel
1319  2  -2.7   -46  45  190 -115 -130  133  -128 -121  $pl 11 clad
1320  1  -1.00  -47  46  191 -116 -130  133  -128 -121  $pl 12 wg
1321  2  -2.7   -48  47  190 -115 -130  133  -128 -121  $pl 12 clad
1322  2  -2.7   -49  48  190 -115 -130  131  -128 -121  $pl 12 clad
1323  2  -2.7   -49  48  190 -115 -132  133  -128 -121  $pl 12 clad
1324  2  -2.7   -50  47  115 -116 -130  133  -128 -121  $pl 12 clad on top
1325  2  -2.7   -50  47  191 -190 -130  133  -128 -121  $pl 12 clad on bot
1326  3  -3.88  -49  48  190 -115 -131  132  -128 -121  $pl 12 fuel
1327  2  -2.7   -50  49  190 -115 -130  133  -128 -121  $pl 12 clad
1328  1  -1.00  -51  50  191 -116 -130  133  -128 -121  $pl 13 wg
1329  2  -2.7   -52  51  190 -115 -130  133  -128 -121  $pl 13 clad
1330  2  -2.7   -53  52  190 -115 -130  131  -128 -121  $pl 13 clad
1331  2  -2.7   -53  52  190 -115 -132  133  -128 -121  $pl 13 clad
1332  2  -2.7   -54  51  115 -116 -130  133  -128 -121  $pl 13 clad on top
1333  2  -2.7   -54  51  191 -190 -130  133  -128 -121  $pl 13 clad on bot
1334  3  -3.88  -53  52  190 -115 -131  132  -128 -121  $pl 13 fuel
1335  2  -2.7   -54  53  190 -115 -130  133  -128 -121  $pl 13 clad
1336  1  -1.00  -55  54  191 -116 -130  133  -128 -121  $pl 14 wg
1337  2  -2.7   -56  55  190 -115 -130  133  -128 -121  $pl 14 clad
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1338  2  -2.7   -57  56  190 -115 -130  131  -128 -121  $pl 14 clad
1339  2  -2.7   -57  56  190 -115 -132  133  -128 -121  $pl 14 clad
1340  2  -2.7   -58  55  115 -116 -130  133  -128 -121  $pl 14 clad on top
1341  2  -2.7   -58  55  191 -190 -130  133  -128 -121  $pl 14 clad on bot
1342  3  -3.88  -57  56  190 -115 -131  132  -128 -121  $pl 14 fuel
1343  2  -2.7   -58  57  190 -115 -130  133  -128 -121  $pl 14 clad
1344  1  -1.00  -59  58  191 -116 -130  133  -128 -121  $pl 15 wg
1345  2  -2.7   -60  59  190 -115 -130  133  -128 -121  $pl 15 clad
1346  2  -2.7   -61  60  190 -115 -130  131  -128 -121  $pl 15 clad
1347  2  -2.7   -61  60  190 -115 -132  133  -128 -121  $pl 15 clad
1348  2  -2.7   -62  59  115 -116 -130  133  -128 -121  $pl 15 clad on top
1349  2  -2.7   -62  59  191 -190 -130  133  -128 -121  $pl 15 clad on bot
1350  3  -3.88  -61  60  190 -115 -131  132  -128 -121  $pl 15 fuel
1351  2  -2.7   -62  61  190 -115 -130  133  -128 -121  $pl 15 clad
1352  1  -1.00  -63  62  191 -116 -130  133  -128 -121  $pl 16 wg
1353  2  -2.7   -64  63  190 -115 -130  133  -128 -121  $pl 16 clad
1354  2  -2.7   -65  64  190 -115 -130  131  -128 -121  $pl 16 clad
1355  2  -2.7   -65  64  190 -115 -132  133  -128 -121  $pl 16 clad
1356  2  -2.7   -66  63  115 -116 -130  133  -128 -121  $pl 16 clad on top
1357  2  -2.7   -66  63  191 -190 -130  133  -128 -121  $pl 16 clad on bot
1358  3  -3.88  -65  64  190 -115 -131  132  -128 -121  $pl 16 fuel
1359  2  -2.7   -66  65  190 -115 -130  133  -128 -121  $pl 16 clad
1360  1  -1.00  -67  66  191 -116 -130  133  -128 -121  $pl 17 wg
1361  2  -2.7   -68  67  190 -115 -130  133  -128 -121  $pl 17 clad
1362  2  -2.7   -69  68  190 -115 -130  131  -128 -121  $pl 17 clad
1363  2  -2.7   -69  68  190 -115 -132  133  -128 -121  $pl 17 clad
1364  2  -2.7   -70  67  115 -116 -130  133  -128 -121  $pl 17 clad on top
1365  2  -2.7   -70  67  191 -190 -130  133  -128 -121  $pl 17 clad on bot
1366  3  -3.88  -69  68  190 -115 -131  132  -128 -121  $pl 17 fuel
1367  2  -2.7   -70  69  190 -115 -130  133  -128 -121  $pl 17 clad
1368  1  -1.00  -71  70  191 -116 -130  133  -128 -121  $pl 18 wg
1369  2  -2.7   -72  71  190 -115 -130  133  -128 -121  $pl 18 clad
1370  2  -2.7   -73  72  190 -115 -130  131  -128 -121  $pl 18 clad
1371  2  -2.7   -73  72  190 -115 -132  133  -128 -121  $pl 18 clad
1372  2  -2.7   -74  71  115 -116 -130  133  -128 -121  $pl 18 clad on top
1373  2  -2.7   -74  71  191 -190 -130  133  -128 -121  $pl 18 clad on bot
1374  3  -3.88  -73  72  190 -115 -131  132  -128 -121  $pl 18 fuel
1375  2  -2.7   -74  73  190 -115 -130  133  -128 -121  $pl 18 clad
1376  1  -1.00  -75  74  191 -116 -130  133  -128 -121  $pl 19 wg
1377  2  -2.7   -76  75  190 -115 -130  133  -128 -121  $pl 19 clad
1378  2  -2.7   -77  76  190 -115 -130  131  -128 -121  $pl 19 clad
1379  2  -2.7   -77  76  190 -115 -132  133  -128 -121  $pl 19 clad
1380  2  -2.7   -78  75  115 -116 -130  133  -128 -121  $pl 19 clad on top
1381  2  -2.7   -78  75  191 -190 -130  133  -128 -121  $pl 19 clad on bot
1382  3  -3.88  -77  76  190 -115 -131  132  -128 -121  $pl 19 fuel
1383  2  -2.7   -78  77  190 -115 -130  133  -128 -121  $pl 19 clad
1384  1  -1.00  -79  78  191 -116 -130  133  -128 -121  $pl 20 wg
1385  2  -2.7   -80  79  190 -115 -130  133  -128 -121  $pl 20 clad
1386  2  -2.7   -81  80  190 -115 -130  131  -128 -121  $pl 20 clad
1387  2  -2.7   -81  80  190 -115 -132  133  -128 -121  $pl 20 clad
1388  2  -2.7   -82  79  115 -116 -130  133  -128 -121  $pl 20 clad on top
1389  2  -2.7   -82  79  191 -190 -130  133  -128 -121  $pl 20 clad on bot
1390  3  -3.88  -81  80  190 -115 -131  132  -128 -121  $pl 20 fuel
1391  2  -2.7   -82  81  190 -115 -130  133  -128 -121  $pl 20 clad
1392  1  -1.00  -83  82  191 -116 -130  133  -128 -121  $pl 21 wg
1393  2  -2.7   -84  83  190 -115 -130  133  -128 -121  $pl 21 clad
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1394   2  -2.7   -85  84  190 -115 -130  131  -128 -121  $pl 21 clad
1395   2  -2.7   -85  84  190 -115 -132  133  -128 -121  $pl 21 clad
1396   2  -2.7   -86  83  115 -116 -130  133  -128 -121  $pl 21 clad on top
1397   2  -2.7   -86  83  191 -190 -130  133  -128 -121  $pl 21 clad on bot
1398   3  -3.88  -85  84  190 -115 -131  132  -128 -121  $pl 21 fuel
1399   2  -2.7   -86  85  190 -115 -130  133  -128 -121  $pl 21 clad
1400   1  -1.00  -87  86  191 -116 -130  133  -128 -121  $pl 22 wg
1401   2  -2.7   -88  87  190 -115 -130  133  -128 -121  $pl 22 clad
1402   2  -2.7   -89  88  190 -115 -130  131  -128 -121  $pl 22 clad
1403   2  -2.7   -89  88  190 -115 -132  133  -128 -121  $pl 22 clad
1404   2  -2.7   -90  87  115 -116 -130  133  -128 -121  $pl 22 clad on top
1405   2  -2.7   -90  87  191 -190 -130  133  -128 -121  $pl 22 clad on bot
1406   3  -3.88  -89  88  190 -115 -131  132  -128 -121  $pl 22 fuel
1407   2  -2.7   -90  89  190 -115 -130  133  -128 -121  $pl 22 clad
1408   1  -1.00  -91  90  191 -116 -130  133  -128 -121  $pl 23 wg
1409   2  -2.7   -92  91  190 -115 -130  133  -128 -121  $pl 23 clad
1410   2  -2.7   -93  92  190 -115 -130  131  -128 -121  $pl 23 clad
1411   2  -2.7   -93  92  190 -115 -132  133  -128 -121  $pl 23 clad
1412   2  -2.7   -94  91  115 -116 -130  133  -128 -121  $pl 23 clad on top
1413   2  -2.7   -94  91  191 -190 -130  133  -128 -121  $pl 23 clad on bot
1414   3  -3.88  -93  92  190 -115 -131  132  -128 -121  $pl 23 fuel
1415   2  -2.7   -94  93  190 -115 -130  133  -128 -121  $pl 23 clad
1416   1  -1.00  -95  94  191 -116 -130  133  -128 -121  $pl 24 wg
1417   2  -2.7   -96  95  190 -115 -130  133  -128 -121  $pl 24 clad
1418   2  -2.7   -97  96  190 -115 -130  131  -128 -121  $pl 24 clad
1419   2  -2.7   -97  96  190 -115 -132  133  -128 -121  $pl 24 clad
1420   2  -2.7   -98  95  115 -116 -130  133  -128 -121  $pl 24 clad on top
1421   2  -2.7   -98  95  191 -190 -130  133  -128 -121  $pl 24 clad on bot
1422   3  -3.88  -97  96  190 -115 -131  132  -128 -121  $pl 24 fuel
1423   2  -2.7   -98  97  190 -115 -130  133  -128 -121  $pl 24 clad
1424   1  -1.0   -99  98  193 -118 -130  133  -128 -121  $outer water gap
1425   1  -1.0   -98  3   116 -117 -130  133  -128 -121  $fuel top water
1426   1  -1.0   -98  3   192 -191 -130  133  -128 -121  $fuel bot water
1427   6  +0.0803 -98  3  117 -118 -130  133  -128 -121  $fuel top hanger
1428   6  +0.0803 -98  3  193 -192 -130  133  -128 -121  $fuel bot hanger
c
c
c
1429    1  -1.0   -3   2   193 -118 -142  126  128 -121  $pl 1 wg
1430    2  -2.7   -4   3   190 -115 -142  126  128 -121  $pl 1 clad
1431    2  -2.7   -5   4   190 -115 -142  143  128 -121  $pl 1 clad
1432    2  -2.7   -5   4   190 -115 -125  126  128 -121  $pl 1 clad
1433    2  -2.7   -6   3   115 -116 -142  126  128 -121  $pl 1 clad on top
1434    2  -2.7   -6   3   191 -190 -142  126  128 -121  $pl 1 clad on bot
1435    3  -3.88  -5   4   190 -115 -143  125  128 -121  $pl 1 fuel
1436    2  -2.7   -6   5   190 -115 -142  126  128 -121  $pl 1 clad
1437    1  -1.00  -7   6   191 -116 -142  126  128 -121  $pl 2 wg
1438    2  -2.7   -8   7   190 -115 -142  126  128 -121  $pl 2 clad
1439    2  -2.7   -9   8   190 -115 -142  143  128 -121  $pl 2 clad
1440    2  -2.7   -9   8   190 -115 -125  126  128 -121  $pl 2 clad
1441    2  -2.7   -10  7   115 -116 -142  126  128 -121  $pl 2 clad on top
1442    2  -2.7   -10  7   191 -190 -142  126  128 -121  $pl 2 clad on bot
1443    3  -3.88  -9   8   190 -115 -143  125  128 -121  $pl 2 fuel
1444    2  -2.7   -10  9   190 -115 -142  126  128 -121  $pl 2 clad
1445    1  -1.00  -11  10  191 -116 -142  126  128 -121  $pl 3 wg
1446    2  -2.7   -12  11  190 -115 -142  126  128 -121  $pl 3 clad
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1447   2  -2.7   -13  12  190 -115 -142  143  128 -121  $pl 3 clad
1448   2  -2.7   -13  12  190 -115 -125  126  128 -121  $pl 3 clad
1449   2  -2.7   -14  11  115 -116 -142  126  128 -121  $pl 3 clad on top
1450   2  -2.7   -14  11  191 -190 -142  126  128 -121  $pl 3 clad on bot
1451   3  -3.88  -13  12  190 -115 -143  125  128 -121  $pl 3 fuel
1452   2  -2.7   -14  13  190 -115 -142  126  128 -121  $pl 3 clad
1453   1  -1.00  -15  14  191 -116 -142  126  128 -121  $pl 4 wg
1454   2  -2.7   -16  15  190 -115 -142  126  128 -121  $pl 4 clad
1455   2  -2.7   -17  16  190 -115 -142  143  128 -121  $pl 4 clad
1456   2  -2.7   -17  16  190 -115 -125  126  128 -121  $pl 4 clad
1457   2  -2.7   -18  15  115 -116 -142  126  128 -121  $pl 4 clad on top
1458   2  -2.7   -18  15  191 -190 -142  126  128 -121  $pl 4 clad on bot
1459   3  -3.88  -17  16  190 -115 -143  125  128 -121  $pl 4 fuel
1460   2  -2.7   -18  17  190 -115 -142  126  128 -121  $pl 4 clad
1461   1  -1.00  -19  18  191 -116 -142  126  128 -121  $pl 5 wg
1462   2  -2.7   -20  19  190 -115 -142  126  128 -121  $pl 5 clad
1463   2  -2.7   -21  20  190 -115 -142  143  128 -121  $pl 5 clad
1464   2  -2.7   -21  20  190 -115 -125  126  128 -121  $pl 5 clad
1465   2  -2.7   -22  19  115 -116 -142  126  128 -121  $pl 5 clad on top
1466   2  -2.7   -22  19  191 -190 -142  126  128 -121  $pl 5 clad on bot
1467   3  -3.88  -21  20  190 -115 -143  125  128 -121  $pl 5 fuel
1468   2  -2.7   -22  21  190 -115 -142  126  128 -121  $pl 5 clad
1469   1  -1.00  -23  22  191 -116 -142  126  128 -121  $pl 6 wg
1470   2  -2.7   -24  23  190 -115 -142  126  128 -121  $pl 6 clad
1471   2  -2.7   -25  24  190 -115 -142  143  128 -121  $pl 6 clad
1472   2  -2.7   -25  24  190 -115 -125  126  128 -121  $pl 6 clad
1473   2  -2.7   -26  23  115 -116 -142  126  128 -121  $pl 6 clad on top
1474   2  -2.7   -26  23  191 -190 -142  126  128 -121  $pl 6 clad on bot
1475   3  -3.88  -25  24  190 -115 -143  125  128 -121  $pl 6 fuel
1476   2  -2.7   -26  25  190 -115 -142  126  128 -121  $pl 6 clad
1477   1  -1.00  -27  26  191 -116 -142  126  128 -121  $pl 7 wg
1478   2  -2.7   -28  27  190 -115 -142  126  128 -121  $pl 7 clad
1479   2  -2.7   -29  28  190 -115 -142  143  128 -121  $pl 7 clad
1480   2  -2.7   -29  28  190 -115 -125  126  128 -121  $pl 7 clad
1481   2  -2.7   -30  27  115 -116 -142  126  128 -121  $pl 7 clad on top
1482   2  -2.7   -30  27  191 -190 -142  126  128 -121  $pl 7 clad on bot
1483   3  -3.88  -29  28  190 -115 -143  125  128 -121  $pl 7 fuel
1484   2  -2.7   -30  29  190 -115 -142  126  128 -121  $pl 7 clad
1485   1  -1.00  -31  30  191 -116 -142  126  128 -121  $pl 8 wg
1486   2  -2.7   -32  31  190 -115 -142  126  128 -121  $pl 8 clad
1487   2  -2.7   -33  32  190 -115 -142  143  128 -121  $pl 8 clad
1488   2  -2.7   -33  32  190 -115 -125  126  128 -121  $pl 8 clad
1489   2  -2.7   -34  31  115 -116 -142  126  128 -121  $pl 8 clad on top
1490   2  -2.7   -34  31  191 -190 -142  126  128 -121  $pl 8 clad on bot
1491   3  -3.88  -33  32  190 -115 -143  125  128 -121  $pl 8 fuel
1492   2  -2.7   -34  33  190 -115 -142  126  128 -121  $pl 8 clad
1493   1  -1.00  -35  34  191 -116 -142  126  128 -121  $pl 9 wg
1494   2  -2.7   -36  35  190 -115 -142  126  128 -121  $pl 9 clad
1495   2  -2.7   -37  36  190 -115 -142  143  128 -121  $pl 9 clad
1496   2  -2.7   -37  36  190 -115 -125  126  128 -121  $pl 9 clad
1497   2  -2.7   -38  35  115 -116 -142  126  128 -121  $pl 9 clad on top
1498   2  -2.7   -38  35  191 -190 -142  126  128 -121  $pl 9 clad on bot
1499   3  -3.88  -37  36  190 -115 -143  125  128 -121  $pl 9 fuel
1500   2  -2.7   -38  37  190 -115 -142  126  128 -121  $pl 9 clad
1501   1  -1.00  -39  38  191 -116 -142  126  128 -121  $pl 10 wg
1502   2  -2.7   -40  39  190 -115 -142  126  128 -121  $pl 10 clad
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1503    2  -2.7   -41  40  190 -115 -142  143  128 -121  $pl 10 clad
1504    2  -2.7   -41  40  190 -115 -125  126  128 -121  $pl 10 clad
1505    2  -2.7   -42  39  115 -116 -142  126  128 -121  $pl 10 clad on top
1506    2  -2.7   -42  39  191 -190 -142  126  128 -121  $pl 10 clad on bot
1507    3  -3.88  -41  40  190 -115 -143  125  128 -121  $pl 10 fuel
1508    2  -2.7   -42  41  190 -115 -142  126  128 -121  $pl 10 clad
1509    1  -1.00  -43  42  191 -116 -142  126  128 -121  $pl 11 wg
1510    2  -2.7   -44  43  190 -115 -142  126  128 -121  $pl 11 clad
1511    2  -2.7   -45  44  190 -115 -142  143  128 -121  $pl 11 clad
1512    2  -2.7   -45  44  190 -115 -125  126  128 -121  $pl 11 clad
1513    2  -2.7   -46  43  115 -116 -142  126  128 -121  $pl 11 clad on top
1514    2  -2.7   -46  43  191 -190 -142  126  128 -121  $pl 11 clad on bot
1515    3  -3.88  -45  44  190 -115 -143  125  128 -121  $pl 11 fuel
1516    2  -2.7   -46  45  190 -115 -142  126  128 -121  $pl 11 clad
1517    1  -1.00  -47  46  191 -116 -142  126  128 -121  $pl 12 wg
1518    2  -2.7   -48  47  190 -115 -142  126  128 -121  $pl 12 clad
1519    2  -2.7   -49  48  190 -115 -142  143  128 -121  $pl 12 clad
1520    2  -2.7   -49  48  190 -115 -125  126  128 -121  $pl 12 clad
1521    2  -2.7   -50  47  115 -116 -142  126  128 -121  $pl 12 clad on top
1522    2  -2.7   -50  47  191 -190 -142  126  128 -121  $pl 12 clad on bot
1523    3  -3.88  -49  48  190 -115 -143  125  128 -121  $pl 12 fuel
1524    2  -2.7   -50  49  190 -115 -142  126  128 -121  $pl 12 clad
1525    1  -1.00  -51  50  191 -116 -142  126  128 -121  $pl 13 wg
1526    2  -2.7   -52  51  190 -115 -142  126  128 -121  $pl 13 clad
1527    2  -2.7   -53  52  190 -115 -142  143  128 -121  $pl 13 clad
1528    2  -2.7   -53  52  190 -115 -125  126  128 -121  $pl 13 clad
1529    2  -2.7   -54  51  115 -116 -142  126  128 -121  $pl 13 clad on top
1530    2  -2.7   -54  51  191 -190 -142  126  128 -121  $pl 13 clad on bot
1531    3  -3.88  -53  52  190 -115 -143  125  128 -121  $pl 13 fuel
1532    2  -2.7   -54  53  190 -115 -142  126  128 -121  $pl 13 clad
1533    1  -1.00  -55  54  191 -116 -142  126  128 -121  $pl 14 wg
1534    2  -2.7   -56  55  190 -115 -142  126  128 -121  $pl 14 clad
1535    2  -2.7   -57  56  190 -115 -142  143  128 -121  $pl 14 clad
1536    2  -2.7   -57  56  190 -115 -125  126  128 -121  $pl 14 clad
1537    2  -2.7   -58  55  115 -116 -142  126  128 -121  $pl 14 clad on top
1538    2  -2.7   -58  55  191 -190 -142  126  128 -121  $pl 14 clad on bot
1539    3  -3.88  -57  56  190 -115 -143  125  128 -121  $pl 14 fuel
1540    2  -2.7   -58  57  190 -115 -142  126  128 -121  $pl 14 clad
1541    1  -1.00  -59  58  191 -116 -142  126  128 -121  $pl 15 wg
1542    2  -2.7   -60  59  190 -115 -142  126  128 -121  $pl 15 clad
1543    2  -2.7   -61  60  190 -115 -142  143  128 -121  $pl 15 clad
1544    2  -2.7   -61  60  190 -115 -125  126  128 -121  $pl 15 clad
1545    2  -2.7   -62  59  115 -116 -142  126  128 -121  $pl 15 clad on top
1546    2  -2.7   -62  59  191 -190 -142  126  128 -121  $pl 15 clad on bot
1547    3  -3.88  -61  60  190 -115 -143  125  128 -121  $pl 15 fuel
1548    2  -2.7   -62  61  190 -115 -142  126  128 -121  $pl 15 clad
1549    1  -1.00  -63  62  191 -116 -142  126  128 -121  $pl 16 wg
1550    2  -2.7   -64  63  190 -115 -142  126  128 -121  $pl 16 clad
1551    2  -2.7   -65  64  190 -115 -142  143  128 -121  $pl 16 clad
1552    2  -2.7   -65  64  190 -115 -125  126  128 -121  $pl 16 clad
1553    2  -2.7   -66  63  115 -116 -142  126  128 -121  $pl 16 clad on top
1554    2  -2.7   -66  63  191 -190 -142  126  128 -121  $pl 16 clad on bot
1555    3  -3.88  -65  64  190 -115 -143  125  128 -121  $pl 16 fuel
1556    2  -2.7   -66  65  190 -115 -142  126  128 -121  $pl 16 clad
1557    1  -1.00  -67  66  191 -116 -142  126  128 -121  $pl 17 wg
1558    2  -2.7   -68  67  190 -115 -142  126  128 -121  $pl 17 clad
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1559   2  -2.7   -69  68  190 -115 -142  143  128 -121  $pl 17 clad
1560   2  -2.7   -69  68  190 -115 -125  126  128 -121  $pl 17 clad
1561   2  -2.7   -70  67  115 -116 -142  126  128 -121  $pl 17 clad on top
1562   2  -2.7   -70  67  191 -190 -142  126  128 -121  $pl 17 clad on bot
1563   3  -3.88  -69  68  190 -115 -143  125  128 -121  $pl 17 fuel
1564   2  -2.7   -70  69  190 -115 -142  126  128 -121  $pl 17 clad
1565   1  -1.00  -71  70  191 -116 -142  126  128 -121  $pl 18 wg
1566   2  -2.7   -72  71  190 -115 -142  126  128 -121  $pl 18 clad
1567   2  -2.7   -73  72  190 -115 -142  143  128 -121  $pl 18 clad
1568   2  -2.7   -73  72  190 -115 -125  126  128 -121  $pl 18 clad
1569   2  -2.7   -74  71  115 -116 -142  126  128 -121  $pl 18 clad on top
1570   2  -2.7   -74  71  191 -190 -142  126  128 -121  $pl 18 clad on bot
1571   3  -3.88  -73  72  190 -115 -143  125  128 -121  $pl 18 fuel
1572   2  -2.7   -74  73  190 -115 -142  126  128 -121  $pl 18 clad
1573   1  -1.00  -75  74  191 -116 -142  126  128 -121  $pl 19 wg
1574   2  -2.7   -76  75  190 -115 -142  126  128 -121  $pl 19 clad
1575   2  -2.7   -77  76  190 -115 -142  143  128 -121  $pl 19 clad
1576   2  -2.7   -77  76  190 -115 -125  126  128 -121  $pl 19 clad
1577   2  -2.7   -78  75  115 -116 -142  126  128 -121  $pl 19 clad on top
1578   2  -2.7   -78  75  191 -190 -142  126  128 -121  $pl 19 clad on bot
1579   3  -3.88  -77  76  190 -115 -143  125  128 -121  $pl 19 fuel
1580   2  -2.7   -78  77  190 -115 -142  126  128 -121  $pl 19 clad
1581   1  -1.00  -79  78  191 -116 -142  126  128 -121  $pl 20 wg
1582   2  -2.7   -80  79  190 -115 -142  126  128 -121  $pl 20 clad
1583   2  -2.7   -81  80  190 -115 -142  143  128 -121  $pl 20 clad
1584   2  -2.7   -81  80  190 -115 -125  126  128 -121  $pl 20 clad
1585   2  -2.7   -82  79  115 -116 -142  126  128 -121  $pl 20 clad on top
1586   2  -2.7   -82  79  191 -190 -142  126  128 -121  $pl 20 clad on bot
1587   3  -3.88  -81  80  190 -115 -143  125  128 -121  $pl 20 fuel
1588   2  -2.7   -82  81  190 -115 -142  126  128 -121  $pl 20 clad
1589   1  -1.00  -83  82  191 -116 -142  126  128 -121  $pl 21 wg
1590   2  -2.7   -84  83  190 -115 -142  126  128 -121  $pl 21 clad
1591   2  -2.7   -85  84  190 -115 -142  143  128 -121  $pl 21 clad
1592   2  -2.7   -85  84  190 -115 -125  126  128 -121  $pl 21 clad
1593   2  -2.7   -86  83  115 -116 -142  126  128 -121  $pl 21 clad on top
1594   2  -2.7   -86  83  191 -190 -142  126  128 -121  $pl 21 clad on bot
1595   3  -3.88  -85  84  190 -115 -143  125  128 -121  $pl 21 fuel
1596   2  -2.7   -86  85  190 -115 -142  126  128 -121  $pl 21 clad
1597   1  -1.00  -87  86  191 -116 -142  126  128 -121  $pl 22 wg
1598   2  -2.7   -88  87  190 -115 -142  126  128 -121  $pl 22 clad
1599   2  -2.7   -89  88  190 -115 -142  143  128 -121  $pl 22 clad
1600   2  -2.7   -89  88  190 -115 -125  126  128 -121  $pl 22 clad
1601   2  -2.7   -90  87  115 -116 -142  126  128 -121  $pl 22 clad on top
1602   2  -2.7   -90  87  191 -190 -142  126  128 -121  $pl 22 clad on bot
1603   3  -3.88  -89  88  190 -115 -143  125  128 -121  $pl 22 fuel
1604   2  -2.7   -90  89  190 -115 -142  126  128 -121  $pl 22 clad
1605   1  -1.00  -91  90  191 -116 -142  126  128 -121  $pl 23 wg
1606   2  -2.7   -92  91  190 -115 -142  126  128 -121  $pl 23 clad
1607   2  -2.7   -93  92  190 -115 -142  143  128 -121  $pl 23 clad
1608   2  -2.7   -93  92  190 -115 -125  126  128 -121  $pl 23 clad
1609   2  -2.7   -94  91  115 -116 -142  126  128 -121  $pl 23 clad on top
1610   2  -2.7   -94  91  191 -190 -142  126  128 -121  $pl 23 clad on bot
1611   3  -3.88  -93  92  190 -115 -143  125  128 -121  $pl 23 fuel
1612   2  -2.7   -94  93  190 -115 -142  126  128 -121  $pl 23 clad
1613   1  -1.00  -95  94  191 -116 -142  126  128 -121  $pl 24 wg
1614   2  -2.7   -96  95  190 -115 -142  126  128 -121  $pl 24 clad
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1615    2  -2.7   -97  96  190 -115 -142  143  128 -121  $pl 24 clad
1616    2  -2.7   -97  96  190 -115 -125  126  128 -121  $pl 24 clad
1617    2  -2.7   -98  95  115 -116 -142  126  128 -121  $pl 24 clad on top
1618    2  -2.7   -98  95  191 -190 -142  126  128 -121  $pl 24 clad on bot
1619    3  -3.88  -97  96  190 -115 -143  125  128 -121  $pl 24 fuel
1620    2  -2.7   -98  97  190 -115 -142  126  128 -121  $pl 24 clad
1621    1  -1.0   -99  98  193 -118 -142  126  128 -121  $outer water gap
1622    1  -1.0   -98  3   116 -117 -142  126  128 -121  $fuel top water
1623    1  -1.0   -98  3   192 -191 -142  126  128 -121  $fuel bot water
1624    6  +0.0803 -98 3   117 -118 -142  126  128 -121  $fuel top hanger
1625    6  +0.0803 -98 3   193 -192 -142  126  128 -121  $fuel bot hanger
c
c
1626     2  -2.7   -100 99    196 -120         -121      $outer pr. vessel
1627     1  -1.0   -160 100   196 -120         -121      $control rod ch.
1628     1  -1.0   -163 160   196 -164         -121      $control rod ch.
1629     1  -1.0   -101 163   196 -120         -121      $control rod ch.
1630     2  -2.7   -161 160   164 -120         -121      $al clad of rod
1631     7  +0.0797 -162 161  164 -120         -121      $control rod meat
1632     2  -2.7   -163 162   164 -120         -121      $al clad of rod
c
1633     4  -1.85  -102 101   194 -119         -121      $be
1634     1  -1.0   -103 102   194 -119         -121      $be-gr h20
1635     2  -2.7   -104 103   194 -119         -121      $inner al case
1636    12   2.38e-5  -105   104  194  -119   -121      $inner he layer
c
1637     5  -1.65  -108  105  194 -119  -144 -121  -128   $homo graphite
1638     5  -1.65  -108  105  194 -119   144 -128  -121   $homo graphite
1639     5  -1.65  -108  105  194 -119  -145  128  -121   $homo graphite
1640     5  -1.65  -108  105  194 -119   145 -121   128   $homo graphite
1641     2  -2.7   -108  101  195 -194       -121   $graphite bottom support
c
c
1642     1  -1.0   -109 108   195 -119     -121       $h2o
1643     2  -2.7   -110 109   195 -119     -121       $al
1644     1  -1.0   -111 110   195 -119     -121       $h2o
1645     1  -1.0   -111 101   119 -120     -121       $top h2o
1646     1  -1.0   -111 101   196 -195     -121       $bot h2o
c
1647     0         120:-196:111
c
c
1648     1  -1.0   -180       117 -120           $irradiation tube
c      this line is replaced for tube1
c      1649     1  -1.0   -180       192 -117           $irradiation tube
1650     1  -1.0   -180       196 -192           $irradiation tube
1651     2  -2.7   -181 180   196 -120           $irradiation tube
1652     1  -1.0   -182       117 -120           $irradiation tube
c      this line is replaced for tube2
c      1653     1  -1.0   -182       192 -117           $irradiation tube
1654     1  -1.0   -182       196 -192           $irradiation tube
1655     2  -2.7   -183 182   196 -120           $irradiation tube
1656     1  -1.0   -184 188   117 -120           $irradiation tube
c      this line is replaced for tube3
c      1657     1  -1.0   -184 188   192 -117           $irradiation tube
1658     1  -1.0   -184 188   196 -192           $irradiation tube
```

