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TITLE Fluence Analysis Report for Boat Samples - Nine Mile Pt. 1

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PURPOSE AND SUMMARY OF RESULTS:

Objectives of this analysis are:

1. Calculate the time-average fast flux and corresponding fluence for boat samples V9 and V10
2. Estimate the uncertainty in the results

Results of this Analysis

The results are given in Section D of this document.

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TABLE OF CONTENTS

A Background and Objectives

BACKGROUND

In mid 1997, Niagara Mohawk Power Co. (NMPC) contracted with Framatome Technologies Inc (FTI) to calculate the neutron fluence on two boat samples that were cut from the core shroud of the Nine Mile Point Unit 1 reactor. The boat samples were shipped to McDermott Technologies' Inc. Lynchburg Research Center (LRC) for metallurgical testing and dosimetry measurements. The boat samples were cut from the shroud as shown in Sketches E-3-1 and E-3-2. Dosimeters were cut from the boat samples as shown in Sketch E-3-3.

The neutron fluence exposures for three radial locations in each boat sample were estimated in this analysis by the methods and procedures presented in Section B.

OBJECTIVES

This analysis was performed to:

1. Determine the time-average fast flux and the corresponding accumulated fast fluence exposure experienced by the two samples. Flux and fluence at three points in each sample were determined in the supporting analysis and are reported herein.

2. Estimate the uncertainty in the fluences

B Methodology

Equation B-2 below expresses the methodology used to estimate the fast flux (defined as flux of energy greater than 1.0 MeV) at each dosimeter location in each boat sample. It is noted that the calculated flux is directly proportional to the measured dosimeter activity. Application of the non-saturation factor, NSF, in the denominator effectively saturates the measured activity, which means that the flux calculated in this way (Equation B-2) corresponds to the full power flux. Fluence is then obtained by multiplying the full power flux by the effective full power seconds. Since each measured activity is different, four activities and four corresponding (and different) fluxes at each dosimeter location were determined for each boat sample. The differences between the calculated fluxes at each location were relatively small, so the simple average flux was calculated for each location. The validity of this procedure was verified in the uncertainty analysis (Section E-5).

Three quantities are needed to calculate the flux that corresponds to the measured

activities: (1) the measured activity itself, (2) the "non-saturation factor", and (3) the spectrum-weighted average response function. Each of these quantities are discussed individually below.

1. MTI (LRC) determined the specific activity in units of µCi (product isotope)/g(target isotope) in each dosimeter for each of the following three dosimeter reactions: $^{54}Fe(n,p)^{54}Mn$, $^{58}Ni(n,p)^{58}Co$, and $^{59}Co(n,\gamma)^{60}Co$. It is noted, however, that Co is not used in the fluence analysis because it does not have a meaningful response in the energy range of interest. These activities were carefully checked and verified as reasonable in Section E-3-1 and will occasionally be referred to by the symbol "M", hereafter.

2. NMPC has provided [1] the neutron spectrum at three points that are co-incident with locations in one or both of the samples (see Sketch E-2-4). These spectra were used in the following equation to determine the spectrum-weighted average reaction response function, (specific activity per unit flux) for the two fast neutron dosimeter reactions given above:

$$\overline{RF}_d = \frac{\frac{1.62772x10^{-5}}{AM_d} * \sum_g \phi_g * \sigma_{g,d}}{\sum_g \phi_g} \qquad [\text{B-1}]$$

where:

$\overline{RF}_d$ = Reaction "d" response function, which is defined as the spectrum-averaged specific activity (µCi(P)/g(T)) per unit flux (n/cm^2-sec)

AM_d = Atomic mass of target isotope, grams/mole

$1.62772x10^{-5}$ = 6.02257(+23)atoms/mole * 2.7027(-5)µCi-s/dis *10^{-24} cm^2/b

ϕ_g = neutron flux at dosimeter location in energy group "g" (n/cm^2-s)

$\sigma_{g,d}$ = reaction "d" cross section for group "g" [b]

