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Effects of Nuclear Data Library on BFS and ZPPR Fast Reactor Core Analysis Results Part 1 : ZPPR Analysis Results

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Effects of Nuclear Data Library on BFS and ZPPR Fast Reactor Core Analysis Results
Part I: ZPPR Analysis Results

Guennadi MANTOUROV *)

ABSTRACT

This work was fulfilled in the frame of JNC-IPPE Collaboration on Experimental Investigation of Excess of Weapon Pu Disposition in BN-600 Reactor Using BFS-2 Facility.

The data processing system CONSYST/ABBN coupled with ABBN-93 nuclear data library was used in analysis of BFS and ZPPR fast reactor cores applying JNC core calculation code CITATION. FFCP cell code was used for taking into account the spatial cell heterogeneity and resonance effects based on the first flight collision probability method and subgroup approach. Especially a converting program was written to transmit the prepared effective cross sections to JNC standard PDS files. Then the CITATION code was applied for 3-D XYZ neutronics calculations of BFS and ZPPR JUPITER experiments series cores.

The effects of nuclear data library have been studied by comparing the former results based on JENDL-3.2 nuclear data library. The comparison results using IPPE and JNC nuclear data libraries for k-effective parameter for ZPPR-9, ZPPR-13A and ZPPR-17A cores are presented. The calculated correction factor in all cases was less than 1.0%. So the uncertainty in C value caused by possible errors in calculation of these corrections is expected to be less than 0.3% in case of ZPPR-13A and ZPPR-17A cores, and rather less for ZPPR-9 core.

The main result of this study is that the effect of applying ABBN-93 nuclear data in JNC calculation route revealed a large enough discrepancy in k-eff for ZPPR-9 (about 0.6%) and ZPPR-17A (about 0.5%) cores.

For BFS-62-1 and BFS-62-2 cores such analysis is in progress. Stretch cell models for both BFS cores were formed and cell calculations using FFCP code have started. Some results of cell calculations are presented.

KEY WORDS: BFS-62, ZPPR, CONSYST/ABBN system, ABBN-93 nuclear data set, CITATION code, JENDL-3.2 nuclear data library.

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BFS 及び ZPPR 高速臨界実験解析における核データライブラリ効果の評価
ー 第1部 ZPPR 実験解析における効果 ー

(研究報告書)

ゲナディ マントゥロフ*

要旨

BFS-2 臨界実験装置利用による BN-600 における解体核余剰 Pu 処分のための JNC-IPPE 共同研究の一環として、本研究を実施した。

ABBN-93 核データライブラリに基づく実効定数計算システム CONSYST/ABBN と核燃料サイクル開発機構 (JNC) の炉心計算コード CITATION を組み合わせ、BFS 及び ZPPR 高速臨界実験解析を行った。セル内の空間非均質性と共鳴干渉効果の評価は、衝突確率法とサブグループ法が適用可能な格子計算コード FFCP を用いることにより行った。FFCP により計算された実効断面積は、専用の変換プログラムにより、JNC で使用されている PDS ファイル形式に変換される。次に、CITATION コードを用いて、BFS 及び ZPPR における JUPITER 臨界実験シリーズ炉心の 3 次元体系計算を行った。

今回得られた結果と以前に JNC により得られていた JENDL-3.2 核データライブラリに基づく結果との比較を行うことにより、核データライブラリ効果の評価を行った。具体的には、ZPPR-9、ZPPR-13A、ZPPR-17A の臨界性に対して、IPPE 及び JNC それぞれのライブラリを用いることによる解析結果の比較を行った。いずれの炉心に対しても臨界性の解析補正量は 1.0%以下であることから、解析値の不確かさは、ZPPR-13A 及び ZPPR-17A に対しては 0.3%以下、ZPPR-9 に対しては更に小さいことが推測される。

ライブラリ効果の評価を行ったところ、非常に顕著に見られることが分かり、ZPPR-9 に対しては約 0.6%、ZPPR-17A に対しては約 0.5%の差が見られることが明らかとなった。

BFS-62-1 及び BFS-62-2 炉心に対する解析として、FFCP コードによりプレートストレッチモデルを用いた格子計算を実施した。

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Эффект Влияния Библиотеки Ядерных Данных на Результаты Анализа БФС и ZPPR Экспериментов.

Часть I: Результаты Анализа ZPPR Экспериментов.

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АННОТАЦИЯ

Эта работа выполнена в рамках Российско-Японского Сотрудничества между JNC и ФЭИ по «Экспериментальным Исследованиям на Стенде БФС-2 Физических Аспектов Утилизации в Реакторе БН-600 Избытка Оружейного Плутония».

Система подготовки констант CONSYST/ABBN вместе с библиотекой констант БНАБ-93 была применена для анализа БФС и ZPPR экспериментов с использованием JNC стандартного расчетного инструмента, основанного на программе CITATION. Ячеечная программа FFCP использовалась для учёта пространственной и резонансной гетерогенности с применением метода ВПС и подгруппового подхода. Специальная интерфейсная программа была написана для преобразования рассчитанных эффективных сечений в формат JNC стандартных PDS файлов. Затем JNC стандартный путь, основанный на программе CITATION, был применен для 3-D XYZ нейтронно-физических расчетов серии критических сборок БФС и ZPPR (JUPITER эксперименты). Эффект различных библиотек ядерных данных изучался.

Проведено сравнение результатов расчетов, полученнных с использованием библиотек констант ФЭИ и JNC, для параметра к-эфф для сборок ZPPR-9, ZPPR-13A и ZPPR-17A. Полные поправки во всех случаях не превысили 1.0%. Погрешности в расчетных величинах, обусловленные возможными ошибками при вычислении этих поправок, как ожидается, равны менее 0.3% для случая сборок ZPPR-13A и ZPPR-17A, и гораздо меньше в случае сборки ZPPR-9.

Основной результат проведенного исследования состоит в том, что эффект использования БНАБ-93 констант в JNC расчетном пути выявил достаточно большие расхождения в к-эфф для сборок ZPPR-9 (около 0.6%) и ZPPR-17A (около 0.5%).

Для сборок БФС-62-1 и БФС-62-2 такой анализ ещё не завершен. Составлены модели плоских ячеек для программы FFCP. Некоторые результаты расчетов представлены.

В будущем планируется провести также анализ наблюдаемых расхождений с использованием коэффициентов чувствительности для изучения причин этих расхождений.

КЛЮЧЕВЫЕ СЛОВА: БФС-62, ZPPR, система CONSYST/ABBN, система констант БНАБ-93, программа CITATION, библиотека ядерных данных JENDL-3.2.

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1. INTRODUCTION

BFS-62 /1/ as well as ZPPR JUPITER series /2-7/ MOX cores are used as "benchmark" cores for validation of JNC and IPPE codes and nuclear data, which have been used in the study of loading a significant amount of Pu in BN-600 reactor core.

The BFS-62 experiment is a joint research program between IPPE of the Russian Federation and JNC of Japan on Experimental Investigation of Excess of Weapon Pu Disposition in BN-600 Reactor Using BFS-2 Facility.

The JUPITER critical experiment /2-7/ was a joint research program between US DOE and PNC of Japan, using ZPPR facility at ANL-Idaho in 1978 - 1988. The aim of JUPITER experiment was to study the nuclear physics characteristics of large LMFBR cores. This is the most important data sources in FBR core study as the largest experimental core size in FBR history. It covers wide variety of core concepts and structures, and various kinds of parameters measured.

The JUPITER program was consisted of four series of experiments. The first series was JUPITER-I (ZPPR-9 through 10D/2), a set of critical experiments for conventional two-zone homogeneous cores of 600 to 800 MW(e) class FBRs, including a clean benchmark core and six engineering mock-up cores /2,3/.

The second set was JUPITER-II (ZPPR-13A through 13C) for studying a radial heterogeneity - six cores of 650 MW(e) class FBRs with various arrangements of internal ring-shaped blanket regions /4,5/.

For the third series, half of JUPITER-III (ZPPR-17A through 17C) was dedicated to study axial heterogeneity - three cores of 650 MW(e) class, including one clean benchmark core /6/.

At last, ZPPR-18A through 19B cores, both the later half of JUPITER-III and Io series, five 1,000 MW(e) class homogeneous cores with enriched uranium in the outer core region had the largest core volume of 8,500 litters in the world /7/.

In this work we considered three representatives of JUPITER experiment, three Pu benchmark cores: ZPPR-9, ZPPR-13A and ZPPR-17A /8/.

The nuclear data provides the main uncertainty in calculation of neutronics characteristics of MOX cores. So it means that a study of influence of different nuclear data libraries on main neutronics characteristics of MOX cores and estimation of associated uncertainty is necessary and is being required.

