WCAP-13948

WEC PROPRIETARY CLASS 3

EVALUATION OF PRESSURIZED THERMAL SHOCK FOR MCGUIRE UNIT 1

P. A. Peter

February 1994

Westinghouse Energy Systems

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PREFACE

This report has been technically reviewed and verified by:

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1.0 INTRODUCTION

A limiting condition on reactor vessel integrity known as Pressurized Thermal Shock (PTS) may occur during a severe system transient such as a Loss-Of-Coolant-Accident (LOCA) or a steam line break. Such transients may challenge the integrity of a reactor vessel under the following conditions:

- severe overcooling of the inside surface of the vessel wall followed by high repressurization;

- significant degradation of vessel material toughness caused by radiation embrittlement; and

- the presence of a critical-size defect in the vessel wall.

In 1985 the Nuclear Regulatory Commission (NRC) issued a formal ruling on PTS. It established screening criteria on pressurized water reactor (PWR) vessel embrittlement as measured by the nil-ductility reference temperature, termed RT_{PTS}[1]. RT_{PTS} screening values were set for beltline axial welds, forgings or plates and for beltline circumferential weld seams for the end-of-license plant operation. The screening criteria were determined using conservative fracture mechanics analysis techniques. All PWR vessels in the United States have been required to evaluate vessel embrittlement in accordance with the criteria through end of license. The NRC recently amended its regulations for light water nuclear power plants to change the procedure for calculating radiation embrittlement. The revised PTS Rule was published in the Federal Register, May 15, 1991 with an effective date of June 14, 1991[2]. This amendment makes the procedure for calculating RT_{PTS} values consistent with the methods given in Regulatory Guide 1.99, Revision 2[3].

The purpose of this report is to determine the RT_{PTS} values for the McGuire Unit 1 reactor vessel to address the revised PTS Rule. Section 2 discusses the Rule and its requirements. Section 3 provides the methodology for calculating RT_{PTS}. Section 4 provides the reactor vessel beltline region material properties for the McGuire Unit 1 reactor vessel. The neutron fluence values used in this analysis are presented in Section 5. The results of the RT_{PTS} calculations are presented in Section 6. The conclusions and references for the PTS evaluation follow in Sections 7 and 8, respectively.

2.0 PRESSURIZED THERMAL SHOCK

The PTS Rule requires that the PTS submittal be updated whenever there are changes in core loadings, surveillance measurements or other information that indicates a significant change in projected RT_{PTS} values. The Rule outlines regulations to address the potential for PTS events on pressurized water reactor vessels in nuclear power plants that are operated with a license from the United States Nuclear Regulatory Commission (USNRC). PTS events have been shown from operating experience to be transients that result in a rapid and severe cooldown in the primary system coincident with a high or increasing primary system pressure. The PTS concern arises if one of these transients acts on the beltline region of a reactor vessel where a reduced fracture resistance exists because of neutron irradiation. Such an event may result in the propagation of flaws postulated to exist near the inner wall surface, thereby potentially affecting the integrity of the vessel.

The Rule establishes the following requirements for all domestic, operating PWRs:

* All plants must submit projected values of RT_{PTS} for reactor vessel beltline materials by giving values for time of submittal, the expiration date of the operating license, and the projected expiration date if a change in the operating license or renewal has been requested. This assessment must be submitted within six months after the effective date of this Rule if the value of RT_{PTS} for any material is projected to exceed the screening criteria. Otherwise, it must be submitted with the next update of the pressure-temperature limits, or the next reactor vessel surveillance capsule report, or within 5 years from the effective date of this Rule change, whichever comes first. These values must be calculated based on the methodology specified in this rule. The submittal must include the following:

    1) the bases for the projection (including any assumptions regarding core loading patterns), and

    2) copper and nickel content and fluence values used in the calculations for each beltline material. (If these values differ from those previously submitted to the NRC, justification must be provided.)

* The RT_{PTS} (mea ure of fracture resistance) screening criteria for the reactor vessel beltline region is:

  270 °F for plates, forgings, axial welds; and

  300 °F for circumferential weld materials.

