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BN-600 MOX Core Benchmark Analysis

Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculational Uncertainties of the LMFR Reactivity Effects

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BN-600 MOX CORE
BENCHMARK ANALYSIS

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BN-600 MOX CORE BENCHMARK ANALYSIS

RESULTS FROM PHASES 4 AND 6 OF A COORDINATED RESEARCH PROJECT ON UPDATED CODES AND METHODS TO REDUCE THE CALCULATIONAL UNCERTAINTIES OF THE LMFR REACTIVITY EFFECTS

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FOREWORD

For those Member States that have or have had significant fast reactor development programmes, it is of utmost importance that they have validated up to date codes and methods for fast reactor physics analysis in support of R&D and core design activities in the area of actinide utilization and incineration. In particular, some Member States have recently focused on fast reactor systems for minor actinide transmutation and on cores optimized for consuming rather than breeding plutonium; the physics of the breeder reactor cycle having already been widely investigated. Plutonium burning systems may have an important role in managing plutonium stocks until the time when major programmes of self-sufficient fast breeder reactors are established. For assessing the safety of these systems, it is important to determine the prediction accuracy of transient simulations and their associated reactivity coefficients.

In response to Member States' expressed interest, the IAEA sponsored a coordinated research project (CRP) on Updated Codes and Methods to Reduce the Calculational Uncertainties of the LMFR Reactivity Effects. The CRP started in November 1999 and, at the first meeting, the members of the CRP endorsed a benchmark on the BN-600 hybrid core for consideration in its first studies. Benchmark analyses of the BN-600 hybrid core were performed during the first three phases of the CRP, investigating different nuclear data and levels of approximation in the calculation of safety related reactivity effects and their influence on uncertainties in transient analysis prediction. In an additional phase of the benchmark studies, experimental data were used for the verification and validation of nuclear data libraries and methods in support of the previous three phases. The results of phases 1, 2, 3 and 5 of the CRP are reported in IAEA-TECDOC-1623, BN-600 Hybrid Core Benchmark Analyses, Results from a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculational Uncertainties of the LMFR Reactivity Effects, which was published in 2010.

With the purpose of investigating a core fully loaded with mixed oxide (MOX) fuel, two new models of the BN-600 reactor core were defined and analysed in the second part of the CRP benchmark study: (i) core with MOX fuel containing weapons-grade Pu and (ii) core with MOX fuel containing Pu and minor actinides from spent light water reactor fuel. These further analyses were identified as phases 4 and 6 of the above mentioned CRP and the corresponding results and achievements are presented in this publication.

The IAEA expresses its appreciation to all participants in the CRP for their dedicated efforts on this publication. The IAEA officer responsible for this publication was S. Monti of the Division of Nuclear Power.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

Benchmark analyses for two BN-600 core designs: (i) with mixed oxide (MOX) fuel containing weapons-grade Pu and (ii) with MOX fuel containing Pu and Minor Actinides (MAs) from spent LWR fuel, both designs incorporating a sodium plenum above the core, are described in the report. These analyses extend studies for the BN-600 hybrid core — with uranium oxide (UOX) and MOX fuels — carried out in 1999–2001. BN-600 is a fast reactor with enriched UOX fuel. The considered MOX and hybrid UOX/MOX designs were proposed to investigate options for utilization of Pu and MAs in this reactor.

This work was carried out within the framework of the IAEA sponsored coordinated research project (CRP) on Updated Codes and Methods to Reduce the Calculational Uncertainties of the LMFR Reactivity Effects. The MOX core benchmark analyses retain the general objective of the CRP which is to validate, verify and improve methodologies and computer codes used for the calculation of reactivity coefficients in fast reactors aiming at enhancing the utilization of plutonium and minor actinides. The scope of the work is to reduce the uncertainties of safety relevant reactor physics parameter calculations of MOX fuelled fast reactors and hence to validate and improve data and methods involved in such analyses.

In the previous benchmark analyses for the BN-600 hybrid core (phases 1, 2 and 3 of the CRP [1]) that closely conforms to a traditional configuration, the comparisons between different options showed that sufficient accuracy was achieved using the diffusion theory approximation, widely applied in fast reactor physics calculations. This finding confirmed the reliability of calculations using standard techniques and computer codes employing the diffusion theory approximation, as used in various countries for their fast reactor development projects. It is noteworthy that a substantial spread in the results of the participants exists for several reactivity coefficients, particularly, in non-fuelled and peripheral regions where the neutron leakage component of a reactivity effect is large compared to its other components [2]. However, the substantial spread in computed parameters did not have a significant impact on the transient simulation results, especially up to the onset of sodium boiling in the ULOF transient analyses. This observation highlights the compensation effect of uncertainties in reactivity coefficients on the reactivity value computed during transient simulations in the specific design of the hybrid core mainly loaded with UOX fuel.

Phase 5 focused on the validation of the employed tools for computing criticality values and sodium void coefficient distributions by comparison with results of measurements made in the BFS-62 critical facility. A series of four BFS-62 critical assemblies have been designed with the aim of studying the changes in the reactor physics behavior of the BN-600 reactor from its current state to that of a hybrid core including MOX fuel. The third of these assemblies, BFS-62-3A, was considered for study in Phase 5 of the benchmark analysis. The sodium void reactivity effects have been determined for four different configurations where sodium has been removed from fuel rods within the BFS-62-3A core. The comparative analyses between experimental and calculated parameters confirmed in general the applicability of the employed codes and data libraries for computing fast reactor safety related parameters.

With the purpose of investigating a core configuration fully loaded with MOX fuel, core models of the BN-600 type reactor, designed to reduce the sodium void effect by installing a sodium plenum above the core, were newly defined for the Phase 4 and Phase 6 of the CRP benchmark studies. The specifications and input data for the neutronics calculations were prepared by IPPE (Russian Federation). The specifications given for the benchmark describe only a preliminary assumption on a possible core arrangement and represent only one conceptual approach to BN-600 full MOX core designs. These core configurations were studied during Phase 4 (for MOX fuel option with weapons-grade Pu) and Phase 6 (for MOX fuel option with Pu and MAs from spent LWR fuel) of the CRP.

The organizations participating in the benchmark analysis for the BN-600 core fully loaded with MOX fuel are: ANL from the USA (only Phase 4), CEA and SERCO Assurance (now SERCO) with combined contribution from France and the UK, respectively, CIAE from China (only Phase 4), FZK/IKET from Germany (now KIT/IKET), IGCAR from India, JNC from Japan, KAERI from the Republic of Korea, IPPE from the Russian Federation. The participants applied their own state-of-the-art basic data, computer codes and methods to the benchmark analysis. Within the scope of these core benchmark analyses, they have validated their efforts to update basic nuclear data, and to improve methodologies and computer codes for calculating safety relevant reactor physics parameters.

This report first introduces the basic data, computer codes, and methodologies applied to the benchmark analysis by various participants.

Then it addresses the benchmark definitions and specifications given for Phase 4, Table 1.1 showing contributions of the participants in the benchmark analysis. The results for integral and local reactivity coefficient values obtained by the participants are inter-compared in terms of uncertainty resulting from different data and method approximations along with their effects on the ULOF and UTOP transient simulation. In addition, the results are evaluated in comparison with those for the hybrid core.

The analyses were concluded by studies of Phase 6 for a core model similar to that investigated in Phase 4, but with MOX fuel containing plutonium and MAs coming from LWR spent fuel [3]. The reasons for choosing the plutonium isotopic composition and MA content in the MOX fuel of Phase 6 are explained. The reactor model, provided by IPPE is described. The obtained — by the participants — results on criticality, burnup reactivity loss and reactivity coefficients are discussed. Outcomes of sensitivity studies on the influence of different nuclear data and of different MOX fuel compositions are described. Some results of ULOF transient analyses are shown.

TABLE 1.1. TASK PARTICIPATIONS IN FULLY MOX FUELLED BN-600 CORE BENCHMARK ANALYSIS (PHASE 4)

Participant	ANL		CEA/SA		CIAE		FZK/IKET		IGCAR		IPPE		JNC		KAERI	
	Cal. Methodhod[1]	Hetero-geneity[2]	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity	Cal. Method	Hetero-geneity
• k_{eff}	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M	D,T	M,T	D,T	M,T	D	M
• Fuel Doppler coefficient and its distribution	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M	D	M	D,T	M,T	D	M
• Steel Doppler coefficient and its distribution	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M	D	M	D,T	M,T	D	M
• Fuel density coefficient and its distribution	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M	D	M	D,T	M,T	D	M
• (Steel density coefficient and its distribution)	D	M	D,T	M,T					D	M	D	M				
• Sodium density coefficient and its distribution	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M	D	M	D,T	M,T	D	M
• (Expansion coefficients and its distributions)											D	M				
• Power distribution for fuel and non-fuelled regions	D	M	D,T	M,T	D	M,T	D,T	M,T	D	M			D,T	M,T	D	M
• β_{eff}	D	M	D	M	D	M,T	D	M,T	D	M	D	M	D	M,T	D	M
• Prompt neutron lifetime	D	M	D	M	D	M,T	D	M,T	D	M	D	M	D	M,T	D	M

Notes : (1) Calculational method: Diffusion theory calculation (D), Transport theory calculation (T)
(2) Heterogeneity calculation: Homogeneous calculation (M), Heterogeneous calculation (T)

2. BASIC DATA AND ANALYTICAL METHODS

Most contents in this chapter are the same as addressed in the previous Synthesis Report for the hybrid BN-600 core benchmark analyses performed during phases 1–3. Minor modifications either by updating and addition to the basic data and computer codes used for the benchmark analysis by the participants will be described.

2.1 BASIC DATA

2.1.1 Nuclear and delayed neutron data

Basic nuclear and delayed neutron data used for the benchmark analyses of Phase 4 by the participants are given in Table 2.1. The standard multi-group cross-sections were generated based on their own evaluated nuclear data library, using their own current state-of-the-art data processing system. Basically common delayed neutron data sets for yield fraction and decay constants, and neutron spectra were used for the calculation of system kinetics parameters.

2.1.2 Energy release per fission and capture

The reactor power is calculated by the following equation, where the flux is normalized to the user-specified reactor power, 1470 MW(th):

$$P = \sum_r V_r \; c \sum_g \left(\sum_n N_{n,r} \sum_i w_i \;\; \sigma_g^{n,i,r} \right) \phi_{g,r} \,,$$

where

- P; reactor thermal power;
- V_r; volume for region r;
- c; conversion factor;
- $N_{n,r}$; number density for nuclide n in region r;
- w_i; energy release per reaction i (fission or capture) (MeV/reaction);
- $\sigma_g^{n,i,r}$; microscopic cross-section for energy group g, nuclide n, reaction i and region r;
- $\varphi_{g,r}$; neutron flux for group g and region r to be normalized.

Energy release (w_i) data per fission and capture used by the participants are given in Table 2.2. JNC calculated thermal power per fission based on the Sher's data [4]. JNC corrected the energy release values per fission given in Table 2.2 by taking into account the energy release due to neutron capture in a typical fast reactor core.

2.2 ANALYTICAL METHODS

Table 2.3 summarizes the basic computer codes used for the benchmark analyses by the participants, details of which are described in the following. The effective cross-sections condensed into broader energy group structure were generated using their own cell calculation code with various self-shielding treatments for homogeneous and heterogeneous cell models. The energy group number of condensed group constant sets ranges from 230 (fine) to 9 (coarse) with the upper energy boundary of ~ 10 MeV. Various specific heterogeneous cell modelling methods and code specific cross-section processing schemes were employed for the treatment of the heterogeneity of control rods.

2.2.1 ANL

Benchmark calculations were performed with the ANL suite of fast reactor physics codes. These tools have been extensively demonstrated in previous US physics experiments and fast spectrum test reactor (EBR-2 and FFTF) applications. Basic nuclear data is taken from the ENDF/B-V.2 multigroup cross-section data that is generated using the MC^2-2 codes [5]. For structural materials, a resonance "screening" procedure was utilized to pre-process broad resonances into the MC^2-2 "smooth data" library at the 2082 group level. Self-shielding effects of the remaining resonances are explicitly evaluated in MC^2-2 assuming the narrow resonance approximation, allowing for Doppler broadening, scattering interference, and taking into account of overlapping of neighboring resonances of different isotopes.

For nine benchmark material compositions (inner core, middle core, outer core, axial blanket, sodium plenum, upper boron shield, axial reflector, radial steel shield, and radial reflector), homogeneous ultra-fine-group flux calculations were performed using MC^2-2. For regions that contained enriched fuel, the consistent P_1 method was used with group-independent buckling search for the fundamental mode spectrum calculations performed with 2082 groups. In regions that do not contain enriched fuel, an infinite-medium fixed source MC^2-2 calculation was done to determine the collapsing spectrum. In these fixed source calculations, the fixed source was an estimated 2082 group leakage spectrum ($DB^2\varphi$) from an adjacent zone.

Two hundred and thirty energy group cross-sections were generated for nine zones of the BN-600 reactor configuration. For each of the enriched fuel regions, the fundamental mode weighting spectrum was determined using the compositions specified in the benchmark. The group constant set used in all axial blanket zones was collapsed using an estimated leakage spectrum from the middle core zone as the fixed source in the MC^2-2 calculation. Furthermore, the group constant set used in all axial reflector zones was collapsed using an estimated leakage spectrum from the axial blanket zone as the fixed source in the MC^2-2 calculation. The group constant sets for the sodium plenum, upper boron shield, radial steel shield, and radial reflector zones were obtained in a similar manner. The group constant sets for the sodium plenum and upper boron shield were computed by employing the flux spectrum obtained with an estimated fixed source that was the neutron leakage spectrum from the sodium plenum zone. Finally, the group constant set for the radial steel shield used an estimated leakage spectrum from the outer core zone as the MC^2-2 fixed source and for the reflector zone calculation was an estimated leakage spectrum from the steel shield zone.

Cross sections were generated at standard operating temperatures and at elevated temperatures so that Doppler coefficients could be determined. Standard operating temperature for the fuel was 1500 K; all other materials were taken to be at 600K. At elevated temperature, the fuel temperature was 2100 K, while for all other materials it was 900 K. Lumped fission product cross-sections were generated at the fuel operating temperatures. The lumped fission product model is based on isotopic data for 180 individual isotopes. Each lump is created from fission yields based on ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu fission and subsequent transmutation in a typical fast reactor spectrum. The system eigenvalue, powers, and fluxes were determined using the finite difference triangle-Z (Tri-Z) option of the DIF3D [6] diffusion theory code and a 230 energy group structure.

The reactivity coefficients were determined by the VARI3D [7] perturbation theory code. The VARI3D code computes kinetics parameters and reactivity coefficients using either first-order or exact perturbation theory (the adjoint flux being always determined for the unperturbed configuration). The flux calculations within the VARI3D code were performed by DIF3D using the finite difference triangle-Z diffusion theory option.

A similar evaluation of cross sections and reactivity coefficients using ENDF/B-Version VI data files is planned for future work.

All calculations were normalized to 1470 MW(th). Regional powers were calculated using two methods. The first method used isotope-dependent MeV/fission and MeV/capture factors which include gamma heating (i.e. local energy deposition model), while the second method assumed isotope independent values of 200 MeV/fission and 0 MeV/capture.

2.2.2 CEA/SA

This sections describes the code and data option employed for producing results provided as joint contributions from France (CEA Cadarache) and the UK (SERCO Assurance sponsored by BNFL, Winfrith).

The proposed benchmark core of the BN-600 reactor has been analysed using the ERANOS code and data system, developed as part of the European collaboration on fast reactors [8]. Version 1.2 of ERANOS was released at the end of 1997, and contains all of the functions required to calculate a complete set of core, shielding and fuel cycle parameters for LMFR cores. This includes a set of automated procedures for the preparation of homogeneous equivalent cross sections for control rod absorbers using the reactivity equivalence method. The nuclear data used for all of the calculations performed during these studies originates from fine and broad group application libraries based on the JEF2.2 nuclear data evaluation.

Cross sections for each spatial region in the Hex-Z core model have been prepared using the ECCO cell code [9]. As required by the benchmark specifications, both a simple homogeneous representation, and a more detailed heterogeneous description, have been used to produce 33 group resonance self-shielded cross-sections and matrices for each material in the whole core model. The cell calculation includes a slowing down treatment in 1968 groups, which uses a sub-group method within each fine group to provide an accurate description of the reaction thresholds and resonances. The nuclear data used for all of the calculations performed during these studies originates from fine and broad group application libraries based on the JEF2.2 nuclear data evaluation.

For the heterogeneous calculations performed during Phase 4, a specific set of procedures has been used within the ERANOS code scheme to prepare homogeneous equivalent cross sections for the shim rod absorber subassembly that includes the effect of the control rod heterogeneity. These procedures employ the reactivity equivalence method for the treatment of heterogeneous geometries which uses the Sn transport option of the BISTRO finite difference module that is included within the ERANOS system. Initially, the shim rod absorber was represented both homogeneously and heterogeneously in an XY geometry with a representative surrounding core fuel zone. The equivalence method was then applied by performing an angular direct flux calculation of the fully heterogeneous control rod together with an adjoint flux calculation of the homogeneous control rod using volume weighted cross sections as an initial guess solution. Perturbation techniques were then used to calculate the reactivity variation between the two solutions. Correction factors were then applied in each energy group, and for each reaction, to the homogeneous cross sections to obtain a zero reactivity variation between the heterogeneous and homogeneous representations of the control rod. The homogeneous adjoint flux solution was then repeated until convergence, or equivalence, was achieved. These homogeneous equivalent absorber cross sections were then used in the whole core calculations.

Whole core spatial flux calculations have been performed in both diffusion and transport theory using the H3D and TGV/VARIANT modules of the ERANOS code scheme. The H3D module consists of a finite difference code capable of providing a three dimensional diffusion theory solution. The TGV/VARIANT module uses a Variational Nodal Method, with an order P_3 angular expansion of the flux and a P_0 anisotropic scattering approximation, to provide a three dimensional transport theory solution. Based on these methods, appropriate modules have been used within the ERANOS code scheme to provide results for each of the requested parameters.

For Phase 6 calculations, a new data library based on JEFF-3.1 was applied in addition to JEF-2.2 data.

2.2.3 CIAE

The one dimensional diffusion code 1DX-EXP which is a modified version of 1DX [10], was used to collapse few-group cross-sections from fine-group constants library LIB-IV-M which is a modified version of LIB-IV [11]. The LIB-IV-M library has a 46 neutron energy group structure and contains ABBN-type self-shielding factors. The few-group cross section set adopts 12 neutron groups.

The analysis of the proposed benchmark core in HEX-Z representation has been carried out with the use of a diffusion theory code. The 1DX code computes total cross section for each fuel isotope using the Bell modification to the rational approximation for heterogeneity geometry. A three dimensional hexagonal nodal code, HND, developed at CIAE has been used to calculate neutronics parameters for steady state. It also can calculate dynamic characteristics by the perturbation model.

Dynamic characteristics have been analysed by the perturbation theory based on the following data:

- Delayed neutron yield: R. J. Tuttle (1975);
- Delayed neutron absolute spectra: D. Saphier (1977).

