Quality Assurance of Chapter 9: Definition of the Beltline

This report documents the results of the quality assurance task for Chapter 9 of the draft technical basis NUREG for the risk-informed Appendix G project. Chapter 9 discusses a more precise definition for the term "beltline." The quality assurance effort for this chapter involved three specific subtasks: (1) plotting axial fluence profiles for several reactor vessels, (2) verifying reference temperature shift calculations, and (3) verifying a check of the Reactor Vessel Integrity Database (RVID2) with license renewal application (LRA) data.

Axial Fluence Profiles

The fluence data was independently extracted from the sources used in the technical basis work. The boiling water reactor (BWR) fluence profiles obtained during the quality assurance (QA) work are shown in Figure 1, while the plots obtained during the technical basis (TB) work are shown in Figure 2. The corresponding plots for pressurized water reactors (PWRs) are shown in Figures 3 and 4, respectively. The figures show reasonable agreement.

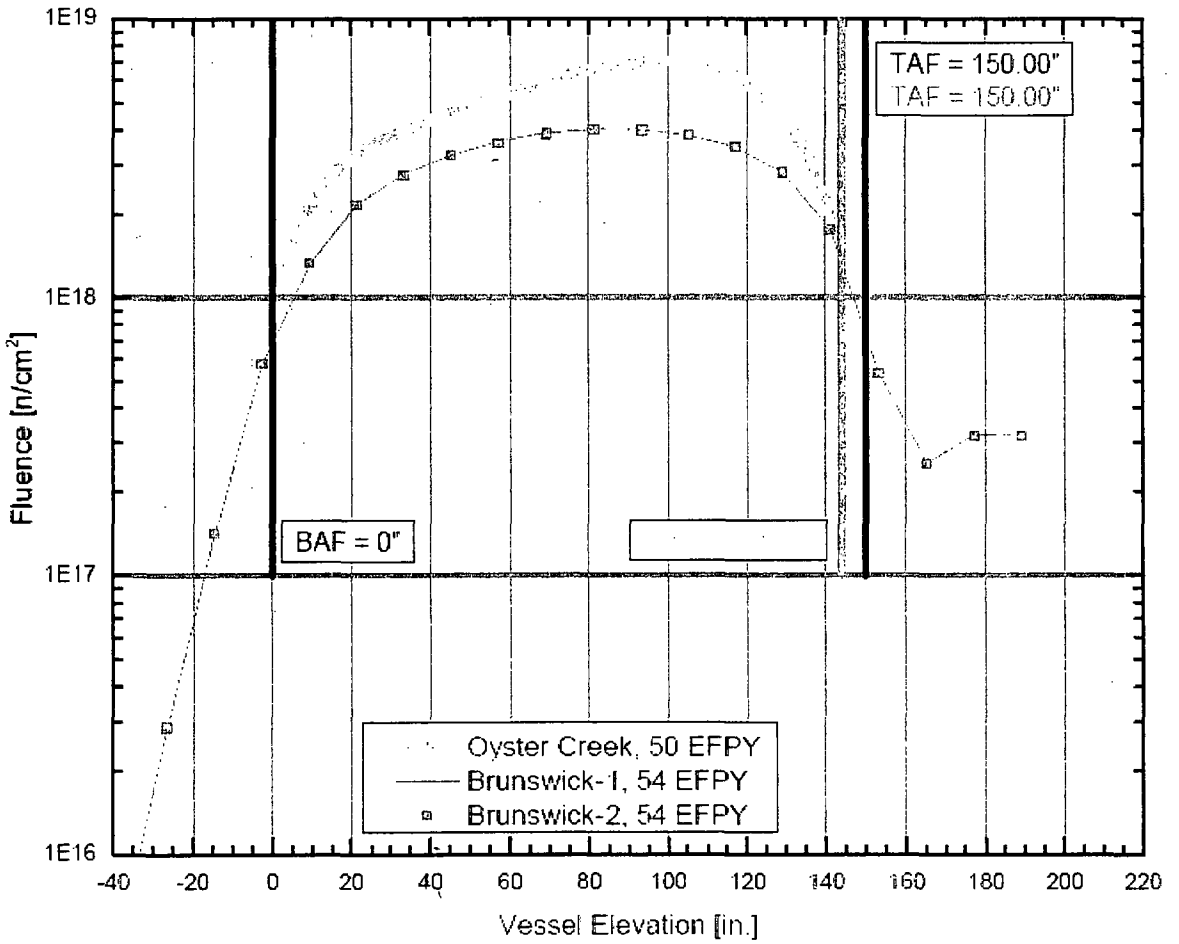

Figure 1: Axial fluence profiles for 3 BWR vessels, as determined during the QA work.

