GE Nuclear Energy

Technical Services Business
General Electric Company
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Surveillance Specimen Program Evaluation

for

River Bend Station

Prepared by: BD Frew
B.D. Frew, Engineer
Materials Applications

Verified by: [signature]
C.L. Chu, Senior Engineer
RPV Integrity

Approved by: P.F. Kachel FOR 4/25/96
B.J. Branlund, Project Manager
RPV Integrity

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

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1. ABSTRACT

River Bend Station (River Bend, RBS) has maintained vessel surveillance programs to meet the requirements of 10CFR50, Appendix H[1]. The current surveillance program schedule requires that the first surveillance capsule be removed at six (6) Effective Full Power Years (EFPY) for RBS.

The original schedule was developed in accordance with the requirements of 10CFR50, Appendix H. This schedule did not account for RBS specific conditions:

- Excellent alloy chemistry (low copper-0.03-0.09%);
- Low RPV 1/4T beltline fluence (<5 $X10^{18}$ n/cm^2 32 EFPY fluence);
- Resulting low shift in the reference nil-ductility temperature (RT_{NDT}), especially for the RBS plate material.

If the current schedule is used, the measured data for the plate material may not be useful, as the expected shift in RT_{NDT} (ΔRT_{NDT}) is low. In addition, the data normally provided by early testing can be obtained from the BWR Owner's Group Supplemental Surveillance Program (SSP). Therefore, the surveillance program's withdrawal schedule should be extended.

The extended schedule can be justified because:

- Actual BWR data shows predicted ΔRT_{NDT} values based on Reg. Guide 1.99 Revision 2[2] (Rev 2) to bound the measured ΔRT_{NDT} values;
- The inherent conservatism present in the pressure-temperature (P-T) curves for BWR's;

- The derived fracture toughness values are lower bound values and are based on crack arrest (K_{Ia}) rather than the higher crack initiation (K_{IC}) toughness;

- The SSP will provide early detection of anomalous (i.e., greater than expected) shifts.

Based on the evaluation presented in this report, the recommended withdrawal schedule for the first surveillance capsule for River Bend is 10.4 EFPY.

2. INTRODUCTION

Vessel fracture toughness is a major consideration for nuclear vessels; irradiation is known to decrease the fracture toughness of vessel materials. Therefore, measurement of the long term effects of vessel irradiation is a key component of surveillance programs. Entergy Operations, Inc. (EOI) maintains a vessel surveillance program at RBS in accordance with 10CFR50, Appendix H[1] to monitor for changes in fracture toughness of vessel beltline materials as required by the NRC.

The River Bend surveillance program meets the requirements of 10CFR50, Appendix H and ASTM E185-73 (for design) for the following reasons:

- The selected base and weld metals are representative of the vessel beltline materials;
- The materials have a similar fabrication history to the vessel;
- The number, type, and design of specimens are consistent with ASTM E185-73.

The surveillance program implemented at River Bend consists of three specimen holders installed in the reactor during vessel construction. The number of holders was determined per ASTM E185-73. River Bend was defined as a case 'A' plant, since the River Bend vessel had a RT_{NDT} shift less than 100°F and the peak fluence was less than 5 $X10^{18}$ n/cm^2 (at 1/4T) over the design lifetime of the plant.

The three specimen holders were designed, built, and analyzed to ASME Section III, 1971 Edition, with Addenda through Summer 1973. The selection of holder location was based on three criteria to duplicate as closely as possible the

temperature history, neutron flux spectrum, and maximum accumulated RPV beltline fluence:

- interference/accessibility with other reactor hardware (e.g., jet pumps);
- peak fluence as a function of height;
- peak fluence as a function of azimuth.

Using these criteria, the three locations selected were the 3°, 177° and 183° vessel azimuths (available areas not occupied by jet pumps); in addition, a neutron dosimeter was placed at the 3° azimuth. Each holder contains twelve (12) Charpy V-notch specimens of the weld, base metal and heat-affected zone, for a total of 36 specimens. To provide baseline information, archive material is available for additional testing.

At the time the capsules were designed, ASTM E185-73 recommended the first and second capsules to be removed when the capsule fluence reaches 100% of the wall fluence at 32 EFPY. The current testing schedule, developed in accordance with 10CFR50, Appendix H and ASTM E185-82, requires that the first specimen holder be removed at 6 EFPY and the second to be removed at 15 EFPY. The testing and reporting is also to be performed in accordance with ASTM E185-82.

Early capsule withdrawal was recommended for two reasons:

1. Data would be provided for future pressure-temperature (P-T) curve calculations. The data would be used to remove conservatism present in the (P-T) calculations. The P-T curves would be recalculated after the first capsule had been removed, using the measured fluence from

the flux wire results instead of the fluence calculated from the first cycle flux wire measurements.

2. The data obtained from the first capsule would be used to identify any anomalous conditions, i.e. a greater than expected shift in RT_{NDT}.

However, early withdrawal at 6 EFPY of the RBS capsule is not essential for continued safe operation for the following four reasons:

1. Data from other BWR surveillance capsules shows that the RBS first cycle flux wire calculations fall within expected data scatter. Therefore, the RBS fluence values calculated from first cycle flux wire measurements are appropriate for use in Rev 2 predictions.

2. Predicted shifts bound the measured results based on review of predicted RT_{NDT} shifts and measured RT_{NDT} shifts from other BWR surveillance capsules. Figure 2-1 is a plot of actual shift measurements versus predicted shifts (calculated per Rev 2) for base material. This figure shows that the predicted shift plus margin conservatively bounds the actual shifts measured from BWR surveillance specimen data. The same plot for weld material (Figure 2-2) again shows the predicted shift plus margin term bounds the measured shift.

3. Based on actual ART calculations performed in accordance with Rev 2 (see Appendix A), the shift for the River Bend plate is calculated to be 80°F at 32 EFPY. If the first capsule is removed at 6 EFPY, the actual shift may not be large enough to be differentiated from the data scatter, since the predicted fluence on the capsule (8.3×10^{17} n/cm^2)

is low, and the chemistry of the River Bend vessel plate material is excellent (0.08-0.09% copper). Thus, the data obtained may not be useful for predicting the material behavior, as it may be indistinguishable from the unirradiated data.

4. SSP specimens will provide early test data about the limiting RBS weld materials (which are the limiting materials). This program supplements the RBS surveillance program by providing timely detection of unusual RT_{NDT} shifts. The fluences on the SSP capsules are comparable to the fluence for the RBS vessel wall in the time frame of interest. Although the RBS plate is not in the SSP program, some of the materials used have chemistries which are similar to River Bend, as well as others with poorer chemistries (i.e. higher copper) which result in a larger predicted shift.

This report shows that the surveillance capsule testing schedule for RBS should be extended for the following reasons:

- The fluence experienced by the RBS vessel wall is low;
- The RBS vessel wall and weld material in the beltline region has excellent alloy chemistry (i.e. low copper-0.03-0.09%);
- The actual shift in the RBS plate material may not be distinguishable from the data scatter with early testing.

The justification for extending the schedule is based on the following reasons:

- Predicted shifts bound the actual BWR industry surveillance results;
- The P-T curve calculations are inherently conservative;

- The supplemental surveillance program will supplement the RBS surveillance program by providing for the timely detection of unusual RT_{NDT} shifts.

Extension of the surveillance program schedule will ensure that credible data is obtained and continued safe operation of RBS is ensured by using the SSP data and maintaining the RBS P-T curves in accordance with Rev 2.