2.2.4 FZK/IKET

For Phase 4 analyses, the FZK 11-group cross-section library was applied. This library — that includes Bondarenko-type f-factor tables — was developed in 1990s on the basis of the KFKINR 26-group cross-section set for application the SIMMER accident analysis code. The library was extended in early 2000s by adding data processed mainly from JEF-2.2, JENDL-3.2 and ENDF/B-VI evaluated nuclear data libraries. To take into account the steel Doppler effect in an approximate manner, Fe data were added from JENDL-3.2 to the 11-group library. Since data for Cr, Ni and Mo are temperature independent, one may expect that the steel Doppler constants computed with that library would be underestimated.

Effective cross-sections for neutron transport calculations were computed with the ZMIX code [12], current-weighted f-factors being employed for transport cross-sections. Both homogeneous and heterogeneous ZMIX options were employed, a model based on the Bell method (with modified background cross-sections for fuel isotopes) being applied for computing effective cross-section for fuel subassemblies in the latter case.

For reactor calculations, the VARIANT nodal transport code was used for diffusion and transport (SP_3) calculations in a stand-alone mode. VARIANT/KIN3D and a FZK post-processing tool were used to compute spatial reactivity and power distributions. Delayed neutron data were taken from ENDF/B-VI.

For Phase 6 analyses, 30-group and 560-group libraries based on JEFF-3.0 were applied. The 30-group library was employed initially for computing all benchmark parameters. The 560-group library was employed then for investigating the effect of the number of energy groups in the basic data library on the computed value for the fuel Doppler coefficient. The neutron transport calculations were performed with 21-group effective cross-sections computed from the 30-group and 560-group libraries by employing the ZMIX code, composition dependent neutron spectra being employed as weighting functions, these spectra being computed for homogeneous media with "critical" buckling values (for fuel media) or zero buckling values (for other ones). The delayed neutron data were taken from JENDL-3.3.

2.2.5 IGCAR

The nuclear data used is XSET-98. It is a 26 group set with ABBN type self-shielding factor table. Only homogeneous model of the core was analysed by diffusion theory. Three dimensional calculations were done by 3DB code in 26 groups with 6 meshes per fuel assembly. No mesh size corrections were applied. Reactivity coefficient distributions were calculated by first order perturbation theory code, 3DPERT. Total fuel Doppler coefficient, total sodium density coefficient, total fuel density coefficient and total steel density coefficient were computed by use of two k_{eff} calculations also. Delayed neutron parameters are derived from the data of Tuttle (1979). Power distribution was calculated assuming that 200 MeV is released at the point of fission and there is zero neutron capture energy release.

2.2.6 IPPE

In contrast to the IPPE results for phases 1 to 3, all values obtained in this benchmark have been obtained by using the 26-group the ABBN-93 nuclear data library, the standard option for fast reactor calculations in The Russian Federation [13]. The ABBN-93 nuclear data were processed into effective cross-sections by the use of the CONSYST code [14], the latter cross-sections being used for the reactor neutronics analyses, including computation of the delayed neutron parameters with R. J. Tuttle's data [15].

The core calculations were carried out with the use of the diffusion theory code, TRIGEX [16], and 18-group effective cross-sections. No transport theory option for calculation of spatial distributions of reactivity coefficients was available for the Hex-Z model. The 18-group cross-sections were obtained by convolution of preliminary computed 26-group cross-sections. To calculate the spatial distribution of reactivity coefficients, diffusion (RHEIN) and transport theory (TWODANT [17]) code calculations were performed for the RZ geometry. The same calculation grids and convergence criteria were used for both calculations. TWODANT analysis was made in P_3S_8 approximation. For both options, first-order perturbation theory relationships were used for determining spatial reactivity coefficients. The TRIGEX code package was also used for perturbation theory calculations, based on diffusion first-order perturbation theory to determine material worth and reactivity coefficients caused by the core expansion. A transport theory mode in the Monte Carlo theory code, MCNP has been used for calculating basic integral reactivity coefficients.

IPPE compared reactivity coefficients provided by the participants and investigated the effect of their discrepancies on the ULOF and UTOP transients for the BN-600 full MOX benchmark core of Phase 4 with a simplified transient model [18]. This model employs the point kinetics approximation without taking into account phase transitions of core materials and sodium boiling. The influence of individual coefficients, e.g. of the radial expansion coefficient, on the transient progression depends on the contribution of the respective reactivity effect to the net reactivity during the transient. Unavailable data for reactivity coefficients, not provided by some participants, were assumed to be the same as computed by the TRIGEX code. A simple truncated core model was used to evaluate the reactivity effect due to radial expansion. To take into account contributions of the steel reflector to the net reactivity variation, the radial reflector steel subassemblies (SSAs) were considered as an additional thermohydraulics channel, the reactivity contributions being only due to sodium temperature variations. For these calculations 1% of the reactor thermal energy was assumed to be released in SSAs.

ULOF analyses were also performed for Phase 6 by employing the same simplified transient model as for Phase 4.

2.2.7 JNC

JNC has applied the following methodology:

- Nuclear data library: JENDL-3.2;
- Delayed neutron yield: R. J. Tuttle (1979);
- Yield fraction and decay constant: Keep in (1965);
- Delayed neutron spectrum: D. Saphier (1977);
- Group constant set JFS-3-J3.2R: 70-group, ABBN-type self-shielding factor table. The group constant set was revised from the previous JFS-3-J3.2 in 2003;
- Effective cross-section: homogeneous, current weighted transport cross-section (SLAROM code);
- Cell model for fuel subassembly (FSA);

  (Case 1) homogeneous model;

  (Case 2) heterogeneous model: one dimensional cylindrical model with Tone's background cross-section method (CASUP code);
- Cell model for control rod;

  (Case 1) homogeneous model;

  (Case 2) heterogeneous model: one dimensional cylindrical super-cell model with the iterative reaction-rate-distribution preservation method (CASUP code);
- Basic diffusion calculation: 18-group and three dimensional Hex-Z model (CITATION code), in which the region dependent fission spectra were applied with;

  (Case 1) homogeneous model;

  (Case 2) heterogeneous model: Benoist's anisotropic diffusion coefficient;

JNC used the directional Benoist's diffusion constant in the three dimensional Hex-Z diffusion calculation to consider the streaming effect in the heterogeneous model. The definition of Benoist's diffusion constant D is formulated by:

$$D_k^g = \left(\sum_i \sum_j \phi_i^g V_i P_{ij,k}^g / \Sigma_{tr,j}^g \right) / \left(3 \sum_i \phi_i^g V_i \right)$$

where k is a direction index for the parallel or the perpendicular. The parallel diffusion constant is used for the axial direction leakage calculation and the perpendicular one for the radial leakage calculation. The one dimensional cylindrical model of the BN-600 FSA used in the cell calculation of JNC is shown in Fig. 2.1:

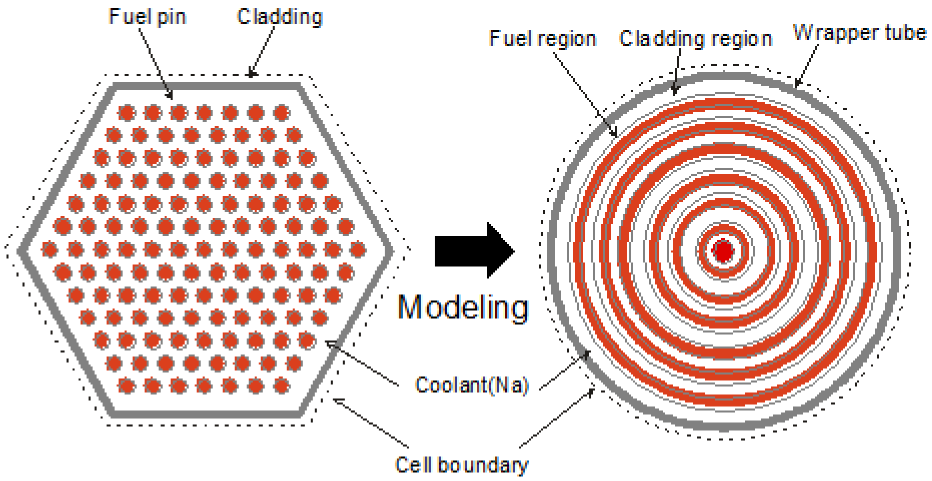


FIG. 2.1. Modelling of BN-600 fuel subassembly into 1-D cylindrical model.

- Transport theory and mesh size correction: 18-group, three dimensional Hex-Z model (NSHEX code based on the Sn-transport nodal method, which was developed by JNC.);
- The generated thermal power per fission was based on the Sher (1981)'s data [4]. The capture thermal energy was corrected based on ENDF/B-IV;

In the analysis of the present CRP core benchmarks, JNC used the JFS-3-J3.2 set for phases 1, 2 and 3, and the JFS-3-J3.2R after Phase 4, both of which are based on the Japanese evaluated nuclear data library, JENDL-3.2. The JFS-3-J3.2R set is a newly generated and revised version of the JFS set. The effect of the JFS set change in phases 1, 2 and 3 was estimated during the Phase 4 study and its results are addressed in Appendix in the report.

2.2.8 KAERI

All calculation procedures and evaluations were performed by using the K-CORE System of KAERI. Based on the self-shielding f-factor approach, the microscopic cross sections for the benchmark model were generated.

For Phase 4 calculations, an 80-group neutron cross section library, KAFAX (KAERI FAst XS)/F22 [19], was prepared in the MATXS library format based on the JEF-2.2 nuclear data. This version contains infinite dilute cross sections for various temperatures and Bondarenko self-shielding f-factors. The composition dependent, 9-group microscopic cross section sets for all reactor constituent materials were generated from KAFAX/F22 at the specified temperatures (1500 K and 2100 K for fuel isotopes including fission product and oxygen, 600 K and 900 K for structural and coolant isotopes) by utilizing the effective cross section generation module composed of TRANSX [20] and TWODANT [21] codes. The data processing in this module includes resonance and spatial self-shielding corrections, reactor and cell flux solutions and cross section group collapsing. Neutron spectra necessary for group collapsing were obtained from the P_3S_8 transport theory calculations for the two dimensional, coarse meshed RZ model for the reference configuration with the TWODANT code. The TWODANT code employing discrete ordinates approximation was used for two dimensional (RZ) model calculations. The 9-group structure has 1.2 and 1.5 lethargy widths for the first two energy groups, and a 1.0 lethargy width for the remaining 7 energy groups, with the highest energy boundary of 20.0 MeV. The 9-group cross section set is used for all neutronics calculations.

The lumped 239-Pu fission product cross sections was generated by collapsing into 9 groups from the cross section library for 172 fission product isotopes of 239-Pu, fission yields, and a typical neutron spectrum of fuel region of BN-600 full MOX core from TWODANT result as a weighting spectrum.

The neutron multiplication factor k_{eff} and basic neutronics parameters such as forward and adjoint neutron flux distribution, power distribution were calculated by using DIF3D [8] associated with the 9-group cross section set. The DIF3D code employs the coarse-mesh nodal diffusion approximation to the Hex-Z geometry model.

Various reactivity parameters such as fuel density and sodium density coefficients, were calculated by using the PERT-K code [22]. The PERT-K code solves the first order perturbation theory equations based on diffusion theory nodal expansion method using the forward and adjoin flux solutions obtained from DIF3D calculations.

The power distribution for fuel and non-fuelled regions is determined by the energy deposition of fission and capture reactions including the energy deposition of structure and coolant materials capture reactions. These energy deposition values implicitly assumed that the energy generated by fission and capture reactions is deposited at the site of the reaction. However, assuming all core power comes from the fission energy deposition, the power for non-fuelled region is completely ignored and the core power is normalized for fuel regions only.

The effective delayed neutron fraction, β_{eff} and the prompt neutron lifetime were calculated by using the BETA-K code [23]. The BETA-K code can generate several kinetic parameters such as the effective delayed neutron fraction, prompt neutron lifetime, fission spectrum and fission yield data for each fissionable isotope, fuel compositions and the whole core, utilizing the DIF3D forward and adjoint flux solutions. For this calculation, the delayed neutron data such as yield numbers for 6 delayed neutron groups were prepared from the ENDF/B-VI file.

For Phase 6 calculations, KAERI employed in addition a new 150-group data library based on JEFF-3.1, the 150-group cross-section being collapsed to 25 groups, the methodology being similar to the one described previously which was used for generating 9-group effective cross-sections from the 80-group data library.

TABLE 2.1. BASIC NUCLEAR AND DELAYED NEUTRON DATA EMPLOYED FOR PHASE 4 ANALYSES

Participant	ANL	CEA/SA	CIAE	FZK/IKET	IGCAR	IPPE	JNC	KAERI
Nuclear Data								
Nuclear data library	ENDF/B-V.2	JEF-2.2	LIB-IV-M	Based on KFKINR, Fe from JENDL-3.2, Cr, Ni, Mo data are temperature-independent	XSET-98	ABBN-93, ENDF/B-VI for MCNP calculation	JENDL-3.2	KAFAX/F22
Standard group constant set (No. of groups)	2082	1968	46	11	26	26 (ABBN-93) 299 groups for main 16 isotopes 26 groups for the rest (ABBN-93.1)	70 (revised in Phase 4)	80
Delayed Neutron Data								
• Delayed neutron yield	• ENDF/B-V	• R. J. Tuttle[1)]	• R. J. Tuttle	• ENDF/B-VI	• R. J.Tuttle	• R.J. Tuttle[1a)]	• R.J. Tuttle[1a)]	• ENDF/B-VI
• Yield fraction and decay constant	• ENDF/B-V	• JEF-2.2 (Pu^{242} from ENDF/B-VI)	• R. J. Tuttle	• ENDF/B-VI	• R.J. Tuttle[1a)]	• R. J. Tuttle	• G. R.Keepin [3)]	• ENDF/B-VI
• Delayed neutron spectrum	• ENDF/B-V	• JEF-2.2 (U^{238} and Pu^{242} from ENDF/B-VI)	• D. Saphier[4)]	• ENDF/B-VI	• D. Saphier	• D. Saphier	• D. Saphier	• ENDF/B-VI

Notes: 1) R. J. Tuttle, “Delayed-Neutron Data for Reactor-Physics Analysis,” Nucl. Sci. and Eng., 56, pp. 37 - 71 (1975),

1a) R. J. Tuttle , "Delayed Neutron Yields in Nuclear Fission," Proc. of the Consultants' Meeting on Delayed Neutron Properties, IAEA, Vienna, March 1979

2) M. C. Brady and T. R. England, “Delayed Neutron Data Group Parameters for 43 Fissioning Systems”, Nucl. Sci. and Eng., 103, pp. 129–149, (1989).

3) G. R. Keepin, “Physics of Nuclear Kinetics” (1965).

4) D. Saphier, et al., “Evaluated Delayed Neutron Spectra and Their Importance in Reactor Calculation,” Nucl. Sci. and Eng., 62, pp. 660 - 694 (1977).

TABLE 2.2. ENERGY RELEASE PER FISSION

Nuclide	ANL		CEA/SA		FZK/IKET		IGCAR	
	Fission	Capture	Fission	Capture	Fission	Capture	Fission	Capture
U^{235}	193.74	6.88	196.29	6.55	200.00	0.00	200.0	0.0
U^{236}	194.49	5.49	194.14	5.12	200.00	0.00	200.0	0.0
U^{238}	198.06	5.68	201.03	5.48	200.00	0.00	200.0	0.0
Pu^{239}	199.92	6.51	200.91	6.53	200.00	0.00	200.0	0.0
Pu^{240}	199.47	5.23	204.18	5.24	200.00	0.00	200.0	0.0
Pu^{241}	201.99	6.30	204.56	6.31	200.00	0.00	200.0	0.0
Pu^{242}	201.58	5.23	206.41	5.03	200.00	0.00	200.0	0.0
FP	0.00	8.00	0.00	8.00	0.00	0.00	0.0	0.0
O	0.00	3.37	0.00	4.14				
Na	0.00	6.94	0.00	6.96			0.00	4.12
Fe	0.00	7.78	0.00	7.65			0.00	7.78
Cr	0.00	8.51	0.00	7.94			0.00	8.64
Ni	0.00	9.27	0.00	7.82			0.00	8.12
Mo	0.00	8.77	0.00	8.00			0.00	6.97
B^{10}	0.00	2.78	0.00	2.79			0.00	2.79
B^{11}	0.00	3.41	0.00	3.37			0.00	2.79
C	0.00	4.94	0.00	4.14				

Nuclide	IPPE		JNC		KAERI		Average	
	Fission	Capture	Fission	Capture	Fission	Capture	Fission	Capture
U^{235}	193.10	6.80	193.71	6.55	198.80	6.89	196.08	6.69
U^{236}	191.60	6.80	191.61	5.13	191.21	5.49	195.24	5.98
U^{238}	193.80	6.80	194.79	4.81	193.71	5.68	196.90	6.02
Pu^{239}	199.60	6.80	199.92	6.53	198.30	6.52	199.21	5.61
Pu^{240}	197.40	6.80	197.79	5.24	194.71	5.23	198.72	4.72
Pu^{241}	201.30	6.80	201.97	6.31	200.10	6.30	200.80	5.46
Pu^{242}	200.30	6.80	200.87	5.03	194.71	5.23	199.96	4.76
FP							0.00	4.00
O							0.00	3.76
Na					0.00	6.95	0.00	6.24
Fe					0.00	7.79	0.00	7.75
Cr					0.00	8.52	0.00	8.40
Ni					0.00	9.28	0.00	8.62
Mo					0.00	8.78	0.00	8.13
B^{10}					0.00	2.79	0.00	2.79
B^{11}					0.00	3.42	0.00	3.25
C					0.00	4.95	0.00	4.54

TABLE 2.3. BASIC COMPUTER CODES USED FOR BENCHMARK ANALYSIS

Participant	ANL	CEA/SA	CIAE	FZK/IKET	IGCAR	IPPE	JNC	KAERI
Effective cross- section Calculation	• MC^2-2 -ultra-fine B_g^2 method	• ECCO - subgroup method	• 1DX-EXP - ABBN f-factor method	• ZMIX - ABBN f-factor method	• EFFCONSY - ABBN f-factor method	• CONSYST - B^2 method • Continuous energy spectrum presentation in real geometry	• SLAROM - ABBN f-factor method	• TRANSX/ TWODANT - ABBN f-factor method
FSA heterogeneity		• ECCO	• 1DX-EXP - Bell method	• ZMIX - Bell method			• CASUP - Tone's background cross section method	• TRANSX
SHR heterogeneity		• ECCO/ BISTRO - reaction rate preservation method					• CASUP - iterative reaction rate distribution preservation method	• TRANSX

TABLE 2.3. BASIC COMPUTER CODES USED FOR BENCHMARK ANALYSIS (cont.)

