REACTOR VESSEL MATERIAL SURVEILLANCE PROGRAM FOR INDIAN POINT UNIT NO. 2 ANALYSIS OF CAPSULE T

by

E. B. Norris

SUPPLEMENT TO FINAL REPORT
SwRI Project No. 02-4531

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Prepared for
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Approved:

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Introduction

As a part of the analysis of Capsule T[1], Southwest Research Institute performed a two-dimensional discrete ordinates transport calculation with the DOT 3.5 code, a 22-group neutron cross section library (CASK), a P_1 expansion of the scattering matrix, and an S_8 order of angular quadrature. A one-eighth segment of a plane through the vertical axis was used to model the core, core barrel, thermal shield, pressure vessel, and three water regions using R-θ coordinates. The surveillance capsules and their holders were not included in the model.

Recent analytical studies show that the perturbation of the neutron flux profile by a surveillance capsule and its holder can be significant.[2] Both the magnitude of the flux and the spectrum-averaged cross sections for the neutron detector reactions are affected. When the capsule perturbation has little effect on the flux incident on the pressure vessel wall (as is generally the case for Westinghouse PWR vessels), the capsule lead factor is also directly affected by the perturbation.

Consolidated Edison asked Westinghouse to update the Indian Point Unit 2 lead factors, group fluxes, and neutron cross sections. The analysis was based on DOT calculations using a 21-group neutron cross section library, an S_8 angular quadrature, and a P_1 cross section expansion.[3] The one-eighth segment used in the R-θ calculation included two specimen capsules and holders as well as the core, core barrel, thermal shield, and pressure vessel described in R-θ coordinates. The core power distribution included rod by rod variations for all peripheral assemblies, and it was representative of time-averaged conditions derived from statistical studies of long-term operation.

Results of Westinghouse Analysis

The relative neutron flux at the 40° capsule location for the top ten energy groups and the resulting reaction cross sections for the iron, nickel, and copper neutron monitors are given in Table A-1. The lead factors (ratio of capsule fast flux to peak vessel fast flux) obtained were 3.90 for the Charpy layer nearest the core, 3.72 for the capsule radial centerline, and 3.14 for the Charpy layer nearest the vessel wall.

Although Westinghouse had not published group fluxes and reaction cross sections for the unperturbed model, a single capsule lead factor of 2.9 had been reported.[4] Thus the perturbed flux is approximately 30 percent higher than the unperturbed flux at the radial centerline of the surveillance capsule.

Discrepancies Between Calculated and Measured Fluxes

The measured average fast neutron flux at the Capsule T location (based on updated spectrum average cross sections by Westinghouse[3]) is 3% lower than the neutron flux calculated by Westinghouse.[3] There are a number of sources of error which can contribute to discrepancies between calculated and measured neutron fluxes. Many, such as counting errors, are relatively small. However, the modeling problem discussed above is of major importance because it not only provides the calculated flux, but it also provides the reaction cross sections to be used in the determination of the measured flux. Significant errors in reaction cross sections can be found by comparing results from use of multiple foils, such as reported for ^{54}Fe and ^{237}Np by McElroy, et al.[2]

Another source of discrepancy, which could be substantial, is the radial position of the capsule which is attached to the outer surface of

TABLE A-1

CALCULATED GROUP FLUXES AND REACTION CROSS SECTIONS[3]
INDIAN POINT UNIT NO. 2

Group No.	Lower Energy in MeV	Relative Flux	$\sigma(E)$, barns		
			$^{54}Fe(n,p)^{54}Mn$	$^{58}Ni(n,p)^{58}Co$	$^{63}Cu(n,\alpha)^{60}Co$
1	7.79[a]	.000852	.592	.607	.035
2	6.07	.00283	.572	.608	.0098
3	4.72	.00447	.464	.535	.00085
4	3.68	.00467	.325	.388	0
5	2.87	.00793	.145	.222	0
6	2.23	.0155	.0494	.113	0
7	1.74	.0219	.0194	.0371	0
8	1.35	.0299	.0089	.0112	0
9	1.05	.0373	.0015	.0043	0
10	.821	.0382	0	0	0
			$\bar{\sigma}_{Fe} = .067$	$\bar{\sigma}_{Ni} = .0899$	$\bar{\sigma}_{Cu} = .00049$

the thermal shield in Westinghouse PWR vessels. In the Indian Point Unit 2 vessel, the radial flux decreases by a factor of nearly 3 while traversing the 8 cm (3 in.) water gap between the capsule and the pressure vessel. If the radius of the thermal shield were to vary 0.25 cm (0.1 in.) from nominal, a 10 percent change in flux could result.

A third source of discrepancy between calculated and measured fluxes is the use of pieces from the test specimens for iron dosimeters. SwRI cut a corner from selected tested Charpy specimens to minimize the exposure of personnel during the counting operations. Because the only orientation information available from a tested Charpy specimen is the direction of the notch, a given corner could be ±0.4 cm (±0.15 in.) from the center of a given Charpy layer. From the results of the Westinghouse calculations, the flux at the Charpy corners would vary about 10% from that at the center of the Charpy layer.[3]

A final major source of discrepancy between the model and the conditions seen by a given capsule is the core power distribution. A long-term statistically-determined core power distribution was used in the calculations.[3] The actual core power distributions during core cycles 1 and 2 were somewhat different from each other as well as being different from the long-term average.