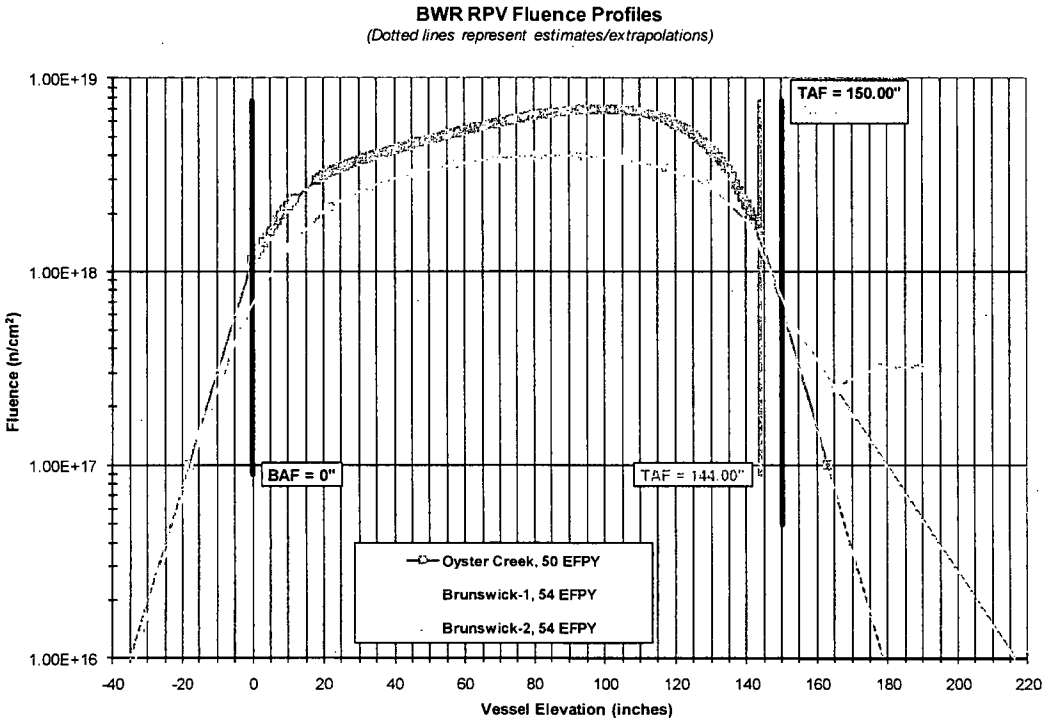

Figure 2: Axial fluence profiles for 3 BWR vessels, as determined during the TB work.