```
1659     2  -2.7   -185 184   196 -120           $irradiation tube
c
1660     2  -2.7   -188       196 -120           $al rod
c
c     the following is the detail sample loading lines for the three tubes
c
2019 1 -1.0  -180  221 -117     $Tube A loc 30
2020 1 -1.0  -180  222 -221     $Tube A loc 29
2021 1 -1.0  -180  115 -222     $Tube A loc 28
2022 1 -1.0  -180  224 -115     $Tube A loc 27
2023 1 -1.0  -180  225 -224     $Tube A loc 26
2024 1 -1.0  -180  226 -225     $Tube A loc 25
2025 1 -1.0  -180  227 -226     $Tube A loc 24
2026 1 -1.0  -180  228 -227     $Tube A loc 23
2027 1 -1.0  -180  229 -228     $Tube A loc 22
2028 1 -1.0  -180  230 -229     $Tube A loc 21
2029 1 -1.0  -180  231 -230     $Tube A loc 20
2030 1 -1.0  -180  232 -231     $Tube A loc 19
2031 1 -1.0  -180  233 -232     $Tube A loc 18
2032 1 -1.0  -180  234 -233     $Tube A loc 17
2033 1 -1.0  -180  112 -234     $Tube A loc 16
2034 1 -1.0  -180  236 -112     $Tube A loc 15
2035 1 -1.0  -180  237 -236     $Tube A loc 14
2036 1 -1.0  -180  238 -237     $Tube A loc 13
2037 1 -1.0  -180  239 -238     $Tube A loc 12
2038 1 -1.0  -180  240 -239     $Tube A loc 11
2039 1 -1.0  -180  241 -240     $Tube A loc 10
2040 1 -1.0  -180  242 -241     $Tube A loc 9
2041 1 -1.0  -180  243 -242     $Tube A loc 8
2042 1 -1.0  -180  244 -243     $Tube A loc 7
2043 1 -1.0  -180  245 -244     $Tube A loc 6
2044 1 -1.0  -180  246 -245     $Tube A loc 5
2045 1 -1.0  -180  190 -246     $Tube A loc 4
2046 1 -1.0  -180  248 -190     $Tube A loc 3
2047 1 -1.0  -180  249 -248     $Tube A loc 2
2048 1 -1.0  -180  192 -249     $Tube A loc 1
2049 1 -1.0  -182  221 -117     $Tube B loc 30
2050 1 -1.0  -182  222 -221     $Tube B loc 29
2051 1 -1.0  -182  115 -222     $Tube B loc 28
2052 1 -1.0  -182  224 -115     $Tube B loc 27
2053 1 -1.0  -182  225 -224     $Tube B loc 26
2054 1 -1.0  -182  226 -225     $Tube B loc 25
2055 1 -1.0  -182  227 -226     $Tube B loc 24
2056 1 -1.0  -182  228 -227     $Tube B loc 23
2057 1 -1.0  -182  229 -228     $Tube B loc 22
2058 1 -1.0  -182  230 -229     $Tube B loc 21
2059 1 -1.0  -182  231 -230     $Tube B loc 20
2060 1 -1.0  -182  232 -231     $Tube B loc 19
2061 1 -1.0  -182  233 -232     $Tube B loc 18
2062 1 -1.0  -182  234 -233     $Tube B loc 17
2063 1 -1.0  -182  112 -234     $Tube B loc 16
2064 1 -1.0  -182  236 -112     $Tube B loc 15
2065 1 -1.0  -182  237 -236     $Tube B loc 14
2066 1 -1.0  -182  238 -237     $Tube B loc 13
2067 1 -1.0  -182  239 -238     $Tube B loc 12
2068 1 -1.0  -182  240 -239     $Tube B loc 11
```