Participant	ANL	CEA/SA	CIAE	FZK/IKET	IGCAR	IPPE	JNC	KAERI
Phase 4 (Hex-Z Model)								
• Condensed group constant Set (No. of groups)	• 230	• 33	• 12	• 11	• 26	• 18	• 18	• 9
• Diffusion theory Flux calculation	• DIF3D - nodal diffusion method	• H3D module	• HND hexagonal nodal method	• VARIANT	• 3DB for Tri-Z model	• TRIGEX	• CITATION	• DIF3D - nodal diffusion method
• Transport theory calculation		• TGV/ VARIANT module - nodal transport method		• VARIANT - SP_3 nodal transport method		• MCNP (transport theory cal. mode in MCNP)	• NSHEX - nodal discrete ordinates method	
• Perturbation theory calculation	• VARI3D for Tri-Z model	• H3D module for diffusion theory	• HND for diffusion theory	• KIN3D	• 3DPERT	• TRIGEX	• PERKY	• PERT-K

3. CORE WITH MOX FUEL (PHASE 4)

3.1 DESCRIPTION OF BENCHMARK MODELS

3.1.1 Homogeneous benchmark model

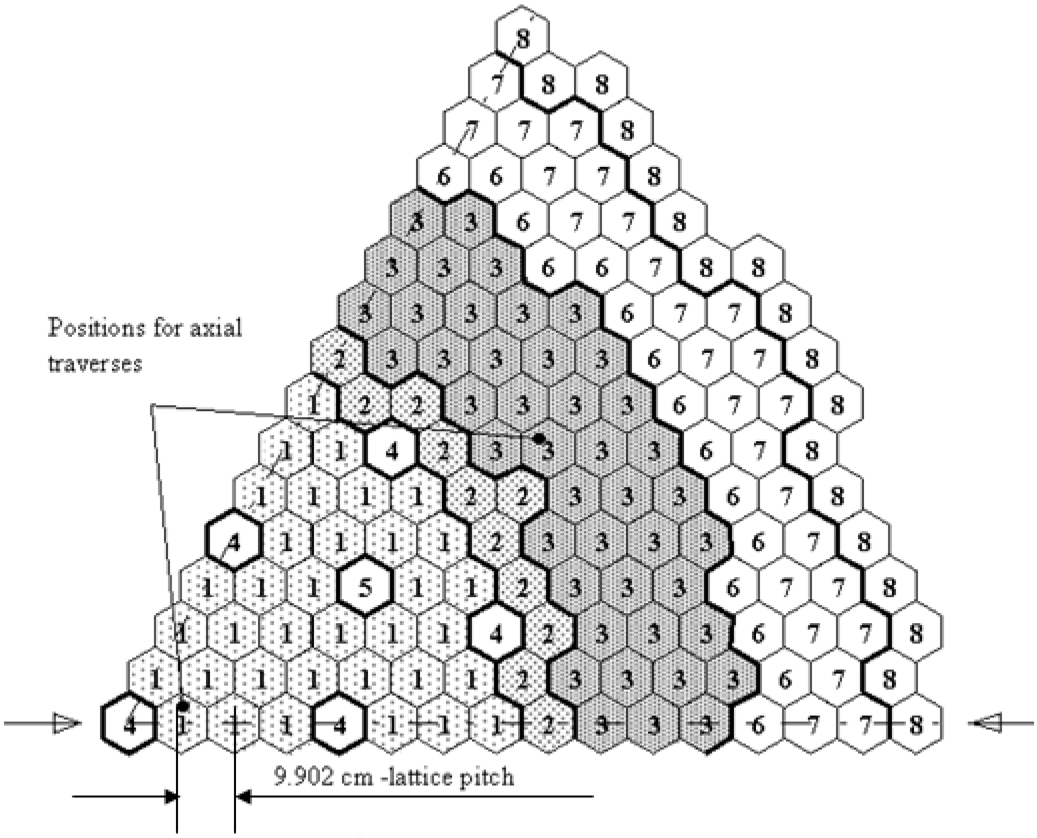
The calculational model, a 60^{o} sector of the layout of the benchmark core, shown in Fig. 3.1, corresponds to the 1470 MW(th) total power BN-600 reactor at the beginning of an equilibrium cycle. In principle, the core layout is the same as that of the hybrid core of BN-600. The core consists of a low enrichment MOX inner zone (LEZ), a middle enrichment MOX zone (MEZ), and a high enrichment MOX zone (HEZ). In addition, there is an internal breeding zone (IBZ) in the central 5.1 cm of the LEZ region. For this benchmark configuration, each enriched zone has a burnup of 2–3%, while the internal breeding zone, which contains relatively more ^{238}U, has a burnup of 1.7%. Three control rods (SCRs) and one shim control rod (SHR) are radially interspersed in the LEZ region. Radially, beyond the HEZ outer drive zone are two steel shielding zones (SSA1 and SSA2) followed by a radial reflector zone (REF). In the control rod zone, the bottom of the absorber is parked 2.55 cm above the core mid-plane, whereas, in the scram rod zone the absorber is parked at the bottom of the upper boron shield region.

The same geometry descriptions for fuel subassemblies (FSAs) and control rods (SCR and SHR) have been retained in a triangular lattice of pitch 9.902 cm, with the same simplifications (60^{o} symmetry and exclusion of automatic compensators) as assumed in the previous benchmark studies.

Compared with the hybrid core model defined in previous benchmark studies, several design modifications have been made in the full MOX core model, compared with the hybrid core model. A sodium plenum followed by a boron shield is located above the core to reduce the sodium void effect. An internal breeding zone (IBZ) of 5.1 cm thickness is inserted in the core mid-plane to achieve the reduction of sodium void effect as sought in the BN-800 core design investigations. To compensate for the reduction in core volume resulting from these design changes, an extra row of FSAs is added in the MEZ region.

All fuel isotopes are modeled at a uniform temperature of 1500 K, and all structural and coolant isotopes are at a uniform temperature of 600 K. Batch-averaged compositions are used and the heterogeneous structure of the core FSAs has been ignored.

The compositions of isotopes specified for each cell are shown in Table 3.1, where FP stands for a pair of fission products. The general description of the compositions for various subassembly types is described in Table 3.2. The arrangement of the compositions and cell heights for each cell are given in Fig. 3.2.



Subassemblies types

1. LEZ FSA

2. MEZ FSA

3. HEZ FSA

4. SHR

FIG. 3.1. Layout of full MOX BN-600 model (60° sector, rotational symmetry).

	dZ cm	dZ cm for output	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2, 3 7	Radial Reflector 8
Reflector	30.0	30.0	22	22	22	22	22	22	22	21
Cones	4.5	4.5	12	12	12	14	16	19	20	21
Upper Boron Shield	15.0	5.0 5.0 5.0	13	13	13	14	16 SCR	19	20	21
Cones	4.5	4.5	12	12	12	14	17	19	20	21
Sodium Plenum	23.0	8.0 8.0 7.0	11	11	11	14	17	19	20	21
Plugs	5.3	5.3	10	10	10	14	17	19	20	21
Core	41.15	8.23 8.23 8.23 8.23 8.23	1 LEZ	2 MEZ	3 HEZ	14 SHR	17	19 SSA1	20 SSA2, 3	21 Radial Reflector
Internal Breeding Zone	5.1	5.1	23 IBZ	2	3	15	18	19	20	21
Core	41.15	8.23 8.23 8.23 8.23 8.23	1 LEZ	2 MEZ	3 HEZ	15	18	19 SSA1	20 SSA2, 3	21 Radial Reflector
Axial Blanket 1	5.5	5.5	7	8	9	15	18	19	20	21
Axial Blanket 2	29.7	9.7 10.0 10.0	4	5	6	15	18	19	20	21
Reflector	30.0	30.0	22	22	22	22	22	22	22	21

FIG. 3.2. Arrangement of the compositions and cell heights of the full MOX core model of BN-600.

TABLE 3.1. ISOTOPIC DENSITY

(Unit: 10^{24} nuclei / cm^3)

	Fuel LEZ	Fuel MEZ	Fuel HEZ	Fuel AB2 LEZ	Fuel AB2 MEZ	Fuel AB2 HEZ	Fuel AB1 LEZ
Isotope	Mat.1	Mat.2	Mat.3	Mat.4	Mat.5	Mat.6	Mat.7
^{235}U	1.792E-05*	1.761E-05	1.728E-05	2.490E-05	2.520E-05	2.560E-05	2.354E-05
^{236}U	6.170E-07	6.062E-07	5.946E-07	6.000E-07	5.000E-07	4.000E-07	8.310E-07
^{238}U	6.780E-03	6.662E-03	6.534E-03	8.901E-03	8.915E-03	8.931E-03	8.840E-03
^{239}Pu	1.122E-03	1.234E-03	1.355E-03	7.680E-05	6.470E-05	5.110E-05	1.287E-04
^{240}Pu	1.002E-04	1.102E-04	1.210E-04	1.500E-06	1.000E-06	7.000E-07	3.455E-06
^{241}Pu	6.397E-06	7.035E-06	7.724E-06	3.000E-08	2.000E-08	2.000E-08	7.621E-08
^{242}Pu	5.121E-07	5.632E-07	6.183E-07	–	–	–	–
^{239}FP	2.370E-04	2.328E-04	2.284E-04	8.200E-06	6.600E-06	4.600E-06	2.456E-05
O	1.658E-02	1.658E-02	1.658E-02	1.803E-02	1.803E-02	1.803E-02	1.803E-02
Na	7.549E-03	7.549E-03	7.549E-03	7.549E-03	7.549E-03	7.549E-03	7.549E-03
Fe	1.287E-02	1.287E-02	1.287E-02	1.287E-02	1.287E-02	1.287E-02	1.287E-02
Cr	2.848E-03	2.848E-03	2.848E-03	2.848E-03	2.848E-03	2.848E-03	2.848E-03
Ni	1.627E-03	1.627E-03	1.627E-03	1.627E-03	1.627E-03	1.627E-03	1.627E-03
Mo	2.176E-04	2.176E-04	2.176E-04	2.176E-04	2.176E-04	2.176E-04	2.176E-04
^{10}B	–	–	–	–	–	–	–
^{11}B	–	–	–	–	–	–	–
C	–	–	–	–	–	–	–

	Fuel AB1 MEZ	Fuel AB1 HEZ	Plugs	Sodium plenum	Cones	Boron shield	SHR
Isotope	Mat.8	Mat.9	Mat.10	Mat.11	Mat.12	Mat.13	Mat.14
^{235}U	2.400E-05	2.458E-05	–	–	–	–	–
^{236}U	7.000E-07	6.000E-07	–	–	–	–	–
^{238}U	8.854E-03	8.883E-03	–	–	–	–	–
^{239}Pu	1.107E-04	8.761E-05	–	–	–	–	–
^{240}Pu	2.500E-06	1.622E-06	–	–	–	–	–
^{241}Pu	5.000E-08	4.889E-08	–	–	–	–	–
^{242}Pu	–	–	–	–	–	–	–
^{239}FP	2.110E-05	1.543E-05	–	–	–	–	–
O	1.803E-02	1.803E-02	–	–	–	–	–
Na	7.549E-03	7.549E-03	7.549E-03	2.020E-02	1.380E-02	6.730E-03	9.653E-03
Fe	1.287E-02	1.287E-02	3.952E-02	6.810E-03	2.050E-02	1.020E-02	1.310E-02
Cr	2.848E-03	2.848E-03	1.003E-02	1.130E-03	5.860E-03	2.130E-03	2.799E-03
Ni	1.627E-03	1.627E-03	7.405E-03	2.160E-05	2.790E-03	8.980E-04	1.322E-03
Mo	2.176E-04	2.176E-04	7.426E-04	7.550E-05	–	2.660E-04	3.140E-04
^{10}B	–	–	–	–	–	6.870E-03	5.113E-03
^{11}B	–	–	–	–	–	2.780E-02	2.045E-02
C	–	–	–	–	–	8.660E-02	6.392E-03

TABLE 3.1. ISOTOPIC DENSITY (cont.)

(Unit: 10^{24} nuclei / cm^3)

	SHR follower	SCR	SCR follower +rod tail	SCR follower	SSA1	SSA2, 3	Radial reflector
Isotope	Mat.15	Mat.16	Mat.17	Mat.18	Mat.19	Mat.20	Mat.21
^{235}U	-	-	-	-	-	-	-
^{236}U	-	-	-	-	-	-	-
^{238}U	-	-	-	-	-	-	-
^{239}Pu	-	-	-	-	-	-	-
^{240}Pu	-	-	-	-	-	-	-
^{241}Pu	-	-	-	-	-	-	-
^{242}Pu	-	-	-	-	-	-	-
^{239}FP	-	-	-	-	-	-	-
O	-	-	-	-	-	-	-
Na	1.958E-02	1.126E-02	1.958E-02	2.027E-02	5.638E-03	5.875E-03	4.860E-03
Fe	7.111E-03	1.092E-02	7.111E-03	5.060E-03	5.252E-02	5.179E-02	4.630E-02
Cr	1.216E-03	2.250E-03	1.216E-03	8.655E-04	7.636E-03	7.530E-03	1.340E-02
Ni	1.212E-04	9.109E-04	1.212E-04	1.438E-05	7.447E-04	7.332E-04	6.280E-03
Mo	7.655E-05	2.360E-04	7.655E-05	8.620E-05	3.589E-04	3.550E-04	-
^{10}B	-	1.780E-02	-	-	-	-	-
^{11}B	-	4.450E-03	-	-	-	-	-
C	-	5.560E-03	-	-	-	-	-

	Axial reflector	Inner Blanket
Isotope	Mat.22	Mat.23
^{235}U	-	2.255E-05
^{236}U	-	7.762E-07
^{238}U	-	8.440E-03
^{239}Pu	-	3.747E-04
^{240}Pu	-	2.301E-05
^{241}Pu	-	1.029E-06
^{242}Pu	-	3.372E-08
^{239}FP	-	1.526E-04
O	-	1.803E-02
Na	1.729E-02	7.549E-03
Fe	1.368E-02	1.287E-02
Cr	2.344E-03	2.848E-03
Ni	4.948E-05	1.627E-03
Mo	1.487E-04	2.176E-04
^{10}B	-	-
^{11}B	-	-
C	-	-

* Read as 1.792E-05 = 1.792×10^{-5}

** For all compositions, ^{239}Pu fission products will be used.

3.1.2 Heterogeneous benchmark model

The model gives a more detailed geometry description for the core, axial blanket and the SHR absorber region. Subassemblies of LEZ, MEZ, and HEZ are of identical geometry, 127 fuel pins being located with triangular pitch of 7.95 mm inside hexagonal wrapper. The cross-section of SHR is shown in Fig. 3.3.

The geometry description of a FSA and a SHR is detailed in Table 3.2, the simplifications of the description being the same as those of Phase 3 study. Nuclear densities for the FSA and SHR sub-regions are listed in Table 3.3. All fuel isotopes are assumed to be at a uniform temperature of 1500 K. All structural and coolant isotopes are at a uniform temperature of 600 K. The value of nuclear density for inter-assembly sodium is taken the same as for sodium inside FSA. For each isotope the amount of nuclei in the heterogeneous model is the same as that in the homogeneous model.

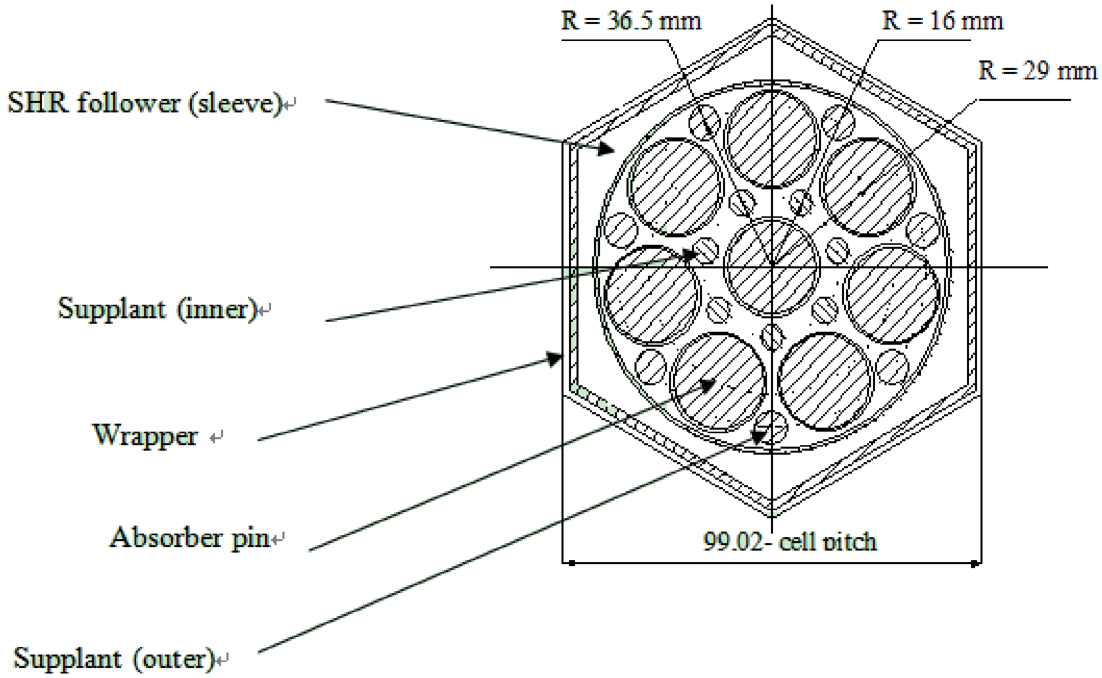


FIG. 3.3. SHR cross-section.

