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COMPUTATIONAL/EXPERIMENTAL TRENDS OF CONTROL ROD WORTH IN LARGE FAST REACTOR DECOUPLED CORES

by

Massimo Salvatores
CEA, Directorate for Nuclear Reactors
Cadarache, France

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Nuclear Science Committee

I. INTRODUCTION

A benchmark, based on the ZPPR-13A critical experiment performed at Argonne National Laboratory, was specified [1] to investigate the reasons for the observed calculation/experiment trends in a series of large core ZPPR experiments (mostly performed in the frame of the joint US-Japan JUPITER program). In fact the analysis of control rod worths at different radial positions and the analysis of radial distributions of reaction rates (such as the fission rate of Pu-239), did show in general different C/E values at core centre and at the core periphery. Japanese and US analysis of these experiments indicated such trends, even if somewhat different in magnitude.

Motivation for the benchmark came from the fact that at the SUPERPHENIX start-up an extensive program of control rod measurements has been performed. Measurements of the reactivity worth of isolated rods of the inner and outer rod rings, and measurements of the inner and outer ring rods banks, had been extensively analysed in the frame of an European Task Force (CEA, AEA, KfK, Siemens), and no significant trend on the observed C/E values was pointed out [2].

It was considered to be of relevance to perform sensitivity analysis of the measured parameters to basic nuclear data, to point out possible different sensitivities to basic data of the same parameter, measured at different radial positions and in different type of configurations. In fact, in such large cores ($H \simeq 100$ cm, $R \geq 120$ cm), specific spatial effects can play an important role due to large neutronic decoupling effects.

2. SOME SIGNIFICANT RESULTS

P.J. COLLINS has summarized in ref. 3, the major trends observed at ANL on ZPPR control rod analysis. The following table is taken from that reference :

TYPE OF CORE	ROD LOCATION	MEAN C/E	
Conventional cores (ZPPR-9, 10A, 10B, 10C, 10D, representative of 700-900 MWe homogeneous cores).	Central	1.023	~ 4.5 %
	Inner ring	1.032	
	Outer ring	1.069	
Radial heterogeneous (ZPPR 13A, representative of a 700 MWe radial heterogeneous core).	Inner ring	0.987	~ 6 %
	Middle ring	1.013	
	Outer ring	1.043	

From ref. 4, we quote observed C/E values obtained in Japan for the conventional ZPPR-10A and ZPPR-10D cores :

TYPE OF CORE	ROD LOCATION	MEAN C/E	
ZPPR-10A	Central	0.95	~ 4 %
	Ring 1	0.947	
	Ring 2	0.988	
ZPPR-10D	Central	0.943	~ 12 %
	Ring 1	0.954	
	Ring 2	1.003	
	Ring 3	1.064	

Smaller C/E radial discrepancy has been found by PNC in the analysis of the ZPPR-13A results. Ikegami (private communication, Oct. 1992) gives the following results :

TYPE OF CORE	ROD LOCATION	MEAN C/E	
ZPPR-13A	Inner	0.924	~ 2.5 %
	Middle	0.921	
	Outer	0.948	

However, the reasons for this less significant trend have not yet been clarified.

The results quoted above have to be taken as indicative of the observed trends since different basic data sets and calculational methods were used. However, method refinements (in particular the use of transport theory) were not found to be effective in eliminating the observed trends for the spatial variation of the control rod C/E.

All the groups have indicated a correlation between the observed C/E variation on control rod worths and a similar trend for the fission rate of Pu-239.

The availability of ZPPR-13A data in the frame of the NEACRP benchmark did allow to intercompare ANL and CEA analysis of the same data on the same calculational model (ref. 5). The following results were obtained :

CONTROL ROD POSITION IN ZPPR-13A	ANL C/E		CEA C/E	
Inner ring	0.98	8 %	1.08	4 %
Middle ring	1.01		1.07	
Outer ring	1.06		1.04	

The CEA results are consistent with the results obtained in the analysis of the SUPER-PHENIX start-up experiments :

	CEA C/E	
Inner ring	1.08	3 %
Outer ring	1.05	

In particular, it is confirmed that the CEA calculation methods and data show a less significant radial C/E trend. Moreover, the trend is somewhat more pronounced in radial heterogeneous cores (I;e. with higher spatial decoupling) than in conventional homogeneous cores of comparable core size.