```
2069 1 -1.0  -182  241 -240     $Tube B loc 10
2070 1 -1.0  -182  242 -241     $Tube B loc 9
2071 1 -1.0  -182  243 -242     $Tube B loc 8
2072 1 -1.0  -182  244 -243     $Tube B loc 7
2073 1 -1.0  -182  245 -244     $Tube B loc 6
2074 1 -1.0  -182  246 -245     $Tube B loc 5
2075 1 -1.0  -182  190 -246     $Tube B loc 4
2076 1 -1.0  -182  248 -190     $Tube B loc 3
2077 1 -1.0  -182  249 -248     $Tube B loc 2
2078 1 -1.0  -182  192 -249     $Tube B loc 1
2079 1 -1.0  -184 188 221 -117     $Tube C loc 30
2080 1 -1.0  -184 188 222 -221     $Tube C loc 29
2081 1 -1.0  -184 188 115 -222     $Tube C loc 28
2082 1 -1.0  -184 188 224 -115     $Tube C loc 27
2083 1 -1.0  -184 188 225 -224     $Tube C loc 26
2084 1 -1.0  -184 188 226 -225     $Tube C loc 25
2085 1 -1.0  -184 188 227 -226     $Tube C loc 24
2086 1 -1.0  -184 188 228 -227     $Tube C loc 23
2087 1 -1.0  -184 188 229 -228     $Tube C loc 22
2088 1 -1.0  -184 188 230 -229     $Tube C loc 21
2089 1 -1.0  -184 188 231 -230     $Tube C loc 20
2090 1 -1.0  -184 188 232 -231     $Tube C loc 19
2091 1 -1.0  -184 188 233 -232     $Tube C loc 18
2092 1 -1.0  -184 188 234 -233     $Tube C loc 17
2093 1 -1.0  -184 188 112 -234     $Tube C loc 16
2094 1 -1.0  -184 188 236 -112     $Tube C loc 15
2095 1 -1.0  -184 188 237 -236     $Tube C loc 14
2096 1 -1.0  -184 188 238 -237     $Tube C loc 13
2097 1 -1.0  -184 188 239 -238     $Tube C loc 12
2098 1 -1.0  -184 188 240 -239     $Tube C loc 11
2099 1 -1.0  -184 188 241 -240     $Tube C loc 10
2100 1 -1.0  -184 188 242 -241     $Tube C loc 9
2101 1 -1.0  -184 188 243 -242     $Tube C loc 8
2102 1 -1.0  -184 188 244 -243     $Tube C loc 7
2103 1 -1.0  -184 188 245 -244     $Tube C loc 6
2104 1 -1.0  -184 188 246 -245     $Tube C loc 5
2105 1 -1.0  -184 188 190 -246     $Tube C loc 4
2106 1 -1.0  -184 188 248 -190     $Tube C loc 3
2107 1 -1.0  -184 188 249 -248     $Tube C loc 2
2108 1 -1.0  -184 188 192 -249     $Tube C loc 1