Reevaluation of Capsule T Dosimetry Data

Neutron fluxes and fluences were recomputed for Capsule T using the updated spectrum-averaged cross sections.[3] In addition, five Charpy specimens from the layer nearest the core were removed from storage and were sampled to provide information to supplement that from the vessel-side layer reported previously.[1] The reevaluated Capsule T dosimetry results are summarized in Table A-2. Since Indian Point Unit No. 2 had operated

TABLE A-2

REEVALUATED CAPSULE T NEUTRON DOSIMETRY DATA
INDIAN POINT UNIT NO. 2

Dosimeter Position[a]	Dosimeter Ident.[b]	Activation Reaction	A_{TOR} (dps/mg)	A_{SAT} (dps/mg)	ϕ, E > 1.0 MeV[c] cm^{-2}-sec^{-1}	ϕ, Thermal[c,d] cm^{-2}-sec^{-1}
Core-side	2-7 (Top)	$^{54}Fe(n,p)^{54}Mn$	1.49×10^3	2.21×10^3	5.26×10^{10}	-
	2-6		1.44×10^3	2.48×10^3	5.90×10^{10}	-
	2-4		1.39×10^3	2.31×10^3	5.50×10^{10}	-
	2-3		1.40×10^3	2.42×10^3	5.77×10^{10}	-
	2-1 (Bottom)		1.61×10^3	2.78×10^3	6.61×10^{10}	-
	Cu (Top)	$^{63}Cu(n,\alpha)^{60}Co$	4.44×10^1	2.73×10^2	8.51×10^{10}	-
	Cu (Bottom)		4.38×10^1	2.70×10^2	8.40×10^{10}	-
	Ni (Middle)	$^{58}Ni(n,p)^{58}Co$	3.18×10^4	4.03×10^4	6.44×10^{10}	-
				Avg =	6.55×10^{10}	
Vessel-side	R-8 (Top)	$^{54}Fe(n,p)^{54}Mn$	1.27×10^3	2.20×10^3	5.23×10^{10}	-
	R-6		1.43×10^3	2.47×10^3	5.89×10^{10}	-
	R-4		1.42×10^3	2.45×10^3	5.84×10^{10}	-
	R-3		1.43×10^3	2.47×10^3	5.89×10^{10}	-
	R-1 (Bottom)		1.38×10^3	2.38×10^3	5.66×10^{10}	-
				Avg =	5.70×10^{10}	
Vessel-side	Co (Top)	$^{59}Co(n,\gamma)^{60}Co$	5.00×10^6	3.08×10^7	-	6.65×10^{10}
	CoCd (Top)		2.36×10^6	1.46×10^7		
	Co (Center)		5.66×10^6	3.49×10^7	-	8.66×10^{10}
	CoCd (Center)		2.24×10^6	1.38×10^7		
	Co (Bottom)		5.14×10^6	3.16×10^7	-	7.14×10^{10}
	CoCd (Bottom)		2.31×10^6	1.42×10^7		

(a) Core-side Charpy layer, vessel-side Charpy layer, or capsule centerline.
(b) For iron dosimeters, identification refers to Charpy specimens which were sampled.
(c) Calculated flux values subject to a ± 16.5% uncertainty.
(d) Calculated per ASTM Method E 262 using a 37.2 barn 2200 m/sec cross-section.

for 517.749 effective full power days up to the Capsule T removal, the following capsule fluences result:

Core-side Layer (B2002-1, B2002-2): 2.93×10^{18} n/cm^2, E > 1 MeV

Vessel-side Layer (B2002-3, Reference): 2.55×10^{18} n/cm^2, E > 1 MeV

Although the iron dosimetry data given in Table A-2 were averaged for each layer, it appears that the samples removed may be biased to the interface between the two radial layers. However, there is too much scatter to conclusively determine the radial location of each sample.

References

1. Norris, E. B., "Reactor Vessel Material Surveillance Program for Indian Point Unit No. 2--Analysis of Capsule T," SwRI Report 02-4531, June 30, 1977.

2. McElroy, W. N., et al, "Analysis of Interpretation of Nuclear Surveillance Results," Irradiation Embrittlement, Thermal Annealing and Surveillance of Reactor Pressure Vessels, International Atomic Energy Agency Report IWG-RRPC-79/3, Vienna, Austria, February 26 to March 1, 1979, pp 144-173.

3. Anderson, S. L., "Analysis of Neutron Flux Levels and Surveillance Capsule Lead Factors for the Indian Point Unit No. 2 Reactor," July 1979.

4. "Indian Point Unit No. 3 Reactor Vessel Radiation Surveillance Program," WCAP-8475, January 1975.