3. SENSITIVITY ANALYSIS

To analyse the impact of the basic nuclear data uncertainties on the observed trends, sensitivity analysis has been performed by several laboratories (ref. 6, 7, 8). For example, the sensitivity analysis performed for the SUPER-PHENIX control rod worths (ref. 8) indicated a significant variation with rod position of the magnitude (and sometimes of sign) of the sensitivity coefficients of U-238 capture, fission and inelastic cross-sections, Pu-239 fission cross-section, and transport cross-sections (i.e. diffusion coefficient). These sensitivity profiles are given in annexe I.

These trends were confirmed in the sensitivity analysis for some ZPPR assemblies of interest (ref. 6). In particular it was indicated that the variation of the ratio of the sensitivity profiles between inner and outer rod rings for the diffusion coefficient is larger in ZPPR-13A (radial heterogeneous core) than in ZPPR-10D (homogeneous core of comparable core size). These sensitivity coefficients are given in annexe II. When the sensitivity coefficients were used in statistical adjustment procedures (ref. 4, 7), the C/E trend was significantly reduced as a result of a combination of cross-sections adjustments, mainly U-238 capture cross-sections and Pu-239 fission cross-sections in the 1 KeV - 1 MeV range.

It is worth to note that, in the case of the CEA analysis of the control rod worth measurements at the SUPER-PHENIX start-up, the observed overestimation by calculation, was mainly attributed (ref. 9) to cross-section data uncertainties. In that analysis it was pointed out the general physical feature of increasing sensitivities to corss-sections data with the increase of the core size (i.e. increase of the neutronic spatial decoupling). As a final remark, Takeda has pointed out (ref. 6) that, beside basic data uncertainties (related to scattering and total cross-sections), the uncertainty of the diffusion coefficient is due to method approximations, which have to be carefully defined, when diffusion theory is used in the control worth analysis.

4. CONCLUSIONS

The present benchmark, has allowed to confirm that spatial C/E trends on control rod worth measured at different radial positions in large fast reactor cores (and on the radial fission rate distributions) can be traced back by a large extent to basic data uncertainties and to approximations in the diffusion coefficient definition. This effect is physically related to the large sensitivities to cross-section data in large, spatially decoupled cores. Moreover, changes in sign are observed in the sensitivity coefficients related to inner and outer rod rings (e.g. in the case of U-238 capture cross-section). Changes in sign are also observed the energy profiles of sensitivities (e.g. in the case of the Pu-239 fission cross-section) which are significantly different for an inner or an outer ring rod.

It is recognized that critical experiments, performed to validate design calculation methods and data, should be representative in that respect. Large scale critical experiments such as those performed on ZPPR in the frame of the JUPITER program or such as those foreseen in the frame of the CONRAD program (ref. 8), are essential to reduce uncertainties associated to core design parameters and to assess significant bias factors, applicable to a large range of core configurations, when the neutronic spatial decoupling plays a relevant role.

5. REFERENCES

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/6/ T. TAKEDA et al. "Cross-section sensitivity of control rod worth in large LMFBRs", see ref. 3.

/7/ W.P. POENITZ and P.J. COLLINS "Utilization of experimental integral data for the adjustment and uncertainty evaluation of reactor design quantities", see ref. 4.

/8/ M. SALVATORES "CEA data and methods for control rod calculations", see ref. 3.

