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MEASUREMENTS OF BUCKLINGS AND DIFFUSION COEFFICIENT CHANGES IN D_2O MODERATED LATTICES OF TUBULAR UO_2 ASSEMBLIES*

by

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DISCLAIMER

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Introduction

Tubular assemblies of natural UO_2 are candidate fuel elements for power reactors being designed at the Savannah River Laboratory(1). The design is done to a large extent with the Cost Optimization Code(2). Within the Code is a subprogram, the BSQ Code(3), which computes macro- and microscopic lattice physics parameters. BSQ was previously normalized to accurately measured material bucklings of heavy water moderated lattices of natural U-metal rod clusters and tubes. To provide normalization data for natural UO_2-tubular assemblies six sets of UO_2 tubes were fabricated for physics studies. The studies included:

- Measurements and calculations of fractional changes in the diffusion coefficient in the vertical direction, $\delta D_z/D$, when D_2O was expelled from one or more coolant channels(4).
- Measurements of material bucklings of lattices(4,5) in which the coolant channels in the assemblies were filled with a mockup of H_2O fog coolant, with D_2O, with air; or some with D_2O and some with air.

Description of Fuel Assemblies

The six sets of UO_2 tubes along with housing tubes were arranged into: SLIDE ONE -- a four tube assembly ABCD with housing tube T_1; a two tube assembly B'C' with housing tube IPT and T_2; and a three tube assembly B'CD with both IPT and T_1. The accompanying table lists information about the assembly components. The coolant channels between any two fuel tubes in the assemblies were 0.180" thick.

The assemblies were designed so that D_2O in one or more coolant channels could be remotely expelled by helium pressure.

The mockup for the H_2O fog was expanded polyethylene $(CH_2)_n$. We used two densities having H_2 concentrations equivalent to H_2O at nominal densities of 0.2 and 0.1 g/cc; actual densities are listed on Table I. The centermost channel (No. 1) was empty in the "fog cooled" assemblies.

The Reference Pile

The measurements were made in the Process Development Pile[6] at triangular lattice pitches of 9.33" and 11.1". The reference fuel assemblies were 31 rod clusters of 0.50" diameter natural UO_2 rods[7]. We substituted up to seven tubular assemblies in the "center hex" lattice positions. The statistical weight of the center hex test region on the 9.33" pitch was 12-14% and 21-22% on the 11.1" pitch.

The heavy water purity was 99.58 mol per cent D_2O, the temperature was 21 ± 1°C.

Description of the Measurements and Results

The ~~technique for~~ method of measuring $\delta D_z/D$ ~~was~~ followed a technique developed by Persson using one-group perturbation theory[8]. One tubular assembly was placed in the center position in the PDP and the pile was taken critical. Water in one or more channels was expelled in several steps by helium under pressure, the pile being held critical by changing the moderator height. The changes in critical moderator height and the corresponding percentage of the channel(s) voided provided data necessary to compute $\delta D_Z/D'$, where D' is the diffusion coefficient of the reference lattice and not of the test assembly. Cell calculations were made to determine the ratio of D'/D; for these lattices the ratio was within 1.00 ± 0.03.

The measurements were made for a variety of channels and channel combinations for the three assemblies at both lattice pitches. The results are plotted on Figure 2 -- SLIDE TWO as a function of the void-to-cell volume ratio "v". They can be described reasonably well by a single function $\delta D_Z/D = 1.528\ v + 0.016\ v^2$. The $\delta D_Z/D$'s were computed using the Benoist theory[9]. A model was chosen in which materials on either side of a voided channel were homogenized. Values of $\delta D_Z/D$'s were computed for fast neutrons only and single channel values were added to get the total change for all channels voided. Though in principle these values, like the measurements, are not single valued functions of the void fraction they were nearly so for these lattices and are shown that way. One reason the calculations slightly underestimate the measured changes is that streaming in several channels at once has been ignored. However the reasonable agreement between calculations and measurements shows that this recipe is adequate for calculating changes in D for tubular fuel assemblies with small voided channels.