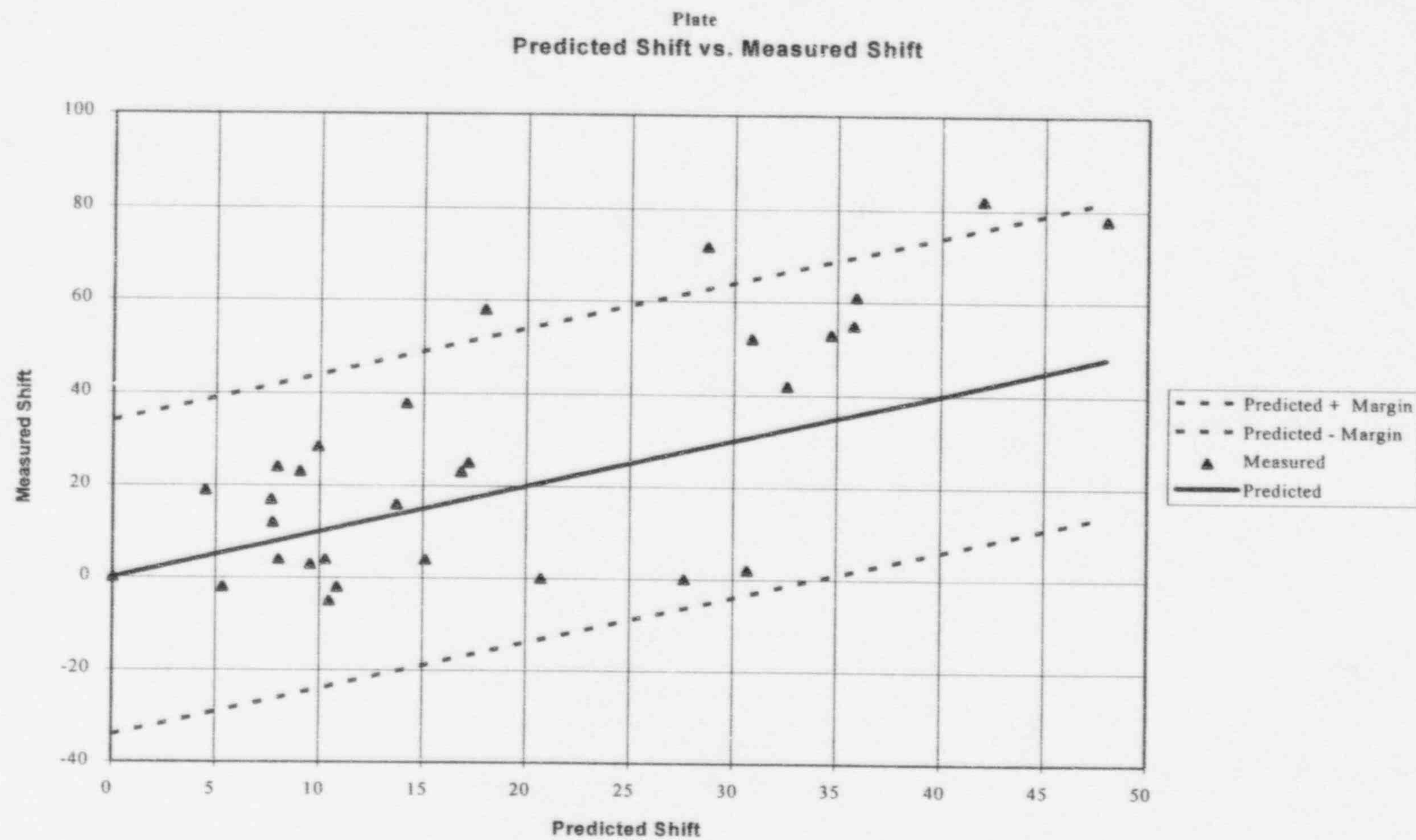

Figure 2-1: Measured Shift vs. Predicted Shift for Base Metal

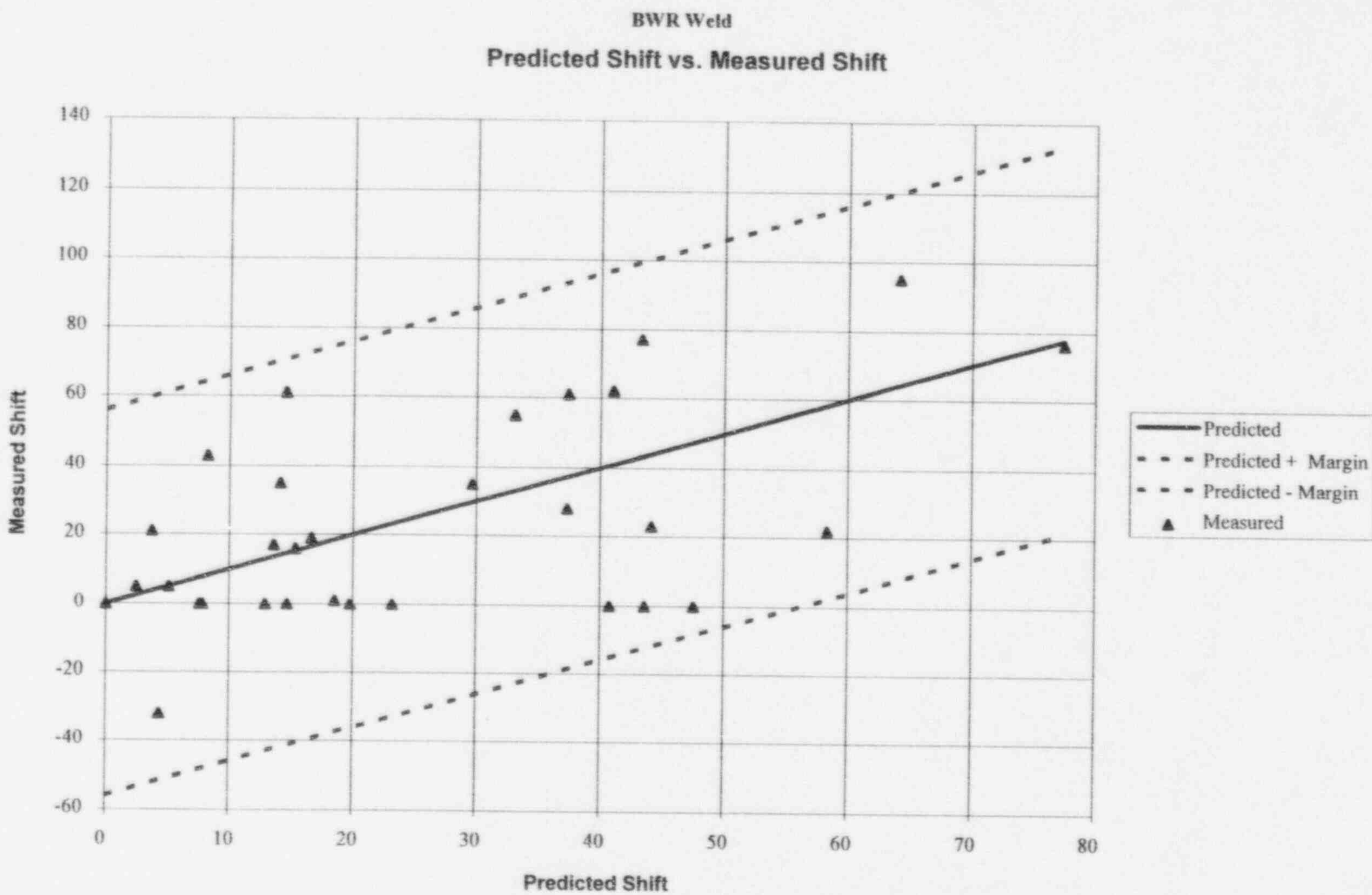

Figure 2-2: Measured Shift vs. Predicted Shift for Weld Metal

3. COMPARISON WITH OTHER SURVEILLANCE DATA

The evaluation of the shift in the RT_{NDT} for River Bend (see Appendix A) was performed using the techniques of Rev 2 for vessel material and the flux wire data from the first cycle (i.e., no additional surveillance data.) These predicted values of RT_{NDT} shift indicate that the River Bend vessel will not experience a large shift over vessel life. To confirm the conservative predicted shift plus margin values (used to modify the surveillance program schedule), a comparison has been made between calculated shift and fluence values and actual measured surveillance data from other BWR's.

A significant number of surveillance capsules from BWR's have been tested. Table 3-1 is a tabulation of the base metal results from these surveillance programs. The most significant feature is, for a range of material chemistries and fluences, the expected shift is bounded by the calculated Rev 2 shift plus margin. For example, the measured BWR/6 shifts are less than the predicted Rev 2 shift plus margin values by an average of 38°F. The results for BWR/6 show a small shift (17°F max.) for capsules removed at an EFPY similar to River Bend's current schedule, and at similar fluence levels. This data indicates that the River Bend shift (measured at 6 EFPY) will be small and may not be distinguishable from data scatter.

Similarly, Table 3-2 lists surveillance capsule data for weld material. The measured shifts are bounded by the predicted shift plus margin values. BWR/6 weld data shows the predicted shift plus margin to exceed the measured values by an average of 64°F. The maximum shift observed was 35°F, while the predicted shift plus margin was 86°F.

The predicted shift plus margin values are plotted against the measured shifts in Figures 3-1 and 3-2 for all BWR data available; the data is from Tables 3-1 and 3-2, respectively. These graphs show that the measured shifts are bounded by the predicted shift ± the margin term[2]. Based on these data, the measured shift for River Bend would be conservatively bounded by the Rev 2 calculation.

Since fluence has a significant effect on the Rev 2 calculation, use of an appropriate fluence value is essential for accurate shift prediction. The shift + margin predictions in Tables 3-1 and 3-2 utilize fluence values determined from flux wires removed early in plant life; Table 3-3 contains the results of actual BWR flux wire testing. As shown in Table 3-3, for a given BWR type and size, the fluence values fall within the data scatter. For example, for BWR/6 218" vessels (as is River Bend), the 32 EFPY capsule fluences range from 4.44 to 5.04×10^{18} n/cm^2. Based on this data, the fluence used for the ART calculations (as described in Appendix A) for RBS is considered accurate.

The fluence used to evaluate the RBS ART was determined from flux wire measurements[3]. The peak ID fluence value of 6.6×10^{18} n/cm^2 is equal to the value in Paragraph 5.3.1.6.2 of the RBS USAR. Therefore, the actual RBS fluence is conservatively bounded by the calculated value.