TABLE 3.2. FSA AND SHR HETEROGENEOUS GEOMETRY DESCRIPTION

SA type	Homogeneous composition No.	Structural element	Heterogeneous composition No.
FSA	1–9	Hexagonal wrapper: external size across flats-96.0 mm, gap between FSAs-3.02 mm thickness-2.0 mm	11
	1–9	Fuel pin (127)	
	1–9	Cladding: external diameter-6.9 mm, thickness-0.4 mm	12
	1–3	Fuel	1–3 respectively
	4–9	Fertile material in AB	4–9 respectively
	23	Fertile material in IBZ	16
	10	Plugs	10
	1–9	Coolant (sodium)	13
SHR	14	Hexagonal follower: external size across flats –96.0 mm, thickness-2.0 mm	11
	14	Rod wrapper external diameter-85.0 mm, thickness-1.0 mm	14
	14	Absorber pin (8)	
		Cladding: external diameter-23.0 mm, thickness - 0.7 mm	15
	14	Absorbing material (B_4C)	17
	14	Inner supplant (7) diameter –6.0 mm	14
	14	Outer supplant (7) diameter –8.0 mm	14
	14	Coolant (sodium)	13

TABLE: 3.3. ISOTOPIC DENSITY FOR HETEROGENEOUS DESCRIPTION

Unit: 10^{24} nuclei / cm^3)

	Fuel LEZ	Fuel MEZ	Fuel HEZ	Fuel AB1 LEZ	Fuel AB1 MEZ	Fuel AB1 HEZ	Fuel AB2 LEZ
Isotope	Mat.1	Mat.2	Mat.3	Mat.4	Mat.5	Mat.6	Mat.7
^{235}U	4.100E-05*	4.029E-05	3.953E-05	5.696E-05	5.765E-05	5.857E-05	5.385E-05
^{236}U	1.412E-06	1.387E-06	1.360E-06	1.373E-06	1.144E-06	9.151E-07	1.901E-06
^{238}U	1.551E-02	1.524E-02	1.495E-02	2.036E-02	2.040E-02	2.043E-02	2.022E-02
^{239}Pu	2.567E-03	2.823E-03	3.100E-03	1.757E-04	1.480E-04	1.169E-04	2.944E-04
^{240}Pu	2.292E-04	2.521E-04	2.768E-04	3.432E-06	2.288E-06	1.601E-06	7.904E-06
^{241}Pu	1.463E-05	1.609E-05	1.767E-05	6.863E-08	4.575E-08	4.575E-08	1.743E-07
^{242}Pu	1.172E-06	1.288E-06	1.415E-06	—	—	—	—
^{239}FP	5.422E-04	5.326E-04	5.225E-04	1.876E-05	1.510E-05	1.052E-05	5.619E-05
O	3.793E-02	3.793E-02	3.793E-02	4.125E-02	4.125E-02	4.125E-02	4.125E-02
Na	—	—	—	—	—	—	—
Fe	—	—	—	—	—	—	—
Cr	—	—	—	—	—	—	—
Ni	—	—	—	—	—	—	—
Mo	—	—	—	—	—	—	—
^{10}B	—	—	—	—	—	—	—
^{11}B	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—

	Fuel AB2 MEZ	Fuel AB2 HEZ	Plugs	Hexagonal wrapper	Fuel cladding	Coolant	SHR rod wrapper Inner and outer supplant
Isotope	Mat.8	Mat.9	Mat.10	Mat.11	Mat.12	Mat.13	Mat.14
^{235}U	5.491E-05	5.623E-05	—	—	—	—	—
^{236}U	1.601E-06	1.373E-06	—	—	—	—	—
^{238}U	2.026E-02	2.032E-02	—	—	—	—	—
^{239}Pu	2.533E-04	2.004E-04	—	—	—	—	—
^{240}Pu	5.719E-06	3.711E-06	—	—	—	—	—
^{241}Pu	1.144E-07	1.118E-07	—	—	—	—	—
^{242}Pu	—	—	—	—	—	—	—
^{239}FP	4.827E-05	3.530E-05	—	—	—	—	—
O	4.125E-02	4.125E-02	—	—	—	—	—
Na	—	—	—	—	—	2.074E-02	—
Fe	—	—	6.097E-02	7.064E-02	6.097E-02	—	5.377E-02
Cr	—	—	1.643E-02	1.096E-02	1.643E-02	—	1.347E-02
Ni	—	—	1.322E-02	1.580E-04	1.322E-02	—	7.619E-03
Mo	—	—	1.201E-03	9.238E-04	1.201E-03	—	1.648E-03
^{10}B	—	—	—	—	—	—	—
^{11}B	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—

* Read as 4.100E-05 = 4.100×10^{-5}.

TABLE: 3.3. ISOTOPIC DENSITY FOR HETEROGENEOUS DESCRIPTION (cont.)

(Unit: 10^{24} nuclei / cm^3)

	SHR absorber cladding	IBZ	SHR absorbing material
Isotope	Mat.15	Mat.16	Mat. 17
^{235}U	-	5.159E-05	-
^{236}U	-	1.776E-06	-
^{238}U	-	1.931E-02	-
^{239}Pu	-	8.572E-04	-
^{240}Pu	-	5.264E-05	-
^{241}Pu	-	2.354E-06	-
^{242}Pu	-	7.715E-08	-
^{239}FP	-	3.491E-04	-
O	-	4.125E-02	-
Na	-	-	-
Fe	5.477E-02	-	-
Cr	1.444E-02	-	-
Ni	1.255E-02	-	-
Mo	1.844E-03	-	-
^{10}B	-	-	1.481E-02
^{11}B	-	-	5.924E-02
C	-	-	1.852E-02

3.2 BENCHMARK CALCULATIONS

Parameters for the benchmark calculation in Phase 4 are calculated with the control rods insertion as shown in Fig. 3.2 and consist of:

- Fuel and steel Doppler coefficients and their distributions;
- Fuel density coefficient and its distribution;
- Sodium density coefficient and its distribution;
- Power distribution for fuel and non-fuelled regions;
- Beta-effective and prompt neutron lifetime.

The definition of the above coefficients is the same as in the previous phases of the CRP.

The above parameters including the effective multiplication factor (k_{eff}) are calculated for the Hex-Z model by all participants, using homogeneous representations of the material regions defined in Section 3.1 and the diffusion theory. Where possible, heterogeneous geometry diffusion/transport theory is optionally used for calculation of distributed reactivity effects and again, optionally, heterogeneous transport theory for integral reactor results; it is expected that the presence of the sodium plenum will make heterogeneity and transport effects important. Detailed heterogeneous geometry configurations are used for the core fuel regions and the control rods in the heterogeneous core model.

Spatial distributions of reactivity coefficients are obtained by the first order perturbation theory method. The spatial distribution of the fuel Doppler coefficients, integrated over energy and isotopes, is given by subassembly type (see Fig. 3.1), and by axial regions. The axial mesh structure consists of 30.0 cm x 1 for lower AR, 10.0 x 2, 9.7, and 5.5 cm for AB, 8.23 cm x 5 for lower core, 5.1 cm for IB, 8.23 cm x 5 for upper core, 5.3 cm for plugs, 7.0, and 8.0 cm x 2 for SP, 4.5 cm for cones, 5.0 cm x 3 for UBS, 4.5 cm for cones, and 30.0 cm for upper AR in the spatial distribution.

The core power distribution is normalized to the total power of 1470 MW(th) based on a local energy deposition model where energy is deposited at the point of fission with an energy of 200 MeV per fission and 0 MeV per capture for all nuclides.

3.3 COMPARISON OF RESULTS

3.3.1 Homogeneous benchmark model

3.3.1.1 Criticality and integral reactivity coefficients

Criticality values and integral reactivity coefficients for the homogeneous benchmark are given in Tables 3.4–3.9 with the mean value and the standard deviation of the results for each coefficient. In these tables, the IPPE results are obtained on the basis of two dimensional transport theory results. That is, the transport values for the reactivity coefficient (RC) are given as $RC^{*}_{HEX,Z} = RC^{Diff}_{HEX,Z} \frac{RC^{Transp}_{R,Z}}{RC^{Diff}_{R,Z}}$. The IPPE results are given only for inter-comparison and not included in the mean value estimation. The comparison of the diffusion and transport results for Phase 4 generally shows good agreement for most parameters. The results of comparisons of each reactivity coefficient are addressed in more detail later.

One may see in Table 3.4 that the Hex-Z diffusion and transport theory calculation options predict k_{eff} as 1.00131 and 1.00664 with relative standard deviations of 0.60% and 0.33%, respectively. In average, the diffusion theory option gives k_{eff} values smaller by 0.53% compared to the transport one.

The fuel Doppler coefficient, one of the most important parameters in transient analyses, is evaluated to be –0.00737 and –0.00729 with relative standard deviations of 9.7% and 8.0% for diffusion and transport theory calculations, respectively. Deviations for the fuel Doppler coefficient from the mean value range from 20.5% (KAERI) to –11.5% (FZK/IKET). The underestimation of the coefficient in the last case is related to the particular nuclear data set, but also influenced by the low number of energy groups as discussed later, in the part of the report related to Phase 6. In Table 3.5, the average diffusion theory value is larger by 1.0% by magnitude compared to the transport theory one.

Table 3.6 shows the results for steel Doppler coefficient obtained by diffusion and transport theory calculations. The steel Doppler coefficients were estimated to be –0.00096 and –0.00093 with relative standard deviations of 24.5% and 33.2% for these two approximations. The diffusion theory predicts the steel Doppler coefficient larger by 3.1% in its magnitude than the transport theory.

One may note that the steel Doppler coefficient is about 8 times smaller than the fuel one, the former one being predicted with a larger dispersion, compared to the latter one. The larger dispersion is attributable to the sum of smaller spatial contributions from the entire reactor system. In the FZK case, neglecting of the temperature variations of the effective cross-sections for all, except iron, steel components leads to the underestimation of this parameter.

Note, that at the initial phase of a transient, one may expect smaller temperature variation in the structure compared to that in the fuel, so that the steel Doppler contribution to the net reactivity variation during this phase may be minor.

The integral sodium density coefficients are 0.00046 and –0.00149 with substantially large relative standard deviations for the diffusion and transport theory results. In Table 3.7, there exists a relatively large dispersion and even values of opposite sign were computed with diffusion theory. This is due to the fact that, by design, a small (close to zero) integral sodium density coefficient was aimed (to achieve low or even below zero sodium void worth). If the ANL result is ignored, the values range from +0.00139 (IPPE) to –0.00199 (CEA/SA). There is also a relatively large difference between the values computed with the diffusion and transport theory options, these values being also of opposite sign. For the core model of the BN-600 type fast reactor including an IBZ zone and an above core sodium plenum, the sodium density coefficient is significantly affected by the nuclear data set used, by approximations in the computation techniques as well as by compensations between positive central terms and negative leakage terms.

As can be seen in Table 3.8, the steel density coefficient has a considerable dispersion between the results obtained by participants. That is, the steel density coefficients were evaluated to be -0.0203 with relative standard deviation of 73.9% for diffusion theory calculations. The results for the sodium and steel density coefficients show a considerable spread in values computed by different participants. This is mainly attributed to differences in the spatial coefficient predictions for non-fuelled regions including control rods, which will be discussed in more detail later.

The average (for all participants) fuel density coefficients are predicted to be 0.3806 and 0.3826 with relative standard deviations of 3.1% and 1.0% for diffusion and transport theory calculations, respectively. These average values — given in Table 3.9 — are in good agreement, thus confirming applicability of the diffusion approximation for this case.

3.3.1.2 Kinetics parameters

The reactor kinetic parameters such as the effective delayed neutron fraction (β_{eff}), group-wise effective delayed neutron fractions, prompt neutron lifetime (l_p), and decay constants are given in Tables 3.10–3.13, respectively. Most parameters obtained by the diffusion theory method are in good agreements as concerns the results provided by different participants employing different computation options.

Tables 3.10 and 3.11 show effective delayed neutron fractions (β_{eff}) and group-wise effective delayed neutron factions for 6 delayed neutron groups provided by the participants, respectively. The effective delayed neutron fraction is simply the sum of the group-wise effective delayed neutron fractions over all groups. In Table 3.11, the group-wise effective delayed neutron factions for the 6 delayed neutron group structure provided by different participants differ within 13.0% of relative standard deviation, the deviations being lower for groups 1, 4 and 6 (within ca. 3.5%). The diffusion theory method predicts in average (for all participants) the effective delayed neutron fraction, $\beta_{eff} = 0.00341$. This value is representative for a fast reactor system dominated by ^{239}Pu (β = 0.0020), but with the contribution ^{238}U (β = 0.0148). The contribution from ^{235}U (β = 0.0064) is minor in this case due to the low content of this isotope in the fuel.

TABLE 3.4. EFFECTIVE MULTIPLICATION FACTORS (k_{eff})

Participant	Diffusion		Transport		Rel. Diff. [2]
	Value	Rel. Dev.[1] (%)	Value	Rel. Dev. (%)	(%)
ANL	1.00374	0.24			
CEA/SA	1.00183	0.05	1.00946	0.28	-0.76
CIAE	0.98834	-1.30			
FZK/IKET	1.00254	0.12	1.00849	0.18	
IGCAR	1.00164	0.03			
IPPE*	1.00578	0.45	1.00589		-0.01
JNC	0.99687	-0.44	1.00196	-0.46	-0.51
KAERI	1.00976	0.84			
Mean	1.00131		1.00664		-0.53
SD +/-	0.00599		0.00333		
Rel. SD (%)	0.60		0.33		

* 1) Relative deviation from the mean = (Value - Mean) / Mean x 100 (%)

* 2) Relative Difference = (Diffusion - Transport) / Transport x 100 (%)

* 2D transport theory calculation for estimation

TABLE 3.5. FUEL DOPPLER COEFFICIENTS (K_D^{fuel}), PCM

Participant	Diffusion		Transport		Rel. Diff.
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	(%)
ANL	-0.00710	-3.60			
CEA/SA	-0.00789	7.16	-0.00788	8.10	0.16
CIAE	-0.00683	-7.33			
FZK/IKET	-0.00652	-11.49	-0.00649	-10.98	0.46
IGCAR	-0.00717	-2.66			
IPPE*	-0.00684	-7.09	-0.00726		-5.73
JNC	-0.00770	4.53	-0.00750	2.88	2.67
KAERI	-0.00888	20.48			
Mean	-0.00737		-0.00729		1.04
SD +/-	0.00071		0.00059		
Rel. SD (%)	9.67		8.05		

*2D transport theory calculation for estimation

TABLE 3.6. STEEL DOPPLER COEFFICIENTS (K_D^{steel}), PCM

Participant	Diffusion		Transport		Rel. Diff.
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	(%)
ANL	-0.00113	17.39			
CEA/SA	-0.00124	29.57	-0.00126	36.01	-1.19
CIAE	-0.00072	-24.59			
FZK/IKET	-0.00052	-46.36	-0.00052	-44.04	-0.58
IGCAR					
IPPE*	-0.00110	14.84	-0.00118		-6.56
JNC	-0.00100	4.16	-0.00100	8.03	0.00
KAERI	-0.00101	4.99			
Mean	-0.00096		-0.00093		3.72
SD +/-	0.00023		0.00031		
Rel. SD (%)	24.48		33.17		

*2D transport theory calculation for estimation

TABLE 3.7. SODIUM DENSITY COEFFICIENTS (W_{NA}), PCM

Participant	Diffusion		Transport		Rel. Diff.
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	(%)
ANL	0.01355	2868.24			
CEA/SA	-0.00199	-536.52	-0.00334	124.55	-40.26
CIAE	-0.00099	-316.28			
FZK/IKET	0.00127	178.16	-0.00045	-69.71	-382.22
IGCAR	0.00090	97.12			
IPPE*	0.00139	205.32	-0.00723		-119.28
JNC	0.00084	82.89	-0.00067	-54.84	-224.44
KAERI	0.00223	389.30			
Mean	0.00046		-0.00149		-130.73
SD +/-	0.00480		0.00131		
Rel. SD (%)	1052.17		88.28		

*2D transport theory calculation for estimation

TABLE 3.8. STEEL DENSITY COEFFICIENTS *(W_{STEEL})*, PCM

Participant	Diffusion		Transport		Rel. Diff. (%)
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	
ANL	-0.0484	147.64			
CEA/SA					
CIAE	-0.0177	-9.25			
FZK/IKET					
IGCAR	-0.0185	-5.25			
IPPE*	-0.0126	-35.58	-0.0135	-44.90	-6.83
JNC	-0.0159	-18.57	-0.0245	0.39	-35.10
KAERI	-0.0041	-78.99			
Mean	-0.0195		-0.0245		
SD +/-	0.0138				
Rel. SD (%)	70.43				

*2D transport theory calculation for estimation

TABLE 3.9. FUEL DENSITY COEFFICIENTS *(W_{FUEL}), PCM*

Participant	Diffusion		Transport		Rel. Diff. (%)
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	
ANL	0.3548	-6.78			
CEA/SA	0.3882	1.99	0.3788	-0.99	2.48
CIAE	0.3915	2.84			
FZK/IKET	0.3900	2.46	0.3815	-0.29	2.23
IGCAR	0.3790	-0.43			
IPPE*	0.3786	-0.54	0.3782	-1.15	0.11
JNC	0.3908	2.67	0.3875	1.28	0.86
KAERI	0.3722	-2.22			
Mean	0.3806		0.3826		-0.51
SD +/-	0.0118		0.0036		
Rel. SD (%)	3.09		0.95		

*2D transport theory calculation for estimation

TABLE 3.10. EFFECTIVE DELAYED NEUTRON FRACTIONS (B_{eff})
(Unit: pcm)

Participant	Diffusion		Transport		Rel. Diff.
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	(%)
ANL	324	-4.86			
CEA/SA	350	2.90			
CIAE	348	2.18			
FZK/IKET	334	-1.93			
IGCAR	346	1.69			
IPPE*	344	0.95	344		
JNC	336	-1.34			
KAERI	342	0.41			
Mean	341				
SD +/-	8.18				
Rel. SD (%)	2.40				

*2D transport theory calculation for estimation

TABLE 3.11. GROUP-WISE EFFECTIVE DELAYED NEUTRON FRACTIONS
(Unit: abs. unit)

Participant	Delayed neutron group						Total
	1	2	3	4	5	6	
ANL	8.120E-05	6.930E-04	6.070E-04	1.160E-03	5.250E-04	1.730E-04	3.240E-03
CEA/SA	8.780E-05	6.777E-04	5.932E-04	1.266E-03	6.343E-04	2.453E-04	3.504E-03
(Hetero.)	8.780E-05	6.777E-04	5.939E-04	1.270E-03	6.380E-04	2.468E-04	3.515E-03
CIAE	8.877E-05	7.268E-04	6.562E-04	1.251E-03	5.693E-04	1.876E-04	3.480E-03
(Hetero.)	8.882E-05	7.271E-04	6.564E-04	1.251E-03	5.693E-04	1.876E-04	3.480E-03
IGCAR	8.790E-05	7.217E-04	6.525E-04	1.246E-03	5.680E-04	1.872E-04	3.463E-03
FZK/IKET	8.273E-05	5.884E-04	5.073E-04	1.187E-03	6.964E-04	2.551E-04	3.340E-03
IPPE	8.410E-05	6.010E-04	5.230E-04	1.230E-03	7.260E-04	2.670E-04	3.440E-03
JNC	8.158E-05	7.012E-04	6.291E-04	1.213E-03	5.533E-04	1.840E-04	3.362E-03
KAERI	8.501E-05	6.027E-04	5.239E-04	1.226E-03	7.211E-04	2.646E-04	3.424E-03
Average	8.489E-05	6.641E-04	5.865E-04	1.222E-03	6.242E-04	2.205E-04	3.407E-03
S.D. +-	2.988E-06	5.749E-05	6.061E-05	3.488E-05	8.116E-05	4.088E-05	8.757E-05
Rel. SD (%)	3.52	8.66	10.33	2.85	13.00	18.54	2.57

TABLE 3.12. PROMPT NEUTRON LIFETIMES
(Unit: 10^{-7} sec)

Participant	Diffusion		Transport		Rel. Diff.
	Value	Rel. Dev.(%)	Value	Rel. Dev. (%)	(%)
ANL	4.107	-4.69			
CEA/SA	4.365	1.28			
CIAE	4.092	-5.05			
FZK/IKET	4.130	-4.16			
IGCAR	4.510	4.66			
IPPE	4.530	5.12			
JNC	4.484	4.05			
KAERI	4.257	-1.21			
Mean	4.309				
SD +/-	0.175				
Rel. SD (%)	4.07				

TABLE 3.13. DECAY CONSTANTS
(Unit: sec^{-1})

Participant	Delayed neutron group					
	1	2	3	4	5	6
ANL	1.300E-02	3.140E-02	1.360E-01	3.450E-01	1.360E+00	3.730E+00
CEA/SA	1.337E-02	3.050E-02	1.175E-01	3.113E-01	9.033E-01	2.956E+00
(Hetero.)	1.337E-02	3.051E-02	1.175E-01	3.114E-01	9.034E-01	2.957E+00
CIAE	1.290E-02	3.111E-02	1.341E-01	3.318E-01	1.268E+00	3.246E+00
(Hetero.)	1.290E-02	3.111E-02	1.341E-01	3.318E-01	1.268E+00	3.246E+00
FZK/IKET	1.337E-02	3.104E-02	1.174E-01	3.084E-01	8.847E-01	2.933E+00
IGCAR	1.300E-02	3.140E-02	1.356E-01	3.450E-01	1.367E+00	3.771E+00
IPPE	1.300E-02	3.140E-02	1.360E-01	3.450E-01	1.360E+00	3.730E+00
JNC*	1.280E-02	3.010E-02	1.238E-01	3.254E-01	1.122E+00	2.697E+00
KAERI						
Average	1.311E-02	3.114E-02	1.294E-01	3.311E-01	1.190E+00	3.394E+00
S.D. +-	1.795E-04	3.903E-04	8.053E-03	1.473E-02	1.990E-01	3.672E-01
Rel. SD (%)	1.37	1.25	6.22	4.45	16.72	10.82

* ^{239}Pu data of fast fission

In Table 3.12, the prompt neutron lifetime values by different participants are given, showing the mean value of 4.309 x 10^{-7} sec for the diffusion theory method with the relative standard deviation of 4.1%.