The bucklings were determined by two methods[7]: a successive substitution technique also developed by Persson from one-group perturbation theory; and a two-group flux matching technique. In the one-group method 1, 3, and 7 tubular assemblies replaced reference assemblies in the center hex. The changes in buckling with respect to the one region reference lattice, the statistical weights of the test regions, and the ratio of one-group diffusion coefficients provided data for extrapolating to the difference in buckling between one-region loadings of the test lattice and the reference lattice.

The second technique utilizes only the data from the seven assembly substitution case. Estimates of the radial diffusion coefficients and migration areas used in the solution of the two-group equations were obtained from the $\delta D_Z/D$ measurements and calculations discussed above.

Table II summarizes the measured bucklings. The values listed are averages between one-group and two-group answers which agreed to within $\pm$ 5 μB in a random manner. Differences in bucklings, for a given assembly and lattice pitch, due to different coolant conditions, are accurate to $\pm$ 5 μB. Absolute bucklings are accurate to $\pm$ 10 μB.

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TABLE I

ACTUAL POLYETHYLENE DENSITIES IN COOLANT CHANNELS OF FOG-COOLED ASSEMBLIES

Assembly	Pitch, inches	Nominal H_2 Equivalent H_2O Density, g/cc	Channel[(a)]: Density of CH_2, g/cc No. 2	No. 3	No. 4	No. 5
ABCD	9.33	0.2	0.141	0.144	0.143	0.133
		0.1	0.066	0.070	0.070	0.065
	11.1	0.2	0.147	0.149	0.149	0.138
		0.1	0.068	0.072	0.072	0.068
B'C'	9.33	0.2	0.153	0.140	0.129	--
		0.1	0.063	0.067	0.072	--
	11.1	0.2	0.162	0.149	0.138	--
		0.1	0.078	0.072	0.068	--

(a) Channel No. 1 in each assembly was filled with air.

