VALIDATION OF LEPRICON ADJUSTED FLUX THROUGH VENUS-1 EXPERIMENTS

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ABSTRACT

The best-estimate pressure vessel fluence is obtained by combining the calculated activities and measured values of dosimeters at the surveillance capsules. In this paper, the LEPRICON adjusted flux at the pressure vessel is validated using the VENUS-1 experimental results. The LEPRICON system is based on a generalized linear least-square method and determines best-estimate group fluxes with uncertainties at the pressure vessel by considering the correlation to the activities at the surveillance capsule. The experiment performed at the VENUS-1 reactor provides activity data at the water gap II and neutron pad which correspond to the downcomer surveillance capsule and pressure vessel locations of a power reactor, respectively. The neutron fluxes and uncertainties at the neutron pad are calculated according to the adjustment procedure using the calculated and measured activities at the water gap II. The LEPRICON adjustment improved the results both at the water gap II and neutron pad. The Calculation-to-Experiment (C/E) ratios of reaction rates at the neutron pad are improved by about 10% while the uncertainties reduced by about 40% as compared to the unadjusted results.

1. INTRODUCTION

The determination of the best-estimate pressure vessel fluence is important for the evaluation of RT_{NDT} and RT_{PTS}, which are used for the fracture toughness analysis of the pressure vessel. Several unfolding code systems based on the least-square statistical approach are being used for the best-estimate pressure vessel fluence and its uncertainty calculation. However, the validation of the calculated fluxes at the pressure vessel is difficult if the measured data at the pressure vessel are not provided. In this analysis, the validation of the vessel flux calculated using the LEPRICON code system[1] is attempted by comparing with the VENUS-1 experimental results.

Most unfolding codes calculate the pressure vessel fluence using the ratio between adjusted and measured reaction rates at the surveillance capsule. This approach may not be adequate because the ratio between adjusted and measured reaction rates at the surveillance capsule is not the same as the ratio at the vessel. Moreover, these codes do not generate the uncertainty of the extrapolated flux. The LEPRICON calculation, however, quantifies and reduces the uncertainties by combining the calculated and measured activities along with the differential data and their covariances[2].

The VENUS-1 reactor[4] has the heterogeneity of the PWR core and provides various measurement data over the whole reactor region. The core has two types of fuels; the inner core zone has 3.3% enriched fuel cells with zircaloy clad while the outer zone has 4.0% enriched fuel cells with stainless steel clad. There are 48 pyrex rods in the 3.3% enriched fuel region. A water hole exists at the center of the core and inner baffle around it. The remaining configuration consists of outer baffle which surrounds the core, core barrel, neutron pad, air jacket and vessel. In this analysis, the fluxes and their uncertainties at the neutron pad are calculated using the measured and calculated reaction rates at the water gap II, differential parameters and their covariances. Also, the reaction rates of indium dosimeters installed on the neutron pad are calculated using these fluxes and compared with the measured values for validating the adjustment procedure.

The method of the transport calculation is described in section 2, and the uncertainties involved in the LEPRICON calculation and the outcome of the unfolding calculation are explained in section 3. Results are summarized in section 4.

2. TRANSPORT CALCULATION

The VENUS-1 reactor is assumed to be of an octant symmetry and modeled using RΘ coordinates. The center of outer surface of the neutron pad, air jacket and vessel is assumed to be a core center. The thickness of the neutron pad is assumed to be an average thickness. The 103x80 meshes are used for the DORT[3] RΘ model as shown in Figure 1. The macroscopic cross sections for the DORT analysis are calculated using 56 group ELXSIR library included in the LEPRICON code system and the GIP code[3].