3. The average flux to which the dosimeter (d) was exposed over the time of irradiation was then calculated using the following equation:

$$\phi_d = \frac{M_d}{NSF_d * \overline{RF_d}} \qquad [B\text{-}2]$$

where:

ϕ_d = fast flux derived from dosimeter type "d" [n/cm^2-sec]

M_d = measured activity of dosimeter type "d" [(μCi/g]

NSF_d = non-saturation factor for dosimeter "d", which is determined from the power history of the reactor. [unitless]

$\overline{RF_d}$ = Spectrum-averaged response function of dosimeter "d", as explained in paragraph 2 above. [(μCi/g)/(n/cm^2-sec)]

4. A statistical analysis was performed (Section E-5) to determine the bias and uncertainty in the fluxes, and to verify the use of the simple averaging techniques to obtain a single-value of the flux at each point.

5. The fluence was calculated for the total irradiation time as discussed in Section E-4.

C Assumptions

1. The neutron energy spectrum at the inside surface of the shroud is not significantly different from the spectrum at a point .86cm into the shroud (from the inside surface). This assumption is justified by the uncertainty analysis (Section E-5) which showed that the uncertainty in the flux due to uncertainty in the spectrum average cross sections was acceptably low.

2. The neutron energy spectrum at the outside surface of the shroud is not significantly different than the spectrum at a point 1.11 cm into the shroud (from the outside surface). This assumption is justified by the uncertainty analysis (Section E-5) which showed that the uncertainty in the flux due to uncertainty in the spectrum average cross sections was acceptably low.

D Results

D-1 Flux and Fluence Results

The fluence results for boat samples V9 and V10 are presented in Tables D-1 and D-2 respectively. The fluxes were calculated for the 20° shroud location using the procedures explained in Sections B and E (fluences for a 10° location were also calculated but are not reported herein, since the fluence calculated at the 10° location was approximately 5% lower. The uncertainty analysis, Section E-5, accounts for the the weld location uncertainty.). Since this method derives the fluences from the measurements, the measured activities were checked carefully and found to be reasonable in magnitude and consistent with trend expectations (Section E-3-1). The uncertainty (Section D-2) supports the contention that the measured activities are reasonable.

TABLE D-1

Calculated Flux & Fluence using explicit neutron Spectrum (20 deg) for each boat sample

BOAT SAMPLE V9 FLUX

Dosimeter	Dos. no.	M	NSF	RF	FLUX	ave flux	FLUENCE
V9 FLAT 1 Fe	1	1.94E+04	0.862	3.578E-08	6.291E+11		
V9 FLAT 2 Fe	2	1.93E+04	0.862	3.578E-08	6.258E+11		
V9 FLAT 1 Ni	3	2.01E+04	0.901	4.382E-08	5.091E+11	5.77E+11	3.088E+20
V9 FLAT 2 Ni	4	2.15E+04	0.901	4.382E-08	5.446E+11		
V9 MID 1 Fe	5	1.60E+04	0.862	3.578E-08	5.188E+11		
V9 MID 2 Fe	6	1.68E+04	0.862	3.578E-08	5.447E+11		
V9 MID 1 Ni	7	1.91E+04	0.901	4.382E-08	4.838E+11	5.03E+11	2.69E+20
V9 MID 2 Ni	8	1.83E+04	0.901	4.382E-08	4.635E+11		
V9 TIP 1 Fe	9	1.31E+04	0.862	3.361E-08	4.521E+11		
V9 TIP 2 Fe	10	1.32E+04	0.862	3.361E-08	4.556E+11	4.25E+11	2.273E+20
V9 TIP 1 Ni	11	1.44E+04	0.901	4.138E-08	3.862E+11		
V9 TIP 2 Ni	12	1.51E+04	0.901	4.138E-08	4.050E+11		