Table 3.13 one may see the group-wise decay constants for 6 groups provided by participants, they are in good agreement within the relative standard deviation of 6.2% except for the 5th and 6th groups.

3.3.1.3 Power distribution

Region-wise normalized power fractions — calculated by the participants with the local energy deposition model — are given in Table 3.14. The results of Table 3.14 are also shown in Fig. 3.4 along with their average (for all participants) values. In the local energy deposition model, the contributions to the power from non-fuelled zones are completely ignored. The comparison of region-wise power distributions shows good agreement in general for the fuel zones of the Hex-Z model. One may see that the HEZ region is the most productive among the fuel regions.

Figure 3.5 illustrates in more details the region-wise power distribution, obtained with the Hex-Z diffusion theory by ANL. As mentioned before, the HEZ region has the largest power output among the fuel regions.

Power fractions for the main fuel regions, i.e. LEZ, MEZ, and HEZ, are calculated within a 4.3% difference (the latter value being observed in the LEZ zone) from the average value, while for blanket regions, i.e. IBZ and ABZ, within a 16.1% difference (in ABZ). Results can be found in Table 3.15. The comparison of region-wise power distributions generally shows good agreement for the HEX-Z model. With the local energy distribution model, approximately 96.5% of the total power is produced in the main fuel regions and 3.5% is produced in the blanket regions. The HEZ region, which contains fuel with an enrichment of 18.5wt% with 91.3wt% ^{239}Pu content, produces 47.5% of the total power.

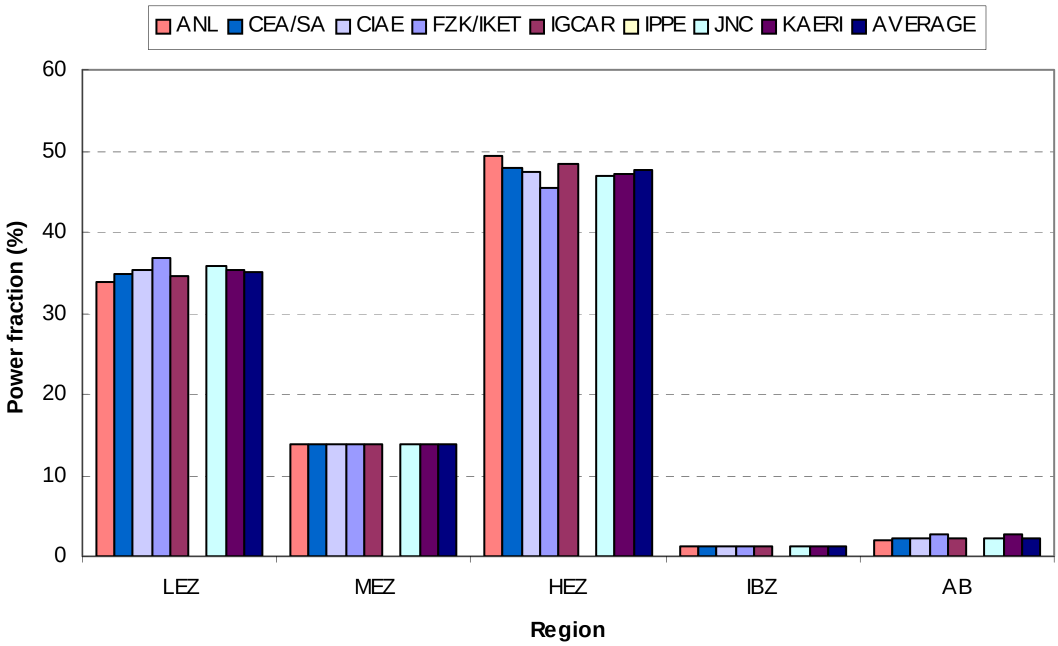


FIG. 3.4. Region-wise power distributions.

TABLE 3.14. POWER DISTRIBUTIONS

(Unit: watt)

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.265E+08	8.730E+07	3.252E+08					
	IBZ	1.660E+07	1.440E+07	5.200E+07					
	Lower Core	2.696E+08	1.006E+08	3.478E+08					
	Core	5.127E+08	2.023E+08	7.250E+08					
	AB	1.421E+07	4.218E+06	1.146E+07					
	LAR								
	Sum	5.269E+08	2.065E+08	7.365E+08					
	Total	1.470E+09							
CEA/SA	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.308E+08	8.647E+07	3.155E+08					
	IBZ	1.751E+07	1.443E+07	5.017E+07					
	Lower Core	2.815E+08	1.016E+08	3.397E+08					
	Core	5.298E+08	2.025E+08	7.054E+08					
	AB	1.540E+07	4.523E+06	1.228E+07					
	LAR								
	Sum	5.452E+08	2.070E+08	7.177E+08					
	Total	1.470E+09							
CIAE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.337E+08	8.694E+07	3.099E+08					
	IBZ	1.740E+07	1.460E+07	4.980E+07					
	Lower Core	2.846E+08	1.025E+08	3.373E+08					
	Core	5.358E+08	2.040E+08	6.970E+08					
	AB	1.496E+07	4.677E+06	1.354E+07					
	LAR								
	Sum	5.507E+08	2.087E+08	7.105E+08					
	Total	1.470E+09							
FZK/IKET	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.420E+08	8.661E+07	2.956E+08					
	IBZ	1.900E+07	1.461E+07	4.768E+07					
	Lower Core	2.971E+08	1.032E+08	3.248E+08					
	Core	5.581E+08	2.045E+08	6.681E+08					
	AB	1.938E+07	5.513E+06	1.440E+07					
	LAR								
	Sum	5.775E+08	2.100E+08	6.825E+08					
	Total	1.470E+09							
IGCAR	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.292E+08	8.651E+07	3.178E+08					
	IBZ	1.709E+07	1.440E+07	5.071E+07					
	Lower Core	2.774E+08	1.012E+08	3.437E+08					
	Core	5.237E+08	2.021E+08	7.122E+08					
	AB	1.529E+07	4.475E+06	1.226E+07					
	LAR								
	Sum	5.390E+08	2.066E+08	7.244E+08					
	Total	1.470E+09							

TABLE 3.14. POWER DISTRIBUTIONS (cont.)

(Unit: watt)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core								
	IBZ								
	Lower Core								
	Core								
	AB								
	LAR								
	Sum								
	Total								
JNC	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.425E+08	8.873E+07	3.106E+08					
	IBZ	1.778E+07	1.454E+07	4.915E+07					
	Lower Core	6.464E+07	2.372E+07	7.904E+07					
	Core	5.440E+08	2.044E+08	6.901E+08					
	AB	1.534E+07	4.429E+06	1.180E+07					
	LAR								
	Sum	5.593E+08	2.088E+08	7.019E+08					
	Total	1.470E+09							
KAERI	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.335E+08	8.593E+07	3.095E+08					
	IBZ	1.812E+07	1.440E+07	4.951E+07					
	Lower Core	2.843E+08	1.012E+08	3.348E+08					
	Core	5.359E+08	2.015E+08	6.938E+08					
	AB	1.859E+07	5.392E+06	1.482E+07					
	LAR								
	Sum	5.545E+08	2.069E+08	7.086E+08					
	Total	1.470E+09							
Mean	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	2.340E+08	8.693E+07	3.120E+08					
	IBZ	1.764E+07	1.448E+07	4.986E+07					
	Lower Core	2.513E+08	9.057E+07	3.010E+08					
	Core	5.343E+08	2.030E+08	6.988E+08					
	AB	1.617E+07	4.747E+06	1.294E+07					
	LAR								
	Sum	5.504E+08	2.078E+08	7.117E+08					
	Total	1.470E+09							
SD	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	6.137E+06	9.009E+05	9.129E+06					
	IBZ	7.695E+05	9.765E+04	1.340E+06					
	Lower Core	8.273E+07	2.949E+07	9.815E+07					
	Core	1.452E+07	1.218E+06	1.805E+07					
	AB	1.980E+06	5.023E+05	1.317E+06					
	LAR								
	Sum	1.602E+07	1.363E+06	1.717E+07					
	Total	6.310E+04							

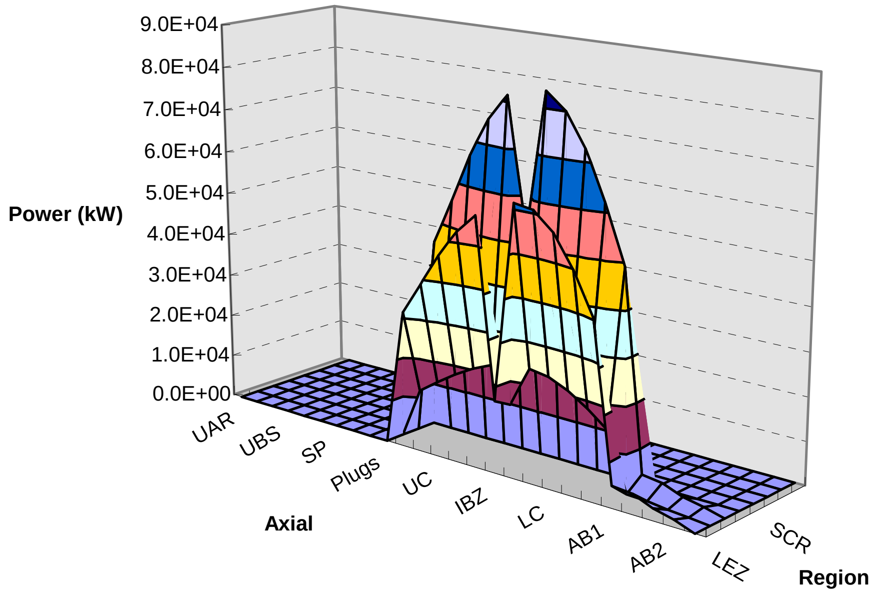


FIG. 3.5. Power distributions (ANL Result).

TABLE 3.15. POWER FRACTIONS FOR FUEL REGIONS

(Unit: %)

Region	LEZ	MEZ	HEZ	IBZ	AB
ANL	33.75	13.76	49.32	1.13	2.03
CEA/SA	34.85	13.77	47.99	1.19	2.19
CIAE	35.26	13.88	47.41	1.18	2.26
FZK/IKET	36.67	13.91	45.45	1.29	2.67
IGCAR	34.46	13.75	48.45	1.16	2.18
IPPE					
JNC	35.80	13.90	46.94	1.21	2.15
KAERI	35.22	13.71	47.20	1.23	2.64
AVERAGE	35.15	13.81	47.54	1.20	2.30

3.3.1.4 Local reactivity coefficients

Distributions of local reactivity coefficients calculated for the Hex-Z model by participants are given in Tables 3.16–3.23. The reactivity coefficients were mainly computed by using the first order perturbation theory method based on the diffusion theory. In case of IGCAR results, the total reactivity coefficients quoted in Tables 3.5 to 3.9 which are based on two k_{eff} calculations which is slightly different from the total of the reactivity coefficient distributions in Tables 3.16 to 3.23 — especially for the sodium density coefficient. The detailed distributions of local reactivity coefficients obtained by each participant are also shown in Figs 3.6–3.13.

In Tables 3.18–3.20 one may see region dependent sodium density coefficients for constituent sub-regions of the whole core system. One may assume that their spatial distributions that can be characterized by a combination of leakage (depending mainly on the location) and non-leakage (depending mainly on isotopic composition) components. In LEZ and MEZ, which contain enriched fuel and are located near the core center, the non-leakage component is stronger than the leakage one. As a result, the overall sodium density coefficient is determined to be negative. The prevailing non-leakage fraction becomes smaller with moving outwards from the core center. It is clearly observed that the leakage fraction becomes higher in HEZ, and, as a result, HEZ gives a positive contribution to the integral sodium coefficient according to all results, except those obtained by ANL and CEA/SA. For the blanket and other non-fuel zones adjacent to the fuel ones, one may also see positive coefficients, indicating that the leakage component is dominant there. In the particular the coefficient is high in the sodium plenum (SP): sodium reflects neutrons back to the code and the corresponding leakage component is prevailing even at radial positions close to core center. Presence of the plenum makes the total sodium density coefficient higher (the total value being positive except for the cases of ANL and CEA/SA).

In Fig. 3.7, the fuel Doppler coefficients for LEZ — that has the largest ^{238}U relative fraction among the fuel core regions — appear to be largest in its magnitude. In this figure, one may see that the region dependent coefficients (provided by different participants) are in better agreement than the integral (or total, summed over all regions) ones. Figure 3.8 shows the axial distribution of the fuel Doppler coefficients for three fuel zones obtained by IPPE. In this figure, one can see substantial variations between the values for different compositions in the axial direction of each fuel zone. Although not shown, the largest difference between the diffusion and transport theory results is obtained in the upper core region adjacent to the sodium plenum.

For the steel Doppler coefficient, which is shown in Fig. 3.9, this point (deviations between the region-wise values as compared to deviations between the total ones) is more evident, because the total value is the sum of very small positive and small negative contributions from the control regions (CR) and other voluminous non-fuelled regions (REF and SSA). The FZK/IKET results for the steel Doppler coefficient appeared to be substantially smaller in its magnitude than those of the other participants. The small magnitude in the FZK/IKET result is at least partially attributable to taking into account only iron in calculating the steel Doppler coefficient.

The mentioned point on the deviations of the integral coefficient and of its spatial components is illustrated also in Figs 3.9 and 3.10. Region-wise sodium density coefficients over the whole core system are shown in Fig. 3.11, including their leakage and non-leakage components along with the average values. In these figures, the first six groups of columns (LEZ, MEZ, HEZ, IBZ, AB and Sum) and the next four groups (SP, UBS, C&P and AR) denote the corresponding values for fuel and non-fuel regions in the core, respectively. The group of columns labelled by SUM denotes the total values for the core. The resultant sodium density coefficient spatial distributions can be explained by considering their leakage and non-leakage components. One may see in these figures that the region-wise coefficients for the core fuel regions are in better agreement than those for other ones. Also the total coefficients (sum over all regions) are in better agreement. This is due to relatively large differences in the spatial contribution for non-fuel regions; the control regions (SCR and SHR) and other large non-fuel regions (REF and SSA); computed by considering a 1% reduction in the sodium density.

More detailed sodium density coefficient distributions in space obtained by each participant are given in Fig. 3.12. Axial distributions of sodium density coefficients for each fuel zone, radial reflector and control rod zones computed at IPPE are shown in Fig. 3.13. Detailed spatial distributions of their leakage and non-leakage components computed at IPPE are shown in Fig. 3.14.

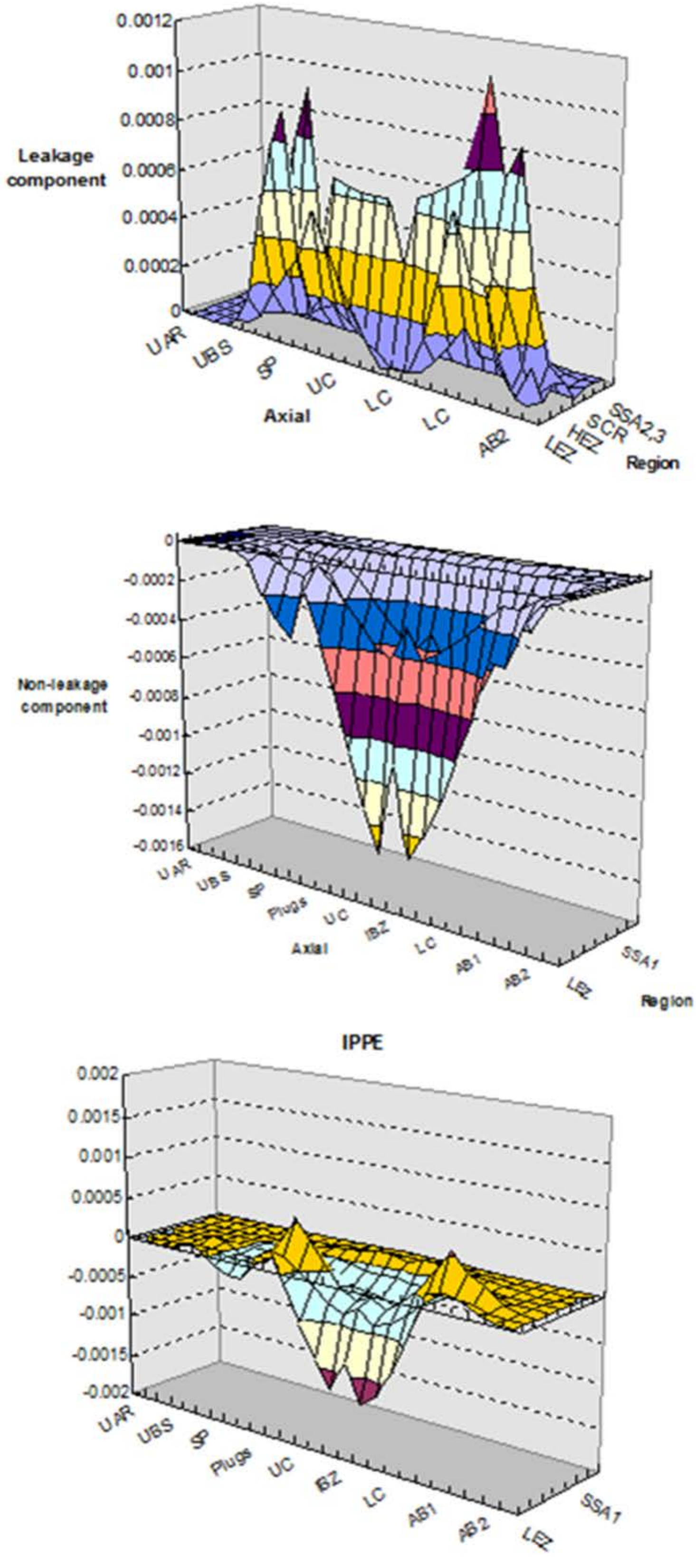


FIG. 3.6. Spatial distributions of leakage and non-leakage components.