The 3-dimensional flux distribution is calculated using general synthesis method. The axial flux distribution is calculated using 2-dimensional RZ flux normalized to 1-dimensional radial flux. The same material zone numbers with those of azimuthal angle 21°in RΘ calculation are assigned. The azimuthal angle 21°corresponds to the position that is expected to have the

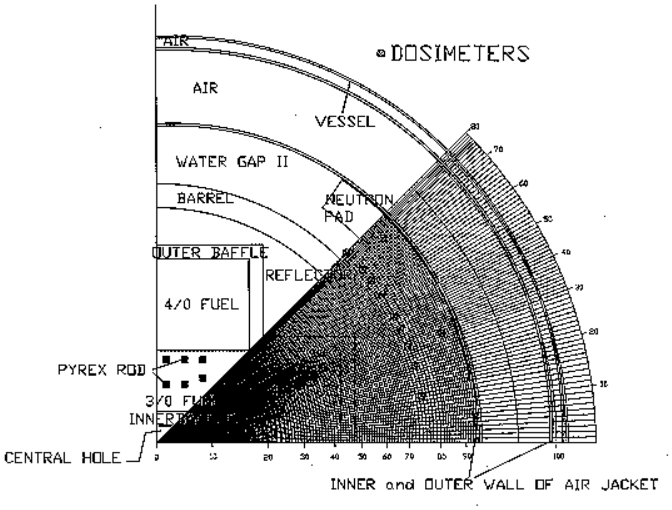

Figure 1. DORT RΘ Modeling

maximum flux at the neutron pad. The axial source distribution is assigned as cosBz, where B is the measured vertical buckling of the core. As the axial source distribution is cosine shape, the distributions in the whole reactor region show similar cosine shape except that the cosine shape gets flatter as going far from the core to the neutron pad. All dosimeters are assumed to be point detectors without surrounding structures, and the reaction rates are calculated using the fluxes at the corresponding detector position.

The C/E ratios for the dosimeters located at the water gap II are shown in Table 1. The values in Table 1 are calculated considering the photo-fission effect and the effect of cadmium sheet surrounding ^{238}U and ^{237}Np fission chambers. The underestimation of the reaction rates is partly due to the use of ENDF/B-V microscopic iron cross sections.

Table 1. C/E Ratios for Dosimeters at Water Gap II Region

Location	Calculation/Experiment		
	^{115}In(n,n')	^{238}U(n,f)	^{237}Np(n,f)
R=55.2 cm, θ=10.8°	0.92	0.86	0.90
R=55.2 cm, θ=16.6°	0.93	0.88	0.87
R=55.2 cm, θ=21.1°	0.92	0.83	-
R=55.2 cm, θ=25.6°	0.94	0.90	0.92
R=55.2 cm, θ=28.8°	0.93	0.89	0.89
R=55.2 cm, θ=33.9°	0.98	0.92	0.97
R=55.2 cm, θ=37.4°	-	0.90	0.92
R=55.2 cm, θ=41.0°	0.97	-	-
R=55.2 cm, θ=45.0°	0.99	0.93	0.90

3. LEPRICON CALCULATION

The LEPRICON adjustment module combines measured and calculated reactor surveillance data and their uncertainties with a database of benchmark experiments to arrive at best estimates of the pressure vessel fluxes with reduced uncertainties. For the LEPRICON calculation of the VENUS-1 reactor, the methodology for the downcomer dosimetry analysis is applied. The group fluxes are adjusted and the flux uncertainties are calculated using the measured and calculated reaction rates, differential parameters and their covariances. The indium reaction rates at the neutron pad are calculated using adjusted group fluxes and compared with the measured values to validate the adjusted group fluxes.

3.1 UNCERTAINTY IN CALCULATED VALUES

The sources of the uncertainty in LEPRICON system come from nuclear data such as total inelastic scattering cross section of steel, ^{235}U fission spectrum and reaction cross section as well as non-nuclear data such as the geometric and material data. Among the bias factors arising from non-nuclear data, the absolute capsule location, 3-dimensional flux synthesis effect and the steel density variation effect are applied for the VENUS-1 analysis. The covariance of the group flux is calculated as the combined contributions of all differential parameters. The standard deviations in the group fluxes at the neutron pad are shown in Table 2. The water gap II group fluxes have also the uncertainty source from capsule location besides the parameters in Table 2.

