CONF-870501--2

APPLICATION OF THE LEPRICON METHODOLOGY TO
LWR PRESSURE VESSEL SURVEILLANCE DOSIMETRY*

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CONF-870501--2

DE87 009675

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*Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555
under Interagency Agreement 0551-0551-A1

NRC FIN No. B0415

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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APPLICATION OF THE LEPRICON METHODOLOGY TO
LWR PRESSURE VESSEL SURVEILLANCE DOSIMETRY

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ABSTRACT: A second example of applying the LEPRICON methodology to an existing pressurized water reactor is described. The present application is an analysis of ad hoc dosimetry inserted into the H. B. Robinson-2 reactor to monitor the effects on pressure vessel fluence produced by the introduction of a low-leakage fuel management scheme during cycle 9. The use of simultaneous dosimetry at both a downcomer location and in the reactor cavity allows a quantitative evaluation to be made by the LEPRICON procedure of the relative merits of each location, and the cavity location is found to be superior. Unfolded results using the dosimetry indicate that the cumulative neutron fluence above 1.0 MeV originally calculated for the critical lower circumferential weld in the pressure vessel during cycle 9, $7.2 \times 10^{17} \text{ n/cm}^2 \pm 15.9 \text{ percent}$, should be adjusted upward by about one standard deviation to a value of $8.8 \times 10^{17} \text{ n/cm}^2$ with a reduced uncertainty of 10.9 percent.

KEY WORDS: pressure vessel surveillance, neutron transport, in-vessel and ex-vessel dosimetry, adjustment methods, sensitivity, covariance, uncertainty

*Research sponsored by Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission under Interagency Agreement 0551-0551-A1 with the U.S. Department of Energy under contract DE-AC05-84OR21400 with the Martin Marietta Energy Systems, Inc.

I. INTRODUCTION

Previous papers^(1,2,3) have described the development of the LEPRICON methodology and code system⁽⁴⁾ and its application to cavity dosimetry measurements performed in the Arkansas Nuclear One-Unit 1 reactor (ANO-1). The purpose of this paper is to present the results of a second application of the LEPRICON system to cycle 9 of H.B. Robinson-2 (HBR-2) this time using the completed set of modules involving both transport and adjustment. In addition, this new application involves an analysis of simultaneous in-vessel and ex-vessel dosimetry as well as considering potential problems introduced by a narrow reactor cavity complicated by the geometry of neighboring detector wells, none of which was present in the previous ANO-1 analysis.

Conventional dosimetry (i.e., sequential extraction of downcomer-positioned surveillance capsules only) had been utilized over the first eight cycles of reactor operation. Investigations into pressurized thermal shock (PTS) suggested that the accumulation of fast neutron fluence should be reduced for reactor operation in order to maintain an adequate margin for the PTS at such locations as the lower circumferential weld (LCW).

To this end, a change in the fuel loading pattern was introduced at the beginning of cycle 9. Instead of being removed, previously burned fuel was placed in the outermost row of the core in the assemblies defining the flats at 0-deg azimuth (see Fig. 1). (The remaining peripheral assemblies were still replaced with fresh fuel, however.) This azimuth defines the location of maximum fluence rate in the pressure vessel and hence is the azimuth at

Fig. 1. R- θ Octal Section at the Midplane of the HBR-2 Reactor. The location of the maximum fluence in the pressure vessel is along the zero-degree azimuth.

which the fluence accumulated at the LCW, located about 1150 mm (3.77 ft) below the reactor midplane, is considered to be of critical importance.