Other than fluence, the most significant effect on the ART is the chemistry factor (CF). The CF is determined from the copper and nickel levels, copper having the more significant effect.

A study has been performed[4] on the copper levels present in BWR beltline materials, in response to NRC letter 92-01, Supplement 1. The intent was to identify the plants with significant variation in the reported copper levels. For

River Bend, the copper level was determined to be consistent with the reported values with no significant variation.

Based on the evaluation of previous surveillance data of actual shifts and fluences, the measured fluence for RBS, and the chemistry of the RBS vessel material, the actual shift for RBS is expected to be conservatively bounded by the calculated value of shift + margin.

PLANT	BWR	RPV ID (in)	Capsule I.D. (deg)	Cu	Ni	CF	>1 MeV FLUENCE (x10^17) (n/cm^2)	@EFPY	1.99,REV2 DELTA RTNDT	REV2 DELTA+ MARGIN	30 FT-LB TEST SHIFT
BWR/2											
AC	2	213	30	0.23	0.46	146.7	3.60	5.80	35.8	69.8	55
						146.7	4.78	7.98	41.9	75.9	82
AS	2	213	210	0.17	0.11	79.5	7.46	8.15	28.7	62.7	72
BWR/3											
H	3	251	215	0.20	0.45	131.0	0.52	6.23	9.0	43.0	23
AR	3	251	215	0.12	0.54	89.5	0.71	5.98	7.7	41.7	12
AL	3	224	210	0.21	0.49	140.7	3.90	9.00	35.9	69.9	61
			300			140.7	6.60	14.80	48.0	82.0	78
A	3	205	30	0.17	0.65	128.3	2.90	7.08	27.6	61.6	
AJ	3	188	10	0.10	0.72	66.0	5.70	6.90	20.7	54.7	0
			190			66.0	12.60	15.85	30.7	64.7	2
AG	3	224	30	0.13	0.63	91.8	2.30	4.17	17.2	51.2	25
W	3	251	215	0.20	0.55	143.0	0.55	6.64	10.3	44.3	4
AB	3	251	215	0.10	0.54	65.0	0.66	5.63	5.3	39.3	-2
BWR/4											
Y	4	251	30	0.14	0.55	98.0	1.52	8.20	14.2	48.2	38
Q	4	218	30	0.21	0.76	164.6	2.30	6.80	30.9	64.9	52
			300			164.6	2.80	11.20	34.7	68.7	53
N	4	183	288	0.15	0.70	112.5	4.90	5.90	32.6	66.6	42
C	4	218	30	0.12	0.63	83.5	2.60	5.98	16.9	50.9	23
K	4	218	30	0.13	0.70	93.5	2.40	5.75	18.0	52.0	58
F	4	218	30	0.08	0.63	51.0	2.30	6.58	9.6	43.6	3
AY	4	251	30	0.09	0.64	58.0	1.42	6.01	8.0	42.0	4
P	4	251	120	0.10	0.54	65.0	1.80	7.53	10.5	44.5	-5
J	4	251	30	0.13	0.63	91.8	1.60	7.58	13.7	47.7	16
AW	4	251	30	0.09	0.61	58.0	1.40	6.68	8.0	42.0	24
AT	4	251	30	0.12	0.63	83.0	1.30	6.20	10.8	44.8	-2
O	4	205	30	0.11	0.66	74.9	0.43	7.54	4.5	38.5	19
BWR/5											
AX	5	251	300	0.14	0.54	97.0	0.90	6.50	9.9	43.9	28
AZ	5	251	300	0.10	0.48	65.0	1.15	6.98	7.8	41.8	N/A
BWR/6											
R	6	218	3	0.029	0.6	20	8.4	5.67	7.7	41.7	17
AE	6	218	177	0.06	0.6	37	9.6	6.85	15.1	49.1	4
AF	6	218	3	0.09	0.58	58	11.0	6.99	25.3	59.3	14

Table 3-1: BWR Surveillance Program Results for Base Metal

PLANT	BWR	RPV ID (in)	Capsule I.D. (deg)	Cu (%)	Ni (%)	CF	>1 MeV FLUENCE (x10^17) (n/cm^2)	@EFPY	1.99,REV2 DELTA RTNDT	REV2 DELTA+ MARGIN	30 FT-LB TEST SHIFT
BWR/2											
AC	2	213	30	0.17	0.07	81	4.78	5.80	23.1	79.1	N/A
			300			81	3.6	7.98	19.8	75.8	N/A
AS	2	213	210	0.29	0.05	131.5	7.5	8.15	47.6	103.6	
BWR/3											
H	3	251	215	0.2	0.45	137	0.52	6.23	9.5	65.5	0
AR	3	251	215	0.2	0.32	119	0.28	5.98	5.1	61.1	5
AL	3	224	210	0.2	1.05	228.5	3.9	9.00	58.3	114.3	22
			300				6.6	14.80	77.4	133.4	76
A	3	205	30	0.05	0.92	68	2.9	7.08	14.6	70.6	
AJ	3	188	10	0.3	0.09	138	5.7	6.90	43.3	99.3	77
			190				12.6	15.85	64.1	120.1	95
AG	3	224	30	0.16	0.79	176.5	2.3	4.17	33.1	89.1	55
W	3	251	215	0.17	0.3	105.5	0.55	6.64	7.6	63.6	0
AB	3	251	215	0.16	0.29	100.1	0.66	5.63	8.2	64.2	43
BWR/4											
Y	4	251	30	0.2	0.33	128	1.52	8.20	18.5	74.5	1
Q	4	218	30	0.23	0.75	194.5	2.4	6.80	37.4	93.4	61
			300				2.8	11.20	41.0	97.0	62
N	4	183	288	0.02	0.95	27	4.9	5.90	7.8	63.8	0
C	4	218	30	0.31	0.72	216	2.6	5.98	43.6	99.6	
K	4	218	30	0.28	0.76	212	2.4	5.75	40.8	96.8	
F	4	218	30	0.13	0.12	68.8	2.3	6.58	12.9	68.9	0
AY	4	251	30	0.08	0.59	105	1.42	6.01	14.5	70.5	61
P	4	251	120	0.1	0.32	84.2	1.8	7.53	13.6	69.6	17
J	4	251	30	0.11	0.41	102.5	1.6	7.58	15.3	71.3	16
AW	4	251	30	0.02	0.95	27	1.4	6.68	3.7	59.7	21
AT	4	251	30	0.02	0.95	27	1.8	6.20	4.3	60.3	-32
O	4	205	30	0.03	0.93	41	0.43	7.54	2.5	58.5	5
BWR/5											
AX	5	251	300	0.21	0.78	194	0.9	6.50	19.8	75.8	35
AZ	5	251	300	0.04	0.89	54	1.15	6.98	6.5	62.5	19
BWR/6											
R	6	218	3	0.072	0.76	97.5	8.4	5.67	37.3	93.3	28
AE	6	218	177	0.08	0.88	108	9.6	6.85	44.1	100.1	23
AF	6	218	3	0.05	0.87	68	11.0	6.99	29.7	85.7	35

Table 3-2: BWR Surveillance Program Results for Weld Metal

PLANT	BWR	RPV ID (in)	Capsule I.D. (deg)	>1 MeV FLUENCE (x10^17) (n/cm^2)	@EFPY
BWR/2					
AC	2	213	30	3.60	5.80
			300	4.78	7.98
AS	2	213	210	7.46	8.15
BWR/3					
H	3	251	215	0.52	6.23
AR	3	251	215	0.71	5.98
AL	3	224	210	3.90	9.00
			300	6.60	14.80
A	3	205	30	2.90	
AJ	3	188	10	5.70	6.90
			190	12.60	15.85
AG	3	224	30	2.30	4.17
W	3	251	215	0.55	6.64
AB	3	251	215	0.66	5.63
BWR/4					
Y	4	251	30	1.52	8.20
Q	4	218	30	2.30	6.80
			300	2.80	11.20
N	4	183	288	4.90	5.90
C	4	218	30	2.60	5.98
K	4	218	30	2.40	5.75
F	4	218	30	2.30	6.58
AY	4	251	30	0.20	1.02
AY	4	251	30	1.42	6.01
P	4	251	120	1.80	7.53
J	4	251	30	1.60	7.58
AW	4	251	30	1.40	6.68
AT	4	251	30	1.30	
O	4	205	30	0.43	7.54
BWR/5					
AX	5	251	30	0.20	1.38
AX	5	251	300	0.90	6.50
AZ	5	251	30	0.21	1.36
AZ	5	251	300	N/A	N/A
AK	5	251	30	0.14	0.90
BWR/6					
R	6	218	3	8.4	5.67
AP	6	251	3	0.26	0.93
AE	6	218	177	9.6	6.85
AF	6	218	3	11.0	6.99
X	6	218	3	1.39	1.00