It is recognized that the calculation methods have the most significant effect on the sodium density coefficient. There are changes in the axial profile of the sodium density coefficient and (even larger changes) in its distribution in plane (in different enrichment zones), depending on the use of the transport or diffusion option in Hex-Z geometry. For example, in the HEZ region, the difference between the results obtained by transport and diffusion Hex-Z options can be as high as ~50%. In general, most results were predicted within the relative standard deviations of ~10% for the core and ~30 % for the whole core system, respectively. Large discrepancies are observed in the HEZ fuel region in the core and even larger spreads in the sodium plenum and other non-fuel regions.

Very similar conclusions can be drawn for the steel density coefficients shown in Fig. 3.15. In these figures, the ANL results for the sodium and steel density coefficients are larger than those of the other participants, particularly for the total values.

The comparison of the region-wise fuel density coefficients for the core shows good agreement between the results obtained by the participants. In Fig. 3.16 one may see that the fuel density effect is the highest in HEZ.

For such a complicated configuration under study, a low number of energy groups (e.g. 10 or less) may not be sufficient to accurately evaluate reactivity coefficients. The use of few group cross-section sets obtained with composition dependent spectra, may smooth out important spectral contributions to the reactivity coefficients. This effect may be especially important for calculations of the fuel Doppler and sodium density coefficients at the top of the core and in the sodium plenum [24]. The latter has an important effect on transient simulation results, as the sodium temperature is at its maximum in these regions.

TABLE 3.16. FUEL DOPPLER COEFFICIENTS

(Unit: abs. unit)

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.044E-03	-3.349E-04	-1.198E-03					
	IBZ	-2.830E-04	-7.320E-05	-2.200E-04					
	Lower Core	-1.588E-03	-4.953E-04	-1.305E-03					
	Core	-2.915E-03	-9.034E-04	-2.723E-03					
	AB	-2.931E-04	-8.243E-05	-1.846E-04					
	LAR								
	Sum	-3.208E-03	-9.858E-04	-2.908E-03					
	Total	-7.102E-03							
CEA/SA	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.178E-03	-3.524E-04	-1.251E-03					
	IBZ	-3.076E-04	-8.084E-05	-2.306E-04					
	Lower Core	-1.972E-03	-5.680E-04	-1.401E-03					
	Core	-3.458E-03	-1.001E-03	-2.883E-03					
	AB	-2.961E-04	-7.918E-05	-1.815E-04					
	LAR								
	Sum	-3.754E-03	-1.080E-03	-3.064E-03					
	Total	-7.898E-03							
CIAE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.180E-03	-3.955E-04	-1.083E-03					
	IBZ	-3.030E-04	-7.794E-05	-1.949E-04					
	Lower Core	-1.676E-03	-4.918E-04	-1.143E-03					
	Core	-3.159E-03	-9.653E-04	-2.421E-03					
	AB	-2.754E-04	-7.483E-05	-1.690E-04					
	LAR								
	Sum	-3.435E-03	-1.040E-03	-2.590E-03					
	Total	-7.064E-03							
FZK/IKET	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-9.987E-04	-2.781E-04	-8.749E-04					
	IBZ	-3.249E-04	-6.492E-05	-1.653E-04					
	Lower Core	-1.693E-03	-4.600E-04	-1.019E-03					
	Core	-3.016E-03	-8.030E-04	-2.059E-03					
	AB	-3.574E-04	-9.023E-05	-1.901E-04					
	LAR								
	Sum	-3.374E-03	-8.932E-04	-2.249E-03					
	Total	-6.516E-03							
IGCAR	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.1105E-03	-3.328E-04	-1.082E-03					
	IBZ	-3.308E-04	-7.489E-05	-2.037E-04					
	Lower Core	-1.758E-03	-5.119E-04	-1.236E-03					
	Core	-3.199E-03	-9.196E-04	-2.521E-03					
	AB	-3.416E-04	-9.128E-05	-2.031E-04					
	LAR								
	Sum	-3.541E-03	-1.011E-03	-2.724E-03					
	Total	-7.276E-03							

TABLE 3.16. FUEL DOPPLER COEFFICIENTS (cont.)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.041E-03	-2.890E-04	-1.024E-03					
	IBZ	-3.030E-04	-6.760E-05	-1.860E-04					
	Lower Core	-1.711E-03	-4.697E-04	-1.165E-03					
	Core	-3.055E-03	-8.263E-04	-2.375E-03					
	AB	-3.138E-04	-8.129E-05	-1.953E-04					
	LAR								
	Sum	-3.368E-03	-9.071E-04	-2.569E-03					
	Total	-6.844E-03							
JNC	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.329E-03	-3.796E-04	-1.126E-03					
	IBZ	-3.473E-04	-7.941E-05	-2.032E-04					
	Lower Core	-1.872E-03	-5.220E-04	-1.215E-03					
	Core	-3.549E-03	-9.810E-04	-2.544E-03					
	AB	-3.317E-04	-8.454E-05	-1.802E-04					
	LAR								
	Sum	-3.880E-03	-1.066E-03	-2.724E-03					
	Total	-7.670E-03							
KAERI	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.413E-03	-4.109E-04	-1.351E-03					
	IBZ	-3.804E-04	-9.394E-05	-2.574E-04					
	Lower Core	-2.246E-03	-6.339E-04	-1.538E-03					
	Core	-4.040E-03	-1.139E-03	-3.147E-03					
	AB	-3.389E-04	-8.863E-05	-1.952E-04					
	LAR								
	Sum	-4.379E-03	-1.227E-03	-3.342E-03					
	Total	-8.948E-03							
Mean	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	-1.162E-03	-3.466E-04	-1.124E-03					
	IBZ	-3.225E-04	-7.659E-05	-2.076E-04					
	Lower Core	-1.815E-03	-5.191E-04	-1.253E-03					
	Core	-3.299E-03	-9.423E-04	-2.584E-03					
	AB	-3.185E-04	-8.405E-05	-1.874E-04					
	LAR								
	Sum	-3.617E-03	-1.026E-03	-2.771E-03					
	Total	-7.415E-03							
SD	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	1.462E-04	4.779E-05	1.457E-04					
	IBZ	3.067E-05	8.946E-06	2.832E-05					
	Lower Core	2.118E-04	5.716E-05	1.615E-04					
	Core	3.690E-04	1.062E-04	3.331E-04					
	AB	2.845E-05	5.739E-06	1.075E-05					
	LAR								
	Sum	3.772E-04	1.062E-04	3.340E-04					
	Total	7.582E-04							

TABLE 3.17. STEEL DOPPLER COEFFICIENTS

(Unit: abs. unit)

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR	8.510E-13	-9.810E-13	-4.380E-11	6.735E-12	1.910E-12	3.120E-12	1.410E-10	5.120E-10
	Cones&Plugs	-1.504E-05	-5.050E-06	-1.838E-05	-1.368E-07	-1.349E-07	-4.444E-06	-4.505E-07	8.976E-08
	UBS	9.974E-09	3.191E-09	9.676E-09	6.354E-09	3.351E-09	-8.370E-08	-7.359E-09	8.430E-09
	SP	-5.000E-06	-1.699E-06	-6.570E-06	-2.736E-07	-2.411E-07	-7.510E-06	-6.281E-07	1.449E-07
	Upper Core	-1.141E-04	-3.979E-05	-1.263E-04	-5.142E-06	-2.885E-06	-1.178E-04	-1.259E-05	1.867E-06
	IBZ	-2.360E-05	-8.830E-06	-2.470E-05	-1.342E-06	-4.170E-07	-2.250E-05	-2.410E-06	3.470E-07
	Lower Core	-1.691E-04	-5.685E-05	-1.427E-04	-1.130E-05	-2.695E-06	-1.256E-04	-1.318E-05	1.912E-06
	Core	-3.068E-04	-1.055E-04	-2.937E-04	-1.779E-05	-5.997E-06	-2.659E-04	-2.818E-05	4.126E-06
	AB	-1.661E-05	-4.791E-06	-1.021E-05	-9.242E-07	-2.298E-07	-7.477E-06	-8.423E-07	1.917E-07
	LAR	-5.940E-07	-1.270E-07	-2.210E-07	-5.744E-08	-2.180E-08	-2.060E-08	-1.160E-08	2.480E-09
	Sum	-3.440E-04	-1.171E-04	-3.291E-04	-1.917E-05	-6.621E-06	-2.854E-04	-3.012E-05	4.564E-06
	Total	-1.127E-03							
CEA/SA	UAR	1.402E-10	3.604E-11	8.365E-11	2.070E-11	8.096E-12	-1.629E-11	-1.036E-10	-2.598E-09
	Cones&Plugs	-1.060E-05	-2.967E-06	-1.210E-05	-5.880E-09	3.283E-10	-1.273E-06	-4.247E-07	1.316E-07
	UBS	1.752E-10	-9.247E-10	-1.556E-08	6.541E-09	1.409E-09	-1.773E-07	-3.306E-07	-3.829E-08
	SP	-3.335E-06	-1.147E-06	-5.239E-06	-2.452E-07	-3.036E-08	-6.532E-06	-4.926E-06	-6.284E-07
	Upper Core	-1.381E-04	-4.343E-05	-1.356E-04	-3.243E-06	-4.134E-07	-6.636E-05	-5.668E-05	-7.496E-06
	IBZ	-2.170E-05	-1.018E-05	-2.671E-05	-2.964E-07	-4.228E-08	-1.221E-05	-1.024E-05	-1.362E-06
	Lower Core	-2.264E-04	-6.844E-05	-1.579E-04	-2.765E-06	-2.860E-07	-7.103E-05	-6.034E-05	-7.855E-06
	Core	-3.862E-04	-1.220E-04	-3.202E-04	-6.304E-06	-7.417E-07	-1.496E-04	-1.273E-04	-1.671E-05
	AB	-1.637E-05	-4.349E-06	-9.071E-06	-2.248E-07	-2.487E-08	-6.530E-06	-7.032E-06	-9.090E-07
	LAR	-3.889E-07	-8.205E-08	-1.623E-07	-3.930E-08	-1.500E-08	-2.399E-08	-1.709E-08	-2.835E-08
	Sum	-4.193E-04	-1.318E-04	-3.516E-04	-6.910E-06	-8.283E-07	-1.664E-04	-1.425E-04	-1.870E-05
	Total	-1.238E-03							
CIAE	UAR	2.445E-10	5.465E-11	1.264E-09	-2.512E-12	2.624E-14	-1.335E-07	-4.367E-07	2.326E-09
	Cones&Plugs	-1.060E-05	-2.967E-06	-1.210E-05	-5.880E-09	3.283E-10	-1.273E-06	-4.247E-07	1.316E-07
	UBS	7.880E-08	2.533E-08	8.712E-08	3.003E-08	1.691E-08	1.323E-07	3.747E-08	2.351E-08
	SP	-2.482E-06	-7.663E-07	-3.504E-06	-1.208E-07	-5.172E-08	-2.482E-06	-6.352E-07	2.296E-07
	Upper Core	-9.535E-05	-2.875E-05	-8.363E-05	-3.318E-06	-1.962E-06	-2.714E-05	-1.049E-05	2.236E-06
	IBZ	-2.151E-05	-7.125E-06	-1.733E-05	-1.069E-06	-4.952E-07	-5.244E-06	-2.015E-06	4.005E-07
	Lower Core	-1.555E-04	-4.573E-05	-9.968E-05	-8.537E-06	-2.935E-06	-2.854E-05	-1.082E-05	2.383E-06
	Core	-2.723E-04	-8.160E-05	-2.006E-04	-1.292E-05	-5.392E-06	-6.092E-05	-2.332E-05	5.020E-06
	AB	-2.323E-04	-6.782E-05	-1.426E-04	3.530E-07	8.559E-08	-1.720E-06	-5.898E-07	3.667E-07
	LAR	-2.917E-07	-5.939E-08	-1.275E-07	-2.190E-08	-8.240E-09	-8.782E-09	2.017E-09	1.045E-08
	Sum	-5.179E-04	-1.532E-04	-3.589E-04	-1.269E-05	-5.349E-06	-6.641E-05	-2.537E-05	5.784E-06
	Total	-1.134E-03							
FZK/IKET	UAR	-9.424E-12	-1.202E-11	-4.136E-10	-1.657E-12	-2.256E-13	-5.683E-10	-8.737E-10	-3.487E-10
	Cones&Plugs	-7.811E-06	-2.291E-06	-7.938E-06	-7.569E-08	-8.622E-08	-1.225E-06	-6.367E-07	-4.638E-08
	UBS	-4.370E-07	-1.500E-07	-5.810E-07	-2.600E-10	-7.950E-09	-3.340E-07	-1.890E-08	7.240E-09
	SP	-1.791E-06	-5.620E-07	-2.213E-06	-7.587E-08	-7.139E-08	-1.392E-06	-6.234E-07	-4.461E-08
	Upper Core	-6.309E-05	-1.829E-05	-5.256E-05	-2.147E-06	-1.793E-06	-2.207E-05	-1.219E-05	-8.716E-07
	IBZ	-1.425E-05	-4.283E-06	-1.035E-05	-7.515E-07	-2.640E-07	-4.111E-06	-2.246E-06	-1.594E-07
	Lower Core	-1.043E-04	-2.958E-05	-6.312E-05	-7.222E-06	-1.792E-06	-2.413E-05	-1.313E-05	-9.311E-07
	Core	-1.816E-04	-5.216E-05	-1.260E-04	-1.012E-05	-3.850E-06	-5.031E-05	-2.756E-05	-1.962E-06
	AB	-1.191E-05	-3.032E-06	-5.917E-06	-8.462E-07	-2.133E-07	-2.349E-06	-1.435E-06	-1.101E-07
	LAR	-3.812E-07	-7.942E-08	-1.476E-07	-3.939E-08	-1.490E-08	-2.008E-08	-1.464E-08	-4.488E-09
	Sum	-2.047E-04	-5.846E-05	-1.435E-04	-1.124E-05	-4.303E-06	-5.637E-05	-3.080E-05	-2.207E-06
	Total	-5.115E-04							
IGCAR	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core								
	IBZ								
	Lower Core								
	Core								
	AB								
	LAR								
	Sum								
	Total								