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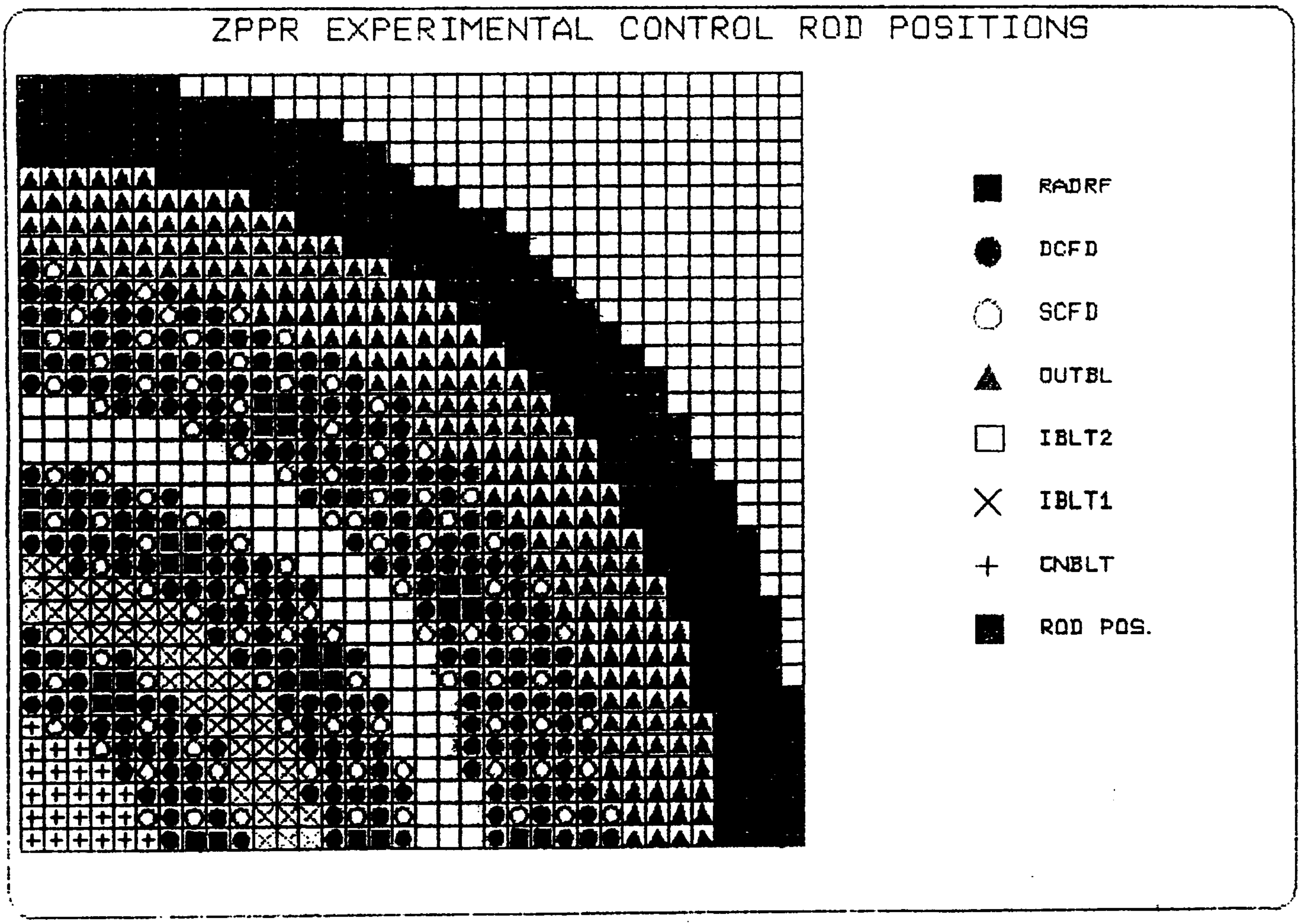
FIGURE 1 - Control rod positions in ZPPR-13A assembly



ANNEXE I

TABLE I - Sensitivity profiles for Super-Phenix control rod worths ($\delta\sigma/\sigma$ = + 10 %)

	U-238											
	σ_{tr}			σ_c			σ_f			σ_{in}		
Group	I.R.(a)	O.R.(a)	I.+O.(a)	I.R.	O.R.	I.+O.	I.R.	O.R.	I.+O.	I.R.	O.R.	I.+O.
1	-0.92	-0.10	-0.23	0	0.01	0.01	-1.40	-2.05	-2.03	0.18	0.80	0.89
2	-0.96	-0.12	-0.25	-0.01	0.03	0.02	-0.04	-0.08	-0.08	-0.14	0.03	0.06
3	-1.81	-0.36	-058	-0.14	0.09	0.01	0	0	0	-0.10	-0.02	-0.04
4	-0.44	-0.16	-0.24	-0.13	0.09	0	0	0	0	0	0	0
5	-0.12	-0.07	-0.10	-0.20	0.14	-0.02	0	0	0	0	0	0
6	0.	-0.01	-0.01	-0.02	0.01	0	0	0	0	0	0	0