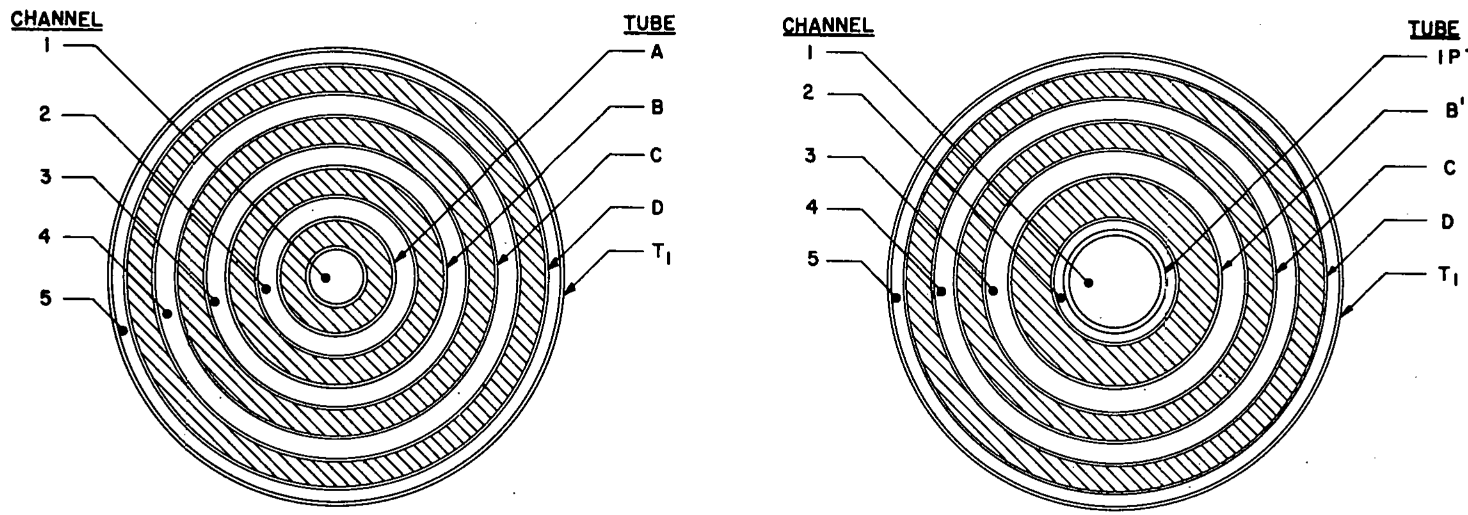
TABLE II

BUCKLINGS OF D_2O MODERATED LATTICES OF UO_2 FUEL TUBES

Assembly	Triangular Lattice Pitch, In.	D_2O or Air Filled Assemblies: Channels Air Filled	Material Buckling	"Fog" Cooled Assemblies[a]: Nominal H_2 Concentration	Material Buckling
ABCD T_1	9.33	None	392 μB*	0.2 g/cc	349 μB*
		2,3,4,5	399	0.1	373
		All	401		
	11.1	None	440	0.2	389
		3	449	0.1	424
		2,3	454		
		2,3,4,5	459		
		All	458		
IPT B'C' T_2	9.33	None	508	0.2	462
		3	514	0.1	484
		2,3,4	503		
		All	500		
	11.1	None	465	0.2	428
		3	471	0.1	452
		4	466		
		3,4	473		
		2,3,4	476		
		All	476		
IPT B'CD T_1	9.33	None	403		
		2,3,4,5	404		
		All	406		
	11.1	None	447		
		3,4,5	461		
		2,3,4,5	462		
		All	463		

*1 μB = 10^{-6} cm^{-2}

(a) Innermost channel in each assembly was air filled.



TUBE	O.D. CLAD. (in.)	I.D. CLAD. (in.)	MATERIAL	DENSITY, g/cc
A	1.12	0.50	UO_2	8.896
B	2.10	1.48	UO_2	8.849
C	3.08	2.46	UO_2	8.872
D	4.06	3.44	UO_2	8.904
T_1	4.38 (O.D.)	4.30 (I.D.)	6061 AL	
IPT	0.97 (O.D.)	0.89 (I.D.)	1100 AL	
B'	2.10	1.18	UO_2	8.928
C'	3.38	2.46	UO_2	8.868
T_2	3.70 (O.D.)	3.62 (I.D.)	6061 AL	