Table 2. Standard Deviations in the Fluxes at Neutron Pad Arising from Parameter Uncertainties

Flux Group	Upper Energy (MeV)	Standard Deviation(%)				Total
		Nuclear Data		Bias Factor		
		χ_{25}	$\Sigma_{steel(n,n')}$	Synthesis	Steel dens.	
1	19.640	14.1	8.7	2.0	3.0	16.96%
2	11.050	10.6	9.1	2.0	3.1	14.43%
3	8.187	8.1	8.8	2.0	3.4	12.57%
4	6.065	6.4	9.4	2.0	3.6	12.11%
5	4.066	6.1	8.7	2.0	3.5	11.36%
6	3.012	5.5	6.4	2.0	3.3	9.25%
7	2.592	5.1	6.3	2.0	3.2	8.91%
8	2.123	5.2	6.1	2.0	3.1	8.80%
9	1.827	5.2	5.8	2.0	3.0	8.59%
10	1.496	5.1	5.9	2.0	2.9	8.55%
11	1.225	5.2	5.3	2.0	2.6	8.12%
12	.907	5.1	3.6	2.0	2.4	6.97%
13	.608	5.1	3.6	2.0	2.1	6.87%
14	.369	5.1	3.6	2.0	1.9	6.83%
15	.213	5.1	3.5	2.0	1.9	6.75%

The dominant parameters of the neutron pad flux uncertainty are fission spectrum and the total iron inelastic scattering cross section. The group flux uncertainty at the neutron pad lies in the range of 7% to 17%. The major parameter of the water gap II flux uncertainty is the capsule location. The contribution from the capsule location for the VENUS-1 reactor is assumed to have the same value with the PWR downcomer surveillance capsule. The uncertainty of group flux at the water gap II lies in the range of 19% to 22%.

The correlation of the calculated dosimeter activities is estimated using the covariance matrix of the bias-corrected fluxes and the covariance matrix of the dosimeter cross sections. The same kind of dosimeters has the same matrix elements in this analysis and the correlation matrix of the calculated dosimeter reaction rates at one location is shown in Table 3.

Table 3. Correlation Matrix of the Calculated Activities at the Water Gap II Location

	Standard Deviation	^{115}In(n. n')	^{238}U(n,f)	^{237}Np(n,f)
^{115}In(n,n')	18.90%	100		
^{238}U(n,f)	18.09%	97	100	
^{237}Np(n,f)	20.89%	88	90	100

3.2 UNCERTAINTY IN MEASURED VALUES

For the calculation of the uncertainty of the measured reaction rate, four different uncertainty sources are considered. The sources of uncertainty are random counting statistics, gamma-ray counter efficiency calibrations, bias factors from competing reactions like photo-fission or coincidence summing, and normalization factors from core power.

The statistical variations in the measured counting rates are assumed to be 1% and uncorrelated among all the measurements. The counting efficiencies of the gamma-ray spectrometer are assumed to be 4% for all measurements. And all measurements are assumed to be uncorrelated because they are known to be performed independently. The bias factors related to measurement arise from other competing reactions leading to the same unstable reaction product. Photo-fission reaction induces corrections to the ^{238}U and ^{237}Np activities. The estimated contributions to ^{238}U and ^{237}Np has been calculated as 4% to 8% and 2% to 4% respectively. The fission chambers are surrounded by cadmium sheet to suppress thermal fissions in fissile impurities and reaction rates of fission chambers are reduced due to cadmium cutoff energy, especially for ^{237}Np dosimeters at water gap II region. The photo-fission reaction and cadmium cut-off energy have opposite effects to the experimental ^{237}Np and ^{238}U reaction rates. In this LEPRICON calculation, the standard deviations of 5% and 3% for ^{237}Np and ^{238}U are applied. A perfect correlation of these two effects is assumed between ^{238}U and ^{237}Np dosimeters, and additionally uncorrelated 3% coincidence summing is applied as a bias factor. The last uncertainty source is the factor related to normalization from core power. The VENUS-1 experiments have the uncertainty of 1.8% from absolute normalization and 1.2% from run-to-run monitoring[4] and they are fully correlated among all experiments. The resulting correlation matrix of the experimental value from all sources of uncertainty is shown in Table 4. Only 8 experiments among all 23 experiments are shown in Table 4. The other experiments show the same trend with these 8 experiments. As shown in Table 4, the experiments have lower correlation compared to PWR dosimetry experiment because of the independence among VENUS-1 experiments.