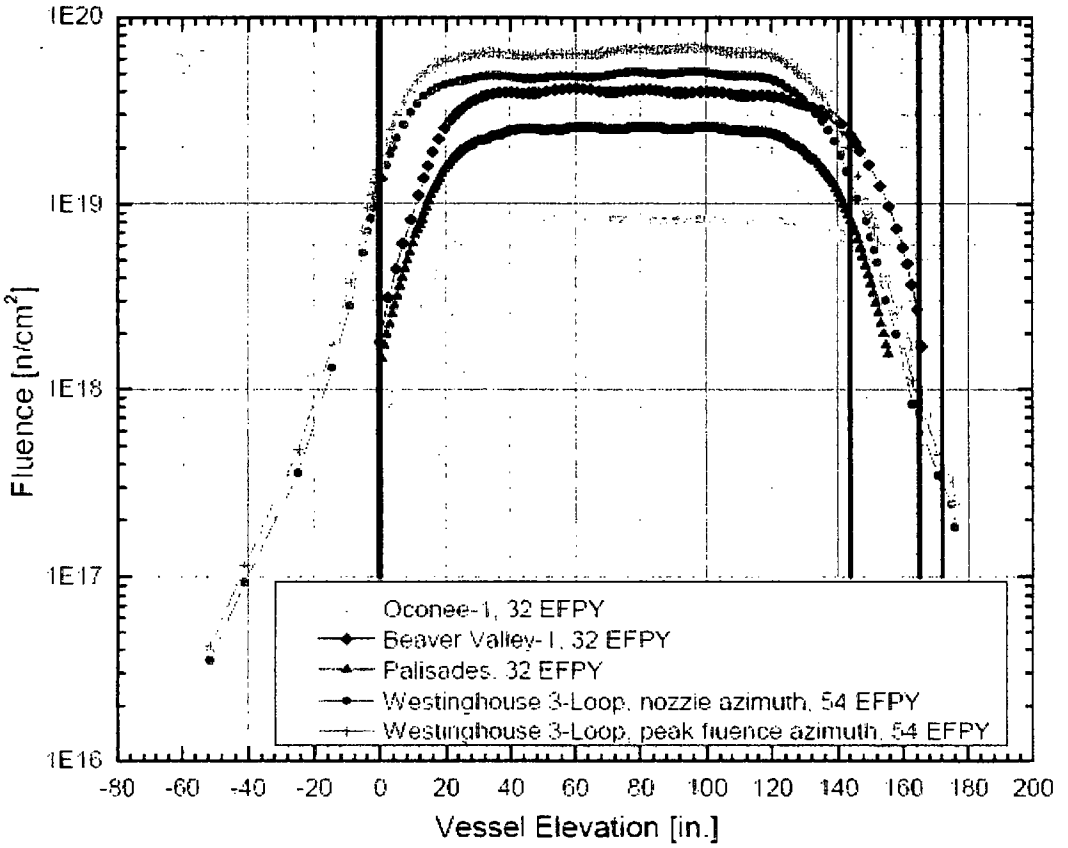

Figure 3: Axial fluence profiles for 5 PWR vessels, as determined during the QA work.

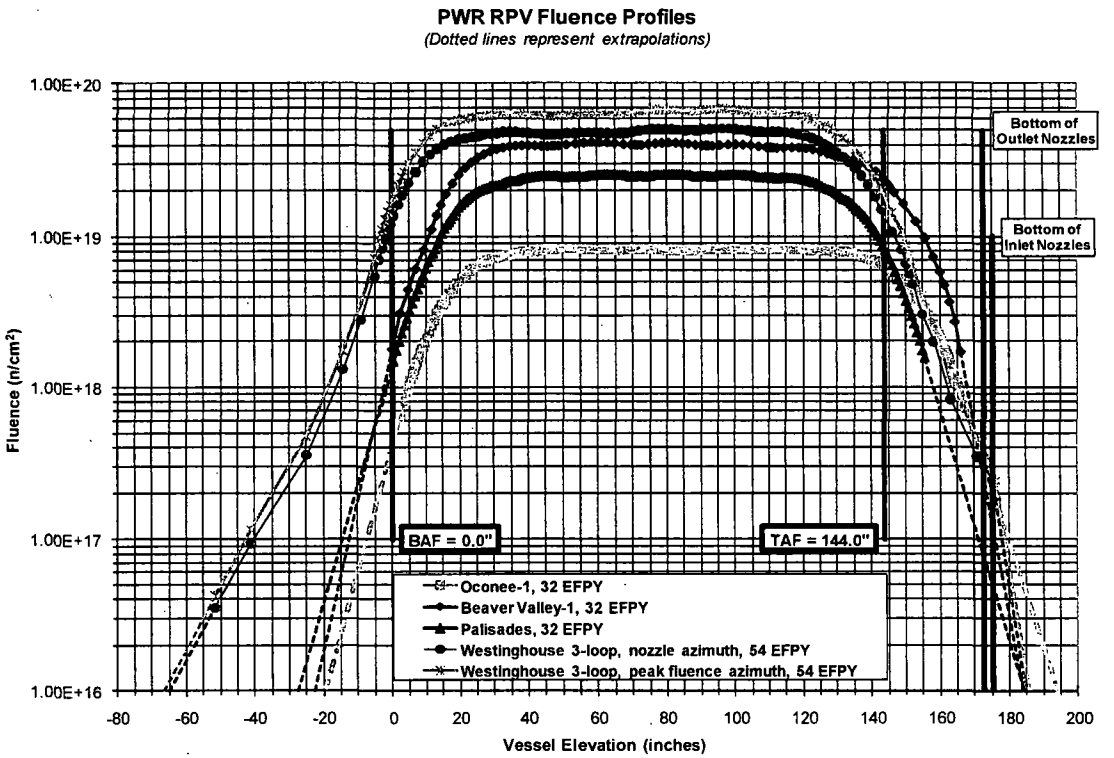

Figure 4: Axial fluence profiles for 5 PWR vessels, as determined during the TB work.