C Surface Cards
1    cz  5.715
2    cz  6.756 $inner al pressure vessel
3    cz  7.036 $plate 1
4    cz  7.074
5    cz  7.125
6    cz  7.163
7    cz  7.366 $plate 2
8    cz  7.404
9    cz  7.455
10    cz  7.493
11    cz  7.696 $plate 3
12    cz  7.734
13    cz  7.785
14    cz  7.823
```

```
15    cz  8.026 $plate 4
16    cz  8.065
17    cz  8.115
18    cz  8.153
19    cz  8.357 $plate 5
20    cz  8.395
21    cz  8.446
22    cz  8.484
23    cz  8.687 $plate 6
24    cz  8.725
25    cz  8.776
26    cz  8.814
27    cz  9.017 $plate 7
28    cz  9.055
29    cz  9.106
30    cz  9.144
31    cz  9.347 $plate 8
32    cz  9.385
33    cz  9.436
34    cz  9.474
35    cz  9.677 $plate 9
36    cz  9.716
37    cz  9.766
38    cz  9.804
39    cz  10.008 $plate 10
40    cz  10.046
41    cz  10.097
42    cz  10.135
43    cz  10.338 $plate 11
44    cz  10.376
45    cz  10.427
46    cz  10.465
47    cz  10.668 $plate 12
48    cz  10.706
49    cz  10.757
50    cz  10.795
51    cz  10.998 $plate 13
52    cz  11.036
53    cz  11.087
54    cz  11.125
55    cz  11.328 $plate 14
56    cz  11.366
57    cz  11.417
58    cz  11.455
59    cz  11.659 $plate 15
60    cz  11.697
61    cz  11.748
62    cz  11.786
63    cz  11.989 $plate 16
64    cz  12.027
65    cz  12.078
66    cz  12.116
67    cz  12.319 $plate 17
68    cz  12.357
69    cz  12.408
70    cz  12.446
```

```
71   cz  12.649 $plate 18
72   cz  12.687
73   cz  12.738
74   cz  12.776
75   cz  12.979 $plate 19
76   cz  13.017
77   cz  13.068
78   cz  13.106
79   cz  13.309 $plate 20
80   cz  13.347
81   cz  13.398
82   cz  13.436
83   cz  13.640 $plate 21
84   cz  13.678
85   cz  13.729
86   cz  13.767
87   cz  13.970 $plate 22
88   cz  14.008
89   cz  14.059
90   cz  14.097
91   cz  14.300 $plate 23
92   cz  14.338
93   cz  14.389
94   cz  14.427
95   cz  14.630 $plate 24
96   cz  14.668
97   cz  14.719
98   cz  14.757
99   cz  14.986
100   cz  15.946 $outer wall
101   cz  17.367 $water channel
102   cz  24.251 $be reflector
103   cz  24.567 $be-gr water
104   cz  24.88  $gr
105   cz  25.05  $gr
106   cz  46.38  $gr
107   cz  46.67  $gr
108   cz  47.147 $gr
109   cz  47.625 $water
110   cz  50.165 $al wall
111   cz  80.165 $outer most water wall
112     pz   0        $core horizontal centerline
113     pz   10       $a non-physical plane for tallying
114     pz   20       $a non-physical plane for tallying
115     pz   30.48    $fuel meat top plane
116     pz   32.385   $fuel plate top plane
117     pz   38.1     $water gap top
118     pz   41.275   $al fuel hanger top (al + water material)
119     pz   45.72    $top plane of be and graphite reflectors
120     pz   75.72    $top of outermost water layer
121   px   0
122   px   0.0508
123   px   0.4318
124   px   0.5842
125     py   0.5842
126     py   0.4318
```