Table 3-3: Flux Wire Results

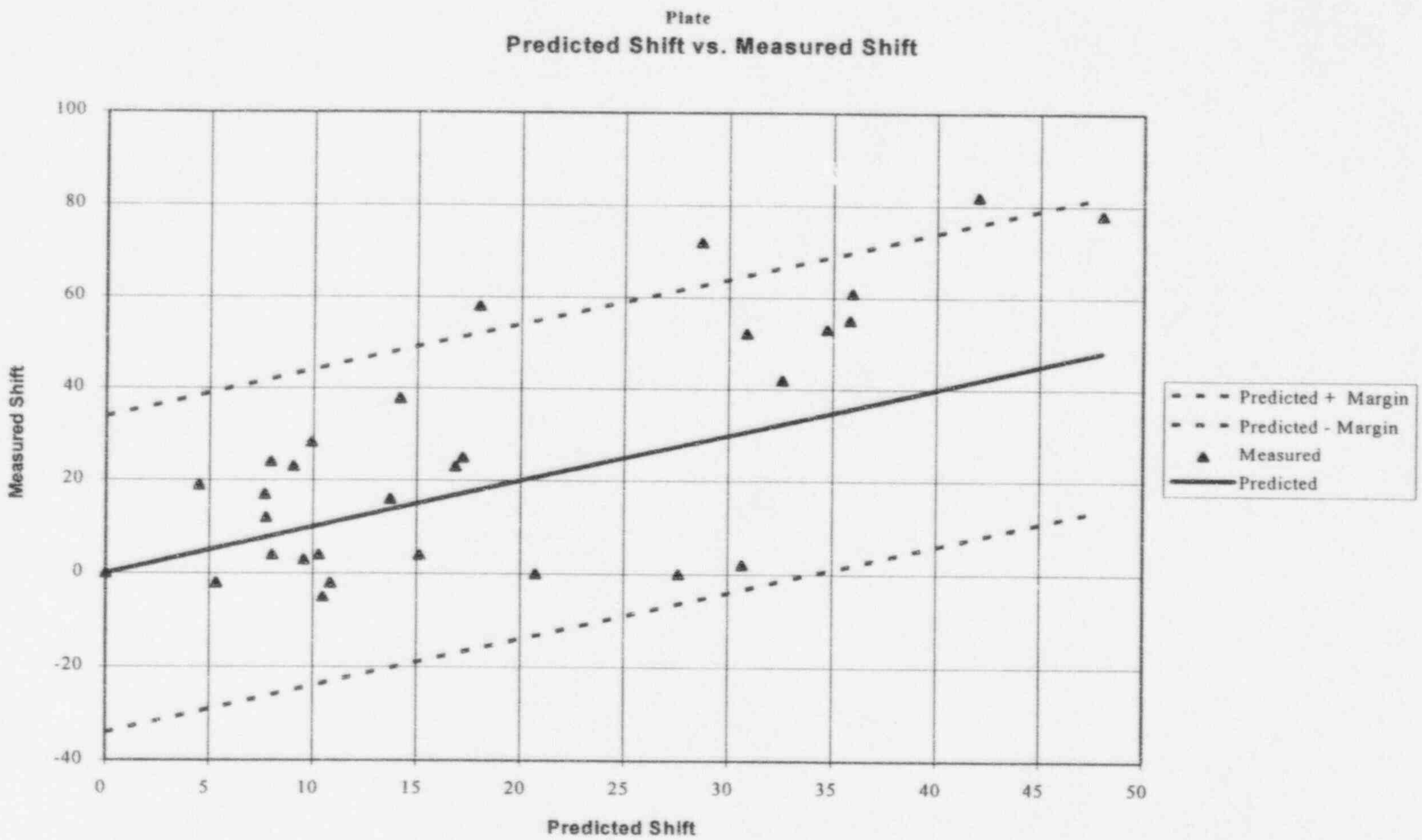

Figure 3-1: Measured Shift vs. Predicted Shift for Base Metal

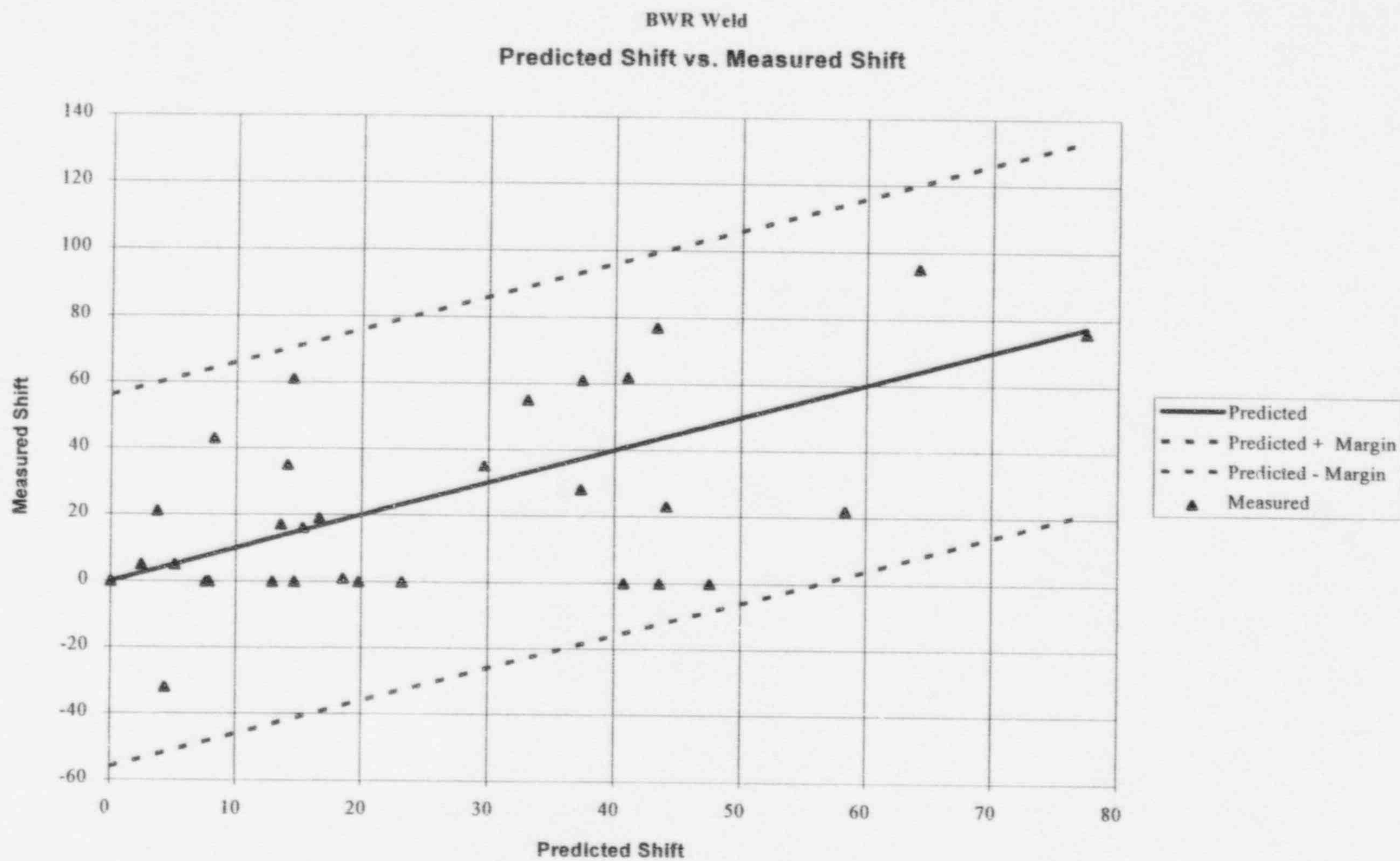

Figure 3-2: Measured Shift vs. Predicted Shift for Weld Metal

4. PRESSURE-TEMPERATURE (P-T) CURVES

The shift in RT_{NDT} obtained from surveillance testing is used to evaluate the long term effects of irradiation on the fracture toughness of the vessel. The reference fracture toughness (K_{IR}) is determined using the shift in RT_{NDT} ; K_{IR} is part of the calculations of the P-T curves performed in accordance with ASME Section III, Appendix G. The current RBS P-T curves were calculated with the 8 EFPY shift in RT_{NDT}.

The K_{IR} correlation was developed from several sets of material data on pressure vessel steel.[5] The K_{IR} curve was drawn to bound the available data. Thus the correlation has inherent conservatism.

In addition, operation of RBS follows the steam saturation curve, therefore, the operating temperatures are expected to be well in excess of the minimum required temperature. During normal and accident conditions, the RBS maintains more than adequate margins. The operational issues of Pressurized Thermal Shock (PTS) and Low Temperature Over Pressurization (LTOP) are not applicable to RBS. The limiting case for RBS is the pressure test.