Table 4. Correlation Matrix of the Measured Activities at the Water Gap II Location

	Standard Deviation	θ=10.8°			θ=16.6°			θ=21.1°	
		^{115}In	^{238}U	^{237}Np	^{115}In	^{238}U	^{237}Np	^{115}In	^{238}U
θ=10.8°									
^{115}In(n,n')	5.54%	100							
^{238}U(n,f)	7.46%	11	100						
^{237}Np(n,f)	6.30%	13	42	100					
θ=16.6°									
^{115}In(n,n')	5.54%	15	11	13	100				
^{238}U(n,f)	7.46%	11	53	42	11	100			
^{237}Np(n,f)	6.30%	13	42	34	13	42	100		
θ=21.1°									
^{115}In(n,n')	5.54%	15	11	13	15	11	13	100	
^{238}U(n,f)	7.46%	11	53	42	11	53	42	11	100

3.3 EFFECTS OF COMBINED EXPERIMENTS

Three LEPRICON calculations are performed to consider the effect of combined experiments on the adjustment procedure and the results are shown in Table 5. The third column represents the calculation prior to adjustment procedure and the forth to sixth columns represent the results of the adjustment calculations. The standard deviations of the unadjusted calculation are in the range of 18% to 21% and the largest difference with the measurements is 26%.

The LEPRICON system solves the problem by combining the PWR data with a database consisting of the results of the analysis of 37 benchmark experiments. It is recommended that 3 experiments from 37 experiments always be deactivated based on R. E. Maerker's previous analysis[5]. From his analysis, the 3 experiments are known to be inconsistent with the remaining 34 experiments. Thus, these deactivated 3 experiments don't actively participate in the

Table 5. Results of LEPRICON According to Combined Experiments

Location	Reaction	E/C-1±σ [1] (%)	(E-A)/C±σ [2] (%)		
			34 Exps[3]	23 Exps[4]	57 Exps[5]
θ=10.8°	^{115}In(n,n')	10.3±18.9	-3.9±17.3	3.9±2.9	3.7±2.8
	^{238}U(n,f)	21.9±18.1	12.5±16.8	13.2±4.3	18.9±3.2
	^{237}Np(n,f)	6.5±20.9	-2.2±18.1	5.1±3.6	6.8±3.2
θ=16.6°	^{115}In(n,n')	8.8±18.9	-5.4±17.3	2.4±2.9	2.2±2.8
	^{238}U(n,f)	18.2±18.1	8.7±16.8	9.5±4.3	15.2±3.2
	^{237}Np(n,f)	10.0±20.9	1.3±18.1	8.7±3.6	10.2±3.2
θ=21.1°	^{115}In(n,n')	9.5±18.9	-4.7±17.3	3.1±2.9	2.8±2.8
	^{238}U(n,f)	26.3±18.1	16.8±16.8	17.5±4.3	23.2±3.2
θ=25.6°	^{115}In(n,n')	7.4±18.9	-6.8±17.3	1.0±2.9	0.8±2.8
	^{238}U(n,f)	16.0±18.1	6.5±16.8	7.2±4.3	13.0±3.2
	^{237}Np(n,f)	4.2±20.9	-4.5±18.1	2.9±3.6	4.5±3.2
θ=28.8°	^{115}In(n,n')	9.0±18.9	-5.2±17.3	2.6±2.9	2.4±2.8
	^{238}U(n,f)	17.7±18.1	8.2±16.8	8.9±4.3	14.7±3.2
	^{237}Np(n,f)	7.6±20.9	-1.1±18.1	6.2±3.6	7.9±3.2
θ=33.9°	^{115}In(n,n')	3.5±18.9	-10.7±17.3	-2.9±2.9	-3.2±2.8
	^{238}U(n,f)	14.7±18.1	5.2±16.8	5.9±4.3	11.7±3.2
	^{237}Np(n,f)	-0.2±20.9	-8.9±18.1	-1.5±3.6	0.2±3.2
θ=37.4°	^{238}U(n,f)	17.4±18.1	7.9±16.8	8.7±4.3	14.4±3.2
	^{237}Np(n,f)	5.5±20.9	-3.2±18.1	4.1±3.6	5.8±3.2
θ=41.0°	^{115}In(n,n')	4.1±18.9	-10.1±17.3	-2.3±2.9	-2.6±2.8
θ=45.0°	^{115}In(n,n')	2.0±18.9	-12.2±17.3	-4.4±2.9	-4.7±2.8
	^{238}U(n,f)	13.4±18.1	3.9±16.8	4.7±4.3	10.4±3.2
	^{237}Np(n,f)	7.4±20.9	-1.3±18.1	6.0±3.6	7.7±3.2
÷^{2} per degree of freedom			1.03642	0.44877	0.85641