In order to validate the effectiveness of the low-leakage core, special dosimetry was introduced during cycle 9 at several locations. A standard Westinghouse surveillance capsule containing only dosimetry was inserted into an available holder at the 20-deg azimuth location in the downcomer as indicated in Fig. 1. This capsule contained dosimetry that included six threshold reactions, as well as several other foils that involved low-energy responses which were not analyzed with LEPRICON. Dosimetry using the same threshold reactions was also simultaneously inserted into the reactor cavity at 0-deg azimuth (see Fig. 1) by means of a thin aluminum holder that could be assumed to be transparent to neutrons. The holder was attached to a stainless steel wire that itself was secured near the top and bottom of the cavity. Both the downcomer dosimetry and the 0-deg cavity dosimetry were located in the reactor midplane and constituted the measurements⁽⁵⁾ to be analyzed in the LEPRICON adjustment procedure. Additional dosimetry measurements were performed in the cavity at 12, 30, and 42 degrees. Except for the 42-deg location (not shown in Fig. 1), all the measurements were located in the same octant.

II. CALCULATIONS OF ACTIVITIES AND PRESSURE VESSEL

FLUENCES DURING CYCLE 9

II.A. Geometry and Materials Description

An octal section through the horizontal midplane of the HBR-2 reactor to beyond the biological shield is shown in Fig. 1 in the

form of a plot of the R- θ variable mesh geometry employed in the transport calculations. The reactor cavity region immediately behind the 241.55-mm (9.51-in.) thick pressure vessel is 170.7 mm (6.72 in.) wide. There are two relatively large detector wells in the cavity at 0 and 45 deg (only the one at 0 deg was approximated in the R- θ geometry and is pictured), each containing an empty 6.35-mm (0.25-in.) thick iron pipe.

II.B. Source Description

The three-dimensional (3-D) source distributions as a function of time throughout cycle 9 were determined in a fashion consistent with the source preparation module DOTSOR⁽⁶⁾ in the LEPRICON system. Through the cooperation of W. K. Cantrell and S. P. Grant of Carolina Power and Light (CP&L), measured data processed by the Westinghouse INCORE program were made available which provided instantaneous assembly power information at various axial levels throughout the core for several different times during the cycle. Pin power distributions calculated by PDQ7 were also supplied at approximately the same cycle exposure increments as those represented by the INCORE results. Fission neutron source data for the midplane R- θ transport calculations were then obtained by normalizing the pin power data to the axially integrated INCORE powers for each peripheral assembly and using an exposure-dependent conversion factor typical of the multiply burned peripheral assemblies at 0 deg azimuth to relate source strength to power level. Fission spectra were also used that were intermediate between the ENDF/B-V values of the fission spectra for ²³⁵U and ²³⁹Pu. In all, eight of these absolute midplane source distributions were determined at roughly

equal exposure increments throughout the cycle. Normalized to full power, they indicated that the core leakage near 0 deg increased by about 60 percent during the cycle.

Daily averages of the reactor power operating levels and accumulated exposures were also furnished by CP&L to inject intensity fluctuations into the eight spatial source distributions on a fine enough scale that the end-of-cycle dosimeter activities and accumulated pressure vessel fluences could be accurately calculated.

The changes in the relative axial distributions during cycle 9 for all peripheral assemblies, as indicated by the INCORE data, were small. The effect was a slightly further flattening of an already flat distribution.

II.C. Reference Calculations

Three reference transport calculations using the ELXSIR cross-section library⁽⁷⁾ were performed - one each in R- θ , R-Z, and R geometries. The axially integrated source for the R- θ calculation was taken to be the one compounded from INCORE and PDQ7 data near midcycle. The DOTSOR module was used to prepare not only the R- θ reference source but also the other remaining seven R- θ distributions. The same module also was used to prepare the reference azimuthally integrated R-Z source. The ex-core R-Z mesh described the geometry at 0 deg azimuth since this is the direction of greatest interest. The DOTSOR module also prepared the reference R source, obtained by integrating the reference R-Z source over Z, for use in a one-dimensional ANISN transport calculation. The results from each of these three reference calculations were then combined in a flux synthesis procedure to yield 3-D reference fluxes throughout the

reactor geometry using the DOTSYN⁽⁸⁾ module of the LEPRICON system.