The P-T curve associated with the pressure test is calculated using the crack arrest fracture toughness, K_{IR} (K_{Ia}). The static crack initiation fracture toughness, K_{IC}, is significantly higher than K_{IR} in the temperature range of interest[6]. Therefore use of K_{IR} conservatively bounds the fracture toughness of the vessel. Figure 4-1 is a plot of K_{Ia} and K_{IC} as a function of T-RT_{NDT}[7]. The K_{Ia} curve is shown to be lower than the K_{IC} curve, conservatively bounding the fracture toughness. For example, at a pressure test temperature of 169°F and a vessel ART of 65°F (corresponding to 12 EFPY for River Bend), the fracture toughness for initiation and arrest are estimated to be:

K_{IC} = 199.2 ksi√in

K_{IR} =83.0 ksi√in

Thus the K_{IC} value is approximately 2.4 times the K_{Ia} value, clearly showing K_{Ia} to conservatively bound the calculations.

The combination of lower bound fracture toughness, the RBS operating characteristics and the conservative fracture toughness values indicate that the RBS vessel fracture toughness is not a significant concern over the life of the plant.

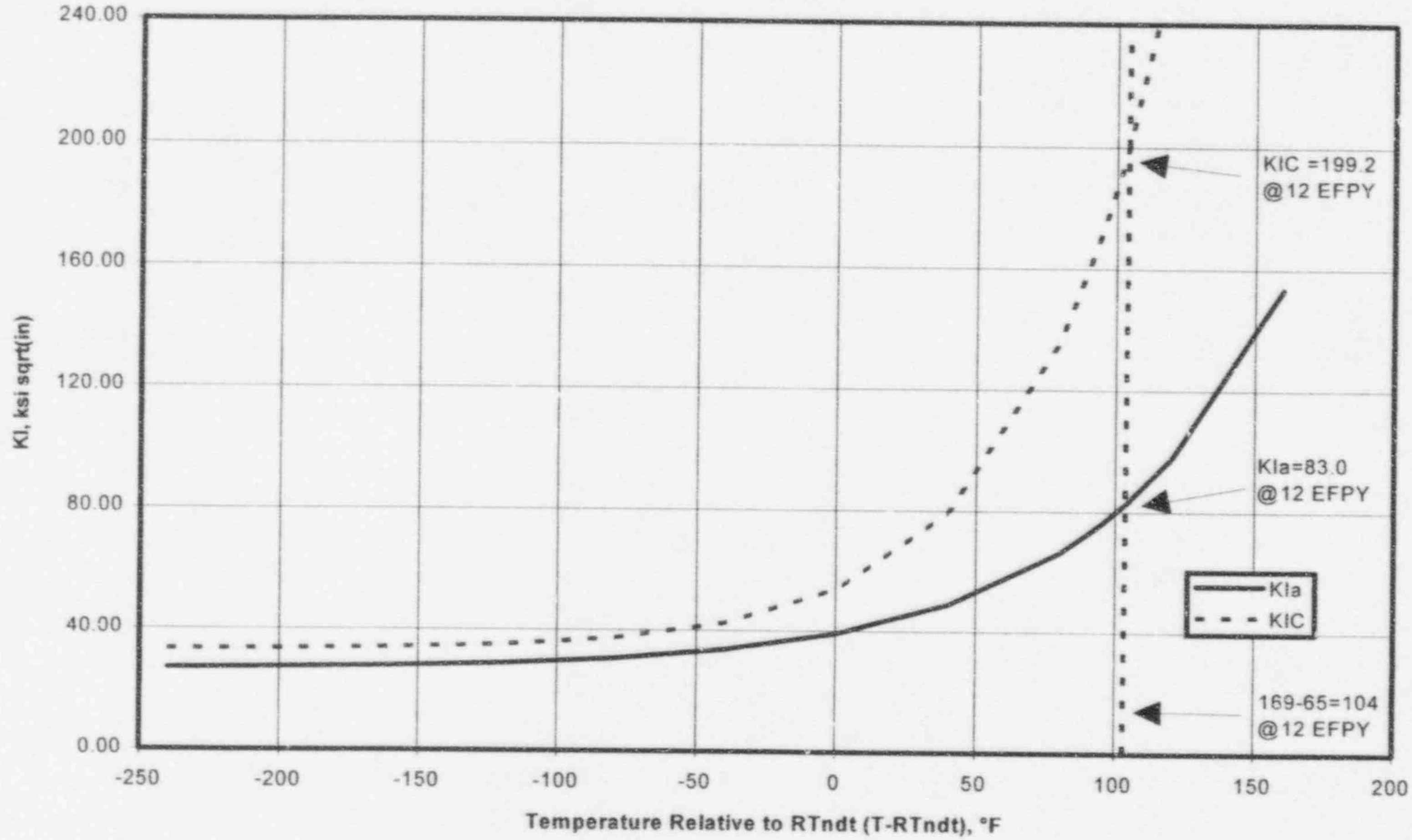

Figure 4-1: Comparison of K_{Ia} and K_{IC}

5. SUPPLEMENTAL SURVEILLANCE PROGRAM

The BWR Owner's Group (BWROG) is in the midst of a supplemental test program designed to significantly increase the amount of BWR surveillance data in a systematic manner which should permit the development of a BWR-specific equivalent to Rev 2.

Description

The BWROG Supplemental Surveillance Program (SSP) was begun in the late 1980s when the BWROG concluded from their review of BWR surveillance data the following:

- Due to the smaller number of capsules per plant and the relatively fewer number of BWRs than PWRs, there is limited BWR surveillance data at higher fluences available to analyze;
- Rev 2 imposed some hardships on pressure testing for BWRs, some of which might be relieved if better predictive models of the BWR embrittlement phenomenon were obtained.

In light of these issues, the BWROG prepared supplemental capsules which were installed in Cooper and Oyster Creek. Specimen withdrawals are planned for 1996, 2000, and 2002.

The results of the SSP will be the equivalent of 84 additional surveillance capsules, compared to about 25 which have been tested to date. These capsules were designed to systematically evaluate embrittlement trends in BWRs. For example:

- The capsules are positioned so that flux differs by a factor of 2. Also, irradiation times differ by a factor of 2. In this way, some capsules have matching flux but with different fluence, while some have matching fluence and at a differing flux level;
- The materials used were selected to bound the range of chemistries in BWR beltline materials, and in most cases *are* BWR beltline materials;
- Irradiations are being done in BWRs to correctly simulate conditions like temperature, neutron spectrum and transient operation.

Relationship to River Bend

The SSP has the RBS limiting weld material among the materials in the capsules. This material is in four of the 7 capsules in the SSP holders. The SSP results will be applicable to River Bend for two reasons:

- Generically, the SSP results will be from representative environmental conditions on materials representative of all BWRs, including RBS;

- Specifically, results will be developed which will provide information on the limiting RBS weld material, and will be directly applicable to the River Bend surveillance program.

The SSP capsules, when tested, will have collected between $5x10^{17}$ n/cm^2 (3.6 EFPY for RBS at 1/4T) and $2x10^{18}$ n/cm^2 (14.3 EFPY for RBS at 1/4T) fluence. Thus, the results of the SSP are complementary to the RBS surveillance program such that postponement of the capsule withdrawals will have minimal impact on the understanding of irradiation effects on the RBS vessel.

6. REVISED SURVEILLANCE SCHEDULE

The surveillance program is intended to characterize the vessel properties as a function of irradiation over the life of RBS. The Charpy impact energy obtained from the prescribed testing is used to evaluate the reference fracture toughness of the RBS vessel (K_{IR}) in accordance with ASME Section III, Appendix G. The schedule for the surveillance program testing should be designed for the expected shift in vessel fracture toughness.

The expected shift in fracture toughness of the RBS weld material (the limiting material) as a function of EFPY is plotted in Figure 6-1. Since the pressure test is the limiting case, the calculated K_{IR} is for a 1025 psig pressure test. The pressure test temperature was modified on eight year intervals for illustration purposes. This figure shows that significant margin remains between the required K_I and the K_{IR} used to calculate the P-T curves. Thus the K_{IR} is expected to conservatively bound the required vessel fracture toughness.

Since the K_{IR} is considered a conservative prediction, and the SSP will identify a greater than expected shift, the first surveillance capsule testing should be at the time at which a majority of the shift in the vessel RT_{NDT} has been achieved. Early testing of the surveillance plate specimens may result in the measured shift being less than the data scatter (sometimes resulting in negative shifts in RT_{NDT}). Correct selection of the removal time will ensure credible data from all specimens. If the shift is greater than expected, then the margin present in the P-T calculations together with the limiting fracture toughness represent an added margin of safety.

Since the SSP can be used to measure anomalous shifts, the first surveillance capsule testing schedule should be developed to measure a significant portion of

the fracture toughness change. To illustrate the change, Figure 6-2 is a plot of the fracture toughness as a function of the predicted shift in RT_{NDT} for the RBS weld material. As is clearly shown, the fracture toughness decreases as a function of the shift. The fracture toughness at the beginning of plant life is 200 ksi√in and at 32 EFPY is 72.1 ksi√in. Therefore, the change in fracture toughness over the design life of the plant is 127.9 ksi√in.

