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STREAMING AND LEAKAGE PROBLEMS IN FAST REACTORS

G. LANGLET, A. KHAIRALLAH

I - INTRODUCTION :

The purpose of this paper is to assess the importance of the treatment of leakage in fast reactors. The following items will be covered, in more or less details :

- Material buckling,
- Reflector savings.
- Sodium void,
- Diluent assemblies

For the first three items, attention will be focused on streaming, i.e. on the effect of heterogeneity on leakage. For the last one, it is focused on the definition of a diffusion coefficient for the diluent assemblies, where classical diffusion theory does not apply.

II - STREAMING :

Streaming will be divided (somewhat arbitrarily) into two effects :

1. general increase of leakage due to the heterogeneity of the lattice, which will be called "leakage increase".

2. preferential leakage in directions in which neutrons may travel in media of large mean free paths, which will be called "leakage anisotropy".

II-1) Theoretical background :

In a regular lattice, directionnal diffusion coefficients are calculated according to the classical Benoist formula [1] :(x)

$$D_k = \frac{1}{3} \frac{\sum_i V_i \phi_i \sum_j P_{ij}^{*k} / \Sigma_{tr}^{j}}{\sum_i V_i \phi_i} \qquad (1)$$

(x) these diffusion coefficients may be, a posteriori, corrected to take into account the effect of the gross flux shape.

where : V_i is the volume of region i of the lattice

ϕ_i is the average flux in region i

Σ_{trj} is the transport cross section in region j

P_{ij}^{*k} is the "transport probability" /1/, in direction k, between region i and j.

To our knowledge, eq. (1) in its general form is never used for standard calculations. One of the following approximations is generally used :

1. An isotropic diffusion coefficient D_h is calculated as if the lattice were homogeneous.

2. An isotropic "average" diffusion coefficient $\bar{D}$ is calculated, by using the usual first flight collision probabilities P_{ij} instead of P_{ij}^{*k}. This is the approach used for standard fast reactor calculations in CEA.

3. Directionnal <u>first flight</u> collision probabilities P_{ij}^{k} are used instead of P_{ij}^{*} (which should include all collisions). Two diffusion coefficients are thus obtained : $D_{\perp}$, in the direction normal to the cell-axis (cylindrical-fuel cells) or to the cell-plane (plate cells), and $D_{//}$ in the other direction.

The effect of these approximations, as well as the importance of further corrections noted in BENOIST work /1/ (secondary collisions, angular distributions, non uniformity, parallel buckling effect, absorption effect) will be assessed.

II-2. EFFECT OF STREAMING ON MATERIAL BUCKLING

In the interpretation of material buckling measurements, the measured buckling must be interpreted in coherence with the calculationnal model.

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For the calculation of material buckling, an isotropic model is used for the diffusion coefficient, and leakage is represented globally by the product DB_m^2, where D is for instance D_h or $\bar{D}$.

On the other hand, one measures two geometrical bucklings, $B^2_{/\!/}$ and $B^2_{\perp}$.
If the leakage were isotropic, the measured material buckling would be :

$$B^2 = B^2_{/\!/} + B^2_{\perp} \qquad (2)$$

The leakage being anisotropic, an effective material buckling $\tilde{B}^2$, to be compared to the calculated one, should be defined as :

$$\tilde{B}^2 = \frac{D_{/\!/}}{D} B^2_{/\!/} + \frac{D_{\perp}}{D} B^2_{\perp} \qquad (3)$$

where the ratios $\frac{D_{/\!/}}{D}$ and $\frac{D_{\perp}}{D}$ must be calculated.

Thus, one gets a correction to the material buckling defined by (2) :

$$\frac{\tilde{B}^2}{B^2} - 1 = \left(\frac{D_{/\!/}}{D} - 1\right) \frac{B^2_{/\!/}}{B^2} + \left(\frac{D_{\perp}}{D} - 1\right) \frac{B^2_{\perp}}{B^2} \qquad (4)$$

Column 3 of Table 1 shows the "leakage-increase" effect (i.e. the use of D_h instead of $\bar{D}$) on B^2 for a number of fast lattices studied either in MASURCA (critical experiments) or in HARMONIE (exponential experiments).

Column 4 shows the "leakage-anisotropy" effect (i.e. the use of $D_{/\!/}$ and $D_{\perp}$ instead of $\bar{D}$) on B^2, while column 5 gives the effect of the corrections mentioned in paragraphe II-1.

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CONCLUSIONS

1. The "leakage-increase" effect is important, since it is larger than the experimental uncertainty of the measured bucklings, and thus, it must be taken into account.

2. The "leakage-anisotropy" effect is small, especially in critical experiments. The reason for this is that $\left(\frac{D_{\parallel}}{D} - 1\right)$ and $\left(\frac{D_{\perp}}{D} - 1\right)$ are of opposite sign, while $\frac{B^2_{\parallel}}{B^2}$ and $\frac{B^2_{\perp}}{B^2}$ have the same sign, so that there is a compensation between the two terms of eq. (4)*. For exponential experiments, no such compensation occurs, and thus the "leakage-anisotropy" effect becomes more important. It should be noticed that this effect has explained part of the experimentally observed differences between material bucklings measured in critical and in exponential experiments /3/.

3."Higher-order" corrections (secondary collision, angular distribution, flux-non uniformity, parallel buckling effect, absorption effect) prove to be, for fast lattices, individually small and to add up to a negligible total correction (**).