This report presents a comparison of k-effective analysis results for BFS-62 cores as well as for ZPPR-9, 13A and 17A cores obtained by using two nuclear data libraries ABBN-93 (IPPE) /9/ and JFS-3-JENDL-3.2 (JNC) /8,10/, and applying the one three-dimensional diffusion JNC core calculation code CITATION /11/. (The full name of the JNC version for the code is CITATION-FBR but below whenever we will refer to it simply as to CITATION.)

The data processing system CONSYST/ABBN coupled with ABBN-93 nuclear data library /9,12/ was used in analysis of BFS and ZPPR fast reactor cores applying JNC core calculation code CITATION. The CONSYST code /13/ with ABBN-93 nuclear data library was used for calculation of effective cross-sections in ABBN standard 28 groups energy structure. FFCP code /14/ used for taking into account the spatial cell heterogeneity and resonance effects based on the first flight collision probability method and subgroup approach. Especially, a converting program was written to transmit the prepared effective cross sections to JNC standard PDS files.

From this study, as we can expect, the effect of nuclear data library can be easily identified, and all of the observed discrepancies have to be referred to the nuclear data library effect.

At the next stage a sensitivity analysis of the observed discrepancies is planed in order to investigate the possible reasons of them.

2. SHORT CUT TO ABBN-93 SYSTEM

ABBN-93 is the new Russian (IPPE design) group constants set developed for producing calculations of neutron and photon radiation fields and their functionals. It has the traditional neutron 28-group energy structure and extended multi-group (n=299) energy-wise structure as well (see Table 1). ABBN-93 is founded on FOND-2 evaluated data files library /15/, which contains selected data from BROND-2, ENDF/B-VI, JENDL-3, JEF-2 evaluated nuclear data files and some other sources. Calculation results by using of the ABBN-93 have been tested in a wide set of various fast and thermal reactor experiments and radiation shielding benchmarks.

ABBN-93 contains data for all natural elements, all important nuclides and isotopes, all important fission products and actinides right up to the Cf^{252}. The interval of considered neutron energies is from 10^{-5} to 20 MeV. Amount of neutron groups is 26 and 28 as the traditional but optionally can be increased up to 299. 28-group energy structure differs from the 26 by spreading the upper energy boundary up to 15 MeV (in case when amount of groups is greater than 28 the upper energy limit is 20 MeV). Amount of groups for description of the thermalization effects is 73 (below 4.65 eV). Amount of groups for photon source calculation is 15 (plus 4 strongest lines) and amount of groups for gamma-field calculation is 15 too.

CONSYST code of CONSYST/ABBN system /13/ is used for preparing group constants for different practical applications. CONSYST code takes into account the resonance self-shielding effects by using the well-known Bondarenko f- factors. During these calculations the Dancoff correction can be applied to effective dilution cross section ($ó_0$) by using formulae of the Equivalence Theory. Thermalization effects CONSYST treats by using thermal P_0 and P_1 multi-group scattering matrices in the energy region below 4.65 eV.

CONSYST code produces effective macro and micro group cross sections in different output formats and allows to adapt ABBN-93 data to such Russian diffusion codes as SYNTES and TRIGEX, which are used in fast reactor core design calculations, but also to transport codes such as ANISN, TWODANT and DORT, which are used in shielding calculations.

Table 1. ABBN Standard Neutron Group Energy Structure.

ABBN group number	Amount of fine groups	Energy low (eV)	Energy high (eV)	Group lethargy width	Fine group lethargy width
-1	5	13.982+6*	15.0+6**	0.07160	0.071595
0	4	10.5+6	13.982+6	0.28638	0.071595
1	6	6.5+6	10.5+6	0.47957	0.079929
2	6	4.0+6	6.5+6	0.48551	0.080918
3	6	2.5+6	4.0+6	0.47000	0.078334
4	8	1.4+6	2.5+6	0.57982	0.072477
5	8	0.8+6	1.4+6	0.55962	0.069953
6	9	0.4+6	0.8+6	0.69315	0.077017
7	9	0.2+6	0.4+6	0.69315	0.077017
8	9	100.0+3	200.0+3	0.69315	0.077017
9	12	46.416+3	100.0+3	0.76753	0.063961
10	12	21.544+3	46.416+3	0.76753	0.063961
11	12	10.0+3	21.544+3	0.76753	0.063961
12	12	4.6416+3	10.0+3	0.76753	0.063961
13	12	2.1544+3	4.6416+3	0.76753	0.063961
14	12	1000.0	2.1544+3	0.76753	0.063961
15	12	464.1589	1000.0	0.76753	0.063961
16	12	215.4434	464.1589	0.76753	0.063961
17	12	100.0	215.4434	0.76753	0.063961
18	12	46.41589	100.0	0.76753	0.063961
19	12	21.54434	46.41589	0.76753	0.063961
20	12	10.0	21.54434	0.76753	0.063961
21	12	4.641589	10.0	0.76753	0.063961
22	12	2.154434	4.641589	0.76753	0.063961
23	12	1.0	2.154434	0.76753	0.063961
24	12	0.464159	1.0	0.76753	0.063961
25	12	0.215443	0.464159	0.76753	0.063961
26	25	0.0253	0.0253		

* - must be read as $13.982 \cdot 10^{+6}$

** - in case of 299 groups the upper energy boundary is 20 MeV

3. CALCULATION SCHEME WITH CITATION CODE

The main idea for this work is to use two nuclear data libraries ABBN-93 (IPPE) and JENDL-3.2 (JNC) in the one – the standard JNC route used for fast reactor in-core neutronics calculations with JNC version of CITATION code.

The CONSYST/ABBN (IPPE) system is used for the treatment of ABBN-93 nuclear data and calculation of the effective cross sections.

In case of the usage of JNC nuclear data cell calculations are performed using 70-groups fast reactor constant set JFS-3 based on JENDL-3.2 and self-shielding treated by a factor table interpolation method. All parameters obtained by core calculations are corrected to results based on the transport theory extrapolated to zero mesh-size in space and angle. The effective cross sections will be prepared by CASUP /16/ or SLAROM /17/ cell codes. These codes provide all of their output data in a form of the standard PDS files, which next will be reprocessed by XMIX and JOINT codes and than read by CITATION code. Next a set of additional codes (LAGOON, PERKY, SAGEP, etc.) can be applied for post CITATION calculations of reaction rates, reactivity worths, material perturbations, etc. Left part of Fig.1 presents the scheme of the JNC route.

In case of the usage of ABBN-93 (IPPE) nuclear data library, the effective cross-sections will be prepared by CONSYST code in one of the standard ABBN 26 or 28 group energy structure (see Table 1). In these calculations FFCP one-dimensional cell code /14/ can be used for taking into account the spatial cell heterogeneity and resonance effects based on the first flight collision probability method and subgroup approach.

To permit to use FFCP code with the quite identically input stream as for CASUP code a special translation program TRANS_CASUP was written, which (1) translates the CASUP input data, (2) makes their print out and (3) creates input data files both for CONSYST and FFCP codes. It allows to exclude many errors at the stage of creating input data for a specific fast reactor core.

In order to permit to use ABBN-93 data in JNC CITATION calculation route a special converting program MAKE_CIT was created to transmit the prepared effective cross sections by CONSYST and FFCP codes to JNC standard PDS files.

Right part of Fig.1 presents the scheme of the route using ABBN-93 cross sections library.