```
127    py   0.0508
128    py   0.0      $a surface for non-ambiguous cell definition
129    py  -0.0508
130    py  -0.4318
131    py  -0.5842
132   p  -1.0  1  0  0.8262     $part of 45 degree side plate # 1
133   p  -1.0  1  0  0.6106     $part of 45 degree side plate # 1
134   p  -1.0  1  0  0.0718     $part of 45 degree side plate # 1
135   p  -1.0  1  0 -0.0718     $part of 45 degree side plate # 2
136   p  -1.0  1  0 -0.6106     $part of 45 degree side plate # 2
137   p  -1.0  1  0 -0.8262     $part of 45 degree side plate # 2
138    p   1.0  1  0  0.8262     $part of -45 degree side plate # 1
139    p   1.0  1  0  0.6106     $part of -45 degree side plate # 1
140    p   1.0  1  0  0.0718     $part of -45 degree side plate # 1
141    p   1.0  1  0 -0.0718     $part of -45 degree side plate # 2
142    p   1.0  1  0 -0.6106     $part of -45 degree side plate # 2
143    p   1.0  1  0 -0.8262     $part of -45 degree side plate # 2
144   p  -0.5774  1  0   0.0   $ 45 degree plane for defining graphite wedge
145   p   0.5774  1  0   0.0   $-45 degree plane for defining graphite wedge
c
160   cz   16.434    $for modelling control blades
161   cz   16.529    $for modelling control blades
162   cz   16.785    $for modelling control blades
163   cz   16.880    $for modelling control blades
164   pz   4.0    $for positioning the control baldes
c
c     the above plane is for modelling partially inserted (now set at
c     4" above core center line) baldes. by changing this plane, the
c     control rods can be inserted or withdrawn by any amount. also, the
c     stainless steel regulating baldes are not taken into account.
c
c
170  px   -0.0508
171  px   -0.4318
172  px   -0.5842
c
c     the following cylinders are used to model the 3 irradiation tubes
c     within the flux trap
c
180  c/z   0.00  2.22  1.694    $1st Tube ID
181  c/z   0.00  2.22  1.905    $1st Tube OD
182  c/z   1.92 -1.11  1.694    $2nd Tube ID
183  c/z   1.92 -1.11  1.905    $2nd Tube OD
184  c/z  -1.92 -1.11  1.694    $3rd Tube ID
185  c/z  -1.92 -1.11  1.905    $3rd Tube OD
186   pz   15       $a non-physical plane for tallying
187   pz  -15       $a non-physical plane for tallying
c
188  c/z  -1.92 -1.11  0.95
c
190  pz   -30.48
191  pz   -32.385
192  pz   -38.10
193  pz   -41.275
194  pz   -45.72
195  pz   -48.92
```

```
196  pz   -75.72
c
c    following plane is added for detailed sample loading
c
221 PZ  35.56      $Sample border #29
222 PZ  33.02      $Sample border #28
c     223 PZ  30.48      $Sample border #27 same with 115
224 PZ  27.94      $Sample border #26
225 PZ  25.40      $Sample border #25
226 PZ  22.86      $Sample border #24
227 PZ  20.32      $Sample border #23
228 PZ  17.78      $Sample border #22
229 PZ  15.24      $Sample border #21
230 PZ  12.70      $Sample border #20
231 PZ  10.16      $Sample border #19
232 PZ   7.62      $Sample border #18
233 PZ   5.08      $Sample border #17
234 PZ   2.54      $Sample border #16
c     235 PZ   0.00      $Sample border #15 same with 112
236 PZ  -2.54      $Sample border #14
237 PZ  -5.08      $Sample border #13
238 PZ  -7.62      $Sample border #12
239 PZ -10.16      $Sample border #11
240 PZ -12.70      $Sample border #10
241 PZ -15.24      $Sample border # 9
242 PZ -17.78      $Sample border # 8
243 PZ -20.32      $Sample border # 7
244 PZ -22.86      $Sample border # 6
245 PZ -25.40      $Sample border # 5
246 PZ -27.94      $Sample border # 4
c     247 PZ -30.48      $Sample border # 3 same with 190
248 PZ -33.02      $Sample border # 2
249 PZ -35.56      $Sample border # 1

C Data Cards
mode  n
imp:n 1 813r  0.7  6r   0.5 4r   1  807r   0.7  6r  0.5  4r  0  1  11r  1 1 86r
kcode 5000   1.1   50   4050  0
c
m1    1001.50c .6667   8016.50c .3333    $H2O
mt1   lwtr.01
m2    13027.50c  1                      $Al
m3    13027.50c  -.600                  $CORE
      92235.50c  -.372
      92238.50c  -.028
m4    4009.50c   1                      $Be
mt4   be.01
m5    6012.50c   -.85
      1001.50c   -.002
      8016.50c   -.016
      13027.50c  -.132
mt5   grph.01
m6    1001.50c  0.4170   8016.50c  0.208    13027.50c  0.3750
mt6   lwtr.01
m7    13027.50c  0.3074  5010.50c  0.1230   5011.55c   0.5094
      6012.50c   0.0602
```

```
c    m8   47000.55c 1
c    m9   48000.50c 1
c    m10  73181.50c 1
c    m11  22000.50c 1
m12  2004.50c  1
m13  6012.50c  1
mt13  grph.01
c    m14  47000.55c 0.5  48000.50c 0.5
c    m15  14000.50c 1
c    m16  26000.50c 0.7  24000.50c 0.2  28000.50c  0.1
c
E0 1.0E-7 10
c    sd4   270.45  2r
c
c    e0    1.0e-6   1.0    15.0
c    c0    0   1
phys:n 15.0  0.0  $cross sections above 15.0 mev will be expunged
print  40  50  60  90  110  120  126
ctme   6000
cut:n  j    0.0  -0.5  -0.1
prdmp  j   20
ksrc  5.0 8.73 2.0   12.39 5.0 11.0   8.73 -5.0 16.0   5.0 -12.39 6.0
c    dbcn  10j   1    3j
```

APPENDIX 5

MCNP MODEL FOR LOADING #1023 – HETEROGENEOUS, BURNUP

```
MURR Criticality Sample w/ FLux Trap for #1023
C  Cell cards
1  1  -1.0      -1  11  13  15 50 -20        $Flux trap
2  1  -1.0      -1      20 -16              $Water above samples
3  1  -1.0      -1      19 -50              $Water below samples
4  2  0.08256    1  -2  45 -21               $Core
5  3  -1.5       1  -2  21 -17              $Top core end plate
6  3  -1.5       1  -2  18 -45              $Bottom end plate
7  1  -1.0       1  -2  17 -16              $Water above core
8  1  -1.0       1  -2  19 -18              $Water below core
9  1  -1.0       2  -3  19 -16              $Water channel
10 4  0.0797     3  -4   9 -16                $Control Rod
11 1  -1.0       3  -4  19  -9              $Water below CR
12 1  -1.0       4  -5  19 -16               $Water gap
13 5  -1.85      5  -6  19 -16                $Be
14 6  -1.6       6  -7  19 -16               $Graphite
15 1  -1.0       7  -8  19 -16               $Water outside graphite
16 7  -2.7     -11  10  50 -20                 $1st tube Al
17 7  -2.7     -13  12  50 -20                 $2nd tube Al
18 7  -2.7     -15  14  50 -20                 $3rd tube Al
19 14 -1.352  -10  21 -20     $Tube A loc 30
20 14 -1.352  -10  22 -21     $Tube A loc 29
21  8 -1.121  -10  23 -22    $Tube A loc 28
22  8 -1.121  -10  24 -23    $Tube A loc 27
23  8 -1.121  -10  25 -24    $Tube A loc 26
24 15 -1.352  -10  26 -25     $Tube A loc 25
25 15 -1.352  -10  27 -26     $Tube A loc 24
26 15 -1.352  -10  28 -27     $Tube A loc 23
27 16 -1.352  -10  29 -28     $Tube A loc 22
28 16 -1.352  -10  30 -29     $Tube A loc 21
29 16 -1.352  -10  31 -30     $Tube A loc 20
30 12 -1.599  -10  32 -31     $Tube A loc 19
31 12 -1.599  -10  33 -32     $Tube A loc 18
32 12 -1.599  -10  34 -33     $Tube A loc 17
33 12 -1.599  -10  35 -34     $Tube A loc 16
34 11 -1.566  -10  36 -35     $Tube A loc 15
35 11 -1.566  -10  37 -36     $Tube A loc 14
36 11 -1.566  -10  38 -37     $Tube A loc 13
37 12 -1.599  -10  39 -38     $Tube A loc 12
38 12 -1.599  -10  40 -39     $Tube A loc 11
39 20 0.02749  -51  41 -400     $Tube A loc 10 (KCl)
40 20 0.02749  -51  42 -41      $Tube A loc 9 (KCl)
109 19 -1.012 (-10 51 41 -400):(-10 400 -40)   $Tube A loc 10 (Al+H2O)
110 19 -1.500 -10  51  42 -41   $Tube A loc 9 (Al+H2O)
41 12 -1.599  -10  43 -42     $Tube A loc 8
42 12 -1.599  -10  44 -43     $Tube A loc 7
43  8 -1.121  -10  45 -44    $Tube A loc 6
44  8 -1.121  -10  46 -45    $Tube A loc 5
```

```
45  8 -1.121  -10  47 -46     $Tube A loc 4
46  8 -1.121  -10  48 -47     $Tube A loc 3
47  8 -1.121  -10  49 -48     $Tube A loc 2
48  8 -1.121  -10  50 -49     $Tube A loc 1
49  8 -1.121  -12  21 -20     $Tube B loc 30
50  8 -1.121  -12  22 -21     $Tube B loc 29
51  8 -1.121  -12  23 -22     $Tube B loc 28
52  8 -1.121  -12  24 -23     $Tube B loc 27
53  8 -1.121  -12  25 -24     $Tube B loc 26
54 13 -0.682  -12  26 -25     $Tube B loc 25
55 13 -0.682  -12  27 -26     $Tube B loc 24
56 13 -0.682  -12  28 -27     $Tube B loc 23
57 13 -0.682  -12  29 -28     $Tube B loc 22
58 13 -0.682  -12  30 -29     $Tube B loc 21
59 13 -0.682  -12  31 -30     $Tube B loc 20
60 12 -1.599  -12  32 -31     $Tube B loc 19
61 12 -1.599  -12  33 -32     $Tube B loc 18
62 12 -1.599  -12  34 -33     $Tube B loc 17
63 12 -1.599  -12  35 -34     $Tube B loc 16
64 12 -1.599  -12  36 -35     $Tube B loc 15
65 12 -1.599  -12  37 -36     $Tube B loc 14
66 21 0.02641  -52  38 -370     $Tube B loc 13(KCl)
67 21 0.02641  -52  39 -38      $Tube B loc 12(KCl)
111 19 -1.012 (-12 52 38 -370):(-12 370 -37)   $Tube B loc 13(Al+H2O)
112 19 -1.500 -12  52  39 -38   $Tube B loc 12(Al+H2O)
68 22 0.02735  -52  40 -390     $Tube B loc 11(KCl)
69 22 0.02735  -52  41 -40      $Tube B loc 10(KCl)
113 19 -1.012 (-12 52 40 -390):(-12 390 -39)   $Tube B loc 11 (Al+H2O)
114 19 -1.500 -12  52  41 -40   $Tube B loc 10 (Al+H2O)
70 12 -1.599  -12  42 -41     $Tube B loc 9
71 12 -1.599  -12  43 -42     $Tube B loc 8
72 23 0.03120  -52  44 -430     $Tube B loc 7(KCl)
73 23 0.03120  -52  45 -44      $Tube B loc 6(KCl)
115 19 -1.012 (-12 52 44 -430):(-12 430 -43)   $Tube B loc 7 (Al+H2O)
116 19 -1.500 -12  52  45 -44   $Tube B loc 6 (Al+H2O)
74  8 -1.121  -12  46 -45     $Tube B loc 5
75  8 -1.121  -12  47 -46     $Tube B loc 4
76  8 -1.121  -12  48 -47     $Tube B loc 3
77  8 -1.121  -12  49 -48     $Tube B loc 2
78  8 -1.121  -12  50 -49     $Tube B loc 1
79  8 -1.121  -14  21 -20     $Tube C loc 30
80  8 -1.121  -14  22 -21     $Tube C loc 29
81 12 -1.599  -14  23 -22     $Tube C loc 28
82 12 -1.599  -14  24 -23     $Tube C loc 27
83 17 -1.352  -14  25 -24     $Tube C loc 26
84 17 -1.352  -14  26 -25     $Tube C loc 25
85 17 -1.352  -14  27 -26     $Tube C loc 24
86 13 -0.682  -14  28 -27     $Tube C loc 23
87 13 -0.682  -14  29 -28     $Tube C loc 22
88 13 -0.682  -14  30 -29     $Tube C loc 21
89 18 -1.352  -14  31 -30     $Tube C loc 20
90 18 -1.352  -14  32 -31     $Tube C loc 19
91 18 -1.352  -14  33 -32     $Tube C loc 18
92 12 -1.599  -14  34 -33     $Tube C loc 17
93 12 -1.599  -14  35 -34     $Tube C loc 16
94 12 -1.599  -14  36 -35     $Tube C loc 15
```