Reference Temperature Shift

The irradiation-induced shift of the 30 ft-lb reference temperature, ΔT_{30}, was calculated for a range of vessels based upon two methods: (1) the Regulatory Guide (RG) 1.99 Revision 2 procedure and (2) the method found in Title 10, Code of Federal Regulations, Part 50.61a (10 CFR 50.61a), "Alternate Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events." The QA team independently extracted the necessary input data from the RVID2 database and performed the calculations. Tables 1 and 2 show a comparison between the TB results and the QA results for PWRs and BWRs, respectively, for the RG 1.99 Revision 2 method. Tables 3 and 4 are the corresponding tables for the RG 1.99 Revision 3 method.

Table 1: Results of the quality assurance check of the RG 1.99 Revision 2 method for PWRs.

Fluence [n/cm^2]	ΔT_{30} [°F]		% difference
	TB	QA	
1.00E+16	1.039	1.039	0.04
2.00E+16	1.930	1.931	0.04
5.00E+16	4.105	4.107	0.04
7.00E+16	5.318	5.320	0.04
1.00E+17	6.923	6.926	0.04
5.00E+17	19.831	19.839	0.04
1.00E+18	29.113	29.124	0.04

Table 2: Results of the quality assurance check of the RG 1.99 Revision 2 method for BWRs.

Fluence [n/cm^2]	ΔT_{30} [°F]		% difference
	TB	QA	
1.00E+16	1.229	1.230	0.06
2.00E+16	2.265	2.266	0.06
5.00E+16	4.767	4.770	0.06
7.00E+16	6.151	6.155	0.06
1.00E+17	7.974	7.979	0.06
5.00E+17	22.422	22.435	0.06
1.00E+18	32.654	32.674	0.06

Table 3: Results of the quality assurance check of the 10 CFR 50.61a method for PWRs.

Fluence [n/cm^2]	ΔT_{30} [°F]		% difference
	TB	QA	
1.00E+16	3.171	3.182	0.33
2.00E+16	4.668	4.683	0.33
5.00E+16	8.200	8.227	0.32
7.00E+16	10.198	10.230	0.31
1.00E+17	12.882	12.921	0.30
5.00E+17	33.864	33.924	0.18
1.00E+18	46.102	46.155	0.12

Table 4: Results of the quality assurance check of the 10 CFR 50.61a method for BWRs.

Fluence [n/cm^2]	ΔT_{30} [°F]		% difference
	TB	QA	
1.00E+16	5.480	5.440	-0.72
2.00E+16	7.690	7.629	-0.78
5.00E+16	12.536	12.431	-0.84
7.00E+16	15.149	15.023	-0.83
1.00E+17	18.571	18.424	-0.79
5.00E+17	43.890	43.750	-0.32
1.00E+18	58.479	58.414	-0.11

The values in Tables 1-4 are shown to the third decimal place to demonstrate the differences in the results. In all cases, the TB results were verified to within 1%.

RVID2-LRA Comparison

As part of the technical basis work for risk-informed Appendix G, the information contained in the RVID2 database was compared to data in LRAs. The purpose of this work was to verify that the RVID2 data was consistent with the latest data submitted in the LRAs. Reference temperature shifts (i.e., ΔT_{30}) were calculated based upon inputs from both sources and the 10 CFR 50.61a method. The QA effort uncovered minor errors in the TB calculations of 1/4t fluence values for certain vessel locations. The corrected plots of RVID2 ΔT_{30} vs. LRA ΔT_{30}

obtained during the QA work and during the TB work, respectively, are shown in Figures 5 and 6.