TABLE D-2

BOAT SAMPLE V10 FLUX

Dosimeter	Dos. no.	M	NSF	RF	FLUX	Ave flux	FLUENCE
V10 TIP 1 Fe	1	8.98E+03	0.862	3.361E-08	3.099E+11		
V10 TIP 2 Fe	2	9.14E+03	0.862	3.361E-08	3.155E+11		
V10 TIP 1 Ni	3	9.72E+03	0.901	4.138E-08	2.607E+11	2.88E+11	1.541E+20
V10 TIP 2 Ni	4	9.91E+03	0.901	4.138E-08	2.658E+11		
V10 MID 1 Fe	5	8.34E+03	0.862	3.348E-08	2.890E+11		
V10 MID 2 Fe	6	8.26E+03	0.862	3.348E-08	2.862E+11	2.58E+11	1.38E+20
V10 MID 1 Ni	7	8.42E+03	0.901	4.121E-08	2.267E+11		
V10 MID 2 Ni	8	8.52E+03	0.901	4.121E-08	2.294E+11		
V10 FLAT 1 Fe	9	6.74E+03	0.862	3.348E-08	2.336E+11		
V10 FLAT 2 Fe	10	6.74E+03	0.862	3.348E-08	2.336E+11	2.08E+11	1.113E+20
V10 FLAT 1 Ni	11	6.75E+03	0.901	4.121E-08	1.818E+11		
V10 FLAT 2 Ni	12	6.80E+03	0.901	4.121E-08	1.831E+11		

D-2 Uncertainty in the Calculated flux and fluence

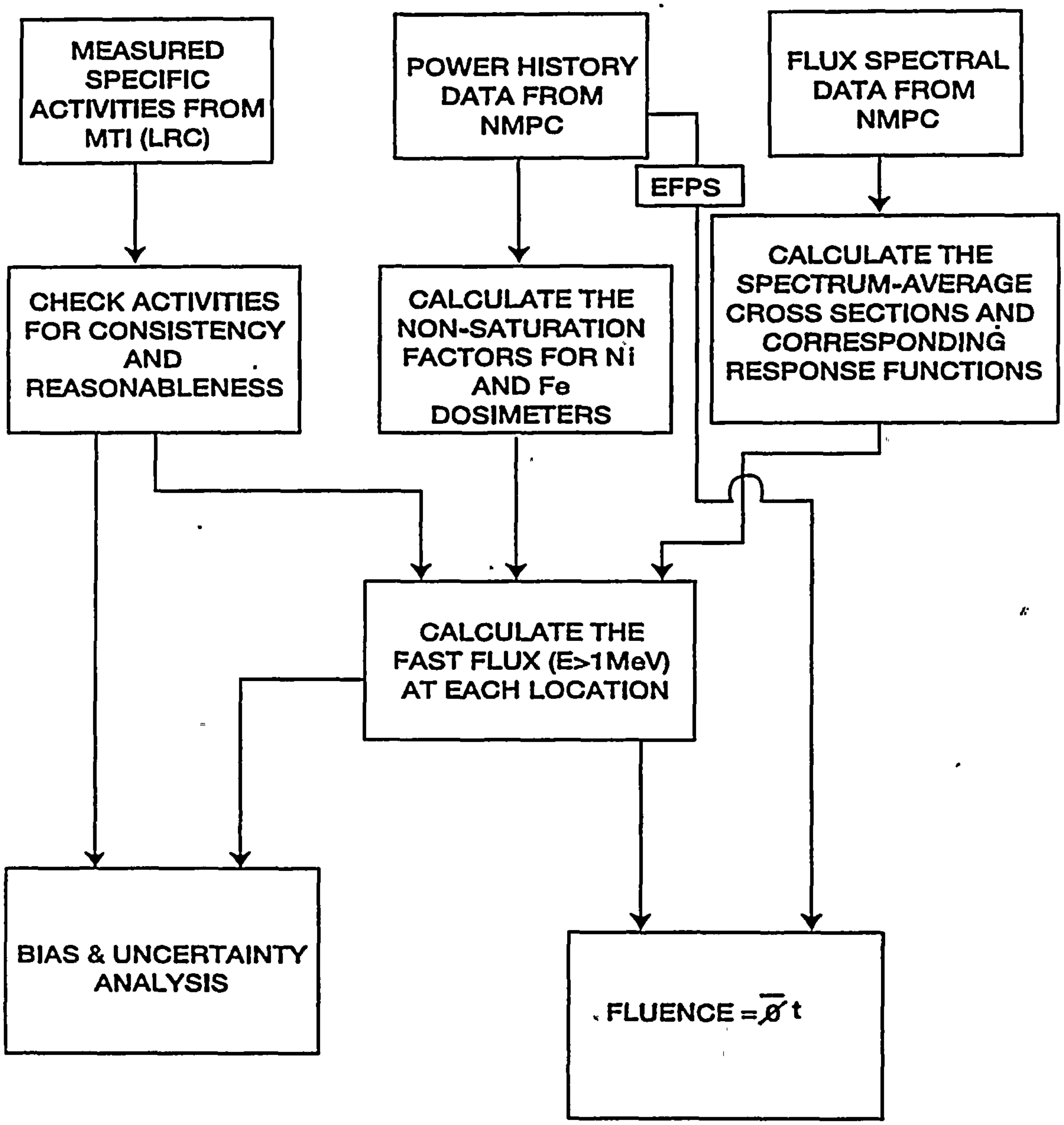
The uncertainty was calculated in Section E-5, and is FTI-proprietary; Section E-5, and only that Section,.is proprietary. The non-proprietary version of this document does not contain Section 5, but is identical in all other respects. The proprietary version of this document contains the full uncertainty analysis and will be available to NMPC, which is bound by the proprietary agreement in the contract. The proprietary document will not be made available to any other entities without written permission of Framatome Technologies, Inc. Should NRC questions on the uncertainty be asked, FTI can respond via proprietary correspondence or in a proprietary presentation.