The azimuthal profile at one-quarter depth into the pressure vessel (the T/4 location) using the results of the reference R- θ calculation indicates that there is about a threefold decrease in the flux above 1.0 MeV at 45 deg compared to the flux above 1.0 MeV at 0 deg. Thus although the azimuth of maximum flux remains 0 deg, the substitution of multiply burned fuel for fresh fuel in the peripheral assemblies near 0 deg in cycle 9 has decreased the flux in the vicinity of the major core axis by about a factor of 2.4 over that of earlier cycles.

The axial profile at 0-deg azimuth on the inner surface of the pressure vessel as determined by the R-Z reference calculation is very similar to that of the source. The critical location of the LCW was observed to lie within the flat part of the profile, so that little error should be introduced in using the flux synthesis procedure at this off-midplane location.

Effects of axial leakage produced by the finite core height are small in HBR-2. Leakage factors, as determined from the R-Z and R reference calculations, are virtually unity for all group fluxes at in-vessel and critical pressure vessel locations, and they lie between 0.92 and 0.98 for the six dosimeter responses in the cavity.

II.D. Time-Dependent Calculations

The procedures described in Refs. 2 and 3 were followed to incorporate the effects of time dependence of the source spatial distribution into the LEPRICON methodology by using an appropriately chosen adjoint function calculated with the same variable mesh R- θ geometry employed in the forward calculation with the reference

source. As suggested in Ref. 3, the $^{54}\text{Fe}(n,p)^{54}\text{Mn}$ reaction cross section was used to generate the adjoint function, with the adjoint source being placed at the location of the 0-deg cavity dosimetry. The resulting adjoint fluxes were then folded with the reference R-0 source in a steady-state calculation using the TIMEPATCH⁽⁹⁾ module, another part of the LEPRICON system. By means of the adjoint-scaling technique introduced and discussed in Refs. 2 and 3, pressure vessel group fluences and all dosimeter end-of-cycle activities were obtained by folding the adjoint function with each of the eight midplane sources in turn, superimposing the power history, and decaying the activities. These operations were all accomplished using the time-dependent option of the TIMEPATCH module.

II.E. Calculated End-of-Cycle Activities and Comparison with Measurements

Calculations of the end-of-cycle dosimeter activities are compared with the measurements in Table I. ENDF/B-V values of 0.06 and 0.06267 were used for ^{137}Cs yields from fission in ^{238}U and ^{237}Np , respectively. After the estimated contributions from several competing reactions in the measurements are considered, the calculated-to-measured (C/E) ratios for the different reactions at a given location are seen to be quite consistent with one another. The average C/E values of 0.93 and 0.66 at the two locations indicate the presence of underpredictory elements in the calculation, however, which have also consistently occurred in past analyses of the PCA and PSF benchmark experiments⁽¹⁾ as well as the ANO-1 reactor⁽²⁾, and which have been ascribed principally to inaccuracies in the ENDF/B-V total iron inelastic cross section (see Section III).

Table I. Comparison of Calculated and Measured End-of-Cycle Activities

Activity in dps/atom						
	$^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$	$^{46}\text{Tl}(n,p)^{46}\text{Sc}$	$^{54}\text{Fe}(n,p)^{54}\text{Mn}$	$^{58}\text{Ni}(n,p)^{58}\text{Co}$	$^{238}\text{U}(n,f)^{137}\text{Cs}$	$^{237}\text{Np}(n,f)^{137}\text{Cs}$
<u>Downcomer Location</u>						
Calculated	3.26-18 ^a	2.78-16	1.23-15	2.21-15	1.60-17	1.19-16
Measured	3.94-18	3.44-16	1.49-15	2.55-15	2.00-17	1.40-16
C/E	0.83	0.81	0.83	0.87	0.80	0.85
<u>0-deg Cavity Location</u>						
Calculated	2.84-20	2.13-18	9.43-18	1.85-17	1.97-19	5.10-18
Measured	3.94-20	3.25-18	1.39-17	2.80-17	3.02-19	8.36-18
C/E	0.72	0.66	0.68	0.66	0.65	0.61

^aRead as 3.26×10^{-18} .