* The following equations must be used to calculate the RT_{PTS} values for each weld, plate or forging in the reactor vessel beltline:

  Equation 1: $RT_{PTS} = I + M + \Delta RT_{PTS}$

  Equation 2: $\Delta RT_{PTS} = CF * f^{(0.28-0.10 \log f)}$

* All values of RT_{PTS} must be verified to be bounding values for the specific reactor vessel. In doing this each plant should consider plant-specific information that could affect the level of embrittlement.

* Plant-specific PTS safety analyses are required before a plant is within 3 years of reaching the screening criteria, including analyses of alternatives to minimize the PTS concern.

* NRC approval for operation beyond the screening criteria is required.

3.0 METHOD FOR CALCULATION OF RT_{PTS}

In the PTS Rule, the NRC Staff has selected a conservative and uniform method for determining plant-specific values of RT_{PTS} at a given time. For the purpose of comparison with the screening criteria, the value of RT_{PTS} for the reactor vessel must be calculated for each weld and plate or forging in the beltline region as follows.

$RT_{PTS} = I + M + \Delta RT_{PTS}$, where $\Delta RT_{PTS} = CF * FF$

I = Initial reference temperature (RT_{NDT}) in °F of the unirradiated material

M = Margin to be added to cover uncertainties in the values of initial RT_{NDT}, copper and nickel contents, fluence and calculational procedures in °F.
M = 66 °F for welds and 48 °F for base metal if generic values of I are used.
M = 56 °F for welds and 34 °F for base metal if measured values of I are used.

FF = fluence factor = $f^{(0.28 - 0.10 \log f)}$, where
f = Neutron fluence (E>1.0 MeV at the clad/base metal interface), divided by 10^{19} n/cm^2

CF = Chemistry factor in °F from the tables[2] for welds and base metals (plates and forgings). If plant-specific surveillance data has been deemed credible per Regulatory Guide 1.99, Revision 2 and is significant, it may be considered in the calculation of the chemistry factor.

4.0 VERIFICATION OF PLANT-SPECIFIC MATERIAL PROPERTIES

Before performing the pressurized thermal shock evaluation, a review of the latest plant-specific material properties for the McGuire Unit 1 vessel was performed. The beltline region is defined by the PTS Rule[2] to be "the region of the reactor vessel (shell material including welds, heat-affected zones and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron irradiation damage to be considered in the selection of the most limiting material with regard to radiation damage." Figure 1 identifies and indicates the location of all beltline region materials for the McGuire Unit 1 reactor vessel.

Material property values were obtained from material test certifications from the original fabrication as well as the additional material chemistry tests performed as part of the surveillance capsule testing program[5]. Pertinent chemistry test results were also obtained from other plants with similar weld materials. The average copper and nickel values were calculated for each of the beltline region materials using all of the available material chemistry information as shown in Table 1. A summary of the pertinent chemical and mechanical properties of the beltline region plates and weld materials of the McGuire Unit 1 reactor vessel are given in Table 2. All of the initial RT_{NDT} values (I) are also presented in Table 2.