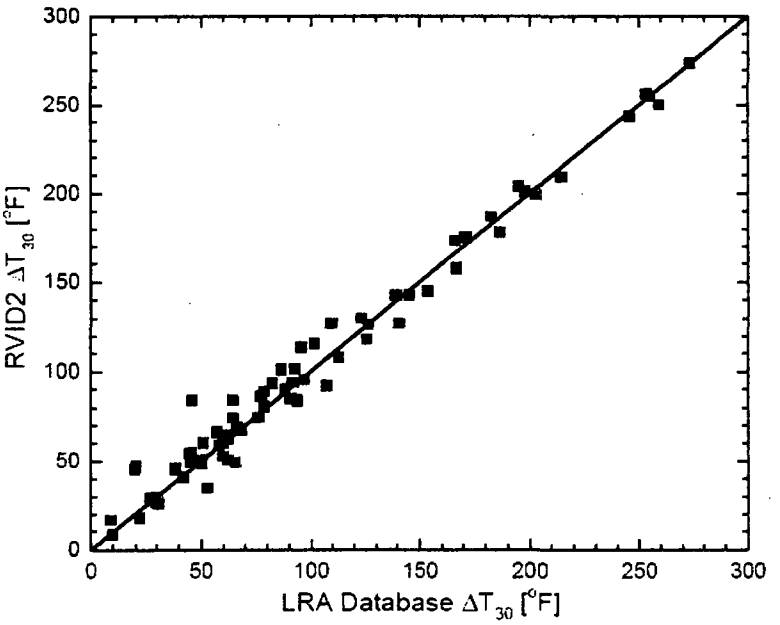

Figure 5: Comparison of ΔT_{30} calculations using two sets of input data, as determined during the QA work.