A comparison of calculated and measured axial cavity profiles at 0 deg indicates reasonable agreement. This conclusion rests on the observation that the off-midplane comparisons are no worse than the midplane values. Since no higher quadrature set was used in the R-Z transport calculation in the cavity than anywhere else (a symmetric S₈ set was used throughout), it can be concluded that there is no obvious streaming problem in the HBR-2 cavity. The flatness of the core source over the axial range investigated probably masks any streaming effects that might otherwise occur here.

III. ESTIMATED UNCERTAINTIES IN THE CALCULATED RESULTS

The LEPRICON procedure identifies and treats various sources of uncertainty that from previous experience in the development of the benchmark data base, as well as from the analysis of the ANO-1 reactor, can lead to non-negligible uncertainties in the calculated pressure vessel fluxes and dosimeter activities. For the particular application to HBR-2, six bias factors in addition to three types of nuclear data were considered in contributing to the covariances of the calculated quantities that were presented in Section II.

The nuclear data considered, standard for all applications, are the total inelastic cross sections of the major components of steel, the spectrum arising from thermal fission of the reactor fuel, and the reaction cross sections of the dosimeters.

The six bias factors deemed applicable to the HBR-2 analysis are listed in Table II. The uncertainties in the geometric and materials data which give rise to the flux uncertainties are based on discussions with qualified researchers⁽¹⁰⁾ as well as our own

Table II. Flux Bias Factors Assumed in the Calculations and Their Correlations

Bias Factor	Source of Bias Factor Uncertainty	Locations	Complete Flux Correlations	
			Auto	Cross
1	Dosimetry capsule location	Downcomer only	0.9	
2	Finite capsule perturbation	Downcomer only	0.9	
3	Pressure vessel out-of-roundness	Cavity and pressure vessel	0.9	0.81 ^a
4	Coolant density	Downcomer, cavity and pressure vessel	0.9	0.81 ^b
5	Three-dimensional flux synthesis	Downcomer, cavity and pressure vessel	0.75	0.375-0.675 ^c
6	Steel density	Downcomer, cavity and pressure vessel	0.9	0.18-0.54 ^d

^aFor combinations involving either pressure vessel location.

^bFor combinations involving either pressure vessel location with either dosimetry location, as well as between the two dosimetry locations.

^c0.375 between downcomer and LCW locations and between LCW and cavity locations;

0.525 between downcomer and cavity locations and between downcomer and T/4 locations;

0.675 between T/4 and cavity locations.

^d0.18 between downcomer and cavity locations; 0.27 between either pressure vessel location and cavity location; 0.54 between downcomer location and either pressure vessel location.

limited experience, and their propagated contributions to the flux uncertainties were obtained from 1-D transport calculations⁽¹¹⁾. The flux uncertainties arising from each bias factor are in general dependent on both detector location and energy.

A breakdown of the various contributions to the flux uncertainties at the 0-deg midplane cavity dosimetry location is shown in Table III. Here the uncertainties in the steel total inelastic cross section dominate those from all other sources, accounting for virtually all of the flux uncertainties above 0.9 MeV. Calculated flux uncertainties in the cavity are seen to lie in the range of 20 to 35%, with the larger values occurring at the higher energies.

The complete correlation matrix of the calculated activities is shown in Table IV, where high degrees of correlation are seen to exist both among the activities at a given dosimetry location (the autocorrelations) and between the activities at different locations (the cross correlations). This is primarily due, of course, to the significant uncertainties in the steel total inelastic cross section that are propagated to all energies via the transport process and hence represent a strong source of correlation among all the calculated fluxes.

