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The Present Status of Sodium Void Effect

Prediction at GfK

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Introduction

In the analysis of fast reactor safety two characteristics of the sodium void effect are of principal interest:

1) The maximum positive void effect
2) The effect of voiding a single subassembly over a given height

Traditionally, therefore, two types of experiments have been performed in critical assemblies:

1) The voiding of a large central zone of variing radius and a height corresponding approximately to the maximum positive effect
2) The voiding of four central elements (corresponding in cross section about to one power reactor subassembly) over an increasing height, usually centered on the core midplane.

While these experiments in their mean features simulate the maximum void effect and single subassembly voiding, respectively, they still deviate in many aspects from the power reactor situations of interest. The most important of these aspects are:

- the plate geometry of most critical experiments as compared to the pin geometry of power reactors
- the size of the critical assemblies and the size of the largest voids, which are, due to material and operational restrictions, considerably smaller than the corresponding sizes in power reactors
- the difference in plutonium isotopic vectors
- the presence of lumped absorbers (control rods) and distributed absorbers (fission products) in power reactors

Therefore a number of experiments were performed in various SNEAK assemblies to deal especially with these problems. Together with the basic experiments (large voids and axial voids in 4 elements) they allow an estimate with what accuracy the Na-void effect for planned power reactors can be predicted.

Methods of Calculations

Calculations were performed for all measurements of the last Na-void series in SNEAK-9C-2 /1/ and for the large voids in the older assemblies with exact perturbation theory in RZ-geometry. Small central and axial voids were calculated in first order perturbation up to SNEAK-9B. The presently used 26 group cross sections are derived from the KFKINR set /2/, using the program KAPER /3/ or, in older work ZERA /4/, for taking into account cell heterogeneity. Some of the older experiments were not calculated with KFKINR data. In these cases the cross sections used are indicated in the tables below. A detailed study of the effect of cross section data, heterogeneity corrections and different calculational methods was performed for the case of radially increasing voids in SNEAK-9B /5/. It showed that exact perturbations and direct k_{eff}-calculations give practically identical results while 1st order perturbation should be used only for very small voids.

Measured and Calculated Results

1. Measurements of large central voids. This type of measurement was performed in SNEAK-6A, 9B and 9C-2 /1,6,7/. The first two of these were zoned cores with a large central Pu-fueled zone and a uranium driver. The last was a small core with all PuO_2UO_2 fuel. Table I shows the most important data of the cores, the largest void investigated (which was always reached in several steps of increasing radius), the size of the effect, and the deviation between calculation and experiment.

TABLE I Measurements of Large Central Voids

Assy.	Core Height, (cm)	Dia.	Largest Void Height (cm)	Dia.	Max.Meas. Effect (¢)	Maximal Effect C/E	C - E (¢)
6A	89.4	118.4	89.4	47.6	25.8	0.82 a)	-4.6
9B	89.7	108.3	60.8	65.0	79	1.08	6.5
9C-2	60.5	72.4	30.2	43.4	10.94	0.74	-2.9

a) Calc. for 6A with Moxtot set /8/ in 12 groups

2. Measurements of axial traverses in 4 elements. These measurements were performed in the assemblies mentioned above and in assembly 2C /9/ which was a 60 cm high mock-up of the SNR-300 with a plutonium fueled sector and central zone. When the void height was increased symmetrically to the core midplane the void effect always reached a maximum between one half and two thirds of the core height and tended to go back to zero for voiding over the total height. Table II gives some typical data.

TABLE II Measurements of Axial Voids in 4 Elements

Assy.	Core Height	Max.Meas. Effect (¢)	C/E	C - E (¢)	Effect of Void over full height (¢)	C - E (¢)
2C	60.3	1.75	0.88 a)	-0.21	0.25	-.88 a)
6A	89.4	5.00	1.0	0	3.2	-0.9
9B	89.7	6.1	0.9	-0.6	3.9	-1.5
9C-2	60.5	3.34	1.0	0		

a) calculated with the MOXTOT set

While the data in Table II correspond to the basic assemblies, axial Na-void traverses were also taken with modified element loadings in order to test the influence of heterogeneity, Pu-isotopic composition, and oxide versus carbide composition on the correspondence between measurements and calculations. The most important results of these measurements are shown in Table III.

TABLE III Axial Voids with Modified Element Loadings

Assy.	Special Effect Investigated	Max.Meas. Effect (¢)	C/E	C – E (¢)	Effect of Void over full height	C – E (¢)
6D	Void in MASURCA rodlet zone a)	2.97	0.99	-0.02	-1.18	-0.06
9B	Comparison of horizontal plate orientation: b)	5.6	1.0	0	3.1	-0.4
	and vertical plate orientation: b)	4.9	1.08	0.4	1.2	0.1
9C-2POZ	Void in High Pu-240 zone using ZEBRA Pu-metal plates	3.45	0.5	-1.73	-0.80	-0.46
9C-2/C	Void in High Pu-240 zone with carbide composition using ZEBRA metal plates	5.97	0.31	-4.13	1.56	-2.95
	as above calculated with D for axial direction($D_\perp$)		0.39	-3.64		-1.12
	REMO correction (from 1 D Perturbation calc.)			-0.14 ¢		-0.06 ¢

a) calculated with the MOXTOT set

b) calculated with direction dependent diffusion coefficients derived by KAPER

As can be seen from the table, an attempt was made to improve the calculations for 9C-2/C by introducing directional diffusion coefficients and a REMO correction, that is, a more detailed treatment of elastic downscattering. The first of these corrections actually reduced the discrepancy, particularly for the void over the full core height. The REMO correction brought a very small change in the opposits direction.