(a) I.R. : Inner Rod Ring inserted
O.R. : Outer Rod Ring inserted
I.+O. : Both rings inserted

ANNEXE I

TABLE II - Sensitivity profiles for Super-Phenix control rod worths ($\delta\sigma/\sigma$ = + 10 %)

	Pu239			Fe						Ox		
	σ_f			σ_{tr}			σ_{in}			σ_{tr}		
Group	I.R.(a)	O.R.(a)	I.+O.(a)	I.R.	O.R.	I.+O.	I.R.	O.R.	I.+O.	I.R.	O.R.	I.+O.
1	-1.94	-0.61	-1.15	-0.61	-0.12	-0.18	0.12	0.50	0.54	-0.59	-0.06	-0.15
2	-2.42	-1.04	-1.74	-0.53	-0.12	-0.17	-0.07	0.02	0.03	-0.97	-0.13	-0.26
3	-3.39	-2.47	-3.02	-0.94	-0.29	-0.36	0	0	0	-1.61	-0.34	-0.54
4	-0.15	-0.91	-0.59	-0.17	-0.08	-0.11	0	0	0	-0.28	-0.10	-0.16
5	1.30	-1.38	-0.07	-0.13	-0.09	-0.12	0	0	0	-0.07	-0.04	-0.06
6	0.28	-0.21	0.03	0	-0.01	-0.01	0	0	0	0	0	0

(a) I.R. : Inner Rod Ring inserted
O.R. : Outer Rod Ring inserted
I.+O. : Both rings inserted

ANNEXE II

Sensitivity coefficients of control rod worth with respect to diffusion coefficient

Energy group	Upper energy	ZPPR-10D center	ZPPR-10D 3rd ring	ZPPR-13A center	ZPPR-13A 3rd ring
1	1.00 E+7 *	1.061	0.058	1.149	-0.431
2	6.07 E+6	4.019	0.184	5.488	-0.529
3	3.68 E+6	9.177	0.342	10.920	-0.618
4	2.23 E+6	10.484	-0.103	15.451	-0.889
5	1.35 E+6	9.233	-0.439	13.618	-0.598
6	8.21 E+5	20.590	-0.457	23.162	-0.554
7	3.88 E+5	20.134	0.270	24.187	-0.971
8	1.83 E+5	20.134	0.937	19.553	-1.168
9	8.65 E+4	10.675	1.151	14.812	-1.290
10	4.09 E+4	6.398	1.458	7.727	-0.896
11	1.93 E+4	4.318	1.340	5.998	0.032
12	9.12 E+3	1.857	0.888	2.087	-0.195
13	4.31 E+3	0.416	0.335	0.156	-0.275
14	2.03 4+3	2.578	1.990	1.771	1.037
15	9.61 E+2	1.099	1.300	0.977	0.167
16	4.54 E+2	0.246	0.661	0.518	-0.442
TOTAL		119.594	9.915	147.511	-7.620

* Read as $1.00 * 10^7$

LIST OF PARTICIPANTS

Prof. Massimo SALVATORES
Directeur de Recherche
Dir. des Reacteurs Nucleaires
Bat. 707 - CE/CADARACHE
F-13108 ST. PAUL LEZ DURANCE CEDEX
FRANCE

Dr. Yuri ORECHWA
Argonne National Laboratory
Applied Physics Division
9700 South Cass Avenue
ARGONNE, IL 60439
USA

Prof. Toshikazu TAKEDA
Osaka University
Department of Nucl. Eng.
Faculty of Engineering
2-1 Yamada-Oka, Suita
OSAKA 565
JAPAN

Dr. Toshio WAKABAYASHI
Power Reactor and Nuclear
Fuel Development Corporation
Technology Development Div.
4002 NARITA, Oarai-Machi
Ibaraki-ken 311-13
JAPAN