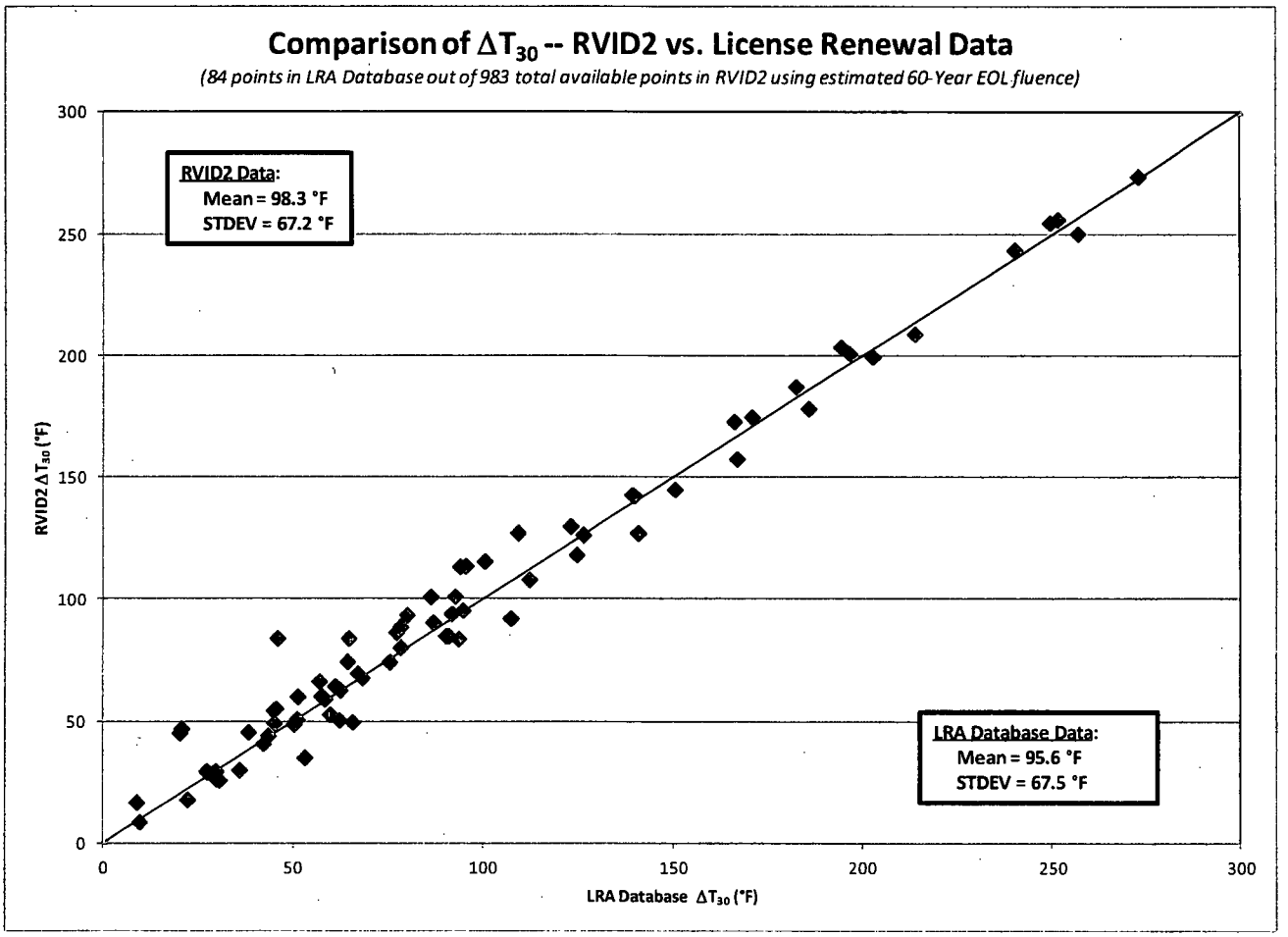

Figure 6: Comparison of ΔT_{30} calculations using two sets of input data, as determined during the TB work.

Qualitatively, Figures 5 and 6 show reasonable agreement.

The input fluence values were independently extracted from license renewal-related documents, in order to provide assurance that calculation inputs were correct. Some of the values were found in responses to Requests for Additional Information, rather than in the LRAs. The results of this work uncovered four cases: (1) the fluence value extracted during the QA work did not agree with the TB value to within 5% (Not Confirmed), (2) the fluence value extracted during the QA work agreed with the TB value to within 5% (OK), (3) the source documents were unclear, such that the TB value could neither be verified nor disproven (Unable to Confirm), and (4) the fluence value extracted from the source documents was for the 1/4t (where t is the vessel thickness) location, rather than the inner diameter location. Table 5 delineates the number of each case, and Table 6 is a detailed comparison of the TB and QA fluence values.

Table 5: Results of the fluence input check: number of each case.

Not Confirmed	7
OK	35
Unable to Confirm	31
1/4t	11
Total	84

Table 5: Results of the fluence input check: detailed comparison.

Plant	Material	Location	QA Fluence at 54 EFPY [n/cm^2]	Fluence at 54 EFPY [n/cm^2]	QA Comments
ARKANSAS NUCLEAR 2	INT. SHELL AXIAL WELDS 2-203A,B,C	ID	5.43375E+19	8.726E+19	not confirmed
ARKANSAS NUCLEAR 2	LOWER SHELL C-8010-1	ID	5.72625E+19	5.726E+19	ok
BEAVER VALLEY 1	LOWER SHELL B6903-1	?	6.09E+19	6.090E+19	unable to confirm
BEAVER VALLEY 1	INTER SHELL AXIAL WELD 19-714	?	1.17E+19	1.170E+19	unable to confirm
BEAVER VALLEY 2	AXIAL WELDS	?	1.78E+19	6.240E+19	unable to confirm
BEAVER VALLEY 2	INTERMEDIATE SHELL B9004-1	?	6.22E+19	6.220E+19	unable to confirm
BROWNS FERRY 1	CIRC WELD WF-154	ID	1.95E+18	1.950E+18	ok
BROWNS FERRY 2	AXIAL WELDS	ID	2.49231E+18	2.388E+18	not confirmed
BROWNS FERRY 3	AXIAL WELDS ES	ID	2.4E+18	2.388E+18	ok
BRUNSWICK 1	CIRCUMFERENTIAL WELD	ID	3.24E+18	3.240E+18	ok
BRUNSWICK 1	LOWER INTERMEDIATE SHELL	ID	4E+18	4.000E+18	ok
BRUNSWICK 2	CIRCUMFERENTIAL WELD	ID	3.22E+18	3.200E+17	ok
BRUNSWICK 2	LOWER INTERMEDIATE SHELL	ID	3.98E+18	3.220E+18	ok
BRUNSWICK 2	NOZZLE FORGING N16A	ID	1.38E+18	1.380E+18	ok
COOPER	LOWER/ LOWER INT. SHELL CIRC WELD 1-240	ID	1.48E+19	1.480E+18	ok
COOPER	LOWER INTERMEDIATE SHELL G-2802-2	ID	1.95E+19	1.950E+18	ok
COOK 1	INT./ LOWER SHELL CIRC WELD 9-442	1/4t	1.9125E+19	3.185E+19	1/4t
COOK 2	INTERMEDIATE SHELL PLATE 10-2	1/4t	1.65938E+19	2.764E+19	1/4t
DRESDEN 2	LOWER SHELL	ID	5.7E+17	5.700E+17	ok
DRESDEN 2	LOWER SHELL AXIAL WELD	ID	5.7E+17	5.700E+17	ok

Table 5 (continued)