To determine the schedule for first capsule withdrawal, a value of 75% of the predicted fracture toughness change ((0.75)(127.9 ksi√in)= 95.9 ksi√in) over the design life of RBS was selected as an appropriate criteria. If a significant shift is to occur, this value is large enough to ensure its detectability. Therefore, the first surveillance capsule should be removed when the 75% criteria has been met. This criteria is met at 200 ksi√in - 95.9 ksi√in, or 104.1 ksi√in. This change in fracture toughness is expected to be achieved when the shift, reading from Figure 6-2, has reached a value of 60°F.

Since the capsule is intended to measure this shift, the value obtained from Figure 6-2 can be used to determine when the capsule has achieved a similar value. Figure 6-3 is a plot of the shift in RT_{NDT} as a function of the capsule EFPY. Using the shift value of 60°F, the capsule will experience a similar shift for the limiting weld material at approximately 10.4 EFPY.

Using a criteria of 75% of the change in predicted fracture toughness as the appropriate measurement of vessel embrittlement for RBS, the first surveillance capsule should be removed at 10.4 EFPY. The combination of the low expected shift for the plate material, SSP data on the weld material, and the inherent margin in the K_{IR} calculations will result in a credible set of surveillance data, while ensuring continued safe operation of RBS.

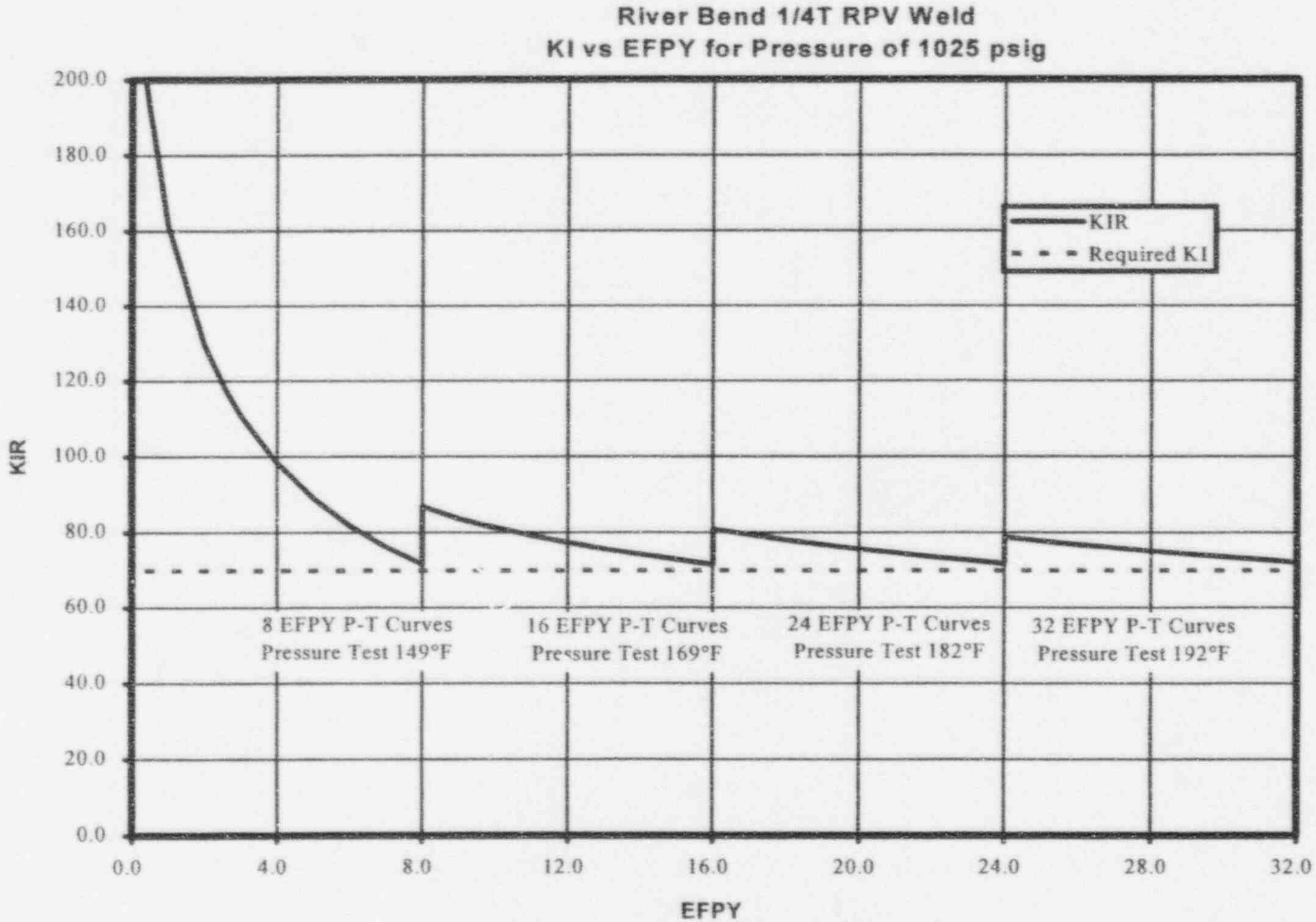

Figure 6-1: K_{IR} vs. EFPY for River Bend Weld Material

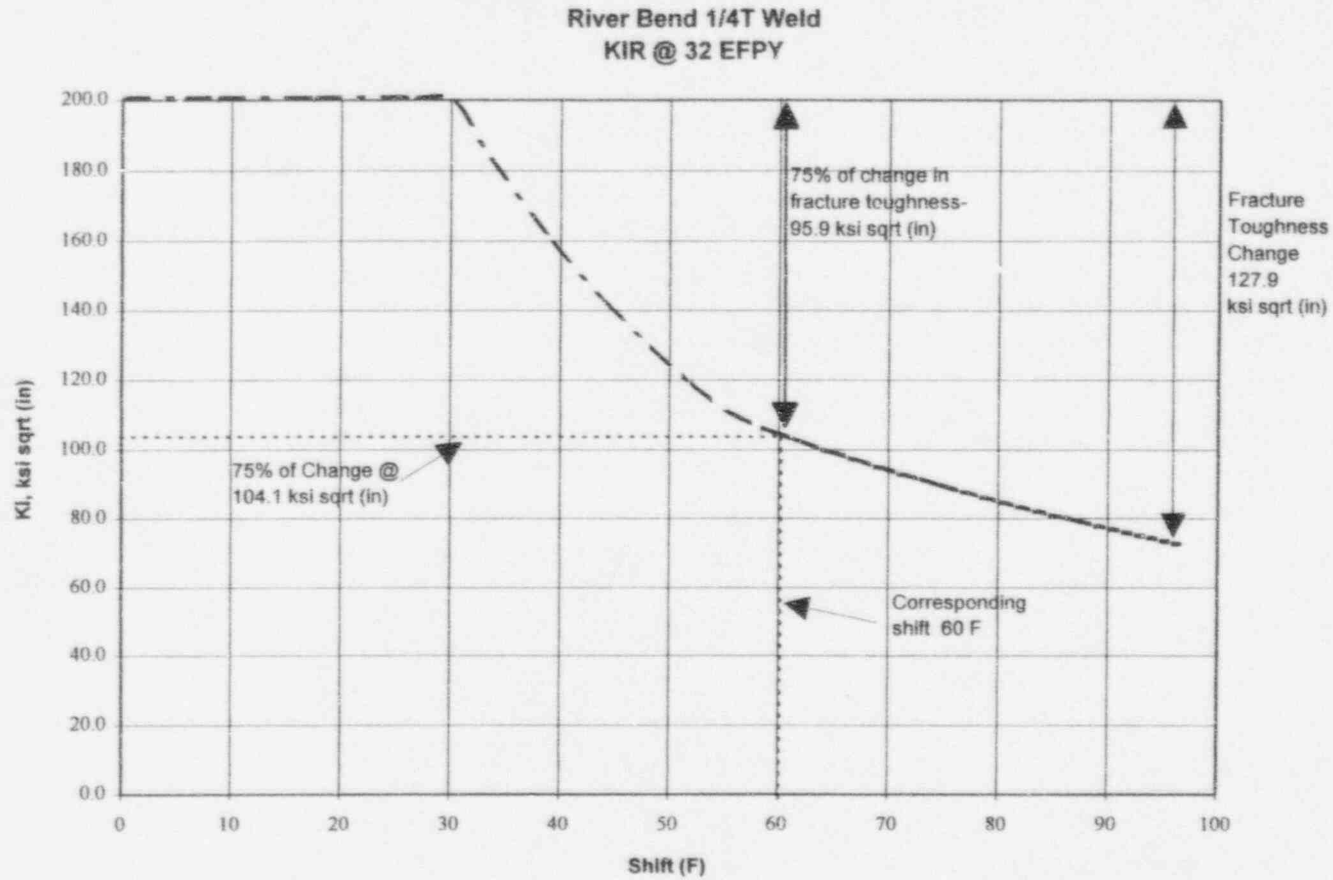

Figure 6-2: K_{IR} vs. Predicted Shift

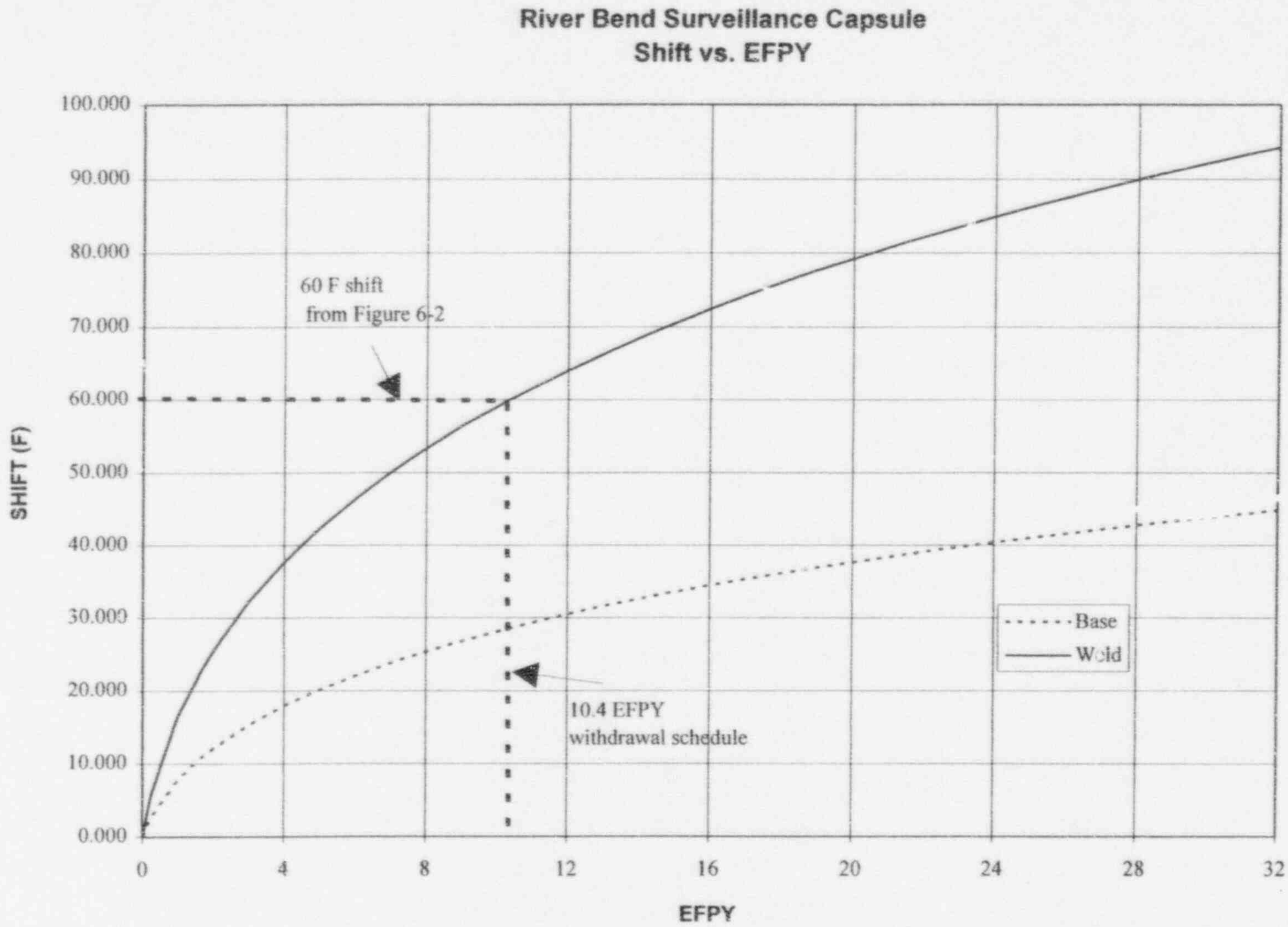

Figure 6-3: Predicted shift vs. EFPY, River Bend Surveillance Capsule

7.0 CONCLUSIONS

The purpose of the vessel surveillance program is to characterize the vessel properties as a function of irradiation. The original schedule for River Bend was determined according to 10CFR50, Appendix H, resulting in a withdrawal schedule of six (6) EFPY for the first surveillance capsule.

Schedules developed according to 10CFR50, Appendix H, however, are general guidelines for all reactor pressure vessels. The schedules do not take into account some specific characteristics of River Bend, a low fluence and excellent alloy chemistry (0.03-0.09% copper), which results in a low shift in RT_{NDT} (especially for the RBS plate material). If the first capsule is removed and tested according to the current schedule (6 EFPY), the data obtained for the plate specimens is likely not to be useful.

If the data is unlikely to be useful, and early information on the limiting RBS weld material can be obtained from the SSP to identify anomalous shifts, the surveillance schedule should be extended. The schedule can be extended for the following reasons:

1. Evaluation of similar data obtained from actual surveillance programs has shown the predictions of fluence, shift and chemistry are bound by expected values. In particular, the BWR/6 data has shown small RT_{NDT} shifts for capsules removed at EFPY similar to the current RBS withdrawal schedule. Therefore, the surveillance capsule withdrawal schedule should be extended based on the conservatism in the calculated shift of RT_{NDT}.

2. In addition, the P-T curves contain inherent conservatism, as noted in Section 4. The fracture toughness values used for these calculations are

considered to be lower bound values and are significantly less than the crack initiation fracture toughness in the temperature range of interest. At operating temperatures, RBS maintains more than adequate margins; the limiting condition is the pressure test. This conservatism provides an added margin of safety; therefore, the capsule withdrawal schedule can be modified.