The results of the uncertainty analysis are:

Bias in the E > 1.0 MeV Fluence = 0.0

Uncertainty in the E > 1.0 MeV Fluence ≤ 13.28%

Fig. (E-1): Methodology



E-1 Non Saturation Factors

Non-Saturation factors (NSF) were calculated using equation (E-1-1), which is based on Equation (4') of ASTM Standard E 1005 [2].

$$NSF_d = \sum_j P_j \{1 - \exp(-\lambda_d t_j)\}\exp(-\lambda_d(T-\tau_j)) \qquad [\text{EQ E-1-1}]$$

where:
- t_j = time duration for constant power period "j"
- P_j = constant relative power during time increment t_j
- λ_d = decay constant for product isotope of dosimeter "d"
- $T-\tau_j$ = Time from end of period j to end of irradiation

The calculated non-saturation factors [9] are:

$NSF_{Fe} = .86242$

$NSF_{Ni} = .90150$

E-2 Spectrum-Averaged Dosimeter-Reaction Response Functions

The spectrum-average response functions for the fast-response dosimeters were calculated as discussed in Section B, using the energy-dependent flux data [1].

The spectrum-averaged cross sections for the iron and nickel dosimeters were calculated for three flux spectra, and are given in Tables E-2-1, E-2-2, and E-2-3. The correspondence between flux spectrum and dosimeter location used in the analysis was:

Spectrum Identifier	Reference [1], Table 2 column number	Dosimeter to which applicable
Flux 1	1 (R=224.16 cm)	V_9 (Mid and Flat)
Flux 2	2 (R=225.43 cm)	V_9 (Tip) & V_{10} (Tip)
Flux 3	3 (R=226.70 cm)	V_{10} (Mid and Flat)