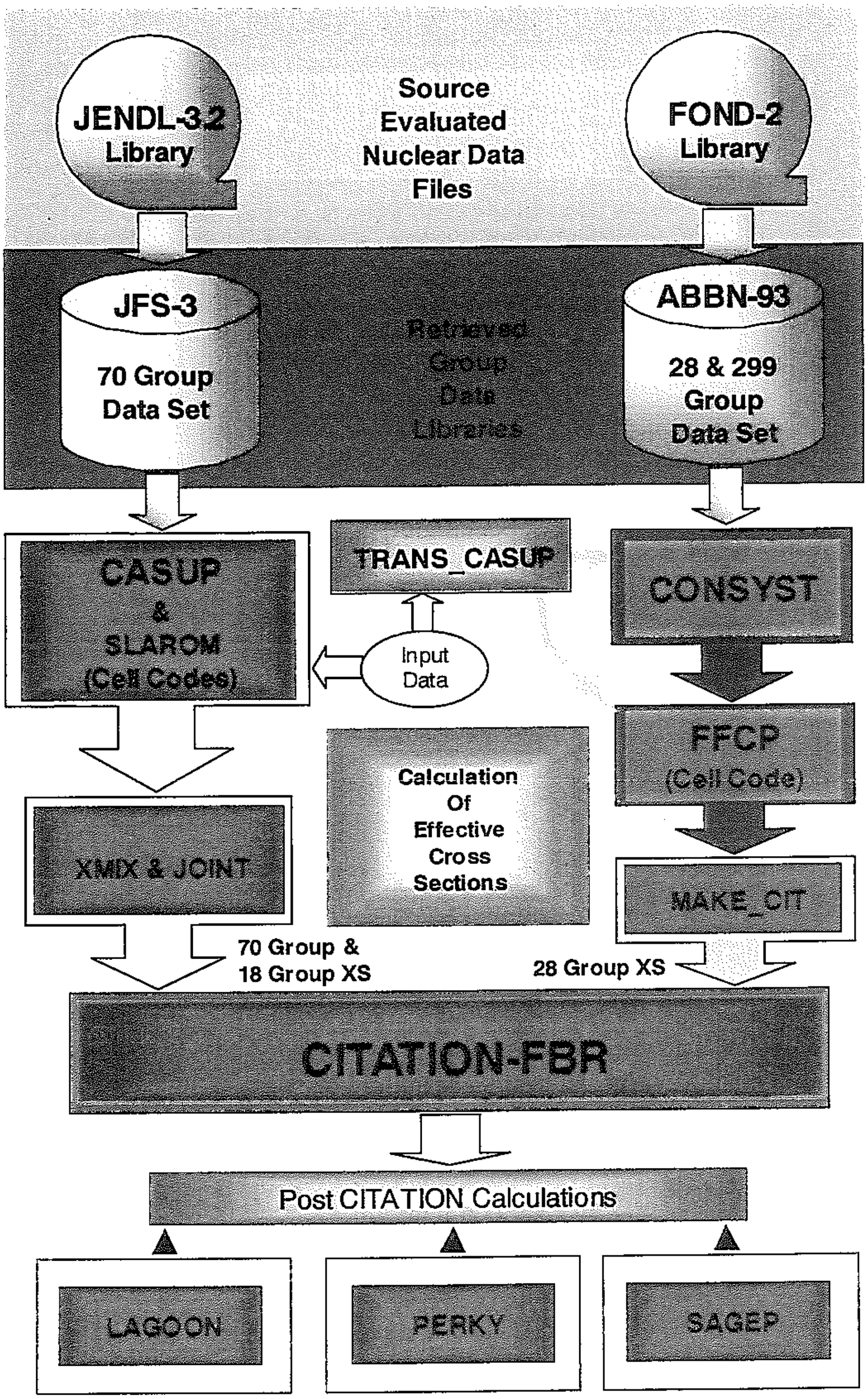

Fig. 1. Scheme of calculations with CITATION code.

4. VERIFICATION OF CONVERTING PROGRAM

MAKE_CIT Fortran program have been written for translation effective cross-sections calculated by CONSYST code to CITATION code. It (1) makes a print out of binary data and (2) prepares data in the PDS files both as for macroscopic cross-sections so for microscopic cross sections too.

To check the validity of MAKE_CIT program and to test the adaptation route for CITATION code to the CONSYST/ABBN prepared effective cross-sections three benchmark tasks were assumed:

(1) SCHERZO-5.56 infinite media made of 5.56% U^{235} and 94.44% U^{238} with k =1;

(2) CSEWG fast reactor benchmark - two region homogeneous core ZPR-6-7 /18/;

(3) ZPPR-9 fast reactor benchmark in RZ homogeneous model /8/.

Only the eigenvalue k-effective (k-eff) for each system was under investigation.

Next codes were used for comparative k-effective calculations:

(1) CONSYST and FFCP for infinite media;

(2) TWODANT /19/ in transport and diffusion options;

(3) CITATION in diffusion option.

4.1. Results for SCHERZO-5.56 and ZPR-6-7

Below the results of calculations for two benchmark tasks SCHERZO-5.56 and ZPR-6-7 are shown and compared.

The TWODANT result is used as a reference one.

SCHERZO-5.56:

As it can be seen from Table 2, all k-eff results for SCHERZO-5.56 infinite media are in very good agreement between each other. Difference between CITATION and other results is negligible.

Table 2. SCHERZO-5.56 k-eff results.

Code	K-eff
CONSYST	1.00301
FFCP	1.00301
TWODANT	1.00300
CITATION	1.00281 (-0.02%)

ZPR-6-7:

As it can be seen from Table 3 in case of TWODANT code the estimated calculated k-eff value (C) with ABBN-93 constants is equal to 0.98515. For ZPR-6-7 RZ model the estimated k-eff experimental value (E) is equal to 0.9854 ± 0.0020. It means C/E value is equal to 1.000 ± 0.002.It is in very good agreement with the experiment.

Table 3. ZPR-6-7 calculated k-eff results.

Geometry	ABBN SET	TWODANT			CITATION	
		Diffusion	Dif.S_4	P_1S_4	Diffusion	Ratio to TWODANT
SPHERE	28 group	.98727	.98903 (+0.18%)	.98753 (+0.02%)	.98768	+0.04%
R-Z	28 group	.98300	.98661 (+0.37%)	.98515 (+0.22%)	.98431	+0.13%
R-Z	26 group	.98280	.98705 (+0.43%)	.98495 (+0.22%)	.98412	+0.13%

In case of CITATION code with ABBN-93 constants the calculated k-eff value is by 0.13% less than the TWODANT one. But this is non-meaningful difference. This value is also in very good agreement with the experimental one.

Table 3 shows also an effect of spreading the neutron energy boundary from 10.5 MeV to 15 MeV (comparing 26 and 28 group calculation results). This effect is very small (+0.02%). The transport correction for ZPR-6-7 core was calculated to be equal to +0.22%. It is within the same range as the difference between CITATION and TWODANT diffusion results. It means in case of ZPR-6-7 core there is a compensation of two effects: (1) difference between diffusion and transport code, and (2) transport correction. As for ZPR-6-7 sphere model these effects are negligible.

4.2. Results for ZPPR-9 RZ model

The verification calculations have been made for k-effective value for ZPPR-9 homogeneous RZ model and several effects were investigated. For this model the homogenized cross sections were prepared by CONSYST code using FFCP cell code for correcting material effective cross sections to spatial and resonance heterogeneous effects.

The following effects were investigated:

- Coincidence of calculation results using either MICRO cross section option or MACRO one (MACRO – only macroscopic cross sections used in calculations; MICRO – only microscopic cross sections and nuclide densities used);
- Uncertainty in FFCP code followed by the subgroup method and associated with non-coincident rebuilding of the homogeneous calculation results.

Five heterogeneous stretch cell models were translated from CASUP to FFCP and used for calculation of homogenized material region cross sections:

- SCF – Single Column Fuel – Inner Core Region;
- DCF – Double Column Fuel – Outer Core Region;
- RBL – Lower Radial Blanket – Radial Blanket Region;
- ABL – Lower Axial Blanket – Axial Blanket Region;
- ABU – Upper Axial Blanket – Axial Blanket Region.

The following calculations have been performed:

- HOMO – calculation of self-shielding Bondarenko f-factors using dilution cross sections σ_0 for each homogeneous region and no FFCP code applied;
- HETERO – calculation of self-shielding Bondarenko f-factors using dilution cross sections σ_0 for each homogeneous region followed by FFCP code correction;
- SM – same using FFCP code with subgroup approach applied to different isotopes.
- HOMO with SM –rebuilding the homogeneous HOMO case using FFCP code with subgroup approach.

For all of these types of calculations MACRO and MICRO optional results have being obtained in order to be sure in the validity of the converting program MAKE_CIT. Table 4 shows the results obtained. As it can be seen the MACRO and MICRO calculation results differ each other about 0.01%. Inaccuracy in FFCP code followed by the subgroup method and associated with non-coincident rebuilding of the homogeneous calculation results in case of ZPPR-9 RZ model is about -0.27%. Table 4 also shows effects in k-eff as for whole reactor so separately for all of 5 cells. This kind of information presented in Fig.2. The full effect of applying the subgroup approach to all meaningful isotopes comparing to HOMO case is equal to +1.25%, but the effect of the stretch model separately is equal to +0.57%.

It should be noted that the fulfilled investigation for ZPPR-9 RZ model was done to prove the adaptation route for ABBN-93 cross sections library to CITATION code only. Next the k-effective analysis results will be obtained based on the full scale XYZ model.