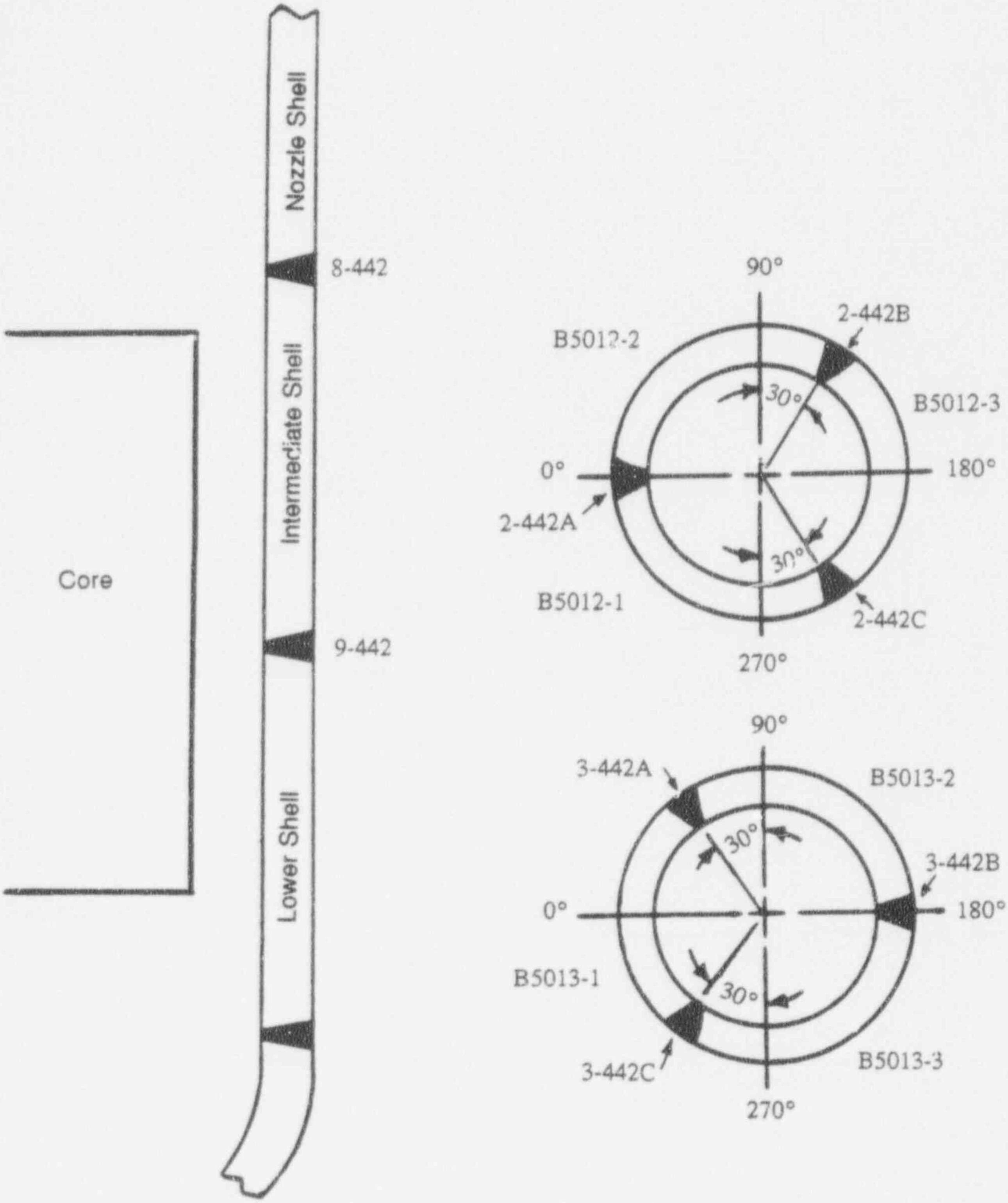

FIGURE 1. IDENTIFICATION AND LOCATION OF BELTLINE REGION MATERIALS FOR THE MCGUIRE UNIT 1 REACTOR VESSEL[30]

TABLE 1

CALCULATION OF AVERAGE CU AND NI WEIGHT% FOR MCGUIRE UNIT 1

Intermediate Shell Longitudinal Weld Seams, 2-442A, B & C
(Ht. 20291 & 12008, Linde 1092, Flux Lot No. 3854)

Reference	wt. % Cu	wt. % Ni
5	0.21	0.88
6	0.20	0.91
32	0.195	0.87
32	0.191	0.848
32	0.193	0.863
Average	0.20	0.87

Intermediate to Lower Shell Circumferential Weld, 9-442
(Ht. 83640, Linde 0091, Flux Lot No. 3490)

Reference	wt. % Cu	wt. % Ni
7	0.050	---
8	0.050	0.120
Average	0.050	0.120

TABLE 1 (CONT'D.)