Remaining possible reasons for the discrepancies are

a) Drifts during the measurements. This is very inprobable, since reference measurements of the same configuration on different days deviated normally by about 0.2 ¢ and maximally (one case) by 0.4 ¢.

b) Error in the mathematical treatment of the very heterogeneous and complicated cell structure used with the ZEBRA metal plates. This appears to be more probable but contradicts the general experience that the influence of heterogeneity on the Na-void effect is well calculated.

c) Inaccurate calculation of the effect of graphite. This would explain the particularly large discrepancy of the measurements in the 9C-2/C zone.

d) Inaccurate data of plate compositions. So far no evidence has been found for this.

Measurements in High Pu-240 test zones were also performed with SNEAK High-240 PuO_2UO_2 plates, which allowed to construct, apart from the isotopic compositions, the same cells as were used in the basic cores. However only small quantities of this type of plates were available, so the test zones had to be of limited size axially as well as radially and the sodium void effect could only be measured in the core center. Table IV gives measured effects and C/E values for these experiments and also for comparison the same value for corresponding experiments in the basic assemblies.

<u>TABLE IV</u> Central Na Void Effect in High Pu-240 Test Zones

Assy.	Test Zone		Void		Void in Basic Assy.		Void in Test Zone	
	Height	Dia.	Height	Dia.	Effect(¢)	C/E	Effect(¢)	C/E
6A a)	18.36	12.3	18.36	12.3	2.32	1.13	2.50	1.1
9C-2POS	30.02	36.85	10.04	12.3	1.84	1.0	2.84	0.69

a) spherical calculation with MOXTOT homogeneous

Here too the agreement is also not satisfactory for 9C-2-POS. However the discrepancy is clearly smaller than for the complicated POZ- and C-cells with the ZEBRA metal plates. The discrepancies are being re-investigated.

The effect of eccentrical voids and the influence of the presence of absorber either in the form of control rods or smeared out over a test zone was last investigated in the older assemblies SNEAK-6A and 2C and has, like some of the older results given in the tables, not yet been calculated with present methods and data sets. The scope and results of these experiments were, in general terms, the following:

1) In SNEAK-2C a radial traverse was measured through the Pu-fueled sector. A void comprising 4 SNEAK elements over a height of 13.2 cm (centered on the midplane) was moved radially outward in the Pu-fueled sector in 14 steps. One-dimensional perturbation calculations with heterogeneity corrected MOXTOT cross sections yielded C/E values between 0.78 and 1.09.

2) Some points of this radial traverse were also measured in the presence of 3 boron absorber rods in the outer core zone. Although the shape of the traverse was changed considerably by the rods, this effect was well reproduced by XY perturbation calculations with the homogeneous NAPPMB cross sections /10/.

3) In SNEAK-6A a test zone was poisoned by replacing in each cell one of five Na-plates by a B_4C plate. The Na-void effect was increased by about 20 %. The C/E ratio for 1 dim. cylindrical perturbation calculations using MOXTOT heterogeneous cross sections was increased from 1.0 to 1.1.

Conclusions for the SNR-300

In judging the accuracy of prediction of the maximum sodium void effect of the SNR-300 one has to state first that even the largest void effect created in SNEAK (79 ¢ in SNEAK-9B) is far smaller than the maximum effect calculated for the SNR-300 (∿ 3 $). This is mainly due to

- the difference in effective core fraction covered by the void
- differences in spectrum and geometry which lead to different relations between high energy, low energy and leakage contributions
- a different Pu-isotopic vector.

The first of these points does not influence the fractional error; the second point tends to decrease it for large cores where compensating effects, which lead to large relativ errors, are not so important. (This trend can also be seen in comparing the results for SNEAK-9C-2 and 9B in Table I.)

Therefore, all measurements except the high Pu-240 measurements in SNEAK-9C-2 would indicate that the maximum positive void effect in SNR-300 is predictable with an accuracy of about 10 %, even taking into account the influence of heterogeneity and absorbers which could be calculated quite well. One complication not treated so far is the presence of partially inserted absorbers. An accurate prediction of the Na-void effect in such a configuration would be possible only by three-dimensional perturbation or very well converged three-dimensional k_{eff}-calculations. Also the presence of fission products has only been simulated by distributed boron absorber.

When high Pu-240 material was introduced in SNEAK-9C-2 this caused an additional deviation between experiment and calculation corresponding to about 2 ¢ for voiding four elements over half the core height or about 0.4 $ extrapolated to a core fraction corresponding to the maximal effect in the SNR-300. Therefore a term of this size must be added to the uncertainty until further experiments involving high Pu-240 compositions are evaluated.

For single subassembly voiding the conclusions are similar: A general accuracy of prediction of about 10 %, no experience near partially inserted absorber rods, a possible significant increase of the error due to the Pu-isotopic vector. For carbide composition only one experiment in SNEAK-9C-2/C has been performed so far, and the deviations found were even larger than for the high Pu-240 oxide compositions (Table III). So, if the use of carbide fuel is definitely envisaged the Na-void effect in this type of composition will have to be further investigated.

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