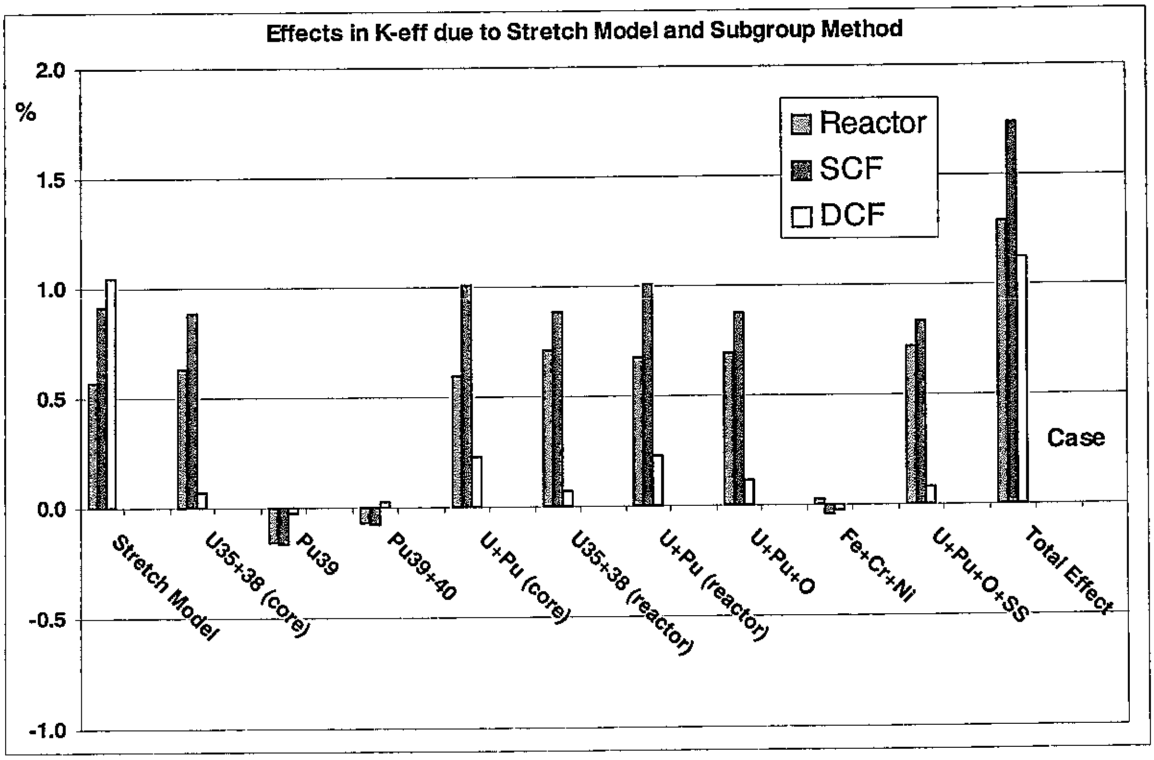

Fig. 2. Effects in k-eff applying different approaches.

Table 4. K-eff values for homogeneous and heterogeneous case, and under applying subgroup method (SM) for different isotopes.

Case		HOMO	HETERO	SM to All
Reactor	MACRO XS	0.98448	0.99003	0.99677
	MICRO XS	0.98443	0.99000	0.99674
	%	-0.01	0.00	0.00
	HOMO with SM	-	-	0.98247
	Ratio to HOMO, %	-	-	-0.21
Cells	SCF	0.99090	0.99990	1.00872
	DCF	0.99204	1.0024	1.00314
	RBL	0.99577	1.00019	1.00019
	ABL	0.99255	1.00300	1.00300
	ABU	0.99147	1.00062	1.00062
		U235+238	Pu39	Pu39+40
Reactor	MACRO XS	0.99710	0.98850	0.98932
	MICRO XS	0.99705	0.98844	0.98927
	%	-0.01	-0.01	-0.01
	HOMO with SM	0.98242	0.98240	0.98204
	Ratio to HOMO, %	-0.21	-0.21	-0.26
Cells	SCF	1.00872	0.99821	0.99911
	DCF	1.00314	1.00218	1.00268
	RBL	1.13591	1.00019	1.00019
	ABL	1.22318	1.00300	1.00300
	ABU	1.18337	1.00062	1.00062
		U+Pu core	U+Pu	U+Pu+O
Reactor	MACRO XS	0.99592	0.99675	0.99690
	MICRO XS	0.99587	0.99669	0.99685
	%	-0.01	-0.01	-0.01
	HOMO with SM	0.98211	0.98212	0.98203
	Ratio to HOMO, %	-0.26	-0.26	-0.26
Cells	SCF	1.01	1.01	1.00870
	DCF	1.00466	1.00466	1.00351
	RBL	1.00019	1.13591	1.13716
	ABL	1.00300	1.22318	1.22560
	ABU	1.00062	1.18337	1.18583
		Fe	SS	U+Pu+O+SS
Reactor	MACRO XS	0.99112	0.99034	0.99721
	MICRO XS	0.99106	0.99028	0.99716
	%	-0.01	-0.01	-0.01
	HOMO with SM	0.98242	0.98245	0.98206
	Ratio to HOMO, %	-0.21	-0.20	-0.26
Cells	SCF	0.99938	0.99943	1.00820
	DCF	1.00204	1.00212	1.00322
	RBL	1.00306	1.00370	1.14123
	ABL	1.00460	1.00550	1.22840
	ABU	1.00234	1.00339	1.18887

5. ZPPR JUPITER SERIES ANALYSIS RESULTS

5.1. Cores Analyzed

The k-effective analysis results have been obtained for three core ZPPR-9, ZPPR-13A and ZPPR-17A of JUPITER experiments series /8/.

ZPPR-9 is the first representative of JUPITER-I series of two-zone homogeneous cores of 600 to 800 MW(e) class (ZPPR-9, ZPPR-10A, B, C and D). This is cylindrical and the simplest of all cores.

ZPPR-13A is the first representative of JUPITER-II series of radial heterogeneous cores of 650 MW(e) class (ZPPR-13A, 13B/1, 13B/2, 13B/3, 13B/4 and 13C).

ZPPR-17A is the first representative of JUPITER-III series of axial heterogeneous cores of 650 MW(e) class (ZPPR-17A, B and C).

Full description of composition, geometry of plate cell models and core layout can be find in /8/.

5.2. Calculation Features

For each core XYZ homogeneous benchmark calculation models were used. In all cases the homogenized cross sections for each material region were prepared by CONSYST code using FFCP cell code. All input data for both CONSYST and FFCP code were prepared by TRANS_CASUP converting program using corresponding input data files for CASUP and SLAROM codes. As an example Fig.3 shows neutron flux spectrum calculated by CONSYST code and used for collapsing cross sections from 299 groups to 28 groups wide structure for a case of single column fuel (SCF) region.

CONSYST code treats the resonance self-shielding effects by using the well-known Bondarenko f- factors. But during these calculations the Dancoff correction can be applied to effective dilution cross sections (σ_0) by using formulae of the Equivalence Theory.

In this work that possibility was realized. Two types of calculations have been performed for all of three ZPPR cores: with Dancoff correction and without one. The Dancoff correction was applied by using GETER option in CONSYST code.

In all calculations the region dependent neutron fission source energy distribution was used.

All necessary corrections have been applied to k-effective values using results of work /8/. They are:

(1) Common correction to mesh effect, multi-drawer, asymmetry, etc.

(2) Transport correction to diffusion approximation in solving Bolzman equation.

(3) Subgroup method correction caused by non-coincident rebuilding of the homogeneous calculation result.

(4) Total cross section correction associated with the usage of current weighted transport cross sections in blanket and reflector regions instead of to use flux weighted cross sections.

The transport correction was evaluated by using IPPE standard route with two-dimensional discrete ordinates transport code TWODANT /19/. In these calculations only the homogeneous models for all ZPPR cores were used. All calculations were performed in 28 groups using within TWODANT code both as the diffusion option so the P_1 order of scattering anisotropy with S_8 angle approximation. The transport correction defined as difference between those two.

For calculation of the total cross section correction the code CONSYST was used which has an option for total cross section definition - flux or current weighted one.