4. These conclusions are not changed if uranium fuel is replaced by plutonium fuel.

5. For power reactors, it was evaluated that these effects should be divided by a factor of about 4, due to the reduction of both the fuel diameter and its density.

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*Theoretically, perfect compensation occurs for $B^2_{\perp} = 2 B^2_{\parallel}$ (this is approximately the case for the R_2 lattice).

**These correctionshave not been evaluated for plate-type lattices.

II-3. EFFECT OF STREAMING ON REFLECTOR SAVINGS

This effect was calculated for the axial (depleted UO_2 + sodium) blanket of MASURCA for R_1 core. The total effect, including "leakage-increase" and " leakage-anisotropy" was found to result in a - 1.3 % reduction of the axial reflector savings, and thus in $- 50.10^{-5} \frac{\delta k}{k}$.

The same calculation was made for the lower axial blanket (non-integrated) of PHENIX, and the effect on reactivity was found to be of the order of $- 10.10^{-5} \frac{\delta k}{k}$.

II-4. EFFECT OF STREAMING ON SODIUM-VOID

Streaming affects the sodium-void effect through its leakage term which is proportionnal to the change in the diffusion coefficient. Calling $C_{//}$ and $C_{\perp}$ the two components of the leakage term in the parallel and normal directions, earlier studies /4/ have shown that :

- the "leakage-increase" ($\bar{D}$ instead of D_h) results in an increase of the total leakage effect (both $C_{//}$ and $C_{\perp}$) by 10 to 12 % (MASURCA assembly R_2 and SNEAK assembly 9B).

- the "leakage-anisotropy" ($D_{//}$ and $D_{\perp}$ instead of $\bar{D}$) results in a ratio $C_{//} / C_{\perp}$ of 1.07 (MASURCA R_2) to 1.15 (SNEAK 9B). The effect of the corrections to first flight $D_{//}$ and $D_{\perp}$ has since been evaluated and was found to result in a small decrease (- 3 %) of the ratio $C_{//} / C_{\perp}$.

Recent reinterpretation /5/ of Sodium-void measurements in MASURCA R_2 and SNEAK 9B has shown that taking into account the streaming effect results in a much better agreement between calculations and experiment.

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II - DIFFUSION COEFFICIENT IN DILUENT SUBASSEMBLIES

Due to the importance of the leakage term for diluent rods (sodium or stainless steel), the approximations used for the rod diffusion coefficient lead to large variations of the calculated rod reactivity worths.

In particular, measurements made in MASURCA for sodium and S-S rods /6/ have shown that the use of the classical diffusion coefficient $D = 1/3\Sigma_{tr}$ in the rod leads to large over-estimations of the rod reactivity worths.

Much better results have been obtained, using an effective diffusion coefficient defined according to the SELENGUT criterium (equality of the flux and of the current at the rod/core interface) and calculated by the code DIFHET /7/.
Table 2 shaws the improvement of the calculated rod worths for central diluent rods. The results are qualitatively the same for off-center rods : DIFHET diffusion coefficient drastically reduces the dispersion of the (E-C)/C results.

It must be stressed, however, that these results have been obtained with a (theoretically) improper use of the DIFHET diffusion coefficient : the latter is a radial diffusion coefficient, but it has been used as well for the axial direction, assuming no anisotropy in the rods.

The validity of the latter assumption is presently under investigation, in cooperation with italian CNEN physicists.

REFERENCES

/1/ P.BENOIST - "Streaming effects and Collision Probabilities in lattices", Nucl. Sc. Eng., 34, 285-307 (1968)

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/3/ A.DESPRETS - internal CEA report

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/6/ Ph.HAMMER et al - "Control rod studies in the CEA fast reactor physics programme", Advanced reactor physics, design and economics, Atlanta, September 1974.

TABLE 1

LATTICE(x)	$(\frac{D_{//}}{D_{\perp}} - 1)$ (%)	$\frac{B^2_{//}}{B^2_{//}+B^2_{\perp}}$	EFFECTS OF		
			leakage (%) increase	leakage (%) anisotropy	other (%) corrections
R_2	+ 1.2	.46	+ 2.	+.15	-.05
R_1	+ 1.25	.36	+ 2.1	+.03	-.02
R_3	+ 1.31	.73	+ 2.1	+ .52	- .04
HUG II	+ .46	- .83	+ 1.	- .54	- .23
HUG III	+ .42	- .80	+ 1.	- .47	- .14
HUG V	+ .36	- 1.03	+ .9	- .49	- .05
	(1)	(2)	(3)	(4)	(5)

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x for the description of these lattices, see reference [2].

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TABLE 2

ROD COMPOSITION	ROD SURFACE (cm^3)	DIFFUSION COEFFICIENT	$\frac{Exp - Calc.}{Calc.}$ (%)			
			R_2	R_1	R_3	Z_1
Na	28	Classical	-15 ± 2	-9. ± 1	-32 ± 4	-7.5 ± 8
		DIFHET	- 6	+ 2	- 8	+ 6
	112	Classical	/	/	/	- 5 ± 2
		DIFHET	/	/	/	- 1
S.S.	28	Classical	/	-12 ± 1	-12 ± 6	/
		DIFHET	/	- 10	- 8	/
	112	Classical	/	/	/	- 1 ± 2
		DIFHET	/	/	/	0