TABLE 3.17. STEEL DOPPLER COEFFICIENTS (cont.)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR	-9.000E-08	-2.970E-11	-4.790E-11	0.000E+00	0.000E+00	-1.740E-09	-2.840E-09	-7.510E-10
	Cones&Plugs	-1.535E-05	-4.687E-06	-1.542E-05	0.000E+00	0.000E+00	-3.132E-06	-1.497E-06	-2.470E-07
	UBS	-2.616E-08	-7.642E-09	-2.474E-08	0.000E+00	0.000E+00	-1.455E-07	-1.167E-07	-2.485E-08
	SP	-4.250E-06	-1.144E-06	-3.668E-06	0.000E+00	0.000E+00	-2.786E-06	-1.420E-06	-2.190E-07
	Upper Core	-1.196E-04	-4.136E-05	-1.338E-04	0.000E+00	0.000E+00	-5.730E-05	-3.131E-05	-4.819E-06
	IBZ	-2.370E-05	-9.480E-06	-2.900E-05	0.000E+00	0.000E+00	-1.070E-05	-5.750E-06	-8.880E-07
	Lower Core	-1.449E-04	-6.342E-05	-2.123E-04	0.000E+00	0.000E+00	-6.314E-05	-3.393E-05	-5.031E-06
	Core	-2.882E-04	-1.143E-04	-3.751E-04	0.000E+00	0.000E+00	-1.311E-04	-7.099E-05	-1.074E-05
	AB	-1.235E-05	-6.159E-06	-2.251E-05	0.000E+00	0.000E+00	-5.680E-06	-3.568E-06	-5.819E-07
	LAR	-9.200E-08	-9.760E-08	-4.260E-07	0.000E+00	0.000E+00	-2.450E-08	-2.170E-08	-1.420E-08
	Sum	-3.218E-04	-1.268E-04	-4.184E-04	0.000E+00	0.000E+00	-1.449E-04	-7.869E-05	-1.199E-05
	Total	-1.103E-03							
JNC	UAR	1.305E-10	1.024E-11	-2.707E-10	6.951E-11	2.337E-11	2.012E-10	1.606E-10	1.133E-09
	Cones&Plugs	-1.885E-05	-5.399E-06	-1.648E-05	-6.771E-08	-1.378E-07	-2.185E-06	-8.927E-07	7.589E-08
	UBS	4.936E-08	1.443E-08	3.897E-08	1.200E-08	1.032E-08	-5.091E-08	-5.181E-08	1.029E-08
	SP	-7.126E-06	-2.064E-06	-6.698E-06	-1.532E-07	-2.503E-07	-4.167E-06	-1.541E-06	1.267E-07
	Upper Core	-1.326E-04	-4.112E-05	-1.097E-04	-3.579E-06	-3.601E-06	-4.347E-05	-1.785E-05	1.511E-06
	IBZ	-2.652E-05	-9.007E-06	-2.180E-05	-1.480E-06	-4.999E-07	-8.168E-06	-3.300E-06	2.770E-07
	Lower Core	-1.880E-04	-5.618E-05	-1.256E-04	-1.298E-05	-3.143E-06	-4.538E-05	-1.840E-05	1.563E-06
	Core	-3.471E-04	-1.063E-04	-2.571E-04	-1.804E-05	-7.244E-06	-9.702E-05	-3.956E-05	3.351E-06
	AB	-1.720E-05	-4.429E-06	-8.749E-06	-9.096E-07	-2.284E-07	-3.508E-06	-1.620E-06	1.851E-07
	LAR	-6.161E-07	-1.242E-07	-2.241E-07	-5.593E-08	-2.145E-08	-2.434E-08	-1.427E-08	4.634E-09
	Sum	-3.908E-04	-1.183E-04	-2.892E-04	-1.921E-05	-7.872E-06	-1.070E-04	-4.368E-05	3.755E-06
	Total	-9.723E-04							
KAERI	UAR	2.419E-11	-2.419E-11	-2.177E-10	0.000E+00	0.000E+00	-2.419E-11	-4.838E-11	3.386E-10
	Cones&Plugs	-1.600E-05	-5.096E-06	-1.959E-05	-1.253E-07	-1.051E-07	-2.617E-06	-1.026E-06	2.854E-08
	UBS	1.742E-08	4.547E-09	4.814E-09	1.280E-08	7.498E-09	-6.016E-08	-6.018E-08	4.160E-09
	SP	-3.629E-06	-1.251E-06	-5.583E-06	-3.023E-07	-1.964E-07	-4.890E-06	-1.712E-06	4.422E-08
	Upper Core	-1.261E-04	-3.992E-05	-1.150E-04	-5.506E-06	-2.980E-06	-4.999E-05	-2.057E-05	6.432E-07
	IBZ	-2.760E-05	-9.179E-06	-2.269E-05	-1.425E-06	-4.403E-07	-9.362E-06	-3.818E-06	1.212E-07
	Lower Core	-1.977E-04	-5.998E-05	-1.322E-04	-1.222E-05	-2.806E-06	-5.285E-05	-2.149E-05	6.952E-07
	Core	-3.514E-04	-1.091E-04	-2.698E-04	-1.915E-05	-6.226E-06	-1.122E-04	-4.588E-05	1.460E-06
	AB	-1.661E-05	-4.380E-06	-8.722E-06	-6.550E-07	-1.464E-07	-4.208E-06	-1.977E-06	8.763E-08
	LAR	-3.928E-07	-8.212E-08	-1.714E-07	-3.253E-08	-1.192E-08	-2.269E-08	-1.422E-08	1.088E-09
	Sum	-3.880E-04	-1.199E-04	-3.039E-04	-2.025E-05	-6.678E-06	-1.240E-04	-5.066E-05	1.626E-06
	Total	-1.012E-03							
Mean	UAR	-1.278E-08	4.863E-12	5.054E-11	1.325E-11	4.739E-12	-1.937E-08	-6.290E-08	8.739E-11
	Cones&Plugs	-1.346E-05	-4.065E-06	-1.457E-05	-5.961E-08	-6.621E-08	-2.307E-06	-7.645E-07	2.343E-08
	UBS	-4.392E-08	-1.587E-08	-6.867E-08	9.636E-09	4.506E-09	-1.028E-07	-7.830E-08	-1.359E-09
	SP	-3.945E-06	-1.233E-06	-4.782E-06	-1.673E-07	-1.202E-07	-4.251E-06	-1.641E-06	-4.951E-08
	Upper Core	-1.127E-04	-3.609E-05	-1.081E-04	-3.276E-06	-1.948E-06	-5.488E-05	-2.310E-05	-9.900E-07
	IBZ	-2.270E-05	-8.298E-06	-2.180E-05	-9.090E-07	-3.084E-07	-1.033E-05	-4.254E-06	-1.805E-07
	Lower Core	-1.694E-04	-5.431E-05	-1.333E-04	-7.860E-06	-1.951E-06	-5.867E-05	-2.447E-05	-1.038E-06
	Core	-3.048E-04	-9.870E-05	-2.632E-04	-1.205E-05	-4.207E-06	-1.239E-04	-5.182E-05	-2.208E-06
	AB	-4.619E-05	-1.357E-05	-2.969E-05	-4.581E-07	-1.082E-07	-4.496E-06	-2.438E-06	-1.100E-07
	LAR	-3.938E-07	-9.312E-08	-2.114E-07	-3.521E-08	-1.333E-08	-2.071E-08	-1.307E-08	-4.055E-09
	Sum	-3.695E-04	-1.179E-04	-3.135E-04	-1.278E-05	-4.522E-06	-1.358E-04	-5.741E-05	-2.453E-06
	Total	-1.014E-03							
SD	UAR	3.405E-08	3.119E-11	5.601E-10	2.609E-11	8.737E-12	5.031E-08	1.648E-07	1.552E-09
	Cones&Plugs	3.870E-06	1.275E-06	4.089E-06	5.762E-08	6.456E-08	1.202E-06	4.014E-07	1.345E-07
	UBS	1.766E-07	6.011E-08	2.290E-07	1.035E-08	7.989E-09	1.420E-07	1.212E-07	2.187E-08
	SP	1.760E-06	5.151E-07	1.693E-06	1.113E-07	1.056E-07	2.224E-06	1.524E-06	2.942E-07
	Upper Core	2.592E-05	9.185E-06	3.023E-05	1.851E-06	1.345E-06	3.188E-05	1.642E-05	3.753E-06
	IBZ	4.363E-06	2.000E-06	6.275E-06	5.819E-07	2.116E-07	6.082E-06	2.933E-06	6.847E-07
	Lower Core	3.965E-05	1.297E-05	4.663E-05	4.927E-06	1.309E-06	3.407E-05	1.763E-05	3.929E-06
	Core	6.720E-05	2.401E-05	8.115E-05	7.093E-06	2.821E-06	7.202E-05	3.698E-05	8.366E-06
	AB	8.208E-05	2.394E-05	5.009E-05	5.054E-07	1.278E-07	2.153E-06	2.245E-06	4.665E-07
	LAR	1.785E-07	2.485E-08	1.012E-07	1.993E-08	7.622E-09	5.551E-09	7.367E-09	1.322E-08
	Sum	9.609E-05	2.903E-05	8.596E-05	7.508E-06	3.030E-06	7.693E-05	4.165E-05	9.375E-06
	Total	2.378E-04							

TABLE 3.18. SODIUM DENSITY COEFFICIENTS
(Unit: abs. unit)

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR	2.070E-07	6.450E-08	1.780E-07	4.373E-08	1.780E-08	1.730E-07	5.700E-07	4.370E-08
	Cones&Plugs	2.970E-04	1.310E-04	4.670E-04	1.667E-05	2.612E-04	5.925E-06	1.315E-05	1.040E-05
	UBS	2.509E-05	8.425E-06	2.723E-05	8.007E-06	9.100E-06	7.916E-07	1.742E-06	8.020E-07
	SP	3.782E-03	3.850E-09	-6.760E-09	6.449E-08	2.550E-08	3.920E-09	2.740E-07	1.840E-07
	Upper Core	-2.935E-03	1.032E-04	3.410E-04	3.205E-05	2.429E-05	-1.305E-05	1.580E-05	1.951E-05
	IBZ	-8.630E-04	-2.900E-04	-3.590E-04	-9.081E-05	-5.570E-05	6.650E-05	5.590E-05	4.390E-05
	Lower Core	-3.574E-03	-1.091E-03	-3.970E-04	2.809E-03	1.209E-03	3.853E-04	3.351E-04	2.428E-04
	Core	-7.372E-03	-2.299E-03	-9.816E-04	2.164E-03	2.078E-03	7.974E-04	6.996E-04	5.218E-04
	AB	2.712E-04	1.430E-04	5.291E-04	3.280E-03	1.404E-03	9.017E-06	3.217E-05	2.211E-05
	LAR	1.720E-04	4.690E-05	9.060E-05	3.421E-05	1.280E-05	9.700E-06	7.620E-06	5.990E-07
	Sum	-2.824E-03	-5.149E-04	5.253E-03	5.502E-03	3.999E-03	8.285E-04	7.739E-04	5.717E-04
	Total	1.359E-02							
CEA/SA	UAR	6.893E-08	2.145E-08	4.212E-07	1.225E-08	4.652E-09	6.175E-07	1.091E-06	4.732E-08
	Cones&Plugs	2.601E-04	1.060E-04	3.573E-04	8.110E-06	9.350E-05	2.432E-05	1.926E-05	6.785E-06
	UBS	9.430E-06	3.260E-06	1.091E-05	7.954E-06	4.995E-06	6.063E-06	4.344E-06	7.318E-07
	SP	1.126E-03	4.366E-04	1.616E-03	-2.379E-05	5.405E-05	2.384E-05	4.428E-05	1.154E-05
	Upper Core	-3.290E-03	-9.746E-04	-1.987E-05	-6.290E-04	1.415E-04	5.722E-04	5.761E-04	1.495E-04
	IBZ	-9.225E-04	-2.909E-04	-2.550E-04	-2.045E-04	-6.919E-05	1.014E-04	1.028E-04	2.737E-05
	Lower Core	-4.041E-03	-1.120E-03	-6.843E-05	1.468E-04	8.549E-05	6.453E-04	6.270E-04	1.573E-04
	Core	-8.254E-03	-2.385E-03	-3.433E-04	-6.867E-04	1.578E-04	1.319E-03	1.306E-03	3.341E-04
	AB	5.262E-05	1.057E-04	3.807E-04	1.183E-03	4.373E-04	6.256E-05	7.663E-05	1.758E-05
	LAR	1.190E-04	2.992E-05	5.780E-05	1.497E-05	5.551E-06	1.016E-05	1.116E-05	4.633E-07
	Sum	-6.715E-03	-1.711E-03	2.076E-03	5.092E-04	7.769E-04	1.448E-03	1.472E-03	3.717E-04
	Total	-1.772E-03							
CIAE	UAR	5.078E-08	8.685E-09	4.365E-07	-7.181E-09	-2.286E-09	4.719E-07	1.514E-06	6.442E-08
	Cones&Plugs	2.601E-04	-2.458E-04	-5.300E-04	-2.166E-04	-7.274E-05	-3.872E-05	-3.556E-05	-8.957E-06
	UBS	1.297E-05	4.112E-06	1.279E-05	6.649E-06	5.340E-06	6.834E-06	3.634E-06	8.235E-07
	SP	1.055E-03	4.038E-04	1.440E-03	-1.033E-05	7.088E-05	3.338E-05	3.125E-05	1.107E-05
	Upper Core	-3.087E-03	-8.957E-04	2.251E-04	-5.620E-04	1.677E-04	5.842E-04	3.670E-04	1.322E-04
	IBZ	-9.467E-04	-2.868E-04	-2.061E-04	-2.108E-04	-7.108E-05	1.035E-04	6.546E-05	2.420E-05
	Lower Core	-4.075E-03	-1.136E-03	9.309E-05	1.749E-04	2.445E-05	6.735E-04	4.096E-04	1.409E-04
	Core	-8.109E-03	-2.319E-03	1.120E-04	-5.979E-04	1.211E-04	1.361E-03	8.420E-04	2.974E-04
	AB	2.055E-04	1.111E-04	3.839E-04	1.214E-03	3.784E-04	7.630E-05	5.589E-05	1.746E-05
	LAR	8.396E-05	2.227E-05	4.274E-05	1.207E-05	4.251E-06	8.490E-06	9.640E-06	5.769E-07
	Sum	-6.492E-03	-1.672E-03	2.349E-03	6.327E-04	6.734E-04	1.511E-03	9.632E-04	3.342E-04
	Total	-1.700E-03							
FZK/IKET	UAR	2.256E-07	6.793E-08	8.639E-07	3.974E-08	1.305E-08	1.177E-06	1.838E-06	1.314E-07
	Cones&Plugs	3.570E-04	1.327E-04	4.303E-04	1.314E-05	1.200E-04	4.660E-05	4.673E-05	1.464E-05
	UBS	1.772E-05	5.304E-06	1.621E-05	9.479E-06	6.684E-06	1.234E-05	7.575E-06	1.695E-06
	SP	1.334E-03	4.652E-04	1.663E-03	-1.252E-05	8.558E-05	7.057E-05	7.905E-05	2.447E-05
	Upper Core	-3.683E-03	-1.032E-03	2.077E-04	-6.245E-04	2.878E-04	9.970E-04	9.001E-04	2.871E-04
	IBZ	-1.081E-03	-3.106E-04	-1.972E-04	-2.099E-04	-7.157E-05	1.798E-04	1.643E-04	5.320E-05
	Lower Core	-4.918E-03	-1.285E-03	5.754E-05	3.921E-04	1.558E-04	1.148E-03	9.920E-04	3.077E-04
	Core	-9.684E-03	-2.627E-03	6.809E-05	-4.422E-04	3.719E-04	2.324E-03	2.056E-03	6.480E-04
	AB	2.238E-04	1.185E-04	4.101E-04	1.564E-03	5.601E-04	1.406E-04	1.274E-04	3.648E-05
	LAR	2.051E-04	4.838E-05	8.981E-05	3.079E-05	1.161E-05	1.587E-05	1.638E-05	1.111E-06
	Sum	-7.544E-03	-1.857E-03	2.678E-03	1.162E-03	1.156E-03	2.612E-03	2.335E-03	7.265E-04
	Total	1.267E-03							
IGCAR	UAR	5.193E-08	9.463E-09	1.2450E-07	3.617E-08	1.401E-08	6.636E-07	1.006E-06	-1.136E-08
	Cones&Plugs	3.323E-04	1.304E-04	4.473E-04	5.288E-06	1.098E-04	1.476E-05	7.621E-06	1.591E-06
	UBS	7.869E-06	2.661E-06	8.807E-06	7.086E-06	5.264E-06	4.540E-06	1.077E-06	2.844E-08
	SP	1.427E-03	5.507E-04	1.903E-03	-2.317E-05	7.791E-05	1.070E-05	8.373E-06	2.061E-06
	Upper Core	-2.729E-03	-8.056E-04	8.589E-05	-6.324E-04	2.694E-04	4.547E-04	2.235E-04	4.559E-05
	IBZ	-8.614E-04	-2.645E-04	-2.486E-04	-1.334E-04	-5.529E-05	8.124E-05	4.137E-05	8.824E-06
	Lower Core	-3.605E-03	-1.026E-03	-9.952E-05	5.122E-04	2.039E-04	5.279E-04	2.565E-04	4.988E-05
	Core	-7.196E-03	-2.096E-03	-2.622E-04	-2.535E-04	4.179E-04	1.064E-03	5.214E-04	1.043E-04
	AB	1.896E-04	1.095E-04	3.943E-04	1.334E-03	4.908E-04	4.391E-05	2.212E-05	3.538E-06
	LAR	9.967E-05	2.758E-05	5.085E-05	1.641E-05	5.992E-06	8.159E-06	7.306E-06	1.412E-08
	Sum	-5.139E-03	-1.275E-03	2.542E-03	1.086E-03	1.108E-03	1.147E-03	5.689E-04	1.115E-04
	Total	1.485E-04							

TABLE 3.18. SODIUM DENSITY COEFFICIENTS (cont.)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR	2.530E-07	7.183E-08	1.462E-07	9.349E-08	8.945E-08	8.363E-07	3.271E-06	2.715E-08
	Cones&Plugs	2.863E-04	1.119E-04	3.749E-04	9.332E-05	4.313E-06	1.875E-05	1.900E-05	2.226E-06
	UBS	2.898E-05	8.899E-06	2.693E-05	6.180E-06	4.813E-07	4.802E-06	3.597E-06	2.860E-07
	SP	1.316E-03	4.792E-04	1.656E-03	-1.882E-05	7.004E-06	3.162E-05	3.231E-05	3.681E-06
	Upper Core	-2.628E-03	-7.254E-04	5.005E-04	-5.165E-04	8.885E-05	3.914E-04	3.874E-04	4.184E-05
	IBZ	-8.649E-04	-2.516E-04	-1.412E-04	-2.325E-04	1.629E-05	7.050E-05	6.927E-05	7.563E-06
	Lower Core	-3.542E-03	-9.660E-04	4.491E-04	7.940E-04	9.635E-05	4.494E-04	4.434E-04	4.426E-05
	Core	-7.035E-03	-1.943E-03	8.084E-04	4.492E-05	2.015E-04	9.113E-04	9.001E-04	9.366E-05
	AB	3.329E-04	1.490E-04	4.538E-04	1.912E-03	1.038E-05	5.490E-05	5.465E-05	5.392E-06
	LAR	1.751E-04	4.589E-05	8.262E-05	1.157E-04	4.877E-07	1.786E-05	1.722E-05	1.559E-07
	Sum	-4.895E-03	-1.148E-03	3.403E-03	2.260E-03	2.242E-04	1.040E-03	1.030E-03	1.054E-04
	Total	2.020E-03							
JNC	UAR	8.573E-08	2.434E-08	4.690E-07	5.449E-08	2.035E-08	1.162E-06	1.509E-06	9.976E-08
	Cones&Plugs	3.429E-04	1.294E-04	4.104E-04	9.035E-06	1.004E-04	2.866E-05	2.472E-05	9.744E-06
	UBS	3.440E-05	1.018E-05	2.948E-05	6.170E-06	8.180E-06	7.388E-06	4.078E-06	1.123E-06
	SP	1.480E-03	5.246E-04	1.815E-03	9.915E-06	1.053E-04	4.990E-05	4.223E-05	1.644E-05
	Upper Core	-2.633E-03	-7.138E-04	5.309E-04	-4.879E-04	2.178E-04	7.030E-04	5.085E-04	1.922E-04
	IBZ	-8.964E-04	-2.582E-04	-1.493E-04	-1.452E-04	-6.209E-05	1.267E-04	9.224E-05	3.512E-05
	Lower Core	-3.601E-03	-9.633E-04	4.801E-04	4.103E-04	1.779E-04	7.911E-04	5.507E-04	1.992E-04
	Core	-7.131E-03	-1.935E-03	8.617E-04	-2.229E-04	3.336E-04	1.621E-03	1.151E-03	4.265E-04
	AB	3.165E-04	1.452E-04	4.650E-04	1.270E-03	4.728E-04	7.772E-05	6.080E-05	2.178E-05
	LAR	1.196E-04	2.990E-05	5.598E-05	2.564E-05	9.681E-06	1.040E-05	1.054E-05	7.456E-07
	Sum	-4.837E-03	-1.096E-03	3.638E-03	1.098E-03	1.030E-03	1.796E-03	1.295E-03	4.765E-04
	Total	3.400E-03							
KAERI	UAR	-4.923E-08	-1.557E-08	2.423E-07	-3.135E-09	-1.076E-09	1.661E-07	3.851E-07	7.851E-08
	Cones&Plugs	1.233E-05	1.840E-05	1.383E-04	-1.290E-05	4.273E-05	2.764E-05	3.612E-05	1.298E-05
	UBS	-1.432E-06	-2.785E-07	5.148E-07	1.978E-06	1.823E-06	1.958E-06	2.209E-06	1.153E-06
	SP	1.862E-04	1.193E-04	9.561E-04	-1.617E-05	2.128E-05	4.483E-05	5.371E-05	2.054E-05
	Upper Core	-2.980E-03	-8.511E-04	1.948E-03	-9.040E-04	-7.482E-05	1.233E-03	9.637E-04	2.787E-04
	IBZ	-9.380E-04	-2.426E-04	3.091E-04	-2.503E-04	-7.404E-05	2.473E-04	1.869E-04	5.215E-05
	Lower Core	-4.005E-03	-1.073E-03	2.526E-03	-6.513E-04	-1.876E-04	1.405E-03	1.051E-03	2.942E-04
	Core	-7.923E-03	-2.166E-03	4.783E-03	-1.805E-03	-3.364E-04	2.885E-03	2.202E-03	6.250E-04
	AB	-4.113E-04	-7.076E-05	5.169E-05	5.426E-04	2.011E-04	6.074E-05	7.919E-05	3.051E-05
	LAR	1.134E-05	7.756E-06	1.708E-05	5.377E-06	1.850E-06	4.641E-06	8.285E-06	8.730E-07
	Sum	-8.126E-03	-2.092E-03	5.947E-03	-1.285E-03	-6.763E-05	3.025E-03	2.381E-03	6.911E-04
	Total	4.747E-04							
Mean	UAR	1.117E-07	3.158E-08	3.602E-07	3.369E-08	1.949E-08	6.584E-07	1.398E-06	6.011E-08
	Cones&Plugs	2.685E-04	6.424E-05	2.619E-04	-1.049E-05	8.241E-05	1.599E-05	1.638E-05	6.176E-06
	UBS	1.688E-05	5.320E-06	1.661E-05	6.688E-06	5.233E-06	5.589E-06	3.532E-06	8.303E-07
	SP	1.463E-03	3.724E-04	1.381E-03	-1.185E-05	5.275E-05	3.311E-05	3.643E-05	1.125E-05
	Upper Core	-2.996E-03	-7.369E-04	4.774E-04	-5.405E-04	1.403E-04	6.153E-04	4.928E-04	1.433E-04
	IBZ	-9.217E-04	-2.744E-04	-1.559E-04	-1.847E-04	-5.533E-05	1.221E-04	9.728E-05	3.154E-05
	Lower Core	-3.920E-03	-1.082E-03	3.802E-04	5.735E-04	2.206E-04	7.531E-04	5.832E-04	1.795E-04
	Core	-7.838E-03	-2.221E-03	6.308E-04	-2.250E-04	4.182E-04	1.535E-03	1.210E-03	3.813E-04
	AB	1.476E-04	1.014E-04	3.836E-04	1.537E-03	4.943E-04	6.571E-05	6.360E-05	1.936E-05
	LAR	1.232E-04	3.232E-05	6.093E-05	3.189E-05	6.528E-06	1.066E-05	1.102E-05	5.673E-07
	Sum	-5.822E-03	-1.421E-03	3.486E-03	1.371E-03	1.112E-03	1.676E-03	1.353E-03	4.236E-04
	Total	2.178E-03							
SD	UAR	1.054E-07	3.255E-08	2.460E-07	3.303E-08	2.949E-08	3.907E-07	9.013E-07	4.414E-08
	Cones&Plugs	1.098E-04	1.309E-04	3.362E-04	8.906E-05	9.735E-05	2.509E-05	2.444E-05	7.695E-06
	UBS	1.200E-05	3.589E-06	1.037E-05	2.204E-06	2.928E-06	3.555E-06	2.011E-06	5.193E-07
	SP	1.023E-03	2.010E-04	6.282E-04	1.169E-05	3.903E-05	2.239E-05	2.492E-05	8.882E-06
	Upper Core	3.603E-04	3.572E-04	6.235E-04	2.638E-04	1.240E-04	3.795E-04	3.211E-04	1.047E-04
	IBZ	7.292E-05	2.352E-05	2.001E-04	5.516E-05	2.983E-05	6.236E-05	5.240E-05	1.782E-05
	Lower Core	4.638E-04	1.044E-04	9.137E-04	9.964E-04	4.178E-04	3.542E-04	2.944E-04	1.007E-04
	Core	8.812E-04	2.345E-04	1.783E-03	1.113E-03	7.108E-04	7.255E-04	6.185E-04	2.142E-04
	AB	2.422E-04	7.174E-05	1.433E-04	8.028E-04	4.085E-04	3.723E-05	3.237E-05	1.123E-05
	LAR	6.143E-05	1.411E-05	2.556E-05	3.523E-05	4.470E-06	4.266E-06	3.820E-06	3.602E-07
	Sum	1.724E-03	5.084E-04	1.416E-03	1.942E-03	1.244E-03	7.738E-04	6.810E-04	2.383E-04
	Total	4.931E-03							