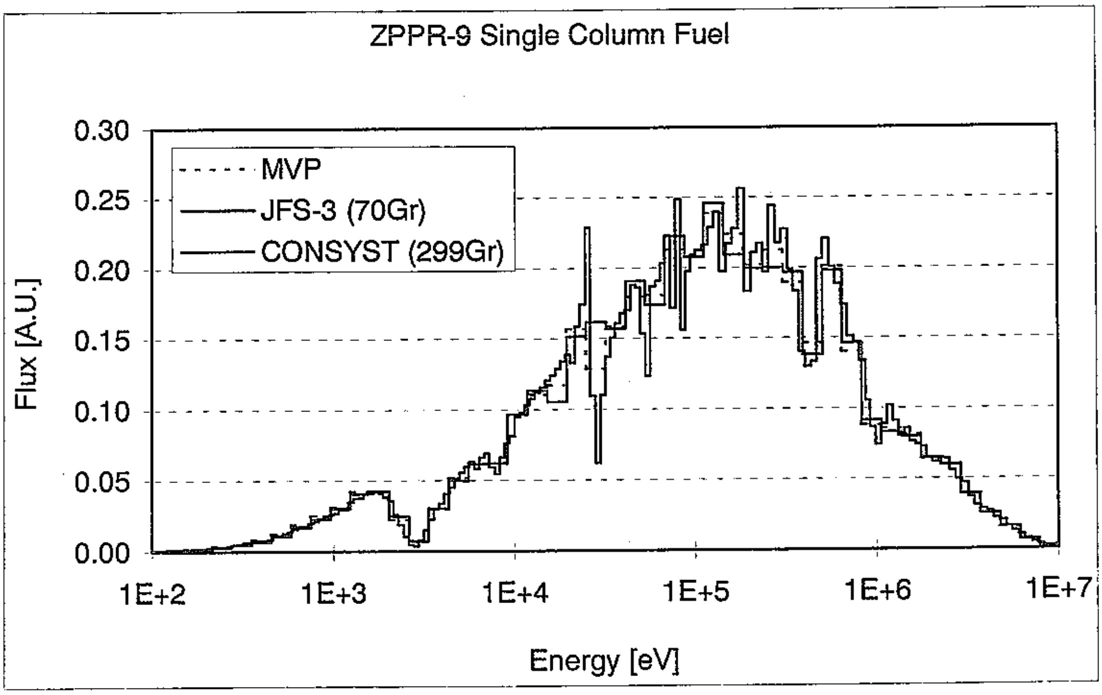

Fig. 3. Comparison of neutron flux spectra.

5.3. Calculation Results

For all of three ZPPR cores the effect of applying the subgroup method for different isotopes was investigated. Table 5 and Fig.4 show the obtained results.

Table 5. Effects in k-effective by applying the subgroup method (SM), in %.

Case	ZPPR-9	ZPPR-13A	ZPPR-17A
With Dancoff Correction:			
SM for U-238 in core	-0.64	-0.29	-0.72
SM for Pu-239	+0.71	+0.56	+0.70
SM for U+Pu in all zones	-0.04	+0.30	+0.00
SM for Fe	-0.29	-0.30	-0.25
SM for Na	-0.29	-0.22	-0.29
With Dancoff Correction:			
Full SM Effect Relative to Heter. Case with D.C.	-0.57	-0.19	-0.50
Full SM Effect Relative to Hom. Case with D.C.	+0.05	+0.36	+0.11
Full SM Effect Relative to Hom. Case without D.C.	+1.04	+0.83	+0.95
SM Correction	+0.21	+0.28	+0.17
Without Dancoff Correction:			
Full SM Effect Relative to Heter. Case	+0.34	+0.23	+0.28
Full SM Effect Relative to Hom. Case	+0.97	+0.79	+0.89
SM Correction	+0.27	+0.31	+0.22

As it can be seen from Table 5 there is big enough positive effect on Pu^{239}, which in case of ZPPR-9 and ZPPR-17A fully compensated by negative effect on U^{238}. Effects from structure material isotopes are negative and 2-3 times smaller. There is also small but positive effect on oxygen. It can be also seen that in case of ZPPR-9 and ZPPR-17A there is very strong correlation of all resonance effects – they are very similar for both cores. Effects on structure material isotopes are similar for all cores. In case of ZPPR-13A effects on Pu^{239} and U^{238} are quite different.

Table 6 presents summarized results of k-effective calculations obtained for all of three ZPPR cores. Fig.5 shows different effects in k-effective associated with applying the Dancoff correction, stretch cell model, subgroup approach, et al.

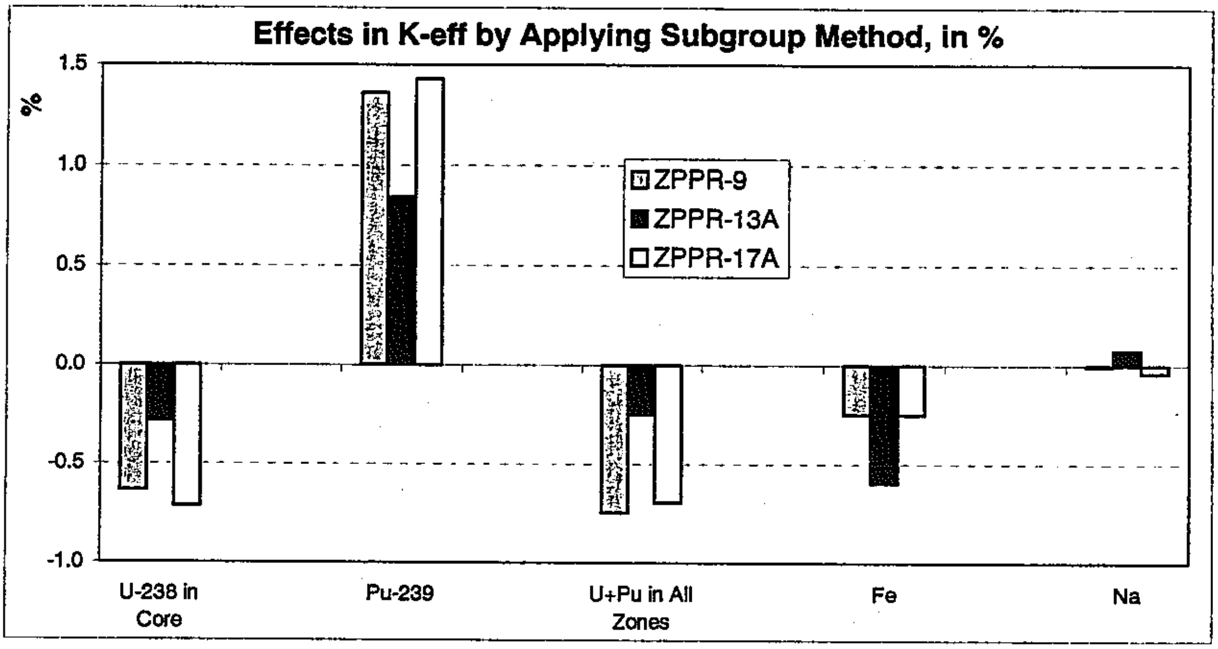

Fig. 4. Effects in k-effective by applying subgroup approach for important isotopes, in %.

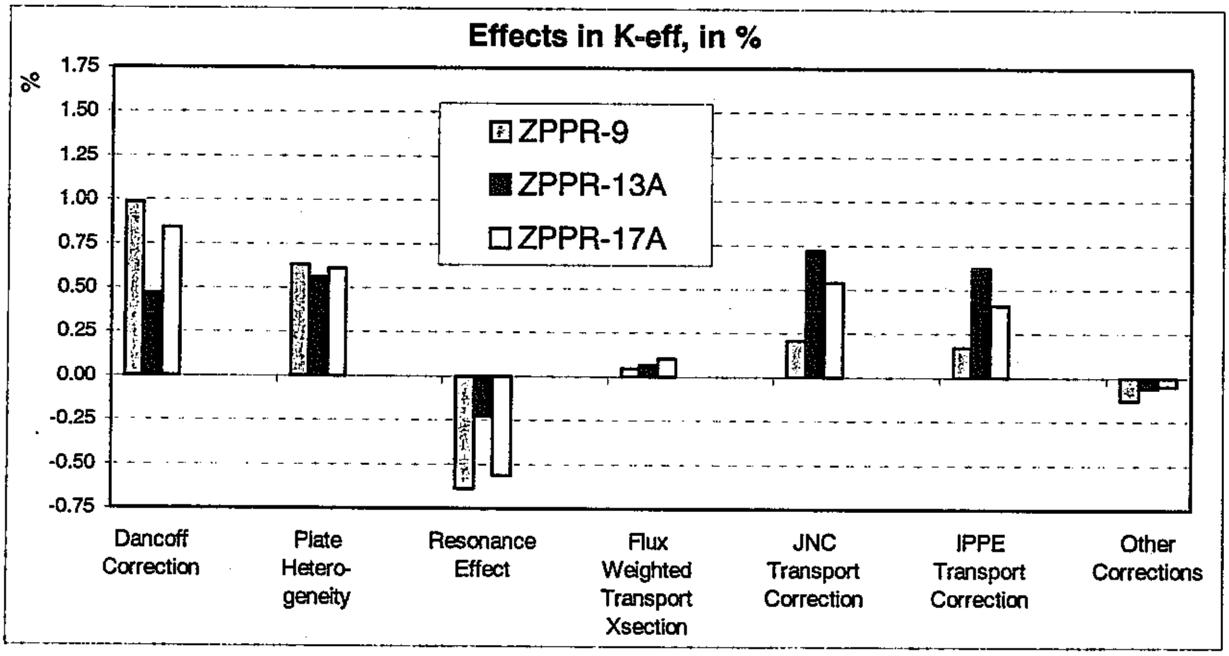

Fig. 5. Different effects in k-effective calculation results, in %.