3. In addition, the SSP data will complement the available data on surveillance specimens and also identify any anomalous information in the predicted values. This characterization will enhance the understanding of vessel embrittlement issues and provide specific data for RBS on the limiting weld material. Hence the change in schedule for the RBS surveillance specimens will not have a significant effect on the understanding of vessel irradiation issues.

These reasons justify extending the withdrawal schedule while maintaining reactor safety margins, and provide for more accurate measured data near EOL. Therefore, the surveillance schedule should be modified.

The material property of most concern is the fracture toughness of the vessel; the surveillance schedule should be based on evaluation of this property. Since the fracture toughness (K_{IR}), is dependent on the shift in RT_{NDT}, the optimum EFPY for removal of the capsule ensures credible data (measuring significant shift), while identifying any anomalous conditions. If such an anomalous shift were to occur, the margin between K_{Im} and K_{IR}, as well as the inherent conservatism of the calculations, can provide a sufficient safety margin for extending the surveillance schedule. In addition, operation of RBS follows the steam saturation curve; the operating temperatures are expected to be well in excess of the minimum required temperature.

As shown in section 6, the appropriate K_{IR} value selected was 75% of the predicted change in K_{IR}. Using this value to determine the appropriate shift in the capsule (hence the appropriate EFPY), the recommended withdrawal schedule for the first River Bend surveillance capsule is 10.4 EFPY. Removal of the capsule at the specified EFPY will obtain the most credible data for fracture toughness predictions.

At this time, a recommended extended schedule for the second surveillance capsule has not been determined. Additional data from the SSP capsules (using the RBS limiting weld material) will soon be available. The first capsule would also provide data on the limiting materials. The combination of these two data sources would be used to develop the appropriate schedule for the second capsule.

8.0 REFERENCES

1. "Reactor Vessel Material Surveillance Program Requirements," Appendix H to Part 50 of Title 10 of the Code of Federal Regulations, December 1995.

2. "Radiation Embrittlement of Reactor Vessel Materials," U.S. NRC Regulatory Guide 1.99, Revision 2, May 1988.

3. "Implementation of Regulatory Guide 1.99 Revision 2 for River Bend Station Unit 1," GE Report SASR 89-20, Revision 1, March 1990.

4. "Bounding Assessment of BWR/2-6 Reactor Pressure Vessel Integrity Issues," GENE Report #523-A106-1195, BWR VIP-08, November 1995.

5. S.T. Rolfe and J.D. Barsom, Fracture and Fatigue Control in Structures, Prentice-Hall, Inc., New Jersey, 1977, p. 447.

6. Ibid., p. 455.

7. ASME Section XI, Appendix A, 1992 Edition through Summer 1993 Addenda.

APPENDIX A

ADJUSTED REFERENCE TEMPERATURE (ART) CALCULATION

The ART is, according to Rev 2, a function of the initial RT_{NDT}, the shift, and a margin term. The shift in RT_{NDT} is dependent on the chemistry (specifically copper and nickel) and fluence. The methods of Rev 2 are used to determine the ART; the method used depends on whether or not surveillance specimen data is available.

In order to re-evaluate the surveillance specimen program schedule, the ART for both the vessel itself and the specimens must be calculated. For River Bend, surveillance specimens have not been tested, which requires the method of evaluating ART without surveillance specimens, as described below.