Lower Shell Longitudinal Weld Seams, 3-442A, B & C
(Ht. 21935 & 12008, Linde 1092, Flux Lot No. 3889)

Reference	wt. % Cu	wt. % Ni
9	0.220	---
10	0.200	---
11	0.22	0.83
12	0.23	0.90
	0.21	0.76
	0.22	0.90
13	0.219	0.86
	0.212	0.88
	0.213	0.90
14	0.225	0.875
	0.213	0.856
	0.225	0.877
Average	0.22	0.86

Lower Shell Longitudinal Weld Seams, 3-442A (Root Weld) *
(Ht. 305424, Linde 1092, Flux Lot No. 3889)

Reference	wt. % Cu	wt. % Ni
15	0.300	0.640
16	0.260	0.620
33	0.230	0.637
Average	0.263	0.632

* The lower shell longitudinal welds also contained a different weld wire heat in the double U root area of the weld. Since the root weld chemistry is not more limiting than the above weld data, it was not utilized in the pressurized thermal shock evaluations.

TABLE 1 (CONT'D.)

Lower Shell Longitudinal Weld Seams, 3-442B & C (Root Weld)*
(Ht. 21935, Linde 1092, Flux Lot No. 3889)

Reference	wt. % Cu	wt. % Ni
17	0.200	---
12	0.21	0.68
	---	0.71
Average	0.21	0.70

Intermediate Shell Plate, B5012-1 (Ht. C4387-2)

Reference	wt. % Cu	wt. % Ni
18, 19	0.13	0.60
5	0.087	---
20	---	0.58
32	0.117	0.643
Average	0.11	0.61

Intermediate Shell Plate, B5012-2 (Ht. C4417-3)

Reference	wt. % Cu	wt. % Ni
18, 21	0.14	0.62
22	---	0.60
Average	0.14	0.61

* The lower shell longitudinal welds also contained a different weld wire heat in the double U root area of the weld. Since the root weld chemistry is not more limiting than the above weld data, it was not utilized in the pressurized thermal shock evaluations.

TABLE 1 (CONT'D.)

Intermediate Shell Plate, B5012-3 (Ht. C4377-2)

Reference	wt. % Cu	wt. % Ni
18, 23	0.11	0.66
20	---	0.65
Average	0.11	0.66

Lower Shell Plate, B5013-1 (Ht. C4315-1)

Reference	wt. % Cu	wt. % Ni
18, 24	0.14	0.56
25	---	0.59
Average	0.14	0.58

Lower Shell Plate, B5013-2 (Ht. C4374-2)

Reference	wt. % Cu	wt. % Ni
18, 26	0.10	0.52
27	---	0.50
Average	0.10	0.51

Lower Shell Plate, B5013-3 (Ht. C4371-2)

Reference	wt. % Cu	wt. % Ni
18, 28	0.10	0.55
29	---	0.54
Average	0.10	0.55

TABLE 2

MCGUIRE UNIT 1 REACTOR VESSEL BELTLINE REGION MATERIAL PROPERTIES

Material Description	Cu (%) *	Ni (%) *	I (°F)[31] (a)
Intermediate Shell Plate, B5012-1	0.11	0.59	34
Intermediate Shell Plate, B5012-2	0.14	0.61	0
Intermediate Shell Plate, B5012-3	0.11	0.66	-13
Lower Shell Plate, B5013-1	0.14	0.58	0
Lower Shell Plate, B5013-2	0.10	0.51	30
Lower Shell Plate, B5013-3	0.10	0.55	15
Inter. Shell Longitudinal Welds, 2-442A, B & C	0.21	0.90	-50
Lower Shell Longitudinal Welds, 3-442A, B & C	0.22	0.86	-56
Circumferential Weld, 9-442	0.05	0.12	-70

(a) Initial RT_{NDT} values were estimated per U.S. NRC Standard Review Plan. The initial RT_{NDT} values for the plates and welds are measured values, except for the lower shell longitudinal welds (which is a generic value).

* Average values of copper and nickel as indicated in Table 1.