Table 6. Main results for ZPPR k-effective calculations.

Case	ZPPR-9	ZPPR-13A	ZPPR-17A
Different Effects:			
Homogeneous Case (1)	0.98749	0.98064	0.98285
Homogeneous Case + Dancoff Correction (2)	0.99722	0.98525	0.99113
Plate Heterogeneity Effect (1)	0.99371	0.98612	0.98883
Plate Heterogeneity Effect + Dancoff Correction (2)	1.00349	0.99066	0.99721
SM Approach (1):			
Subgroup Method Effect (Full)	0.99708	0.98838	0.99158
SM Correction	+0.00268	+0.00307	+0.00221
By Applying Subgroup Method	0.99976	0.99145	0.99379
SM Approach (2):			
Subgroup Method Effect with Dancoff Correction (Full)	0.99772	0.98875	0.99222
SM Correction	+0.00215	+0.00280	+0.00167
By Applying Subgroup Method	0.99987	0.99155	0.99389
Total Cross Section Correction:			
Flux Weighted Transport Cross Section Correction	+0.00045	+0.00066	+0.00102
Calculated C Value:			
C Value (1)	1.00021	0.99211	0.99481
C Value (2)	1.00032	0.99221	0.99491
Difference	0.01%	0.01%	0.01%
Adopted C Value	1.00032	0.99221	0.99491
Applied Corrections:			
COR A (mesh, asymmetry, etc.)	-0.00127	-0.00060	-0.00050
COR B (transport/JNC)	+0.00210	+0.00720	+0.00540
COR B' (transport/IPPE)	+0.00170	+0.00620	+0.00410
COR A+B (JNC)	+0.00083	+0.00660	+0.00490
COR A+B' (IPPE)	+0.00043	+0.00560	+0.00360
Estimated C Value:			
C Value with JNC Correction	1.00115	0.99881	0.99981
C Value with IPPE Correction	1.00075	0.99781	0.99851
Estimated C/E Value:			
C/E Value with JNC Correction	1.00005	0.99831	0.99931
C/E Value with IPPE Correction	0.99965	0.99731	0.99801

It can be noted that Dancoff correction is big enough (see Fig.5) and defers from core to core, but the final results obtained with CONSYST+FFCP do not depend on that whether we apply Dancoff correction in CONSYST code or not. The difference between them is negligible and is about 0.01%.

The calculated transport correction using discrete ordinates transport code TWODANT was appeared to be less about 0.1% then JNC estimated one.

The estimated C/E value for all of three ZPPR cores is in very good agreement to 1.

5.4. Comparison of JNC and IPPE Results

The comparison results using IPPE and JNC nuclear data libraries for k-effective parameter for three ZPPR cores are presented in Table 7. Table 7 also shows results obtained by ERANOS code with ERALIB1 nuclear data library /20/ and obtained by MVP Monte-Carlo code with JENDL-3.2 files.

It can be seen that in case of ZPPR-13A core we have very good agreement between both IPPE and JNC results. In case of two other cores agreement is not so good: for ZPPR-17A we observe the difference about 0.36% but in case of ZPPR-9 the difference is bigger and is equal to 0.6%. Moreover, if we apply the same transport corrections to both IPPE and JNC results, the differences will be increased: for ZPPR-13A – up to 0.49%, for ZPPR-9 – to 0.63%.

Table 7. Comparison of k-eff C/E different results.

Case	ZPPR-9	ZPPR-13A	ZPPR-17A
C/E Value with IPPE Transport Correction /this work/	0.99965	0.99731	0.99801
Total Corrections Applied	0.26%	0.84%	0.53%
C/E JNC Value /8/	0.99371	0.99600	0.99440
Total Corrections Applied	0.08%	0.66%	0.49%
Difference between IPPE and JNC Results	+0.60%	+0.13%	+0.36%
C/E ERANOS/ERALIB1 /20/	0.99726	0.99546	0.99464
C/E MVP/JENDL-3.2	0.99431	0.99270	-

Table 6 also shows the meaningful corrections applied to calculation results. Table 7 also shows the total correction applied.

The total correction in all cases does not exceed 0.84%. So we can expect that the uncertainty in C value caused by possible errors in calculation of these corrections is less than 0.3% (as 1/4 - 1/3 of the value) in case of ZPPR-13A core, but rather less for ZPPR-17A and ZPPR-9 cores.

Table 7 and Fig. 6 show a comparison of different k-eff C/E values for all of three ZPPR cores.

It is important to note that the trend of 3 results, namely, obtained (1) by CITATION with ABBN-93 nuclear data library (this work), (2) by ERANOS with ERALIB1 data library, and (3) by MVP Monte-Carlo code with JENDL-3.2 files, is very similar. And only the results of JNC, obtained by CITATION with JFS-3 data library, have quite different behavior.

We can expect the following reasons only the observed discrepancies to be caused:

(1) Differences in nuclear data libraries.

(2) Difference in effective cross sections calculations (in cell codes).

(3) Not all corrections have been applied.

(4) Possible errors in the applied corrections.

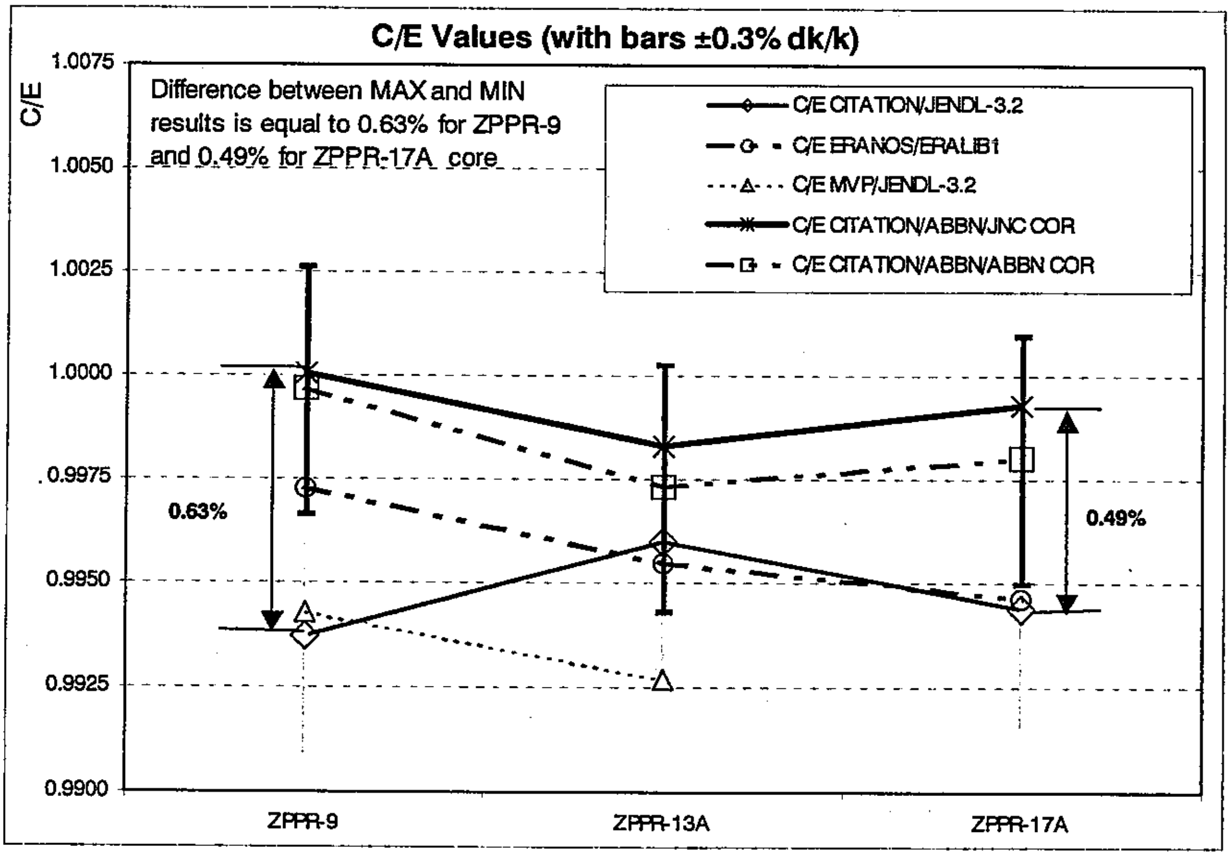

Fig. 6. Comparison of k-eff C/E values for ZPPR cores (all results corrected to transport effect).