1) standard deviation of calculated value
2) relative standard deviation of adjusted value
3) 34 LEPRICON benchmark experiments
4) 23 VENUS-1 experiments
5) 34 LEPRICON benchmark experiments + 23 VENUS-1 experiments
6) E : measured reaction rate, C : unadjusted, calculated reaction rate, A : adjusted reaction rate

adjustment procedure and the results of these experiments are changed only because of the correlation with the other activated experiments.

First adjustment calculation is performed with 34 benchmark experiments included in LEPRICON code system and 3 inconsistent experiments are deactivated. The reaction rates of the VENUS-1 reactor are adjusted based on the 34 LEPRICON benchmark experiments. The adjusted reaction rates show better agreement to the experimental data than the unadjusted results with smaller uncertainties. Even though the adjustment calculation shows improvement, the uncertainty reduction effect of LEPRICON calculation is not clear.

Second unfolding calculation is performed with only 23 VENUS-1 experiments. The results show the best agreement compared to the other calculations with much reduced uncertainties. However, χ^2 per degree of freedom, which represents the consistency among the experiments, lies beyond the acceptable range between 0.8 and 1.2.

Finally, the third adjustment calculation based on 34 LEPRICON benchmark experiments and 23 VENUS-1 experiments shows reduced uncertainties and good agreement to the experimental values. Furthermore χ^2 per degree of freedom is acceptable. The standard deviations of the adjusted reaction rates are in the range of 2.8% to 3.2% of the calculated reaction rates.

3.4 RESULTS OF THE ADJUSTMENT

Table 6 shows the adjusted results from the LEPRICON calculation based on 34 LEPRICON