```
95 12 -1.599  -14  37 -36     $Tube C loc 14
96 24 0.02612  -53  38 -370     $Tube C loc 13(KCl)
97 24 0.02612  -53  39 -38      $Tube C loc 12(KCl)
117 19 -1.012 (-14 53 38 -370):(-14 370 -37)  $Tube C loc 13 (Al+H2O)
118 19 -1.500 -14  53  39 -38   $Tube C loc 12 (Al+H2O)
98 12 -1.599  -14  40 -39     $Tube C loc 11
99 12 -1.599  -14  41 -40     $Tube C loc 10
100 25 0.02882  -53  42 -410     $Tube C loc 9(KCl)
101 25 0.02882  -53  43 -42      $Tube C loc 8(KCl)
119 19 -1.012 (-14 53 42 -410):(-14 410 -41)  $Tube C loc 9 (Al+H2O)
120 19 -1.500 -14  53  43 -42   $Tube C loc 8 (Al+H2O)
102 26 0.03160  -53  44 -430     $Tube C loc 7(KCl)
103 26 0.03160  -53  45 -44      $Tube C loc 6(KCl)
121 19 -1.012 (-14 53 44 -430):(-14 430 -43)  $Tube C loc 7 (Al+H2O)
122 19 -1.500 -14  53  45 -44   $Tube C loc 6 (Al+H2O)
104  8 -1.121  -14  46 -45     $Tube C loc 5
105  8 -1.121  -14  47 -46     $Tube C loc 4
106  8 -1.121  -14  48 -47     $Tube C loc 3
107  8 -1.121  -14  49 -48     $Tube C loc 2
108  8 -1.121  -14  50 -49     $Tube C loc 1
123 0           16:    -19:  8               $Outside

C Surface Cards - Cylinderical
1  CZ  6.8072                         $ID of flux trap
2  CZ  15.946                         $OD of core
3  CZ  16.529                         $ID of control rod meat
4  CZ  16.785                         $OD of control rod meat
5  CZ  17.367                         $ID of Be
6  CZ  24.567                         $OD of Be
7  CZ  47.625                         $OD of Graphite
8  CZ  80.165                         $Outer edge of problem
C Surface Cards - bottom position of control rod
9  PZ  4.0
C Surface Cards - flux tap tubes
10 C/Z  0.00  2.22 1.694                  $1st Tube I.D.
11 C/Z  0.00  2.22 1.905                  $1st Tube O.D.
12 C/Z  1.92 -1.11 1.694                  $2nd Tube I.D.
13 C/Z  1.92 -1.11 1.905                  $2nd Tube O.D.
14 C/Z -1.92 -1.11 1.694                  $3rd Tube I.D.
15 C/Z -1.92 -1.11 1.905                  $3rd Tube O.D.
51 C/Z  0.00  2.22 1.219                  $1st Tube KCl Sample O.D.(KCl Heter)
52 C/Z  1.92 -1.11 1.219                  $2nd Tube KCl Sample O.D.(KCl Heter)
53 C/Z -1.92 -1.11 1.219                  $3rd Tube KCl Sample O.D.(KCl Heter)
C Surface Cards - Verticle care parts
16 PZ  75.00                          $Top of water
17 PZ  32.38                          $Top of fuel end plate
18 PZ -32.38                          $Bottom of fuel plate
19 PZ -75.00                          $Bottom of water
C Surface Cards - Sample holder spacing
20 PZ  33.02      $Sample border #30
21 PZ  30.48      $Sample border #29, top of core
22 PZ  27.94      $Sample border #28
23 PZ  25.40      $Sample border #27
24 PZ  22.86      $Sample border #26
25 PZ  20.32      $Sample border #25
26 PZ  17.78      $Sample border #24
```

```
27 PZ  15.24      $Sample border #23
28 PZ  12.70      $Sample border #22
29 PZ  10.16      $Sample border #21
30 PZ   7.62     $Sample border #20
31 PZ   5.08     $Sample border #19
32 PZ   2.54     $Sample border #18
33 PZ   0.00     $Sample border #17
34 PZ  -2.54     $Sample border #16
35 PZ  -5.08     $Sample border #15
36 PZ  -7.62     $Sample border #14
37 PZ -10.16      $Sample border #13
370 PZ -11.3      $Sample border #KCl
38 PZ -12.70      $Sample border #12
39 PZ -15.24      $Sample border #11
390 PZ -16.38      $Sample border #KCl
40 PZ -17.78      $Sample border #10
400 PZ -18.92      $Sample border #KCl
41 PZ -20.32      $Sample border # 9
410 PZ -21.46      $Sample border #KCl
42 PZ -22.86      $Sample border # 8
43 PZ -25.40      $Sample border # 7
430 PZ -26.54      $Sample border #KCl
44 PZ -27.94      $Sample border # 6
45 PZ -30.48      $Sample border # 5, bottom of core
46 PZ -33.02      $Sample border # 4
47 PZ -35.56      $Sample border # 3
48 PZ -38.10      $Sample border # 2
49 PZ -40.64      $Sample border # 1
50 PZ -43.18      $Sample border # 0

C Data Cards
IMP:N 1 121r 0
E0 6.25E-7 0.5 1 10
PHYS:N 10. 0.
M1  1001 0.6667 8016 0.3333                              $H2O
M2  92235 4.E-3  92238 3.22E-4 1001 .4566
              54135 1.8E-7  8016 .2277   13027 .310698       $CORE
M3  13027 .4 1001 .4 8016 .2                             $End plate
M4  13027 0.3074 5010 0.1230 5011 0.5094 6000 0.0602            $CR
M5  4009 1.0                                     $Be
M6  6000 1.0                                     $Graphite
M7  13027 1.0                                     $Al
M8  13027 -.171 1001  -.092 8016  -.736                     $Spacer
M9  13027 -.710 14000 -.014 67165 -.001 1001  -.023 8016  -.252 $Holmium
M10 19000 0.0159   17035 0.012057 17037 0.003856        $KCl(KCl) with original content
M20 19000 0.01563 17035 0.00802 17037 0.00384         $KCl(KCl) #56 After Depletion
M21 19000 0.01554 17035 0.00703 17037 0.00384         $KCl(KCl) #97 After Depletion
M22 19000 0.01562 17035 0.00789 17037 0.00384         $KCl(KCl) #58 After Depletion
M23 19000 0.01587 17035 0.01148 17037 0.00385         $KCl(KCl) #55 After Depletion
M24 19000 0.01551 17035 0.00676 17037 0.00384         $KCl(KCl) #93 After Depletion
M25 19000 0.01572 17035 0.00925 17037 0.00385         $KCl(KCl) #92 After Depletion
M26 19000 0.01589 17035 0.01186 17037 0.00386         $KCl(KCl) #51 After Depletion
M19 13027 -.601 1001  -.044 8016  -.355                $KCl(Al+H2O)
M11 13027 -.713 14000 -.018 39089 -.007 1001  -.020 8016  -.242 $MicroSpheres
M12 13027 -.294 16000 -.526 1001  -.020 8016  -.160            $P-32
M13 13027 -.282 16032 -.295 1001  -.047 8016  -.376            $P-33
```

```
M14 13027 -.690 14000 -.017 1001  -.024 8016  -.270            $2 Hole Host
M15 13027 -.690 14000 -.017 1001  -.024 8016  -.270            $4 Hole Host
M16 13027 -.690 14000 -.017 1001  -.024 8016  -.270            $4 Hole Host
M17 13027 -.690 14000 -.017 1001  -.024 8016  -.270            $4 Hole Host
M18 13027 -.690 14000 -.017 1001  -.024 8016  -.270            $4 Hole Host
KCODE 8000 1.20 50 4050
KSRC 10.0 0.0 0.0
```

APPENDIX 6

MONTEBURNS MODEL FOR LOADING #1037 – MCNP INPUT FILE