Plant	Material	Location	QA Fluence at 54 EFPY [n/cm^2]	Fluence at 54 EFPY [n/cm^2]	QA Comments
DRESDEN 3	LOWER INTERMEDIATE SHELL	ID	5.7E+17	5.700E+17	ok
DRESDEN 3	LOWER INT. TO LOWER SHELL CIRC WELD	ID	5.7E+17	5.700E+17	ok
DUANE ARNOLD	AXIAL WELDS	ID		4.900E+18	unable to confirm
DUANE ARNOLD	AXIAL WELDS	ID		6.290E+18	unable to confirm
DUANE ARNOLD	CIRC WELD	ID		5.850E+18	unable to confirm
DUANE ARNOLD	CIRC WELD	ID		5.850E+18	unable to confirm
DUANE ARNOLD	AXIAL WELDS	ID		4.900E+18	unable to confirm
DUANE ARNOLD	AXIAL WELDS	ID		6.290E+18	unable to confirm
DUANE ARNOLD	CIRC WELD	ID		5.850E+18	unable to confirm
DUANE ARNOLD	LOWER INTERMEDIATE SHELL 1-20	ID		5.850E+18	unable to confirm
DUANE ARNOLD	LOWER INTERMEDIATE SHELL 1-20	ID		5.850E+18	unable to confirm
DUANE ARNOLD	LOWER INTERMEDIATE SHELL 1-21	ID		7.510E+18	unable to confirm
DUANE ARNOLD	LOWER INTERMEDIATE SHELL 1-21	ID		7.510E+18	unable to confirm
DUANE ARNOLD	NOZZLE N2	ID	6.82E+17	6.820E+17	ok
DUANE ARNOLD	NOZZLE N16	ID	2.89E+18	2.890E+18	ok
FARLEY 1	LOWER SHELL AXIAL WELDS	1/4t	1.25E+19	2.007E+19	1/4t
FARLEY 1	LOWER SHELL B6919-1	1/4t	4E+19	6.470E+19	1/4t
FARLEY 2	INTERMEDIATE SHELL B7212-1	1/4t	3.92E+19	6.290E+19	1/4t
FARLEY 2	INTERMEDIATE SHELL B7212-1	ID		6.290E+19	unable to confirm
FITZPATRICK	LOWER INTERMEDIATE SHELL	ID	3.11E+18	3.110E+18	not confirmed
FITZPATRICK	LOWER SHELL AXIAL WELDS 2-233A/C	ID	2.34E+18	2.340E+18	not confirmed
FITZPATRICK	CIRC WELD 1-240	ID		2.340E+18	unable to confirm

Table 5 (continued)

Plant	Material	Location	QA Fluence at 54 EFPY [n/cm^2]	Fluence at 54 EFPY [n/cm^2]	QA Comments
GINNA	LOWER SHELL	ID	5.03654E+19	5.037E+19	ok
GINNA	INT./LOWER SHELL CIRC. WELD SA-847	ID	5.03654E+19	5.037E+19	ok
KEWAUNEE	INT./LOWER CIRC. WELD	ID	5.56583E+19	5.566E+19	ok
MILLSTONE 2	LOWER SHELL C-506-1	ID	4.05E+19	4.050E+19	ok
MILLSTONE 3	INTERMEDIATE SHELL B9805-1	ID	3.31E+19	3.310E+19	ok
MONTICELLO	WELDS	ID	5.17E+18	5.170E+18	ok
MONTICELLO	LOWER/INT. SHELL I-14	ID	5.17E+18	5.170E+18	ok
NINE MILE POINT 1	UPPER SHELL G-307-4	ID		4.440E+18	unable to confirm
NINE MILE POINT 2	NUMBER 1 SHELL	ID		1.450E+18	unable to confirm
OYSTER CREEK	LOWER-INT. SHELL G-8-6	ID		7.528E+18	unable to confirm
OYSTER CREEK	LOWER-INT. SHELL AXIAL WELDS 2-564D,E,F	ID	4.0068E+18	4.007E+18	ok
PALISADES	D-3804-1	ID		3.821E+19	unable to confirm
PALISADES	INTERMEDIATE SHELL AXIAL WELDS 2-112 A/C	ID		2.656E+19	unable to confirm
PALISADES	LOWER SHELL AXIAL WELDS 3-112A/C	ID		2.656E+19	unable to confirm
PALISADES	CIRC. WELD 9-112	ID		3.821E+19	unable to confirm
PALO VERDE 1	INTERMEDIATE SHELL M-6701-2	ID	2.52625E+19	3.290E+19	not confirmed
PALO VERDE 1	INTERMEDIATE SHELL M-6701-3	ID	2.52625E+19	3.290E+19	not confirmed
PALO VERDE 1	INTERMEDIATE SHELL M-6701-1	ID	2.52625E+19	3.290E+19	not confirmed
POINT BEACH 1	CIRCUMFERENTIAL WELD SA-1101	ID		5.003E+19	unable to confirm
POINT BEACH 2	INTERMEDIATE TO LOWER SHELL CIRC. WELD SA1484	ID		5.186E+19	unable to confirm

