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TEST REPORT

DETERMINATION OF FAST NEUTRON FLUX DENSITY AND FLUENCE: CLINTON STATION

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DETERMINATION OF FAST NEUTRON FLUX DENSITY AND FLUENCE: CLINTON STATION

SUMMARY

The fast neutron flux density and fluence (integrated neutron flux) at a capsule near the reactor vessel wall of the Clinton Station of the Illinois Power Company have been determined to be:

4.6×10^{9}	$n \cdot cm^{-2} \cdot s^{-1}$	>1 MeV full-power flux density
7.4×10^{9}	$n \cdot cm^{-2} \cdot s^{-1}$	>0.1 MeV full-power flux density
1.4×10^{17}	$n \cdot cm^{-2}$	>1 MeV fluence
2.3×10^{17}	$n \cdot cm^{-2}$	>0.1 MeV fluence

following the analysis of irradiated iron flux dosimeters, in accordance with the GE CM&S Method No. 10.1.6.0 R3.

EXPERIMENTAL

Three iron wires were irradiated in a GE pressure vessel capsule holder at Clinton Station from March 31, 1987 (startup) to January 2, 1989 (end of cycle 1). Each wire was removed from the capsule, cleaned with 4N HNO_3, weighed, mounted on a counting card, and analyzed for Mn-54 content by gamma spectrometry at a calibrated 4 cm source-to-detector distance with 100-cc and 80-cc Ge(Li) detector systems.

From daily thermal power generation summary tables, four irradiation time periods for Cycle 1 were calculated. Operating days for each period and the reactor average power fraction are shown in Table 1. Zero power days between periods are also listed.

TABLE 1. Clinton Station Irradiation Periods

Period	Date	Days	Full-Power Fraction*	Between Period Time (Days)
1	03/31/87 - 10/14/87	198	0.316	
				39
2	11/23/87 - 03/18/88	117	0.890	
				47
3	05/05/88 - 11/11/88	191	0.888	
				13
4	11/25/88 - 01/02/89	39	0.673	
* Full power was 2894 MW_t		545 (Total)	0.665 (Av)	

DISCUSSION OF RESULTS

From the activity measurements and power history, a reaction rate for $^{54}Fe(n,p)^{54}Mn$ was calculated. These data appear in Table 2. The Clinton Station >1 MeV flux density reaction cross section for iron was calculated to be 0.142 barns. This value was obtained from measured cross section data functions from more than 65 spectral determinations for BWRs and for the GE Test reactor using activation monitors and spectral unfolding techniques. These data functions were applied to BWR pressure vessel locations based on water gap (fuel to pressure vessel) distances. The >1 MeV/ >0.1 MeV cross section ratio at BWR pressure vessel locations is approximately 1.6.

The determined full-power flux density and actual fluence results at the reactor vessel wall capsule holder location are given in Table 2. The >1 MeV and >0.1 MeV values of 4.6×10^9 and 7.4×10^9 $n \cdot cm^{-2} \cdot s^{-1}$ were calculated by dividing the reaction rate measurement data by 0.142 barns and 0.0888 barns, respectively. The corresponding fluence results, 1.4×10^{17} and 2.3×10^{17} $n \cdot cm^{-2}$ were obtained by multiplying the full-power flux density by the product of the total seconds irradiated (4.709×10^7s) and the full-power fraction (0.665).

The 2σ errors of the values in Table 2 are estimated to be:

± 5% for dps/g

± 10% for dps/nucleus (sat'd)

± 25% for ϕ and ϕt >1 MeV

± 35% for ϕ and ϕt >0.1 MeV

TABLE 2. FLUX DENSITY AND FLUENCE DETERMINATIONS - CLINTON STATION IRRADIATION: MARCH 31, 1987 - JANUARY 2, 1989

Wire (Element)	Wire Weight (g)	dps/g Element (at end of Irradiation)	Reaction Rate [dps/nucleus (sat'd)]	ϕ * FP Flux Density ($n \cdot cm^{-2} \cdot s^{-1}$) >1 MeV	ϕ * FP Flux Density ($n \cdot cm^{-2} \cdot s^{-1}$) >0.1 MeV	ϕt Fluence ($n \cdot cm^{-2}$) >1 MeV	ϕt Fluence ($n \cdot cm^{-2}$) >0.1 MeV
Iron A	0.1410	1.98×10^{5}	6.59×10^{-16}				
Iron B	0.1576	1.96×10^{5}	6.53×10^{-16}				
Iron C	0.1256	1.94×10^{5}	6.46×10^{-16}				
			6.53×10^{-16} (Av)	4.6×10^{9}	7.4×10^{9}	1.4×10^{17}	2.3×10^{17}

* At full Power (2894 MW_t).