As for the last two reasons there is no evidence for them because all visible physics corrections have been identified and applied.

To split effect of nuclear data library and effect of cell code several additional calculations have been made using JNC nuclear data library:

(1) Homogeneous calculations without applying any cell code.

(2) Heterogeneous calculations with and without using of R-parameter treatment in CASUP cell code (a special version of CASUP code was created for such type of calculations).

Below in Table 8 the results of these calculations are presented (noted accordingly as HOM and HET). Table 8 also shows an effect of applying 1-D cell stretch model and an effect of R-parameter treatment in the JNC calculation route. Fig.7 below presents a comparison for k-eff JNC and IPPE calculation results.

The main result of this comparison is that the JNC and IPPE k-eff calculation results for homogeneous case for all ZPPR cores are appeared to be very close each other. Maximal difference between them is about 0.1%. As for the comparison of another effects – they are quite different in case of JNC or IPPE route. It means that an effect of cell code it seems to be very significant.

It is important to note that for all ZPPR cores the calculated effects are appeared to be very close and practically do not differ from core to core. This fact is very surprising because these three investigated ZPPR cores are very different as in composition so in geometry too.

Table 8. Additional calculations with JNC JFS-3-J3 70-groups nuclear data library.

Case	ZPPR-9	ZPPR-13A	ZPPR-17A
HOM	0.98581	0.98056	0.98096
HET without R-parameters	0.99533	0.99025	0.99149
HET with R-parameters	0.99338	0.98863	0.98954
Effects:			
Ratio HET without R-parameters to HOM	+0.97%	+0.99%	+1.07%
Ratio HET with R-parameters to HOM	+0.77%	+0.82%	+0.87%
Ratio HET with to HET without R-parameters	-0.20%	-0.16%	-0.20%

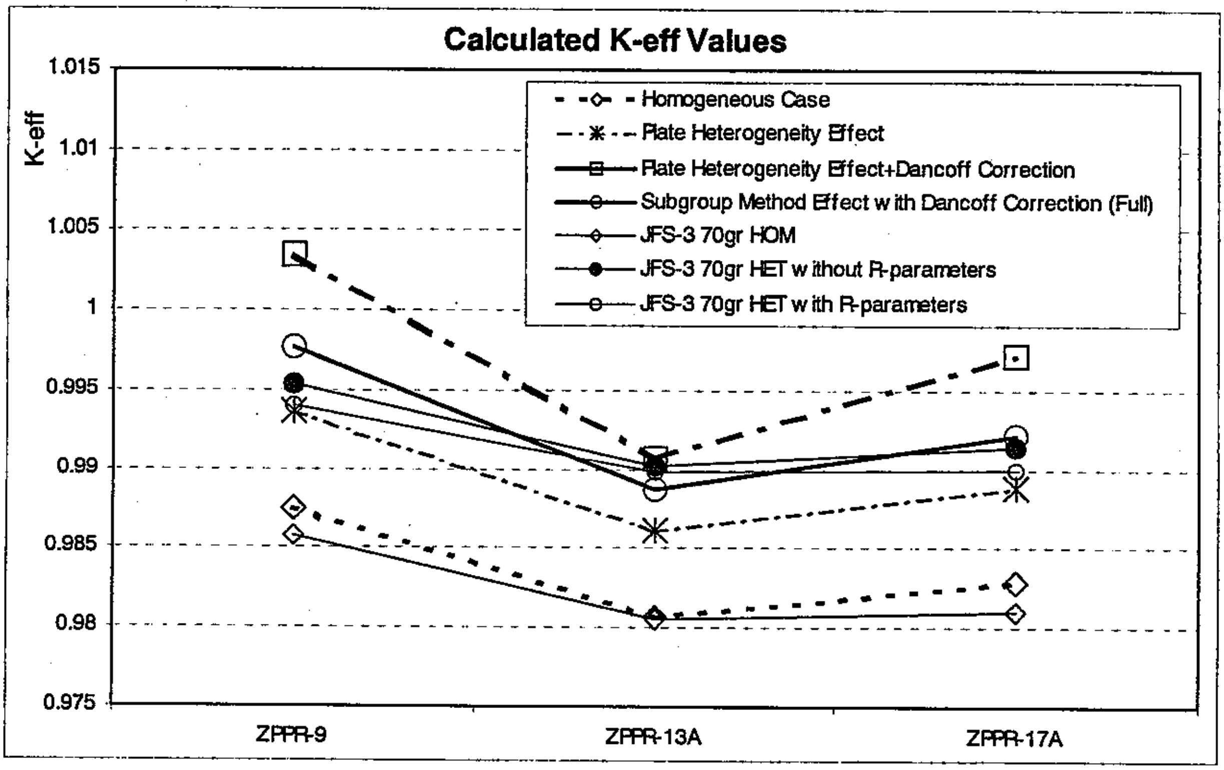

Fig. 7. Comparison of different effects in k-eff for JNC and IPPE calculation results.

6. CELL CALCULATIONS FOR BFS-62 CORES

For BFS-62-1 and BFS-62-2 cores /1/ one-dimensional stretch cell models have formed. Both BFS cores have the same cell structure.

Below there is a list of cells applied to CASUP cell calculations and which has to be used for calculations of homogenized effective cross sections with help of FFCP cell code:

- In low enriched core:

  LEZOLD LEZNEW

- In middle enriched core:

  MEZOLD MEZNEW

- In high enriched core:

  HEZOLD HEZOLDBRIG HEZNEW HEZNEWBRIG

- In blanket regions:

  RDB UBDBOL UBDBOU UBDBNE UAS000

- In safety rod regions:

  ABSOLB ABSOLC ABSNEB ABSNEC ABSMIB

- In control rod regions:

  B4CCOR B4CBLA B4CPW1 B4CPW2

- In the reflector and follower regions:

  FOLOLD FOLNEW FOLMIX

  SUPORT CUPELL SUROND SSREFL.

Table 9 below presents a comparison of critical buckling calculation results obtained by FFCP and CASUP codes. Here: HOM is a result obtained with uniform homogeneous "cell" model; HET – applying the heterogeneous plate cell structure; RES – applying the heterogeneous plate cell structure and the subgroup approach for fuel and structure material nuclides.

Fig.8 presents an example of cell calculation using FFCP code for LEZOLD zone. It presents cell region plate-wised correction factors for U^{235} and U^{238} fission and capture rate, which have to be applied to 3-D CITATION homogeneous calculation results.

Table 9. Comparison of critical buckling calculation results.

Cell	FFCP			CASUP	Ratio to CASUP	
	HOM	HET	RES		HET	RES
LEZOLD	8.33E-04	8.47E-04	8.24E-04	8.30E-04	1.020	0.993
LEZNEW	7.48E-04	7.66E-04	7.45E-04	7.65E-04	1.001	0.973
MEZOLD	1.24E-03	1.25E-03	1.20E-03	1.22E-03	1.028	0.989
MEZNEW	1.16E-03	1.19E-03	1.15E-03	1.17E-03	1.014	0.980
HEZOLD	1.78E-03	1.81E-03	1.81E-03	1.80E-03	1.005	1.007
HEZOLDBRIG	1.77E-03	1.80E-03	1.81E-03	1.79E-03	1.005	1.007
HEZNEW	1.70E-03	1.74E-03	1.74E-03	1.73E-03	1.007	1.004
HEZNEWBRIG	1.70E-03	1.74E-03	1.74E-03	1.73E-03	1.007	1.005
RDB	-6.59E-03	-6.59E-03	-6.46E-03	-6.32E-03	1.043	1.022
UBDOLD	-5.22E-03	-5.22E-03	-4.88E-03	-4.94E-03	1.057	0.989
UBDNEW	-5.07E-03	-5.07E-03	-4.73E-03	-4.76E-03	1.065	0.994