The ART for each beltline material is given by the following equation:

$$ART = Initial\ RT_{NDT} + \Delta RT_{NDT} + Margin \qquad (1)$$

Initial RT_{NDT} is the reference temperature determined according to ASME Section III, Paragraph NB-2331 for the unirradiated material.

The shift in the reference temperature, ΔRT_{NDT}, is determined by a combination of the chemistry and fluence as shown by equation (2):

$$\Delta RT_{NDT} = CF * f^{(0.28-0.10\log f)} \qquad (2)$$

The *CF* is the chemistry factor (dependent on the copper and nickel content) and is determined from the tables for weld and base material in Rev 2. The fluence, *f*, at any depth in the vessel wall, is determined by equation (3),

$$f = f_{surf} * (e^{-0.24x}) \qquad (3)$$

where f_{surf} is the calculated neutron fluence at the vessel ID and x is the depth into the vessel measured from the inner (wetted) surface. For these calculations, the value of f_{surf} used was 6.6 $X10^{18}$ n/cm^2, obtained from the flux wire analysis[3].

The Margin term is included to obtain the upper bound values of the ART. Since the Margin term provides upper bound values of the ART (which is a function of CF and fluence), it is unnecessary to add extra conservatism by using the upper bound fluence. Any uncertainty in the fluence is captured by the Margin term. The Margin term is given by equation (4):

$$Margin = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \qquad (4)$$

where

σ_I = standard deviation of the initial RT_{NDT}

σ_Δ = standard deviation for ΔRT_{NDT}

The standard deviation for ΔRT_{NDT}, σ_Δ, is assumed to be 28°F for welds and 17°F for base metal, except that σ_Δ need not exceed 0.50 times the mean ΔRT_{NDT}[2]. The conservative nature of the RT_{NDT} determination results in σ_I being equal to zero.

Using equations (1) to (4), the ART can be calculated for plants with no surveillance data, including River Bend.

EXAMPLE CALCULATION

To better illustrate the ART methodology, the following calculation was performed for the River Bend base material (Heat #C3054-2); this material was

used in the surveillance capsule. The data was obtained from Table 5.3-1 of the River Bend USAR:

Initial RT_{NDT}:	2°F
Nickel:	0.70%
Copper:	0.09%
Peak Fluence:	6.6 X 10^{18} n/cm^2 (32 EFPY at vessel wall)
Wall Thickness:	5.41 inches

From Table 2 of Rev 2, the chemistry factor for this heat of material is 58. The fluence at the 1/4T depth, determined from equation (3), is equal to:

$$f = (6.6 \text{ X}10^{18}/10^{19}) * e^{(-0.24*1.35)}$$

$$f = .66*0.723$$

$$f = 0.48$$

The change in reference temperature, ΔRT_{NDT}, is calculated according to equation (2):

$$\Delta RT_{NDT} = 58 * 0.48^{(0.28-0.10 \log 0.48)}$$

$$\Delta RT_{NDT} = 58*0.796 = 46°$$

For the margin term, the standard deviation of the initial RT_{NDT}, σ_I, is assumed to be zero. The standard deviation for ΔRT_{NDT}, σ_Δ, is 17°F, as it is base metal.

Therefore, the ART at 32 EFPY for plate C3054-2 is:

ART = 2 + 46 + 34 = <u>82°F</u>

This calculation was repeated for all of the vessel beltline materials. The results of the calculations for all the beltline materials are shown in Table A-1. Figure A-1 is a plot of the ART against EFPY for the expected plant lifetime for the limiting materials, which are the materials with the highest ART after 32 EFPY.

Base
Thickness = 5.41 inches

Weld
Thickness = 5.41 inches

Base
32 EFPY Peak I.D. fluence = 6.60E+18
32 EFPY Peak 1/4 T fluence = 4.77E+18

Weld
32 EFPY Peak I.D. fluence = 6.60E+18
32 EFPY Peak 1/4 T fluence = 4.77E+18

COMPONENT	ID	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RTndt °F	32 EFPY Delta RTndt °F	Margin °F	32 EFPY Shift °F	32 EFPY ART °F
BASE: BELTLINE										
		C3138-2	0.08	0.63	51	9.0	40.5	34.0	74.5	83.5
		C-3054-1	0.09	0.7	58	-20.0	46.0	34.0	80.0	60.0
		C3054-2*	0.09	0.7	58	2.0	46.0	34.0	80.0	82.0
VERTICAL WELDS:										
		492L8471/A421B27AE	0.04	0.95	54	-60.0	42.9	42.9	85.7	25.7
		492L8471/A421B27AF	0.03	0.98	41	-50	32.5	32.5	65.1	15.1
		5P6756/0342(1)*	0.09	0.92	122	-50	96.8	56.0	152.8	102.8
		5P6756/0342(2)*	0.09	0.93	122	-60.0	96.8	56.0	152.8	92.8

* HEAT FROM WHICH SURVEILLANCE SPECIMENS WERE TAKEN

Table A-1: River Bend RPV Material Data

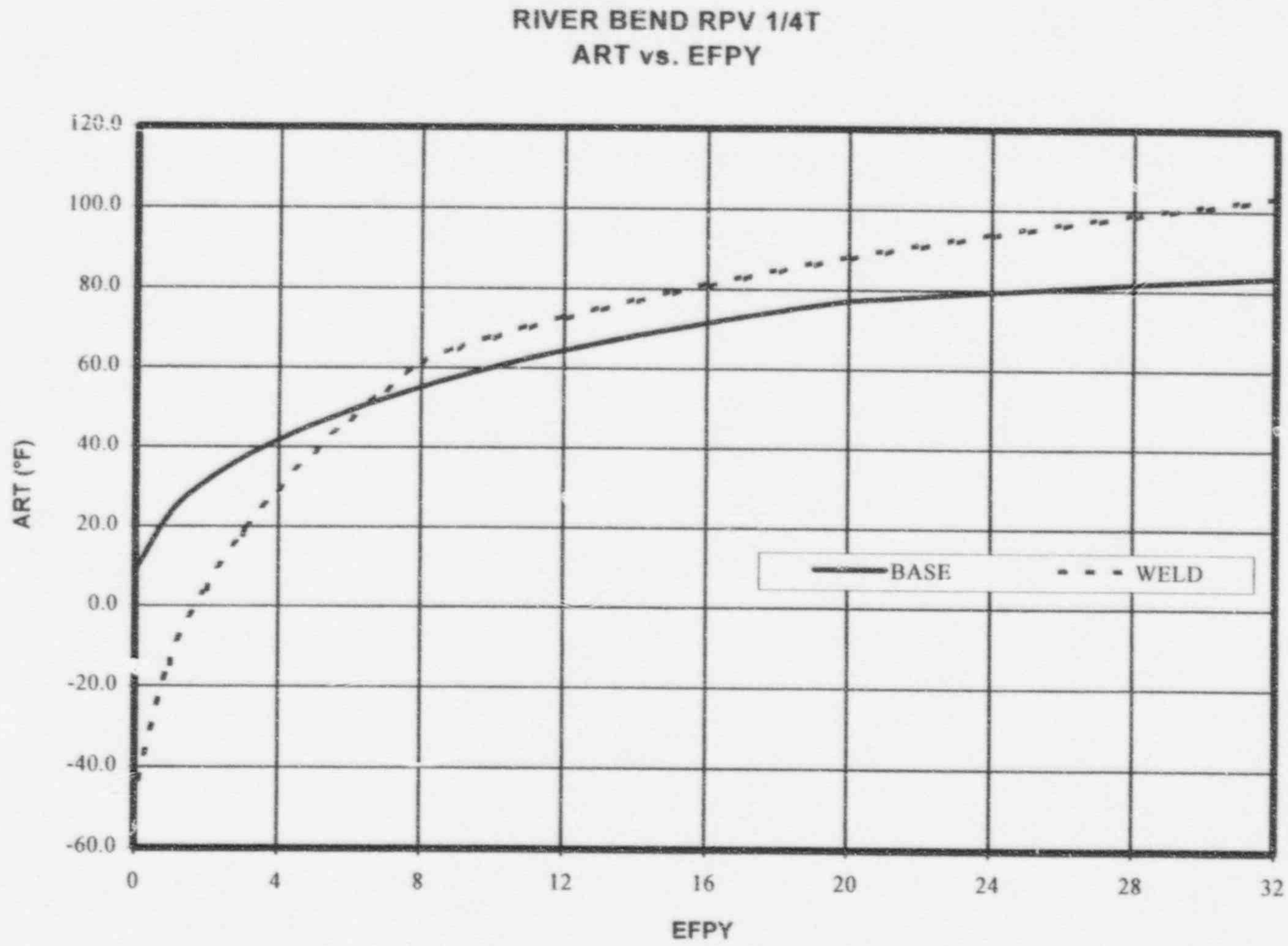

Figure A-1: ART vs. EFPY