Table 6. Comparison of Adjusted Reaction Rates with Calculated and Measured Data

Location	Reaction	Reaction Rate[reactions/sec/atom]			Ratio	
		Experiment	Calculation	Adjustment	C/E	A/E
θ=10.8°	^{115}In(n,n')	5.137E-18±5.54%	4.656E-18±18.90%	4.966E-18±2.65%	0.91	0.97
	^{238}U(n,f)	9.279E-18±7.46%	7.609E-18±18.09%	7.838E-18±3.06%	0.82	0.84
	^{237}Np(n,f)	4.843E-17±6.30%	4.549E-17±20.89%	4.534E-17±3.17%	0.94	0.94
θ=16.6°	^{115}In(n,n')	5.047E-18±5.54%	4.638E-18±18.90%	4.946E-18±2.65%	0.92	0.98
	^{238}U(n,f)	8.911E-18±7.46%	7.537E-18±18.09%	7.764E-18±3.06%	0.85	0.87
	^{237}Np(n,f)	5.083E-17±6.30%	4.620E-17±20.89%	4.605E-17±3.17%	0.91	0.91
θ=21.1°	^{115}In(n,n')	4.903E-18±5.54%	4.479E-18±18.90%	4.777E-18±2.65%	0.91	0.97
	^{238}U(n,f)	9.156E-18±7.46%	7.252E-18±18.09%	7.470E-18±3.06%	0.79	0.82
θ=25.6°	^{115}In(n,n')	4.434E-18±5.54%	4.128E-18±18.90%	4.403E-18±2.65%	0.93	0.99
	^{238}U(n,f)	7.712E-18±7.46%	6.650E-18±18.09%	6.850E-18±3.06%	0.86	0.89
	^{237}Np(n,f)	4.431E-17±6.30%	4.253E-17±20.89%	4.239E-17±3.17%	0.96	0.96
θ=28.8°	^{115}In(n,n')	4.200E-18±5.54%	3.852E-18±18.90%	4.108E-18±2.65%	0.92	0.98
	^{238}U(n,f)	7.313E-18±7.46%	6.214E-18±18.09%	6.401E-18±3.06%	0.85	0.88
	^{237}Np(n,f)	4.258E-17±6.30%	3.959E-17±20.89%	3.946E-17±3.17%	0.93	0.93
θ=33.9°	^{115}In(n,n')	3.551E-18±5.54%	3.431E-18±18.90%	3.659E-18±2.65%	0.97	1.03
	^{238}U(n,f)	6.391E-18±7.46%	5.573E-18±18.09%	5.741E-18±3.06%	0.87	0.90
	^{237}Np(n,f)	3.446E-17±6.30%	3.452E-17±20.89%	3.441E-17±3.17%	1.00	1.00
θ=37.4°	^{238}U(n,f)	6.053E-18±7.46%	5.155E-18±18.09%	5.310E-18±3.06%	0.85	0.88
	^{237}Np(n,f)	3.246E-17±6.30%	3.078E-17±20.89%	3.068E-17±3.17%	0.95	0.95
θ=41.0°	^{115}In(n,n')	3.118E-18±5.54%	2.996E-18±18.90%	3.195E-18±2.65%	0.96	1.02
θ=45.0°	^{115}In(n,n')	2.956E-18±5.54%	2.899E-18±18.90%	3.092E-18±2.65%	0.98	1.05
	^{238}U(n,f)	5.439E-18±7.46%	4.795E-18±18.09%	4.939E-18±3.06%	0.88	0.91
	^{237}Np(n,f)	2.954E-17±6.30%	2.751E-17±20.89%	2.742E-17±3.17%	0.93	0.93

Table 7. Comparison of Group Flux between Calculated and Adjusted Data

Flux Group	Lower Energy (MeV)	Water Gap II		Neutron Pad	
		Calculated(%)	Adjusted(%)	Calculated(%)	Adjusted(%)
1	11.1	0±19.14 1)	-1.35±6.97	0±16.96	0.62 ±8.37
2	8.2	0±17.64	-4.46±6.32	0±14.43	-2.25 ±7.45
3	6.1	0±17.15	9.38±5.58	0±12.57	18.96 ±6.75
4	4.1	0±17.75	9.76±5.37	0±12.11	20.85 ±6.72
5	3.0	0±19.43	7.10±6.31	0±11.36	19.07 ±6.40
6	2.6	0±19.51	0.60±6.22	0± 9.25	10.17 ±5.98
7	2.1	0±19.56	-1.34±6.63	0± 8.91	7.71 ±5.99
8	1.8	0±19.82	-0.94±6.70	0± 8.80	8.27 ±5.81
9	1.5	0±20.69	-1.54±7.11	0± 8.59	8.08 ±5.65
10	1.2	0±20.86	-2.22±7.13	0± 8.55	7.97 ±5.60
11	.9	0±21.52	-4.49±6.93	0± 8.12	8.58 ±5.14
12	.6	0±21.50	-2.57±7.80	0± 6.97	9.56 ±4.20
13	.4	0±21.18	-1.90±7.88	0± 6.87	9.56 ±4.04
14	.2	0±20.78	-1.24±7.85	0± 6.83	9.65 ±3.95
15	.1	0±19.43	-0.65±7.28	0± 6.75	9.50 ±3.92

1) deviation from calculated value is 0% and standard deviation of calculated value is 19.14%

benchmark experiments and 23 VENUS-1 experiments. The uncertainties of the adjusted results are shown to be greatly reduced compared to the unadjusted results, and the adjusted reaction rates show better agreement to the experimental results. Nevertheless the adjusted reaction rates of ^{237}Np and ^{238}U dosimeters doesn't show significant better agreement with the experimental results compared to ^{115}In dosimeters. The reason is that the important energy region of ^{237}Np and ^{238}U dosimeters is above 7 MeV whereas the mainly affected region of the LEPRICON adjustment calculation is in the energy region of 3-8 MeV due to the correction of overestimated ENDF/B-V iron inelastic scattering cross section.