		TABLE E-2-1		
		Spec Avg X-Sect for flux #1		

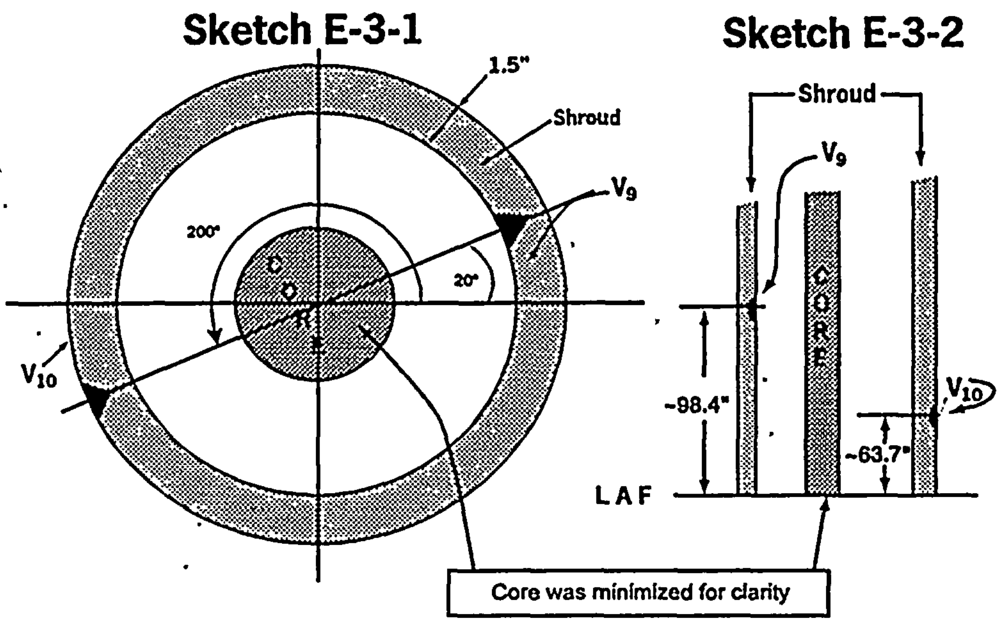
g	sigma(Fe)	sigma(Ni)	flux	sig(Fe)Xflux	sig(Ni)Xflux
1	0.2376	0.2248	2.20E-05	5.227E-06	4.9456E-06
2	0.3944	0.4543	1.12E-04	4.417E-05	5.0882E-05
3	0.4666	0.5846	5.40E-04	0.000252	0.00031568
4	0.4819	0.62224	1.28E-03	0.0006168	0.00079647
5	0.4824	0.62576	2.61E-03	0.0012591	0.00163323
6	0.4788	0.60747	7.28E-03	0.0034857	0.00442238
7	0.4364	0.51342	1.22E-02	0.0053241	0.00626372
8	0.3146	0.38294	2.51E-02	0.0078965	0.00961179
9	0.1953	0.24987	1.87E-02	0.0036521	0.00467257
10	0.1339	0.17178	1.39E-02	0.0018612	0.00238774
11	0.0787	0.12493	1.56E-02	0.0012277	0.00194891
12	0.0567	0.096834	7.62E-03	0.0004321	0.00073788
13	0.0512	0.08855	1.84E-03	9.421E-05	0.00016293
14	0.04503	0.07925	9.16E-03	0.0004125	0.00072593
15	0.0294	0.05069	2.30E-02	0.0006762	0.00116587
16	0.00953	0.028424	2.18E-02	0.0002078	0.00061964
17	0.00297	0.014874	2.94E-02	8.732E-05	0.0004373
18	7.84E-04	0.005915	4.21E-02	3.301E-05	0.00024902
19	9.01E-05	0.001308	2.34E-02	2.108E-06	3.0607E-05
20	6.64E-06	8.94E-04	1.31E-02	8.697E-08	1.1711E-05
21	3.91E-07	5.57E-04	2.66E-02	1.039E-08	1.4806E-05
22		1.68E-04	2.26E-02	0	3.7957E-06
	SUMS		2.32E-01	0.0275697	0.03626782
			sig ave	0.1185456	0.15594604
			RF ave	3.578E-08	4.3821E-08
				Fe	Ni