A very important consideration in the LEPRICON procedure for estimating the a priori covariances for HBR-2 are the cross correlations between the pressure vessel fluxes at the critical LCW location and both sets of dosimeter activities. As indicated in Ref. 2, the elements of this matrix determine the effectiveness of the adjustment procedure, for they indicate the degree to which the calculated pressure vessel fluxes are influenced by changes in the

Table III Standard Deviations in the Fluxes at the
Cavity Dosimeter Location Arising from
Parameter Uncertainties

Flux Group	Lower Energy (MeV)	Standard Deviation (%)						
		χ_{25}	$\sigma_{\text{steel}(n,n')}$	BF3	BF4	BF5	BF6	Total
1	11.1	14.1	29.6	6.7	3.7	2.5	5.5	34.3
2	8.2	10.6	30.8	7.3	4.0	2.5	5.8	34.3
3	6.1	8.1	29.8	7.9	4.4	2.5	6.3	32.9
4	4.1	6.4	32.2	8.6	4.9	2.5	6.6	35.0
5	3.0	6.1	29.8	9.2	5.5	2.5	6.4	33.0
6	2.6	5.5	21.8	9.6	5.7	2.5	6.2	26.0
7	2.1	5.1	21.3	9.9	6.0	2.5	6.0	25.6
8	1.8	5.2	20.6	9.9	6.0	2.5	5.8	25.0
9	1.5	5.2	19.9	10.1	6.2	2.5	5.5	24.5
10	1.2	5.1	20.0	10.2	6.3	2.5	5.2	24.6
11	0.9	5.2	18.0	10.3	6.5	2.5	4.5	22.9
12	0.6	5.1	12.0	10.5	6.4	2.5	3.8	18.5
13	0.4	5.1	12.0	10.6	6.9	2.5	3.4	18.7
14	0.2	5.1	12.2	10.7	6.9	2.5	2.8	18.7
15	0.1	5.1	12.0	10.7	7.1	2.5	2.8	18.7

Table IV. Complete Correlation Matrix of the Calculated Activities*

SD (%)	Downcomer Location						Cavity Location					
	⁶³ Cu	⁴⁶ Ti	⁵⁴ Fe	⁵⁸ Ni	²³⁸ U	²³⁷ Np	⁶³ Cu	⁴⁶ Ti	⁵⁴ Fe	⁵⁸ Ni	²³⁸ U	²³⁷ Np
<u>Downcomer Location</u>												
⁶³ Cu 19.7	100 ^a											
⁴⁶ Ti 20.3	96	100										
⁵⁴ Fe 20.9	93	98	100									
⁵⁸ Ni 21.0	93	97	99	100								
²³⁸ U 21.2	89	92	96	97	100							
²³⁷ Np 23.9	79	82	86	87	90	100						
<u>Cavity Location</u>												
⁶³ Cu 30.6	87	82	76	75	69	59	100					
⁴⁶ Ti 31.7	84	87	83	82	74	62	95	100				
⁵⁴ Fe 32.0	80	86	87	86	80	68	87	96	100			
⁵⁸ Ni 31.4	80	86	88	87	82	69	86	95	100	100		
²³⁸ U 30.0	78	82	86	86	86	74	80	88	95	96	100	
²³⁷ Np 29.0	76	80	83	83	83	89	73	80	85	87	89	100

*Matrix is symmetric; only the lower half is given.

^aAll elements have been multiplied by 100.

calculated activities when comparisons of calculated and measured activities at in-vessel or ex-vessel locations are made. Reasonably high values for these cross correlations are sine qua non to the success of the entire LEPRICON methodology. In the present case, these cross correlations vary between about 0.3 and 0.8 which, while not overwhelming, are probably adequate. The cross correlations between the LCW group fluxes and the cavity dosimetry are higher than those with the downcomer dosimetry by factors of between 1.2 and 1.8, thus clearly indicating the superiority of the cavity location in providing information about flux levels in the pressure vessel.

IV. ESTIMATED UNCERTAINTIES IN THE MEASUREMENTS

Following the procedure outlined in Ref. 2, covariances of the 12 dosimeter measurements in HBR-2 were estimated with the help of the experimentalists.⁽⁵⁾ Five sources of uncertainty were identified: random counting statistics, gamma-ray counter efficiency calibrations, bias factors arising from estimated contributions from competing reactions, bias factors from neglect of possible coincidence summing corrections, and normalization of the measured activities during exposure to one core neutron per second, as required by the LEPRICON adjustment module.