Table 7 shows the calculated and adjusted group fluxes and their uncertainties. The reduction rate of uncertainty for the water gap II dosimeters is greater than that at the neutron pad, because the adjustment calculation is performed using dosimeters in water gap II region. As shown in

Table 8. Exposure Parameters at Neutron Pad

Location	Calculation	Experiment	Adjustment
Neutron Pad, Θ=21.1°			
Flux above 1.0 MeV	$5.689\text{x}10^{6}$±8.85%	-	$6.253\text{x}10^{6}$±5.50%
Flux above 0.1 MeV	$1.510\text{x}10^{7}$±7.46%	-	$1.652\text{x}10^{7}$±4.41%
Indium Reaction Rate	$1.330\text{x}10^{-18}$±9.00%	$1.602\text{x}10^{-18}$±5.54%	$1.473\text{x}10^{-18}$±5.54%
Ratio to Experiment	0.83	1.00	0.92
Neutron Pad, Θ=42.0°			
Flux above 1.0 MeV	$4.196\text{x}10^{6}$±8.88%	-	$4.616\text{x}10^{6}$±5.51%
Flux above 0.1 MeV	$1.100\text{x}10^{7}$±7.48%	-	$1.203\text{x}10^{7}$±4.42%
Indium Reaction Rate	$9.866\text{x}10^{-19}$±9.05%	$1.072\text{x}10^{-18}$±5.54%	$1.094\text{x}10^{-18}$±5.55%
Ratio to Experiment	0.92	1.00	1.02

Table 7 the neutron fluxes in energy range of 3-8 MeV are greatly increased mainly, because of the correction of overestimated inelastic scattering cross section of iron.

The indium reaction rates, the neutron fluxes of energy above 1.0 MeV and the neutron flux of energy above 0.1 MeV at the neutron pad are calculated using group fluxes and adjustment factors taken from LEPRICON calculation. The calculated and adjusted integral parameters are compared with the measured values in Table 8. As found in Table 8, the uncertainties of the integral parameters are reduced through adjustment procedure and the adjusted results show better agreement to the measured values.

4. RESULTS

The 23 water gap II reaction rates obtained from the VENUS-1 experiments are analyzed using the LEPRICON code system. The adjusted water gap II reaction rates are compared with the measured values. The results are in better agreement with the measurements, and have smaller uncertainties, by as much as 15% to 20% of the unadjusted results.

The neutron pad fluxes and uncertainties are calculated with input parameters from downcomer dosimetry analysis. The indium reaction rates at the neutron pad are calculated using the adjusted group fluxes and compared with the measured values. The unadjusted indium reaction rate at azimuthal angle 21.1° is calculated to be 1.33×10^{-18} with uncertainty of 9% and with C/E ratio of 0.83. The adjusted indium reaction rate from the LEPRICON code system is 1.47×10^{-18} with uncertainty of 6% and Adjustment-to-Experiment(A/E) ratio of 0.92. For another dosimeter at azimuthal angle 42.0°, the C/E ratio of indium reaction rate improves from 0.92 to 1.02 (i.e., A/E ratio).

CONCLUSIONS

The VENUS-1 experiments are analyzed for the validation of the LEPRICON adjusted flux. The adjusted water gap II reaction rates show better agreement to the measured values with much reduced uncertainties. The extrapolated neutron pad flux using the transport calculation and water gap II measurements also show better agreement to the measured values.

From analysis of the VENUS-1 reactor, it is expected that the LEPRICON system is reliable for the determination of the best-estimate pressure vessel fluence and its uncertainties.

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