NOTE: ALL CLADDING – .030" THICK, 1100 AL
ABCD OXIDE – .250" THICK
B'C' OXIDE – .400" THICK

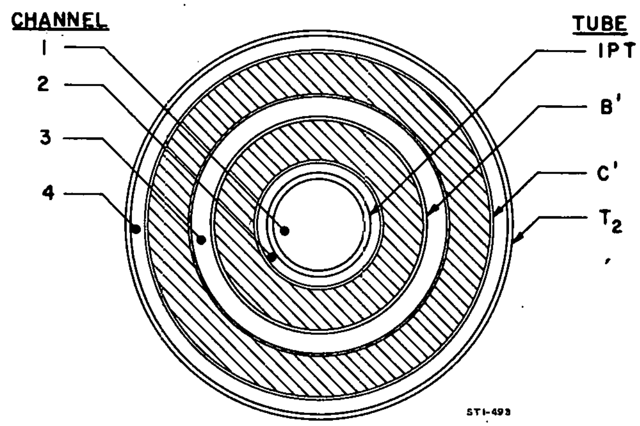


Figure 1. Cross Sections of UO_2 Tube Assemblies for Physics Tests

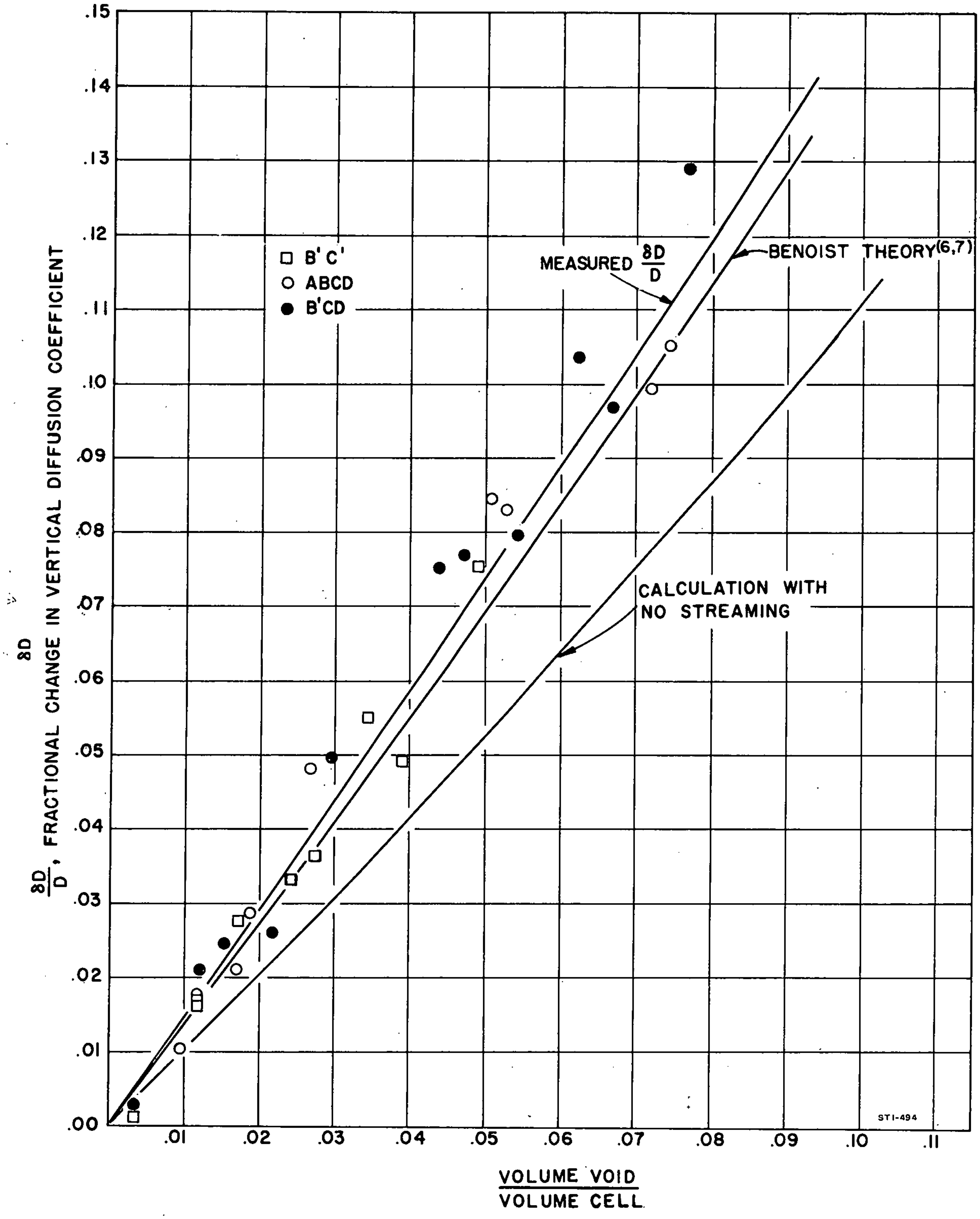


Figure 2. Change in Vertical Diffusion Coefficient on Voiding Coolant Channels in UO_2 Tube Clusters