```
MURR Irradiation Sample w/ FLux Trap for #1037
C  Cell cards
1  1  -1.0      -1      50 -20  11  13  15    $Flux trap
2  1  -1.0      -1      20 -16                $Water above samples
3  1  -1.0      -1      19 -50                $Water below samples
4  2  0.08256    1  -2  45 -21                $Core
5  3  -1.5       1  -2  21 -17                $Top core end plate
6  3  -1.5       1  -2  18 -45                $Bottom end plate
7  1  -1.0       1  -2  17 -16                $Water above core
8  1  -1.0       1  -2  19 -18                $Water below core
9  1  -1.0       2  -3  19 -16                $Water channel
10 4  0.0797     3  -4   9 -16                $Control Rod
11 1  -1.0       3  -4  19  -9                $Water below CR
12 1  -1.0       4  -5  19 -16                $Water gap
13 5  -1.85      5  -6  19 -16                $Be
14 6  -1.6       6  -7  19 -16                $Graphite
15 1  -1.0       7  -8  19 -16                $Water outside graphite
16 7  -2.7      -11  10  50 -20               $1st tube Al
17 7  -2.7      -13  12  50 -20               $2nd tube Al
18 7  -2.7      -15  14  50 -20               $3rd tube Al
19  14 -1.352 -10  51  21 -20     $Tube A loc 30  Outer Layer
20  14 -1.352      -51  21 -20    $Tube A loc 30  Inner Layer
21  14 -1.352 -10  51  22 -21     $Tube A loc 29  Outer Layer
22  14 -1.352      -51  22 -21    $Tube A loc 29  Inner Layer
23  15 -1.483 -10  51  23 -22     $Tube A loc 28  Outer Layer
24  15 -1.483      -51  23 -22    $Tube A loc 28  Inner Layer
25  15 -1.483 -10  51  24 -23     $Tube A loc 27  Outer Layer
26  15 -1.483      -51  24 -23    $Tube A loc 27  Inner Layer
27  15 -1.483 -10  51  25 -24     $Tube A loc 26  Outer Layer
28  15 -1.483      -51  25 -24    $Tube A loc 26  Inner Layer
29  16 -1.352 -10  51  26 -25     $Tube A loc 25  Outer Layer
30  16 -1.352      -51  26 -25    $Tube A loc 25  Inner Layer
31  16 -1.352 -10  51  27 -26     $Tube A loc 24  Outer Layer
32  16 -1.352      -51  27 -26    $Tube A loc 24  Inner Layer
33  16 -1.352 -10  51  28 -27     $Tube A loc 23  Outer Layer
34  16 -1.352      -51  28 -27    $Tube A loc 23  Inner Layer
35  17 -1.352 -10  51  29 -28     $Tube A loc 22  Outer Layer
36  17 -1.352      -51  29 -28    $Tube A loc 22  Inner Layer
37  17 -1.352 -10  51  30 -29     $Tube A loc 21  Outer Layer
38  17 -1.352      -51  30 -29    $Tube A loc 21  Inner Layer
39  17 -1.352 -10  51  31 -30     $Tube A loc 20  Outer Layer
40  17 -1.352      -51  31 -30    $Tube A loc 20  Inner Layer
41  12 -1.599 -10  51  32 -31     $Tube A loc 19  Outer Layer
42  12 -1.599      -51  32 -31    $Tube A loc 19  Inner Layer
43  12 -1.599 -10  51  33 -32     $Tube A loc 18  Outer Layer
44  12 -1.599      -51  33 -32    $Tube A loc 18  Inner Layer
45  18 -1.275 -10  51  34 -33     $Tube A loc 17  Outer Layer
46  18 -1.275      -51  34 -33    $Tube A loc 17  Inner Layer
```

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47  18 -1.275 -10  51  35 -34     $Tube A loc 16  Outer Layer
48  18 -1.275      -51  35 -34    $Tube A loc 16  Inner Layer
49  11 -1.566 -10  51  36 -35     $Tube A loc 15  Outer Layer
50  11 -1.566      -51  36 -35    $Tube A loc 15  Inner Layer
51  11 -1.566 -10  51  37 -36     $Tube A loc 14  Outer Layer
52  11 -1.566      -51  37 -36    $Tube A loc 14  Inner Layer
53  11 -1.566 -10  51  38 -37     $Tube A loc 13  Outer Layer
54  11 -1.566      -51  38 -37    $Tube A loc 13  Inner Layer
55  12 -1.599 -10  51  39 -38     $Tube A loc 12  Outer Layer
56  12 -1.599      -51  39 -38    $Tube A loc 12  Inner Layer
57  12 -1.599 -10  51  40 -39     $Tube A loc 11  Outer Layer
58  12 -1.599      -51  40 -39    $Tube A loc 11  Inner Layer
59   9 -1.500 -10  51  41 -40    $Tube A loc 10  Outer Layer
60  30 0.02125     -51  41 -40     $Tube A loc 10  Inner Layer
61   9 -1.500 -10  51  42 -41    $Tube A loc 9  Outer Layer
62  30 0.02125     -51  42 -41     $Tube A loc 9  Inner Layer
63  12 -1.599 -10  51  43 -42     $Tube A loc 8  Outer Layer
64  12 -1.599      -51  43 -42    $Tube A loc 8  Inner Layer
65  12 -1.599 -10  51  44 -43     $Tube A loc 7  Outer Layer
66  12 -1.599      -51  44 -43    $Tube A loc 7  Inner Layer
67   8 -1.121 -10  51  45 -44    $Tube A loc 6  Outer Layer
68   8 -1.121      -51  45 -44   $Tube A loc 6  Inner Layer
69   8 -1.121 -10  51  46 -45    $Tube A loc 5  Outer Layer
70   8 -1.121      -51  46 -45   $Tube A loc 5  Inner Layer
71   8 -1.121 -10  51  47 -46    $Tube A loc 4  Outer Layer
72   8 -1.121      -51  47 -46   $Tube A loc 4  Inner Layer
73   8 -1.121 -10  51  48 -47    $Tube A loc 3  Outer Layer
74   8 -1.121      -51  48 -47   $Tube A loc 3  Inner Layer
75   8 -1.121 -10  51  49 -48    $Tube A loc 2  Outer Layer
76   8 -1.121      -51  49 -48   $Tube A loc 2  Inner Layer
77   8 -1.121 -10  51  50 -49    $Tube A loc 1  Outer Layer
78   8 -1.121      -51  50 -49   $Tube A loc 1  Inner Layer
79   8 -1.121 -12  52  21 -20    $Tube B loc 30  Outer Layer
80   8 -1.121      -52  21 -20   $Tube B loc 30  Inner Layer
81   8 -1.121 -12  52  22 -21    $Tube B loc 29  Outer Layer
82   8 -1.121      -52  22 -21   $Tube B loc 29  Inner Layer
83   8 -1.121 -12  52  23 -22    $Tube B loc 28  Outer Layer
84   8 -1.121      -52  23 -22   $Tube B loc 28  Inner Layer
85   8 -1.121 -12  52  24 -23    $Tube B loc 27  Outer Layer
86   8 -1.121      -52  24 -23   $Tube B loc 27  Inner Layer
87  13 -0.682 -12  52  25 -24     $Tube B loc 26  Outer Layer
88  13 -0.682      -52  25 -24    $Tube B loc 26  Inner Layer
89  13 -0.682 -12  52  26 -25     $Tube B loc 25  Outer Layer
90  13 -0.682      -52  26 -25    $Tube B loc 25  Inner Layer
91  13 -0.682 -12  52  27 -26     $Tube B loc 24  Outer Layer
92  13 -0.682      -52  27 -26    $Tube B loc 24  Inner Layer
93  13 -0.682 -12  52  28 -27     $Tube B loc 23  Outer Layer
94  13 -0.682      -52  28 -27    $Tube B loc 23  Inner Layer
95  13 -0.682 -12  52  29 -28     $Tube B loc 22  Outer Layer
96  13 -0.682      -52  29 -28    $Tube B loc 22  Inner Layer
97  13 -0.682 -12  52  30 -29     $Tube B loc 21  Outer Layer
98  13 -0.682      -52  30 -29    $Tube B loc 21  Inner Layer
99  12 -1.599 -12  52  31 -30     $Tube B loc 20  Outer Layer
100  12 -1.599      -52  31 -30    $Tube B loc 20  Inner Layer
101  12 -1.599 -12  52  32 -31     $Tube B loc 19  Outer Layer
102  12 -1.599      -52  32 -31    $Tube B loc 19  Inner Layer
```