		TABLE E-2-2			
	Spec Avg X-Sect for flux #2				
g	sigma(Fe)	sigma(Ni)	flux	sig(Fe)Xflux	sig(Ni)Xflux
1	0.2376	0.2248	1.74E-05	4.1342E-06	3.912E-06
2	0.3944	0.4543	8.92E-05	3.518E-05	4.052E-05
3	0.4666	0.5846	4.25E-04	0.00019831	0.0002485
4	0.4819	0.62224	1.00E-03	0.0004819	0.0006222
5	0.4824	0.62576	2.05E-03	0.00098892	0.0012828
6	0.4788	0.60747	5.67E-03	0.0027148	0.0034444
7	0.4364	0.51342	9.44E-03	0.00411962	0.0048467
8	0.3146	0.38294	1.95E-02	0.0061347	0.0074673
9	0.1953	0.24987	1.47E-02	0.00287091	0.0036731
10	0.1339	0.17178	1.12E-02	0.00149968	0.0019239
11	0.0787	0.12493	1.27E-02	0.00099949	0.0015866
12	0.0567	0.096834	6.17E-03	0.00034984	0.0005975
13	0.0512	0.08855	1.54E-03	7.8848E-05	0.0001364
14	0.04503	0.07925	7.64E-03	0.00034403	0.0006055
15	0.0294	0.05069	1.93E-02	0.00056742	0.0009783
16	0.00953	0.028424	1.88E-02	0.00017916	0.0005344
17	0.00297	0.014874	2.57E-02	7.6329E-05	0.0003823
18	7.84E-04	0.005915	3.84E-02	3.0106E-05	0.0002271
19	9.01E-05	0.001308	2.12E-02	1.9099E-06	2.773E-05
20	6.64E-06	8.94E-04	1.16E-02	7.7012E-08	1.037E-05
21	3.91E-07	5.57E-04	2.48E-02	9.6894E-09	1.38E-05
22		1.68E-04	2.06E-02	0	3.46E-06
				0	0
				0	0
		SUMS	1.94E-01	0.02167536	0.0286567
			sig ave	0.11137525	0.1472477
			RF ave	3.3613E-08	4.138E-08

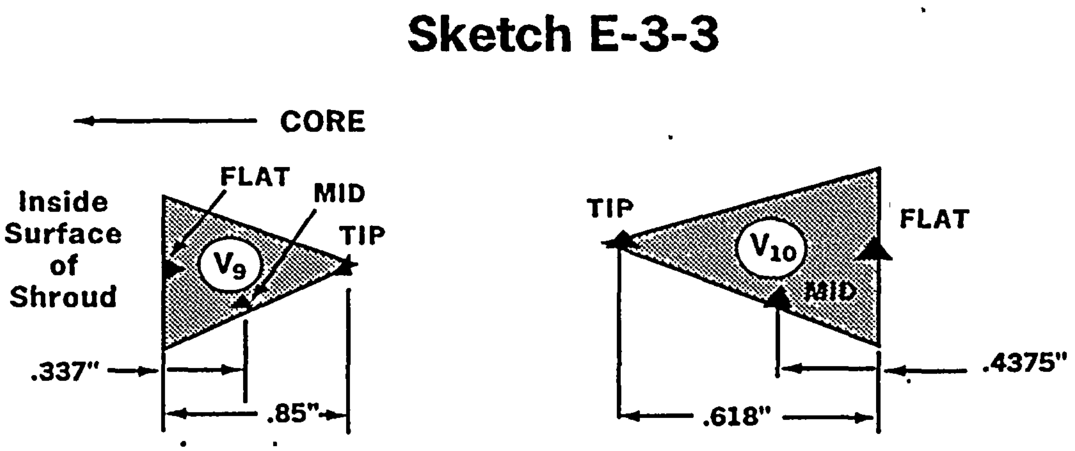
		TABLE E-2-3			
	Spec Avg X-Sect for flux #3				
g	sigma(Fe)	sigma(Ni)	flux	sig(Fe)Xflux	sig(Ni)Xflux
1	0.2376	0.2248	1.37E-05	3.25512E-06	3.07976E-06
2	0.3944	0.4543	7.00E-05	0.000027608	0.000031801
3	0.4666	0.5846	3.31E-04	0.000154445	0.000193503
4	0.4819	0.62224	7.81E-04	0.000376364	0.000485969
5	0.4824	0.62576	1.58E-03	0.000762192	0.000988701
6	0.4788	0.60747	4.33E-03	0.002073204	0.002630345
7	0.4364	0.51342	7.11E-03	0.003102804	0.003650416
8	0.3146	0.38294	1.46E-02	0.00459316	0.005590924
9	0.1953	0.24987	1.11E-02	0.00216783	0.002773557
10	0.1339	0.17178	8.36E-03	0.001119404	0.001436081
11	0.0787	0.12493	9.42E-03	0.000741354	0.001176841
12	0.0567	0.096834	4.55E-03	0.000257985	0.000440595
13	0.0512	0.08855	1.18E-03	0.000060416	0.000104489
14	0.04503	0.07925	5.73E-03	0.000258022	0.000454103
15	0.0294	0.05069	1.43E-02	0.00042042	0.000724867
16	0.00953	0.028424	1.43E-02	0.000136279	0.000406463
17	0.00297	0.014874	1.94E-02	0.000057618	0.000288556
18	7.84E-04	0.005915	2.99E-02	2.34416E-05	0.000176859
19	9.01E-05	0.001308	1.72E-02	1.54955E-06	2.24976E-05
20	6.64E-06	8.94E-04	9.07E-03	6.02157E-08	8.10858E-06
21	3.91E-07	5.57E-04	1.98E-02	7.73586E-09	1.10207E-05
22		1.68E-04	1.65E-02	0	2.77118E-06
	SUMS		1.47E-01	0.016337419	0.021601546
			sig ave	0.110929104	0.146671894
			RF ave	3.34784E-08	4.12148E-08
				Fe	Ni