The resulting correlation matrix of the 12 dosimeter measurements from all sources of uncertainty is shown in Table V. The uncertainties in the measured activities are seen to be three to five times less than those of the calculations. It is for this reason that the measurements play such a critical role in directing the course of the adjustment procedure.

Table V. Complete Correlation Matrix of the Measured Activities*

	SD (X)	Downcomer Location						Cavity Location					
		⁶³ Cu	⁴⁶ Ti	⁵⁴ Fe	⁵⁸ Ni	²³⁸ U	²³⁷ Np	⁶³ Cu	⁴⁶ Ti	⁵⁴ Fe	⁵⁸ Ni	²³⁸ U	²³⁷ Np
<u>Downcomer Location</u>													
⁶³ Cu	6.72	100*											
⁴⁶ Ti	6.16	31	100										
⁵⁴ Fe	6.16	31	64	100									
⁵⁸ Ni	6.16	31	55	72	100								
²³⁸ U	8.00	24	26	26	26	100							
²³⁷ Np	6.65	29	32	32	32	78	100						
<u>Cavity Location</u>													
⁶³ Cu	6.72	54	31	31	31	24	29	100					
⁴⁶ Ti	6.16	31	64	44	42	26	32	31	100				
⁵⁴ Fe	6.16	31	44	64	47	26	32	31	64	100			
⁵⁸ Ni	6.16	31	42	47	64	26	32	31	55	72	100		
²³⁸ U	11.79	16	18	18	18	26	24	16	18	18	18	100	
²³⁷ Np	7.93	24	27	27	27	29	46	24	27	27	27	84	100
*Matrix is symmetric; only the lower half is shown.													

*Matrix is symmetric; only the lower half is given.

^aAll elements have been multiplied by 100.

V. RESULTS OF THE ADJUSTMENT

Table VI summarizes the results of the adjustment module⁽¹²⁾ for the critical LCW fluxes, based on activating various combinations of the HBR-2 downcomer and cavity dosimeters. It is again apparent that the cavity location is superior to the downcomer location when comparisons of the individual adjustments (based on activating only one location) with those of the combined adjustment (last column) are made. The deactivated cavity dosimeter in the last two columns of Table VI is the $^{237}\text{Np}(n,f)$ measurement, the exclusion of which changes the value of chi-square per degree of freedom from 1.15 to 1.00, and is hence considered the optimum adjustment. The standard deviations appearing in the column labeled "None" represent the a priori values, and it can be seen that these uncertainties have been reduced in the adjustment procedure by factors of between 1.2 and 1.9. Based on the optimum adjustment, a comparison of the values and standard deviations of various spectrally weighted fluences accumulated at the critical LCW location during cycle 9 are shown in Table VII for the a priori and a posteriori conditions.

VI. CONCLUSIONS

It has been demonstrated that the LEPRICON computer code system, as it now exists, can be successfully applied to the analysis of simultaneous in-vessel and ex-vessel dosimetry. Since the reactor design as well as in-core instrumentation analysis procedures for the HBR-2 and ANO-1 reactors are different, the code system has been shown to be sufficiently general to be able to treat geometries of considerable diversity, as well as being capable of taking advantage of core-follow analysis routinely performed by

Table VI. Flux Adjustments and Standard Deviations at the Critical LCW Pressure Vessel
Location as Functions of HBR-2 Measurements Activated