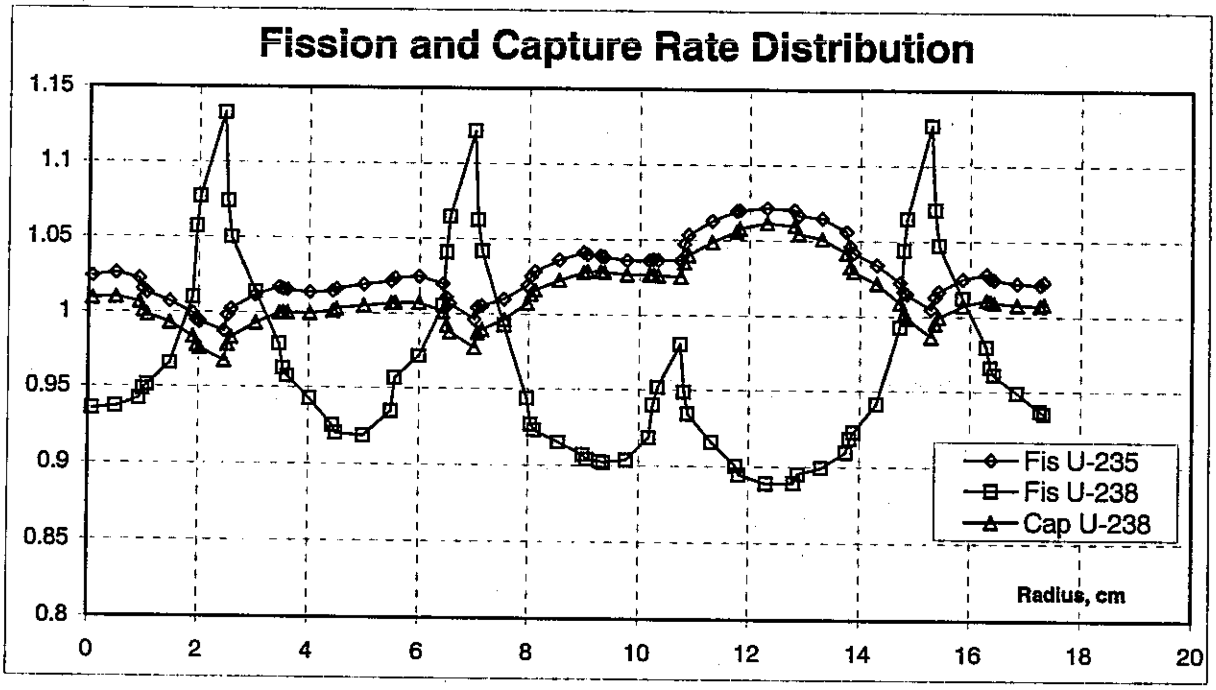

Fig. 8. Correction factors for U^{235} and U^{238} fission and capture rate for applying to homogeneous calculation results

7. CONCLUSIONS

For ZPPR-9, ZPPR-13A and ZPPR-17A JUPITER experiments series cores the k-effective analysis results using JNC CITATION code and using IPPE ABBN-93 nuclear data library have been obtained.

In these calculations different effects in k-eff have been investigated (as heterogeneous spatial and resonance effects, subgroup method effects, Dancoff correction, transport correction, etc.).

The main result of this study is that the effect of applying ABBN-93 nuclear data in JNC calculation route revealed a large enough discrepancy in k-eff for ZPPR-9 (about 0.6%) and for ZPPR-17A (0.5%) cores.

Fulfilled additional calculations with JNC nuclear data library have shown the very good agreement between results based on JNC and IPPE nuclear data for a case of homogeneous effective cross sections calculation without applying any cell code. It gives a thought that perhaps the reason of the observed discrepancies caused by the difference in the applied cell codes.

For BFS-62 cores such analysis is still finished. For BFS-62-1 and BFS-62-2 cores such analysis is still not finished. Stretch cell models for both BFS cores have been formed and some results of cell calculations using FFCP code presented.

Next the sensitivity analysis of the observed discrepancies is planed to investigate the possible reasons of them.

8. AKNOWLEDGEMENTS

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REFERENCES:

1. K. Sugino, T. Iwai, A. Shono. Analysis on the BFS Critical Experiments : An Analysis on the BFS-62-1 Assembly. - Report JNC TN9400 2000-098 (2000).

2. M.J. Lineberry, et al., Experimental Studies of Large Conventional LMFBR Cores at ZPPR, Proc. of Fast Reactor Physics 1979, Aix-en-Provence, IAEA-SM-244/86, Vol.1, P.187 (1979).

3. S.G. Carpenter, et al., Experimental Studies of 6000-Litre LMFBR Cores at ZPPR, Proc. of Conf. 1980 Advances in Reactor Physics and Shielding, Sun Valley, Idaho, P.521 (1980).

4. H.F. McFarlane, S.G. Carpenter, P.J. Collins, et al., Experimental Studies of Radially Heterogeneous Liquid-Metal Fast Breeder Reactor Critical Assemblies at the Zero-Power Plutonium Reactor, Nucl. Sci. Eng., Vol.87, P.204 (1984).

5. P.J. Collins, et al., Measurements and Analysis of Control Rod Worths in Large Heterogeneous LMFBR Cores. – Proc. Top. Mtg. on Reactor Physics and Shielding, Sept. 1984, Chicago, p.647.

6. S.R. Brumrach, et al., Experiments and Analysis for an Axially Heterogeneous Liquid-Metal Reactor Assembly at the Zero-Power Physics Reactor. – Nucl. Sci. Eng., 103, p.219 (1989).

7. S.R. Brumrach, et al., Experiments and Analysis for Large Conventional Fast Reactors in ZPPR-18/19. – Proc. Int. Conf. On the Physics of Reactors (PHYSOR'90), Marseille, p.V-63 (1990).

8. M. Ishikawa, W. Sato, K. Sugino, et al., Development of a Standard Data Base for FBR Core Nuclaer Design (VIII) – Computation of JUPITER Analytical Results. – Report PNC TN9410 97-099, 1997 (in Japanese). Also: M. Ishikawa. Consistency Evaluation of JUPITER Expariment and Analysis for Large FBR Cores. – Proc. Int. Conf. on the Physics of Reactors (PHYSOR'96), Sept. 16-20, 1996, Mito, Ibaraki, Japan. Vol.2, p. E-36, 1996 (in English).

9. G.N. Manturov, M.N. Nikolaev, A.M. Tsiboulia. "ABBN-93 Group Data Library. Part 1: Nuclear Data for calculation of Neutron and Photon Radiation Fields", Vienna, IAEA, INDC(CCP)-409/L (1997), p.65-110 (in English).

10. T. Nakagawa, et al., Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2, J. Nucl. Sci. Technol., 32(12), p.1259 (1995).

11. T.B. Fowler et al. Nuclear Reactor Physics Code: CITATION. Report ORNL TM – 2496, Rev. 2, Oak Ridge National Laboratory, 1971 (in English). Also: M. Nakagawa et al. Code System for Fast Reactor Neutronic Analysis. – JAERI–M 83-066, 1983 (in Japanese).

12. RSICC Peripheral Routine Program Collection DLC-182 " ABBN-90: Multigroup Constant Set for Calculation of Neutron and Photon Radiation Fields and Functionals, Including the CONSYST Program", ORNL (1992).

13. G.N. Manturov. CONSYST Code for Constants Preparation. Description of Appliance. Preprint IPPE-2828, Obninsk, 2000 (in Russian).

14. A.A. Bezborodov, et al., Calculation of Heterogeneity Effects in Fast Critical Assemblies by First Flight Collision Probability Method. - J. VANT, Series: Physics and Technique of Nuclear Reactors (1986), v.2, p.8 (in Russian).

15. A.I. Blokhin, B.I. Fursov, A.V. Ignatyuk, et al., Current Status of Russian Evaluated Neutron Data Libraries. Proc. Inter. Conf. on Nucl. Data for Science and Technology. Gatlinburg, Tennesee, May 9-13, 1994, v.1, p. 695.

16. T. Takeda, et al. Study on Neutron Streaming Effect in Large Fast Critical Assembly. – Report PNC ZJ265 81-01, 1981 (in Japanese). Also: T. Tone. A Numerical Study of Heterogeneity Effects in Fast Reactor Critical Assemblies. – J. Nucl. Sci. Technol., 12(8), p. 467, 1975 (in English).

17. M. Nakagawa, K. Tsuchihashi. SLAROM: A Code for Cell Homogenization Calculation of Fast Reactor. – JAERI -1294, 1984 (in English).

18. CSEWG Benchmark Specification (ENDF-202). BNL-19302 (1979).

19. RSICC Computer Code Collection CCC-547/TWODANT-SYS "One- and Two-Dimensional, Multigroup, Discrete-Ordinates Transport Code System", ORNL (1992).

20. K. Sugino and G. Rimpault: Analyses of the JUPITER Fast Reactor Experiments Using the ERANOS and JNC Code Systems. Proc. ANS Int. Top. Mtg. on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium (PHYSOR 2000), May 7-12, 2000, Pittsburgh, Pennsylvania, X.E.-1 (2000).