5.0 NEUTRON FLUENCE VALUES

The calculated fast neutron fluence (E>1.0 MeV) at the inner surface of the McGuire Unit 1 reactor vessel is shown in Table 3. These values were projected using the results of the Capsule V radiation surveillance program[4]. The RT_{PTS} calculations were performed using the peak fluence value, which occurs at the 45° azimuth for all materials in the McGuire Unit 1 reactor vessel beltline region, except for the intermediate and lower shell longitudinal welds, which are located at the 0° and 30° azimuths, and do not experience the peak fluence.

TABLE 3

NEUTRON EXPOSURE PROJECTIONS* AT KEY LOCATIONS ON THE MCGUIRE UNIT 1 PRESSURE VESSEL CLAD/BASE METAL INTERFACE FOR 7.241 AND 32 EFPY[4]

EFPY	0°	15°	30°	45°
7.241	0.3015	0.4457	0.3301	0.4562
32	1.332	1.969	1.459	2.016

* Fluence in 10^{19} n/cm^2 (E>1.0 MeV)

6.0 DETERMINATION OF RT_{PTS} VALUES FOR ALL BELTLINE REGION MATERIALS

Using the prescribed PTS Rule methodology, RT_{PTS} values were generated for all beltline region materials of the McGuire Unit 1 reactor vessel for fluence values at the present time (7.241 EFPY per Capsule V analysis) and end of license (32 EFPY). The PTS Rule requires that each plant assess the RT_{PTS} values based on plant specific surveillance capsule data whenever:

- Plant specific surveillance data has been deemed credible as defined in Regulatory Guide 1.99, Revision 2, and

- RT_{PTS} values change significantly. (Changes to RT_{PTS} values are considered significant if the value determined with RT_{PTS} equations (1) and (2), or that using capsule data, or both, exceed the screening criteria prior to the expiration of the operating license, including any renewed term, if applicable, for the plant.)

Although the RT_{PTS} value changes are not significant for McGuire Unit 1, plant specific surveillance capsule data for intermediate shell plate B5012-1 and intermediate shell longitudinal welds is provided because of the following reasons:

1) There have been three capsules removed from the reactor vessel, and the data is deemed credible per Regulatory Guide 1.99, Revision 2.

2) The surveillance capsule materials are representative of the actual vessel plates and intermediate shell longitudinal weld materials.

The chemistry factors for intermediate shell plate B5012-1 and intermediate shell longitudinal welds were calculated using the surveillance capsule data as shown in Table 4. The chemistry factors were also calculated using Tables 1 and 2 from 10 CFR 50.61[2]. Tables 5 and 6 provide a summary of the RT_{PTS} values for all beltline region materials for 7.241 EFPY and 32 EFPY, respectively, using the PTS Rule.

TABLE 4

CALCULATION OF CHEMISTRY FACTORS USING

MCGUIRE UNIT 1 SURVEILLANCE CAPSULE DATA[4]

Material	Capsule	Fluence	FF	ΔRT_{NDT}	$FF^*\Delta RT_{NDT}$	FF^2
Inter. Shell Plate, B5012-1 (Longitudinal)	U	4.719×10^{18}	0.790	45	35.550	0.624
	X	1.4091×10^{19}	1.095	45	49.275	1.199
	V	2.1858×10^{19}	1.212	85	103.020	1.469
Inter. Shell Plate, B5012-1 (Transverse)	U	4.719×10^{18}	0.790	50	39.500	0.624
	X	1.4091×10^{19}	1.095	65	71.175	1.199
	V	2.1858×10^{19}	1.212	85	103.020	1.469
				Sum:	401.54	6.584
	Chemistry Factor = 401.54 ÷ 6.584 = 61.0 ≈ 61					
Intermediate Shell Longitudinal Welds, 2-442A, B & C	U	4.719×10^{18}	0.790	160	126.400	0.624
	X	1.4091×10^{19}	1.095	165	180.675	1.199
	V	2.1858×10^{19}	1.212	175	212.100	1.469
				Sum:	519.175	3.292
	Chemistry Factor = 519.175 ÷ 3.292 = 157.7 ≈ 158					