E-3 Measured Activities

The two boat samples, V9 and V10, were cut from the core shroud at the locations indicated in Sketches E-3-1 and E-3-2, below.



Three sub-samples were cut from each boat sample, to be used as dosimeters (as shown in Sketch E-3-3, below). Each sample was cut into two Ni dosimeters, two Fe dosimeters, and two Co dosimeters (for this analysis, the Co dosimeters are not considered because they do not respond to fast flux).



The McDermott Technologies Inc's (MTI) Lynchburg Research Center (LRC) determined the measured specific activities of the various dosimeters [2]. The specific activities are given in column 3 of Tables D-1 and D-2. Measured activities were checked for internal consistency by the use of M/M checks and an absolute magnitude check, as discussed below.

E-3-1 Check of Measured Dosimeter Activities

The specific activities were checked in three ways [9]:

1. Consistency of Fe/Ni ratios
   This check determined the standard deviation of the iron/nickel ratio to be about 5.05%

2. Linearity of ln(M) vs. penetration data
   Exponential variation of the flux as a function of penetration is expected, and was demonstrated in Reference [9].

3. Rough check on absolute-magnitude of Fe dosimeter specific activity (V9 flat)
   A calculation was performed in Reference [9] which determined an independent value of the specific activity of the iron dosimeter in sample V_9 (flat). The value was within 13.3% of the measured activity.

These tests demonstrate the accuracy of the LRC results.

E-4 Flux and Fluence on Samples V_9 and V_{10}

The flux of energy greater than or equal to 1.0 MeV was calculated in Reference [9] using the methodology presented in detail in Section B. At each location, V9 (flat, mid, and tip) and V10 (tip, mid, and flat), the flux was calculated for each dosimeter (Fe and Ni) and then averaged for each location. As shown in Section E-5, simple averaging does not introduce any significant error because the flux derived from the Fe dosimeters is not much different than the flux derived from the Ni dosimeters (at each location).

The corresponding fluence was calculated by use of the equation:

Fluence [n/cm^2] = Calculated Fast Flux [n/cm^2-s] * Time [efps]
The operation time, in effective full power seconds, was derived from the power history data [9] and had a value of 6192.62 EFPD.

F. REFERENCES

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[9] 32-1266250-00, "Fluence Analysis for Boat Samples - Nine Mile Point-1", S. Q. King and J. R. Worsham III, Jan., 1998