APPENDIX B

COMPARISON OF IRRADIATION EMBRITTLEMENT PREDICTIONS OF REGULATORY GUIDE 1.99, REVISIONS 1 AND 2

FOR

CLINTON UNIT 1

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

No. 2 Shell Ring Plate: 22-1 Thickness 5.59 inches

Material Heat: C4363-2

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.18	1.3	0.013	0.011	0.25	0.06	0.62	0.55

Initial RTndt: RTndt-I = -30 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 37

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	12.1	12.1	24.2	-5.8	16.6	-13.4
8	17.0	17.0	34.1	4.1	23.4	-6.6
12	20.4	20.4	40.8	10.8	28.7	-1.3
16	23.0	23.0	45.9	15.9	33.1	3.1
20	25.1	25.1	50.1	20.1	37.1	7.1
24	26.8	26.8	53.7	23.7	40.6	10.6
28	28.4	28.4	56.7	26.7	43.8	13.8
32	29.7	29.7	59.4	29.4	46.9	16.9

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

No. 2 Shell Ring Plate: 22-3 Thickness 5.59 inches

Material Heat: C4380-2

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.19	1.3	0.013	0.011	0.23	0.07	0.63	0.56

Initial RTndt: RTndt-I = -20 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 44

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	14.4	14.4	28.8	8.8	16.6	-3.4
8	20.2	20.2	40.5	20.5	23.4	3.4
12	24.2	24.2	48.5	28.5	28.7	8.7
16	27.3	27.3	54.6	34.6	33.1	13.1
20	29.8	29.8	59.6	39.6	37.1	17.1
24	31.9	31.9	63.8	43.8	40.6	20.6
28	33.7	33.7	67.5	47.5	43.8	23.8
32	35.3	34.0	69.3	49.3	46.9	26.9

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

No. 2 Shell Ring Plate: 22-4 Thickness 5.59 inches

Material Heat: C4320-2

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.18	1.3	0.012	0.015	0.25	0.05	0.64	0.53

Initial RTndt: RTndt-I = -20 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 31

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	10.1	10.1	20.3	0.3	15.3	-4.7
8	14.3	14.3	28.5	8.5	21.6	1.6
12	17.1	17.1	34.2	14.2	26.5	6.5
16	19.2	19.2	38.5	18.5	30.6	10.6
20	21.0	21.0	42.0	22.0	34.2	14.2
24	22.5	22.5	45.0	25.0	37.5	17.5
28	23.8	23.8	47.5	27.5	40.5	20.5
32	24.9	24.9	49.8	29.8	43.3	23.3

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Shell Course No. 1 Plate : 21-1-1 Thickness 5.59 inches

Material Heat: A2758-1

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.22	1.34	0.011	0.015	0.25	0.1	0.64	0.58

Initial RTndt: RTndt-I = -10 F, Sigma-I = 0 F

32 EFPY Fluence (f): Calculated Peak 1/4T f = 4.9E+17 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.5E+17 n/cm^2
Rev 2 Attenuated 1/4T f = 4.6E+17 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 65.4

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	4.9	4.9	9.8	-0.2	5.9	-4.1
8	7.9	7.9	15.9	5.9	8.3	-1.7
12	10.3	10.3	20.6	10.6	10.2	0.2
16	12.3	12.3	24.7	14.7	11.7	1.7
20	14.1	14.1	28.2	18.2	13.1	3.1
24	15.7	15.7	31.3	21.3	14.4	4.4
28	17.1	17.1	34.2	24.2	15.5	5.5
32	18.4	18.4	36.8	26.8	16.6	6.6

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Shell Course No. 1 Plate : 21-1-2 Thickness 5.59 inches

Material Heat: A2740-1

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.19	1.28	0.012	0.015	0.23	0.11	0.66	0.56

Initial RTndt: RTndt-I = -30 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 4.9E+17 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.5E+17 n/cm^2
Rev 2 Attenuated 1/4T f = 4.6E+17 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 74.9

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	5.6	5.6	11.2	-18.8	7.0	-23.0
8	9.1	9.1	18.2	-11.8	10.0	-20.0
12	11.8	11.8	23.6	-6.4	12.2	-17.8
16	14.1	14.1	28.3	-1.7	14.1	-15.9
20	16.1	16.1	32.3	2.3	15.8	-14.3
24	17.9	17.9	35.9	5.9	17.3	-12.7
28	19.6	19.6	39.1	9.1	18.6	-11.4
32	21.1	21.1	42.1	12.1	19.9	-10.1

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Beltline Region Weld : Thickness 5.59 inches

Material Heat: 3P4955 , Lot 0342 (Single Wire)

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.054	1.28	0.016	0.01	0.55	0.023	0.95	0.54