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103  12 -1.599 -12  52  33 -32    $Tube B loc 18  Outer Layer
104  12 -1.599      -52  33 -32    $Tube B loc 18  Inner Layer
105  12 -1.599 -12  52  34 -33    $Tube B loc 17  Outer Layer
106  12 -1.599      -52  34 -33    $Tube B loc 17  Inner Layer
107  12 -1.599 -12  52  35 -34    $Tube B loc 16  Outer Layer
108  12 -1.599      -52  35 -34    $Tube B loc 16  Inner Layer
109  12 -1.599 -12  52  36 -35    $Tube B loc 15  Outer Layer
110  12 -1.599      -52  36 -35    $Tube B loc 15  Inner Layer
111   9 -1.500 -12  52  37 -36    $Tube B loc 14  Outer Layer
112  31 0.02467     -52  37 -36    $Tube B loc 14  Inner Layer
113   9 -1.500 -12  52  38 -37    $Tube B loc 13  Outer Layer
114  31 0.02467     -52  38 -37    $Tube B loc 13  Inner Layer
115   9 -1.500 -12  52  39 -38    $Tube B loc 12  Outer Layer
116  32 0.02039     -52  39 -38    $Tube B loc 12  Inner Layer
117   9 -1.500 -12  52  40 -39    $Tube B loc 11  Outer Layer
118  32 0.02039     -52  40 -39    $Tube B loc 11  Inner Layer
119  12 -1.599 -12  52  41 -40    $Tube B loc 10  Outer Layer
120  12 -1.599      -52  41 -40    $Tube B loc 10  Inner Layer
121  12 -1.599 -12  52  42 -41    $Tube B loc 9  Outer Layer
122  12 -1.599      -52  42 -41    $Tube B loc 9  Inner Layer
123  12 -1.599 -12  52  43 -42    $Tube B loc 8  Outer Layer
124  12 -1.599      -52  43 -42    $Tube B loc 8  Inner Layer
125  12 -1.599 -12  52  44 -43    $Tube B loc 7  Outer Layer
126  12 -1.599      -52  44 -43    $Tube B loc 7  Inner Layer
127   8 -1.121 -12  52  45 -44    $Tube B loc 6  Outer Layer
128   8 -1.121      -52  45 -44    $Tube B loc 6  Inner Layer
129   8 -1.121 -12  52  46 -45    $Tube B loc 5  Outer Layer
130   8 -1.121      -52  46 -45    $Tube B loc 5  Inner Layer
131   8 -1.121 -12  52  47 -46    $Tube B loc 4  Outer Layer
132   8 -1.121      -52  47 -46    $Tube B loc 4  Inner Layer
133   8 -1.121 -12  52  48 -47    $Tube B loc 3  Outer Layer
134   8 -1.121      -52  48 -47    $Tube B loc 3  Inner Layer
135   8 -1.121 -12  52  49 -48    $Tube B loc 2  Outer Layer
136   8 -1.121      -52  49 -48    $Tube B loc 2  Inner Layer
137   8 -1.121 -12  52  50 -49    $Tube B loc 1  Outer Layer
138   8 -1.121      -52  50 -49    $Tube B loc 1  Inner Layer
139   8 -1.121 -14  53  21 -20    $Tube C loc 30  Outer Layer
140   8 -1.121      -53  21 -20    $Tube C loc 30  Inner Layer
141   8 -1.121 -14  53  22 -21    $Tube C loc 29  Outer Layer
142   8 -1.121      -53  22 -21    $Tube C loc 29  Inner Layer
143   8 -1.121 -14  53  23 -22    $Tube C loc 28  Outer Layer
144   8 -1.121      -53  23 -22    $Tube C loc 28  Inner Layer
145   8 -1.121 -14  53  24 -23    $Tube C loc 27  Outer Layer
146   8 -1.121      -53  24 -23    $Tube C loc 27  Inner Layer
147  19 -1.352 -14  53  25 -24    $Tube C loc 26  Outer Layer
148  19 -1.352      -53  25 -24    $Tube C loc 26  Inner Layer
149  19 -1.352 -14  53  26 -25    $Tube C loc 25  Outer Layer
150  19 -1.352      -53  26 -25    $Tube C loc 25  Inner Layer
151  19 -1.352 -14  53  27 -26    $Tube C loc 24  Outer Layer
152  19 -1.352      -53  27 -26    $Tube C loc 24  Inner Layer
153  13 -0.682 -14  53  28 -27    $Tube C loc 23  Outer Layer
154  13 -0.682      -53  28 -27    $Tube C loc 23  Inner Layer
155  13 -0.682 -14  53  29 -28    $Tube C loc 22  Outer Layer
156  13 -0.682      -53  29 -28    $Tube C loc 22  Inner Layer
157  13 -0.682 -14  53  30 -29    $Tube C loc 21  Outer Layer
158  13 -0.682      -53  30 -29    $Tube C loc 21  Inner Layer
```

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159  20 -1.352 -14  53  31 -30     $Tube C loc 20  Outer Layer
160  20 -1.352      -53  31 -30     $Tube C loc 20  Inner Layer
161  20 -1.352 -14  53  32 -31     $Tube C loc 19  Outer Layer
162  20 -1.352      -53  32 -31     $Tube C loc 19  Inner Layer
163  20 -1.352 -14  53  33 -32     $Tube C loc 18  Outer Layer
164  20 -1.352      -53  33 -32     $Tube C loc 18  Inner Layer
165  12 -1.599 -14  53  34 -33     $Tube C loc 17  Outer Layer
166  12 -1.599      -53  34 -33     $Tube C loc 17  Inner Layer
167  12 -1.599 -14  53  35 -34     $Tube C loc 16  Outer Layer
168  12 -1.599      -53  35 -34     $Tube C loc 16  Inner Layer
169  12 -1.599 -14  53  36 -35     $Tube C loc 15  Outer Layer
170  12 -1.599      -53  36 -35     $Tube C loc 15  Inner Layer
171  12 -1.599 -14  53  37 -36     $Tube C loc 14  Outer Layer
172  12 -1.599      -53  37 -36     $Tube C loc 14  Inner Layer
173   9 -1.500 -14  53  38 -37     $Tube C loc 13  Outer Layer
174  33 0.02015      -53  38 -37     $Tube C loc 13  Inner Layer
175   9 -1.500 -14  53  39 -38     $Tube C loc 12  Outer Layer
176  33 0.02015      -53  39 -38     $Tube C loc 12  Inner Layer
177   9 -1.500 -14  53  40 -39     $Tube C loc 11  Outer Layer
178  34 0.02467      -53  40 -39     $Tube C loc 11  Inner Layer
179   9 -1.500 -14  53  41 -40     $Tube C loc 10  Outer Layer
180  34 0.02467      -53  41 -40     $Tube C loc 10  Inner Layer
181  12 -1.599 -14  53  42 -41     $Tube C loc 9  Outer Layer
182  12 -1.599      -53  42 -41     $Tube C loc 9  Inner Layer
183  12 -1.599 -14  53  43 -42     $Tube C loc 8  Outer Layer
184  12 -1.599      -53  43 -42     $Tube C loc 8  Inner Layer
185  12 -1.599 -14  53  44 -43     $Tube C loc 7  Outer Layer
186  12 -1.599      -53  44 -43     $Tube C loc 7  Inner Layer
187  12 -1.599 -14  53  45 -44     $Tube C loc 6  Outer Layer
188  12 -1.599      -53  45 -44     $Tube C loc 6  Inner Layer
189   8 -1.121 -14  53  46 -45     $Tube C loc 5  Outer Layer
190   8 -1.121      -53  46 -45     $Tube C loc 5  Inner Layer
191   8 -1.121 -14  53  47 -46     $Tube C loc 4  Outer Layer
192   8 -1.121      -53  47 -46     $Tube C loc 4  Inner Layer
193   8 -1.121 -14  53  48 -47     $Tube C loc 3  Outer Layer
194   8 -1.121      -53  48 -47     $Tube C loc 3  Inner Layer
195   8 -1.121 -14  53  49 -48     $Tube C loc 2  Outer Layer
196   8 -1.121      -53  49 -48     $Tube C loc 2  Inner Layer
197   8 -1.121 -14  53  50 -49     $Tube C loc 1  Outer Layer
198   8 -1.121      -53  50 -49     $Tube C loc 1  Inner Layer
199  0          16:    -19:  8               $Outside

C Surface Cards - Cylinderical
1  CZ  6.8072                        $ID of flux trap
2  CZ  15.946                        $OD of core
3  CZ  16.529                        $ID of control rod meat
4  CZ  16.785                        $OD of control rod meat
5  CZ  17.367                        $ID of Be
6  CZ  24.567                        $OD of Be
7  CZ  47.625                        $OD of Graphite
8  CZ  80.165                        $Outer edge of problem
C Surface Cards - bottom position of control rod
9  PZ 10.6
C Surface Cards - flux tap tubes
10 C/Z  0.00  2.22 1.694                 $1st Tube I.D.
11 C/Z  0.00  2.22 1.905                 $1st Tube O.D.
```

```
12 C/Z  1.92 -1.11 1.694                $2nd Tube I.D.
13 C/Z  1.92 -1.11 1.905                $2nd Tube O.D.
14 C/Z -1.92 -1.11 1.694                $3rd Tube I.D.
15 C/Z -1.92 -1.11 1.905                $3rd Tube O.D.
51 C/Z  0.00  2.22 1.219                $1st Tube KCl O.D.
52 C/Z  1.92 -1.11 1.219                $2nd Tube KCl O.D.
53 C/Z -1.92 -1.11 1.219                $3rd Tube KCl O.D.
C Surface Cards - Vertical core parts
16 PZ  75.00                        $Top of water
17 PZ  32.38                        $Top of fuel end plate
18 PZ -32.38                        $Bottom of fuel plate
19 PZ -75.00                        $Bottom of water
C Surface Cards - Sample holder spacing
20 PZ  33.02      $Sample border #30
21 PZ  30.48      $Sample border #29, top of core
22 PZ  27.94      $Sample border #28
23 PZ  25.40      $Sample border #27
24 PZ  22.86      $Sample border #26
25 PZ  20.32      $Sample border #25
26 PZ  17.78      $Sample border #24
27 PZ  15.24      $Sample border #23
28 PZ  12.70      $Sample border #22
29 PZ  10.16      $Sample border #21
30 PZ   7.62      $Sample border #20
31 PZ   5.08      $Sample border #19
32 PZ   2.54      $Sample border #18
33 PZ   0.00      $Sample border #17
34 PZ  -2.54      $Sample border #16
35 PZ  -5.08      $Sample border #15
36 PZ  -7.62      $Sample border #14
37 PZ -10.16      $Sample border #13
38 PZ -12.70      $Sample border #12
39 PZ -15.24      $Sample border #11
40 PZ -17.78      $Sample border #10
41 PZ -20.32      $Sample border # 9
42 PZ -22.86      $Sample border # 8
43 PZ -25.40      $Sample border # 7
44 PZ -27.94      $Sample border # 6
45 PZ -30.48      $Sample border # 5, bottom of core
46 PZ -33.02      $Sample border # 4
47 PZ -35.56      $Sample border # 3
48 PZ -38.10      $Sample border # 2
49 PZ -40.64      $Sample border # 1
50 PZ -43.18      $Sample border # 0

C Data Cards
IMP:N 1 197r 0
C E0 6.25E-7 0.5 1 10
PHYS:N 10. 3E-6
M1  1001 0.6667 8016 0.3333                          $H2O
M2  92235 4.E-3  92238 3.22E-4 1001 .4566
          54135 1.8E-7  8016 .2277   13027 .310698       $CORE
M3  13027 .4 1001 .4 8016 .2                       $End plate
M4  13027 0.3074 5010 0.1230 5011 0.5094 6000 0.0602        $CR
M5  4009 1.0                                 $Be
M6  6000 1.0                                 $Graphite
```

```
M7  13027 1.0                                    $Al
M8  13027 -.171 1001  -.092 8016  -.736                  $Spacer
M9  13027 -.601 1001  -.044 8016  -.355                  $KCl(Al+H2O)
M10 19000 .0159 17035  .120 17037  .00385                   $KCl(KCl) Without Burnup
M11 13027 -.713 14000 -.018 39089 -.007 1001  -.020 8016  -.242 $MicroSpheres
M12 13027 -.294 16000 -.526 1001  -.020 8016  -.160           $P-32
M13 13027 -.282 16032 -.295 1001  -.047 8016  -.376           $P-33
M14 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M15 13027 -.737 14000 -.012 1001  -.022 8016  -.299           $3 Hole Host
M16 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M17 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M18 13027 -.690 14000 -.017 1001  -.024 8016  -.270  67165 -.000206          $Holumium
M19 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M20 13027 -.690 14000 -.017 1001  -.024 8016  -.270           $4 Hole Host
M30 19000 0.01586 17035 0.01148 17037 0.03854               $KCl(KCl) Tube A loc 9
M31 19000 0.01552 17035 0.00789 17037 0.03837               $KCl(KCl) Tube B loc 13
M32 19000 0.01554 17035 0.00802 17037 0.03838               $KCl(KCl) Tube B loc 11
M33 19000 0.01566 17035 0.00925 17037 0.03844               $KCl(KCl) Tube C loc 12
M34 19000 0.01588 17035 0.01186 17037 0.03855               $KCl(KCl) Tube C loc 10
KCODE 8000 1.20 5 55
KSRC 10.0 0.0 0.0
```

APPENDIX 7

MONTEBURNS MODEL FOR LOADING #1037 – MONTEBURNS INPUT FILE

```
MURR FT Ho-166 Product Calculation for #1037@ 10MW
PC
2       ! Number of MCNP materials to burn
18      ! MCNP material #1 for Ho
2       ! MCNP material # for Fuel
0       ! Material volume, 0 to use mcnp value
0       ! Material volume, 0 to use mcnp value
10.0     ! Power in MWt
-200.   ! Recov. energy/fis (MeV)
6.52375    ! Total number of days burned (used if no feed)
2       ! Number of outer burn steps
10      ! Number of internal burn steps
1       ! Number of predictor steps
0       ! Step number to restart after
PWRU      ! number of default origen2 lib - next line is origen2 lib location
C:\ORIGEN22\libs
.001     ! Fractional importance
1         ! Intermediate keff calculation
1         ! Number of automatic tally isotopes for Ho
67165.66c
11          ! Number of automatic tally isotopes for Fuel
92234.50c   ! U234
92235.50c   ! U235
92236.50c   ! U236
92238.50c   ! U238
93237.50c   ! Np237
94238.50c   ! Pu238
94239.50c   ! Pu239
94240.50c   ! Pu240
94241.50c   ! Pu241
94242.50c   ! Pu242
95241.50c   ! Am241
```

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