Table 5 (continued)

Plant	Material	Location	QA Fluence at 54 EFPY [n/cm^2]	Fluence at 54 EFPY [n/cm^2]	QA Comments
QUAD CITIES 1	LOWER SHELL	ID	5.7E+17	4.229E+17	ok
QUAD CITIES 1	LOWER INT. TO LOWER SHELL CIRC WELD	ID	5.7E+17	4.229E+17	ok
QUAD CITIES 2	LOWER SHELL	ID	5.7E+17	4.179E+17	ok
QUAD CITIES 2	LOWER INTERMEDIATE & LOWER SHELL AXIAL WELDS	ID	5.7E+17	5.700E+17	ok
ROBINSON 2	UPPER CIRC WELD 10-273	ID	2.7E+19	2.700E+19	ok
ROBINSON 2	UPPER SHELL W10201-2	ID		2.700E+19	unable to confirm
ROBINSON 2	INTERMEDIATE SHELL AXIAL WELDS 2-273A,B,C	ID	4.8168E+19	2.700E+19	ok
ROBINSON 2	UPPER SHELL W10201-3	ID		2.700E+19	unable to confirm
SUSQUEHANNA 1	LOWER INTERMEDIATE SHELL 22-2	ID	1.41E+18	1.410E+18	ok
SUSQUEHANNA 2	LOWER INTERMEDIATE SHELL 22-1	ID	1.42E+18	1.420E+18	ok
TMI-1	LOWER SHELL	ID	2.04577E+19	2.047E+19	ok
TMI-1	NOZZLE BELT/ UPPER SHELL CIRC WELD WF-70	ID	1.90662E+19	1.907E+19	ok
SUMMER	WELDS	ID		6.400E+19	unable to confirm
SUMMER	INTERMEDIATE SHELL	ID		6.400E+19	unable to confirm
VERMONT YANKEE	WELDS	1/4t		5.390E+17	1/4t
VERMONT YANKEE	WELDS	ID		5.390E+17	unable to confirm
VERMONT YANKEE	LOCATION UNKNOWN 1-14	ID	1.24E+18	5.390E+17	ok
VERMONT YANKEE	LOCATION UNKNOWN 1-15	1/4t	3.98E+17	5.390E+17	1/4t
VOGTLE 1	INTERMEDIATE SHELL B8805-2	1/4t	1.91E+19	3.032E+19	1/4t
VOGTLE 1	AXIAL AND GIRTH WELDS	1/4t	1.91E+19	8.451E+17	1/4t
VOGTLE 2	AXIAL WELDS	1/4t	1.8E+19	7.299E+17	1/4t
VOGTLE 2	LOWER SHELL B8628-1	1/4t	1.8E+19	7.299E+17	1/4t

Extracting fluence values from LRAs or related documents is a tedious process with large potential for error. The manner in which licensees report projected fluence values varies from document to document. In addition to the issue of location (i.e., 0.25t or inner diameter), the Effective Full Power Years number may vary from document to document. Therefore, the data must be extracted and used with due care and attention to detail.

Conclusions

The results of the QA effort for the beltline chapter support the following conclusions.

1. Fluence maps reported in the draft TB document were independently confirmed.
2. ΔT_{30} calculations using both the RG 1.99 Revision 2 method and the 10 CFR 50.61a method were independently confirmed.
3. With the exception of small errors in inputs, which were corrected, the calculations performed to benchmark the use of the RVID2 database against license renewal data were independently confirmed.
4. The extraction of license renewal fluence data was not completely confirmed, although some agreement was observed. This process has a large potential for error, since the data can be reported over a range of vessel locations and EFPY. Proper use of the data requires careful attention to the differences in the way these values are reported.