Initial RTndt: RTndt-I = -20 F, Sigma-I = 0 F

32 EFPY Fluence (f): Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 31.2

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	10.2	10.2	20.4	0.4	20.4	0.4
8	14.4	14.4	28.7	8.7	28.8	8.8
12	17.2	17.2	34.4	14.4	35.3	15.3
16	19.4	19.4	38.7	18.7	40.8	20.8
20	21.1	21.1	42.3	22.3	45.6	25.6
24	22.6	22.6	45.3	25.3	50.0	30.0
28	23.9	23.9	47.8	27.8	54.0	34.0
32	25.1	25.1	50.1	30.1	57.7	37.7

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Beltline Region Weld : Thickness 5.59 inches

Material Heat: 3P4955 , Lot 0342 (Tandem Wire)

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.035	1.33	0.016	0.011	0.56	0.025	0.9	0.52

Initial RTndt: RTndt-I = -20 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 34

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	11.1	11.1	22.3	2.3	20.4	0.4
8	15.6	15.6	31.3	11.3	28.8	8.8
12	18.7	18.7	37.5	17.5	35.3	15.3
16	21.1	21.1	42.2	22.2	40.8	20.8
20	23.0	23.0	46.1	26.1	45.6	25.6
24	24.7	24.7	49.3	29.3	50.0	30.0
28	26.1	26.1	52.1	32.1	54.0	34.0
32	27.3	27.3	54.6	34.6	57.7	37.7

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Beltline Region Weld : Thickness 5.59 inches

Material Heat: 5P6756

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.13	1.89	0.008	0.012	0.07	0.08	0.96	0.48

Initial RTndt: RTndt-I = -60 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 108

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	35.3	35.3	70.7	10.7	10.2	-49.8
8	49.7	49.7	99.4	39.4	14.4	-45.6
12	59.5	56.0	115.5	55.5	17.7	-42.3
16	67.0	56.0	123.0	63.0	20.4	-39.6
20	73.2	56.0	129.2	69.2	22.8	-37.2
24	78.3	56.0	134.3	74.3	25.0	-35.0
28	82.8	56.0	138.8	78.8	27.0	-33.0
32	86.7	56.0	142.7	82.7	28.8	-31.2

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Beltline Region Weld : Thickness 5.59 inches

Material Heat: 76492 , Lot L430B27AE

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.05	1.23	0.016	0.013	0.48	0.1	1.08	0.64

Initial RTndt: RTndt-I = -30 F, Sigma-I = 0 F

32 EFPY Fluence (f): Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 135

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev 1 ART
4	44.2	44.2	88.3	58.3	25.5	-4.5
8	62.1	56.0	118.1	88.1	36.1	6.1
12	74.4	56.0	130.4	100.4	44.2	14.2
16	83.8	56.0	139.8	109.8	51.0	21.0
20	91.4	56.0	147.4	117.4	57.0	27.0
24	97.9	56.0	153.9	123.9	62.4	32.4
28	103.5	56.0	159.5	129.5	67.5	37.5
32	108.4	56.0	164.4	134.4	72.1	42.1

COMPARISON OF REG. GUIDE 1.99 REVISIONS 1 AND 2
FOR CLINTON UNIT 1 BELTLINE MATERIALS

Beltline Region Weld : Thickness 5.59 inches

Material Heat: 431T1831 , Lot A626B27AG

Chemistry:	C	Mn	P	S	Si	Cu	Ni	Mo
	0.05	1.25	0.013	0.015	0.51	0.03	0.98	0.54

Initial RTndt: RTndt-I = -40 F, Sigma-I = 0 F

32 EFPY Fluence (f):
Calculated Peak 1/4T f = 5.2E+18 n/cm^2 (used with Rev 1)
Calculated Peak I.D. f = 6.9E+18 n/cm^2
Rev 2 Attenuated 1/4T f = 4.9E+18 n/cm^2 (basis for Rev 2 delta RT)

Surveillance Testing Affecting Rev 1 Shift Calculation:

Surveillance testing not yet done.
Correction factor applied = 1

Chemistry Factor for Rev 2 Shift: CF= 41

Comparison of Rev 1 and Rev 2 SHIFT and ART (degrees F) versus EFPY:

EFPY	Rev 2 Delta RT	Rev 2 Margin	Rev 2 SHIFT	Rev 2 ART	Rev 1 SHIFT	Rev AR
4	13.4	13.4	26.8	-13.2	16.6	-23.
8	18.9	18.9	37.7	-2.3	23.4	-16.
12	22.6	22.6	45.2	5.2	28.7	-11.
16	25.4	25.4	50.9	10.9	33.1	-6.
20	27.8	27.8	55.5	15.5	37.1	-2.
24	29.7	29.7	59.5	19.5	40.6	0.
28	31.4	31.4	62.9	22.9	43.8	3.
32	32.9	32.9	65.8	25.8	46.9	6.