Flux Group	Lower Energy (MeV)	None	34 Benchmarks +			
			6 Downcomer Only	6 Cavity Only	5 Cavity Only	6 Downcomer + 5 Cavity
1	11.1	0 ± 20.6 ^a	-0.5 ± 12.5	4.5 ± 11.2	5.7 ± 11.3	8.2 ± 11.0
2	8.2	0 ± 19.0	-3.5 ± 12.4	2.1 ± 10.9	3.3 ± 10.9	6.3 ± 10.5
3	6.1	0 ± 17.8	22.9 ± 12.1	26.7 ± 10.8	27.5 ± 10.8	29.9 ± 10.3
4	4.1	0 ± 18.2	25.3 ± 12.9	29.0 ± 11.4	29.5 ± 11.4	32.0 ± 10.8
5	3.0	0 ± 18.1	23.2 ± 13.5	27.3 ± 12.1	27.4 ± 12.1	30.1 ± 11.5
6	2.6	0 ± 16.5	12.2 ± 13.8	15.5 ± 12.4	16.7 ± 12.4	20.3 ± 11.8
7	2.1	0 ± 16.5	9.2 ± 14.2	12.4 ± 12.7	13.9 ± 12.7	17.9 ± 12.1
8	1.8	0 ± 16.5	9.9 ± 14.1	13.5 ± 12.7	14.6 ± 12.7	18.4 ± 12.2
9	1.5	0 ± 16.5	9.7 ± 14.2	13.5 ± 12.9	14.6 ± 12.9	18.4 ± 12.3
10	1.2	0 ± 16.5	9.6 ± 14.3	13.8 ± 12.9	14.5 ± 12.9	18.3 ± 12.3
11	0.9	0 ± 16.2	10.4 ± 14.1	15.9 ± 12.8	15.2 ± 12.8	18.7 ± 12.3
12	0.6	0 ± 15.5	11.4 ± 13.9	19.0 ± 12.8	15.5 ± 12.9	18.2 ± 12.5
13	0.4	0 ± 15.7	11.5 ± 14.1	18.8 ± 13.0	15.5 ± 13.1	18.3 ± 12.7
14	0.2	0 ± 15.6	11.6 ± 14.0	18.5 ± 13.0	15.7 ± 13.0	18.5 ± 12.7
15	0.1	0 ± 15.7	11.4 ± 14.1	18.2 ± 13.0	15.5 ± 13.1	18.5 ± 12.7

^aRead as a change of 0 percent with a standard deviation of 20.6 percent.

Table VII. Weighted Fluences at the Critical Pressure Vessel Location Accumulated During Cycle 9 with Standard Deviations Before and After Unfolding

	Before	After
Fluence above 1.00 MeV	$7.23(17) \pm 1.15(17)^a$	$8.75(17) \pm 0.96(17)$
Fluence above 0.098 MeV	$1.99(18) \pm 0.30(18)$	$2.37(18) \pm 0.27(18)$
dpa above 0.098 MeV	$1.11(-3) \pm 0.17(-3)^b$	$1.34(-3) \pm 0.15(-3)$

^aRead as $7.23 \times 10^{17} \pm 1.15 \times 10^{17}$ n/cm².

^bRead as $1.11 \times 10^{-3} \pm 0.17 \times 10^{-3}$ displacements per atom of iron.

different vendors such as Westinghouse and Babcock and Wilcox.

Of the two dosimetry locations simultaneously employed in HBR-2, those in the cavity offer more information on the pressure vessel fluxes because they possess higher sensitivity to inaccuracies in the steel transport cross sections which strongly affect the pressure vessel fluxes; they are also sensitive to the same bias factors that influence the pressure vessel fluxes.

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10. Minutes of ASTM Subcommittee 10.05.01 meeting held in January 1980.
11. It has recently been suggested that the uncertainties in the pressure vessel out-of-roundness bias factor proposed in Ref. 10 should be revised downward. As long as the uncertainties are dominated by the iron inelastic cross section, however, this reassessment should result in minor changes in the adjustments. The author is indebted to F. Walters, N. Snidow, and D. Nitti of Babcock and Wilcox for making this suggestion.
12. B. L. Broadhead, R. E. Maerker, and J. J. Wagschal, "The LEPRICON Adjustment Module: A Generalized Linear Least Squares Data Analysis Program with Application to PWR Surveillance Dosimetry," Electric Power Research Institute, to be published.