TABLE 5
RT_{PTS} VALUES FOR MCGUIRE UNIT 1 FOR 7.241 EFPY

Material	CF (°F)	FF*	I (°F)	M (°F)	RT_{PTS} (°F)
Inter. Shell Plate, B5012-1 Using S/C data**	74.2 61	0.7815 0.7815	34 34	34 34	125.99 115.67
Inter. Shell Plate, B5012-2	100.25	0.7815	0	34	112.35
Inter. Shell Plate, B5012-3	74.9	0.7815	-13	34	79.54
Lower Shell Plate, B5013-1	99.1	0.7815	0	34	111.45
Lower Shell Plate, B5013-2	65.0	0.7815	30	34	114.80
Lower Shell Plate, B5013-3	65.0	0.7815	15	34	99.80
Inter. Long. Weld, 2-442A Using S/C data**	204.2 158	0.6716 0.6716	-50 -50	56 56	143.13 112.11
Inter. Long. Weld, 2-442B&C Using S/C data**	204.2 158	0.6951 0.6951	-50 -50	56 56	147.94 115.83
Lower Long. Weld, 3-442B	209.6	0.6716	-56	66	150.76
Lower Long. Weld, 3-442A&C	209.6	0.6951	-56	66	155.69
Circumferential Weld	39.8	0.7815	-70	56	17.10

* FF (Fluence factor) based upon peak inner surface neutron fluence of 4.562×10^{18} n/cm^2 (E>1.0 MeV)[4] at the 45° azimuthal angle, except for the longitudinal weld seams (which are located at the 0° and 30° azimuthal angles with fluences of 3.015×10^{18} n/cm^2 and 3.301×10^{18} n/cm^2, respectively).

** Numbers were calculated using a chemistry factor (CF) based on surveillance capsule data.

TABLE 6
RT_{PTS} VALUES FOR MCGUIRE UNIT 1 FOR 32 EFPY

Material	CF (°F)	FF*	I (°F)	M (°F)	RT_{PTS} (°F)
Inter. Shell Plate, B5012-1 Using S/C data**	74.2 61	1.1912 1.1912	34 34	34 34	156.39 140.66
Inter. Shell Plate, B5012-2	100.25	1.1912	0	34	153.42
Inter. Shell Plate, B5012-3	74.9	1.1912	-13	34	110.22
Lower Shell Plate, B5013-1	99.1	1.1912	0	34	152.05
Lower Shell Plate, B5013-2	65.0	1.1912	30	34	141.43
Lower Shell Plate, B5013-3	65.0	1.1912	15	34	126.43
Inter. Long. Weld, 2-442A Using S/C data**	204.2 158	1.0797 1.0797	-50 -50	56 56	226.48 176.60
Inter. Long. Weld, 2-442B&C Using S/C data**	204.2 158	1.1047 1.1047	-50 -50	56 56	231.58 180.54
Lower Long. Weld, 3-442B	209.6	1.0797	-56	66	236.31
Lower Long. Weld, 3-442A&C	[illegible]9.6	1.1047	-56	66	241.54
Circumferential Weld	39.8	1.1912	-70	56	33.41

* FF (Fluence factor) based upon peak inner surface neutron fluence of 4.562 x 10^{18} n/cm^2 (E>1.0 MeV)[4] at the 45° azimuthal angle, except for the longitudinal weld seams (which are located at the 0° and 30° azimuthal angles with fluences of 3.015 x 10^{18} n/cm^2 and 3.301 x 10^{18} n/cm^2, respectively).

** Numbers were calculated using a chemistry factor (CF) based on surveillance capsule data.

7.0 CONCLUSIONS

As shown in Tables 5 and 6, all RT_{PTS} values remain below the NRC screening values for PTS using fluence values for the present time (7.241 EFPY) and projected fluence values for the end of license (32 EFPY). A plot of the RT_{PTS} values versus fluence shown in Figure 2 illustrates the available margin for the most limiting material in the McGuire Unit 1 reactor vessel beltline region, Lower Shell Longitudinal Welds, 3-442A & C.

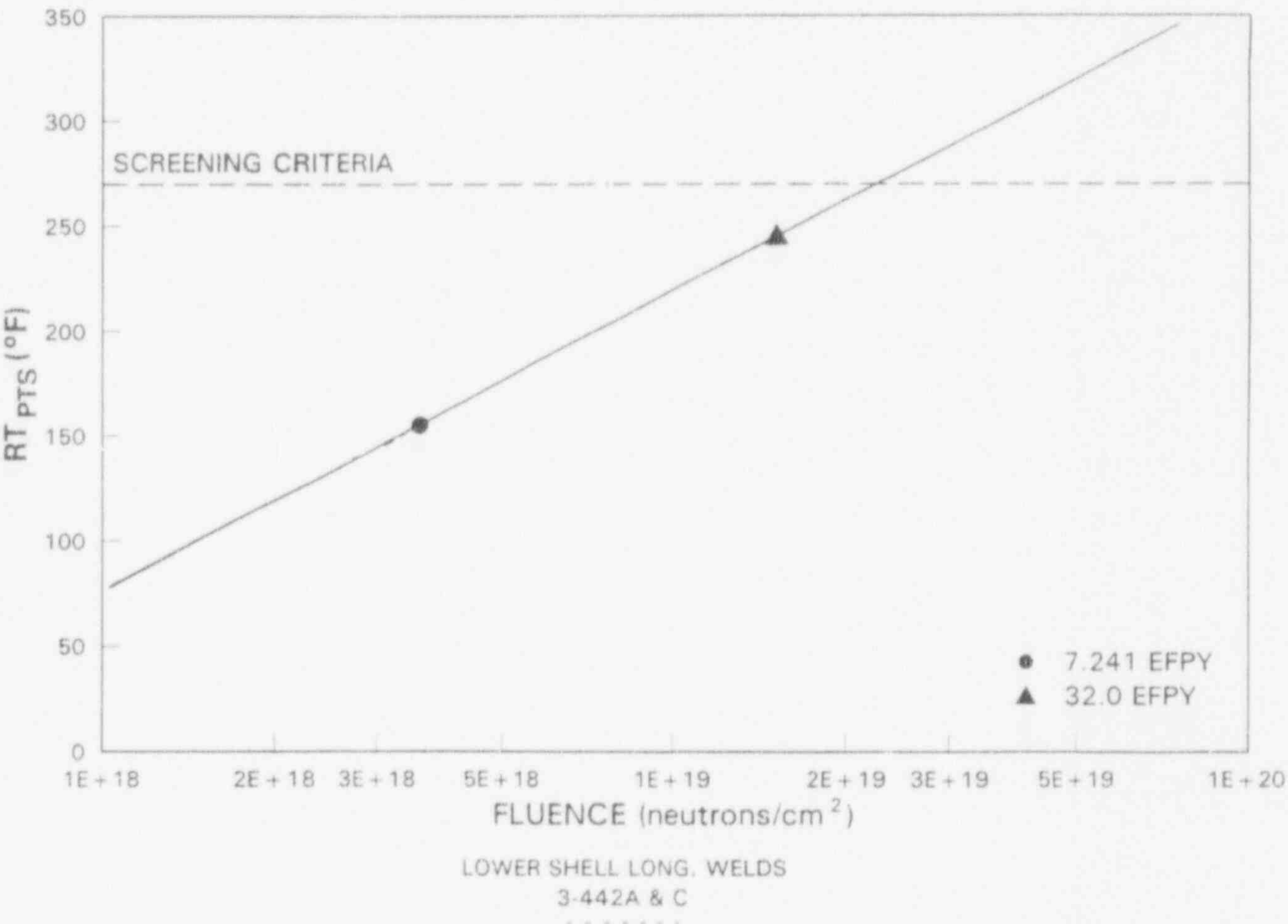

FIGURE 2. RT_{PTS} VERSUS FLUENCE CURVES FOR MCGUIRE UNIT 1 LIMITING MATERIAL - LOWER SHELL LONGITUDINAL WELDS, 3-442A&C

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