TABLE 3.19. REGION WISE SODIUM DENSITY COEFFICIENTS (TOTAL)

(Unit: abs. unit)

Participant	CORE															
	LEZ	**MEZ**	**HEZ**	**IBZ**	**AB**	**Sum**	SP	UBS	C&P	AR	SUM	SHR	SCR	SSA	REF	Total
ANL	-6.509E-03	-2.299E-03	-9.816E-04	-8.630E-04	9.433E-04	-9.710E-03	1.036E-02	6.075E-05	8.950E-04	3.099E-04	1.913E-03	5.502E-03	3.999E-03	1.602E-03	5.717E-04	1.359E-02
CEA/SA	-7.331E-03	-2.385E-03	-3.433E-04	-9.225E-04	5.390E-04	-1.044E-02	3.178E-03	2.360E-05	6.847E-04	2.072E-04	-6.349E-03	5.092E-04	7.769E-04	2.920E-03	3.717E-04	-1.772E-03
CIAE	-7.162E-03	-2.319E-03	1.120E-04	-9.467E-04	7.005E-04	-9.615E-03	2.898E-03	2.987E-05	7.234E-04	1.495E-04	-5.814E-03	6.327E-04	6.734E-04	2.474E-03	3.342E-04	-1.700E-03
IGCAR	-6.335E-03	-2.096E-03	-2.622E-04	-8.614E-04	6.934E-04	-8.861E-03	3.881E-03	1.934E-05	9.100E-04	1.783E-04	-3.872E-03	1.086E-03	1.108E-03	1.715E-03	1.115E-04	1.485E-04
FZK/IKET	-8.603E-03	-2.627E-03	6.809E-05	-1.081E-03	7.524E-04	-1.149E-02	3.462E-03	3.923E-05	9.200E-04	3.444E-04	-6.725E-03	1.162E-03	1.156E-03	4.947E-03	7.265E-04	1.267E-03
IPPE	-6.170E-03	-1.943E-03	8.084E-04	-8.649E-04	4.426E-04	-7.727E-03	3.452E-03	6.480E-05	7.732E-04	3.041E-04	-3.133E-03	2.260E-03	2.242E-04	2.070E-03	1.054E-04	1.527E-03
JNC	-6.234E-03	-1.935E-03	8.617E-04	-8.964E-04	9.267E-04	-7.278E-03	3.820E-03	7.406E-05	8.826E-04	2.061E-04	-2.295E-03	1.098E-03	1.030E-03	3.091E-03	4.765E-04	3.400E-03
KAERI	-6.985E-03	-2.166E-03	4.783E-03	-9.380E-04	-4.304E-04	-5.737E-03	1.262E-03	-1.195E-06	1.691E-04	3.635E-05	-4.271E-03	-1.285E-03	-6.763E-05	5.406E-03	6.911E-04	4.747E-04

* Fuelled regions are denoted by bolded.

TABLE 3.20. REGION WISE SODIUM DENSITY COEFFICIENTS (LEAKAGE COMPONENT)

Participant	CORE															
	LEZ	**MEZ**	**HEZ**	**IBZ**	**AB**	**Sum**	SP	UBS	C&P	AR	SUM	SHR	SCR	SSA	REF	Total
ANL																
CEA/SA																
CIAE	2.962E-03	1.163E-03	7.367E-03	2.551E-05	2.344E-03	1.386E-02	4.698E-03	5.340E-05	1.139E-03	2.172E-04	1.997E-02	3.639E-03	1.706E-03	3.778E-03	5.033E-04	2.960E-02
IGCAR	2.776E-03	1.136E-03	6.881E-03	2.468E-05	2.351E-03	1.317E-02	5.752E-03	4.745E-05	1.334E-03	2.580E-04	2.056E-02	3.767E-03	1.964E-03	3.351E-03	2.444E-04	2.989E-02
FZK/IKET																
IPPE	3.050E-03	1.155E-03	7.205E-03	2.181E-05	2.493E-03	1.393E-02	5.202E-03	8.682E-05	1.177E-03	3.418E-04	2.073E-02	5.985E-03	0.000E+00	3.985E-03	3.984E-04	3.110E-02
JNC	3.101E-03	1.221E-03	7.652E-03	1.454E-05	2.481E-03	1.447E-02	5.338E-03	9.693E-05	1.239E-03	2.860E-04	2.143E-02	3.970E-03	1.933E-03	4.072E-03	5.423E-04	3.195E-02
KAERI																

TABLE 3.21. REGION WISE SODIUM DENSITY COEFFICIENTS (NON-LEAKAGE COMPONENT)

Participant	CORE															
	LEZ	**MEZ**	**HEZ**	**IBZ**	**AB**	**Sum**	SP	UBS	C&P	AR	SUM	SHR	SCR	SSA	REF	Total
ANL																
CEA/SA																
CIAE	-1.012E-02	-3.482E-03	-7.255E-03	-9.722E-04	-1.644E-03	-2.348E-02	-1.800E-03	-2.353E-05	-4.160E-04	-6.775E-05	-2.578E-02	-3.007E-03	-1.033E-03	-1.304E-03	-1.691E-04	-3.130E-02
IGCAR	-9.110E-03	-3.233E-03	-7.143E-03	-8.861E-04	-1.658E-03	-2.203E-02	-1.872E-03	-2.812E-05	-4.241E-04	-7.971E-05	-2.443E-02	-2.681E-03	-8.566E-04	-1.636E-03	-1.329E-04	-2.974E-02
FZK/IKET																
IPPE	-9.219E-03	-3.098E-03	-6.397E-03	-8.866E-04	-1.557E-03	-2.116E-02	-1.750E-03	-2.107E-05	-4.032E-04	-3.740E-05	-2.337E-02	-3.767E-03	0.000E+00	-1.251E-03	-1.712E-04	-2.856E-02
JNC	-9.335E-03	-3.157E-03	-6.791E-03	-9.109E-04	-1.554E-03	-2.175E-02	-1.518E-03	-2.288E-05	-3.568E-04	-7.996E-05	-2.373E-02	-2.872E-03	-9.030E-04	-9.803E-04	-6.581E-05	-2.855E-02
KAERI																

TABLE 3.22. STEEL DENSITY COEFFICIENTS
(Unit: abs. unit)

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR	1.310E-08	6.380E-09	2.130E-08	1.032E-08	4.620E-09	3.440E-08	1.170E-07	1.790E-07
	Cones&Plugs	2.540E-04	1.872E-04	6.760E-04	1.959E-05	2.847E-05	-7.966E-05	1.951E-05	4.288E-05
	UBS	4.672E-05	4.672E-05	4.672E-05	4.672E-05	4.672E-05	4.672E-05	4.672E-05	4.672E-05
	SP	2.833E-04	2.833E-04	2.833E-04	2.833E-04	2.833E-04	2.833E-04	2.833E-04	2.833E-04
	Upper Core	-9.979E-03	-3.602E-03	-7.359E-03	-9.654E-04	-2.172E-05	-6.059E-04	4.584E-04	9.750E-04
	IBZ	-2.390E-03	-2.390E-03	-2.390E-03	-2.390E-03	-2.390E-03	-2.390E-03	-2.390E-03	-2.390E-03
	Lower Core	-1.323E-02	-4.569E-03	-8.450E-03	-1.974E-04	-3.170E-05	-5.061E-04	5.122E-04	1.006E-03
	Core	-2.560E-02	-9.091E-03	-1.777E-02	-1.257E-03	-7.752E-05	-1.222E-03	1.052E-03	2.163E-03
	AB	8.570E-05	1.271E-04	6.225E-04	3.665E-04	9.841E-05	-1.374E-04	5.401E-05	9.119E-05
	LAR	3.990E-05	1.140E-05	2.230E-05	8.311E-06	3.110E-06	2.380E-06	1.740E-06	2.600E-06
	Sum	-2.489E-02	-8.630E-03	-1.601E-02	-8.398E-04	8.226E-05	-1.599E-03	1.157E-03	2.369E-03
	Total	-4.835E-02							
CEA/SA	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core								
	IBZ								
	Lower Core								
	Core								
	AB								
	LAR								
	Sum								
	Total								
CIAE	UAR	6.968E-08	1.698E-08	4.564E-07	-3.728E-09	-1.202E-09	4.719E-07	1.084E-06	8.529E-07
	Cones&Plugs	1.327E-03	5.845E-04	9.144E-04	3.348E-05	4.289E-05	1.400E-04	1.149E-04	7.998E-05
	UBS	3.740E-05	1.181E-05	3.741E-05	1.335E-05	7.527E-06	5.003E-05	2.435E-05	1.056E-05
	SP	1.521E-02	2.007E-04	6.331E-04	2.109E-05	3.540E-05	1.976E-04	1.931E-04	1.131E-04
	Upper Core	-9.521E-03	-3.016E-03	-3.087E-03	-7.985E-04	4.779E-05	3.234E-03	2.064E-03	1.406E-03
	IBZ	-2.689E-03	-9.136E-04	-9.350E-03	-9.137E-05	-3.741E-05	5.699E-04	3.652E-04	2.717E-04
	Lower Core	-1.415E-02	-4.307E-03	-4.067E-03	-5.556E-05	-3.307E-05	3.813E-03	2.322E-03	1.579E-03
	Core	-2.636E-02	-8.236E-03	-1.650E-02	-9.455E-04	-2.270E-05	7.617E-03	4.752E-03	3.257E-03
	AB	5.547E-04	2.865E-04	8.023E-04	5.663E-04	1.769E-04	4.916E-04	3.484E-04	3.464E-04
	LAR	8.534E-05	2.245E-05	4.418E-05	1.156E-05	4.076E-06	8.655E-06	9.491E-06	7.304E-06
	Sum	-9.142E-03	-7.130E-03	-1.407E-02	-2.997E-04	2.441E-04	8.505E-03	5.443E-03	3.815E-03
	Total	-1.264E-02							
FZK/IKET	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core								
	IBZ								
	Lower Core								
	Core								
	AB								
	LAR								
	Sum								
	Total								
IGCAR	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core								
	IBZ								
	Lower Core								
	Core								
	AB								
	LAR								
	Sum								
	Total								

TABLE 3.22. STEEL DENSITY COEFFICIENTS (cont.)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR	2.398E-07	7.016E-08	3.378E-07	8.637E-08	9.491E-07	2.873E-06	4.858E-06	2.815E-07
	Cones&Plugs	1.284E-03	5.188E-04	1.495E-03	6.030E-05	5.252E-05	1.350E-04	1.113E-04	2.416E-05
	UBS	7.405E-05	2.306E-05	7.372E-05	2.302E-05	6.677E-06	5.450E-05	2.225E-05	3.239E-06
	SP	5.857E-04	2.056E-04	6.067E-04	1.003E-04	8.796E-05	2.370E-04	1.976E-04	4.038E-05
	Upper Core	-8.389E-03	-2.572E-03	-2.549E-03	-8.521E-04	1.013E-03	3.334E-03	2.093E-03	4.428E-04
	IBZ	-2.494E-03	-8.320E-04	-1.068E-03	-1.141E-04	1.838E-04	6.089E-04	3.742E-04	7.994E-05
	Lower Core	-1.314E-02	-3.973E-03	-3.337E-03	5.322E-05	1.091E-03	4.098E-03	2.418E-03	4.666E-04
	Core	-2.402E-02	-7.377E-03	-6.954E-03	-9.130E-04	2.288E-03	8.042E-03	4.885E-03	9.893E-04
	AB	8.544E-04	3.659E-04	1.111E-03	7.503E-04	1.276E-04	4.850E-04	3.406E-04	5.860E-05
	LAR	1.476E-04	3.870E-05	7.011E-05	6.062E-05	5.204E-06	1.523E-05	1.446E-05	1.640E-06
	Sum	-2.107E-02	-6.225E-03	-3.596E-03	8.157E-05	2.569E-03	8.971E-03	5.576E-03	1.118E-03
	Total	-1.258E-02							
JNC*	UAR	1.341E-07	4.113E-08	5.278E-07	6.292E-08	2.015E-08	1.071E-06	1.398E-06	1.192E-06
	Cones&Plugs	1.553E-03	6.153E-04	1.780E-03	4.831E-05	3.933E-05	1.547E-04	1.518E-04	1.086E-04
	UBS	-4.863E-05	-4.863E-05	-4.863E-05	-4.863E-05	-4.863E-05	-4.863E-05	-4.863E-05	-4.863E-05
	SP	6.123E-04	2.088E-04	6.616E-04	1.151E-04	4.413E-05	2.861E-04	2.707E-04	1.855E-04
	Upper Core	-9.103E-03	-2.763E-03	-2.700E-03	-4.970E-04	3.409E-05	3.876E-03	2.994E-03	2.081E-03
	IBZ	-2.519E-03	-8.273E-04	-1.084E-03	-6.393E-05	-2.473E-05	6.988E-04	5.381E-04	3.772E-04
	Lower Core	-1.272E-02	-3.737E-03	-3.199E-03	-9.304E-06	4.697E-06	4.428E-03	3.231E-03	2.145E-03
	Core	-2.435E-02	-7.327E-03	-6.983E-03	-5.703E-04	1.406E-05	9.002E-03	6.763E-03	4.603E-03
	AB	8.330E-04	3.625E-04	1.118E-03	5.294E-04	1.390E-04	4.863E-04	3.888E-04	2.428E-04
	LAR	1.197E-04	2.986E-05	5.765E-05	2.351E-05	8.842E-06	1.042E-05	1.029E-05	9.223E-06
	Sum	-2.113E-02	-6.082E-03	-3.282E-03	1.606E-04	2.579E-04	9.994E-03	7.614E-03	5.163E-03
	Total	-7.307E-03							
KAERI	UAR	-1.608E-08	-3.316E-09	3.094E-07	5.894E-10	1.568E-10	2.378E-07	4.624E-07	9.944E-07
	Cones&Plugs	1.233E-04	1.174E-04	6.661E-04	5.125E-07	1.994E-05	2.193E-04	2.745E-04	1.550E-04
	UBS	7.680E-06	2.618E-06	9.486E-06	5.016E-06	2.898E-06	2.007E-05	1.990E-05	1.424E-05
	SP	2.010E-04	8.229E-05	4.111E-04	-4.294E-06	1.222E-05	3.774E-04	4.220E-04	2.477E-04
	Upper Core	-9.390E-03	-2.997E-03	7.656E-04	-9.933E-04	-5.475E-05	9.522E-03	6.993E-03	3.273E-03
	IBZ	-2.455E-03	-8.005E-04	-4.931E-05	-9.674E-05	-2.529E-05	1.911E-03	1.349E-03	6.105E-04
	Lower Core	-1.376E-02	-4.157E-03	1.468E-03	-3.750E-04	-8.188E-05	1.089E-02	7.628E-03	3.453E-03
	Core	-2.560E-02	-7.954E-03	2.185E-03	-1.465E-03	-1.619E-04	2.233E-02	1.597E-02	7.337E-03
	AB	-4.841E-04	-3.036E-05	4.278E-04	2.575E-04	6.708E-05	5.524E-04	6.223E-04	3.652E-04
	LAR	2.730E-05	1.100E-05	2.412E-05	6.485E-06	2.292E-06	5.677E-06	8.516E-06	1.103E-05
	Sum	-2.573E-02	-7.772E-03	3.723E-03	-1.200E-03	-5.749E-05	2.350E-02	1.732E-02	8.131E-03
	Total	1.792E-02							
Mean	UAR	7.662E-08	2.255E-08	2.812E-07	2.339E-08	2.382E-07	9.043E-07	1.630E-06	5.769E-07
	Cones&Plugs	7.468E-04	3.520E-04	9.380E-04	2.847E-05	3.595E-05	1.037E-04	1.301E-04	7.551E-05
	UBS	4.146E-05	2.105E-05	4.183E-05	2.202E-05	1.596E-05	4.283E-05	2.831E-05	1.869E-05
	SP	4.071E-03	1.930E-04	4.835E-04	1.001E-04	1.047E-04	2.738E-04	2.740E-04	1.711E-04
	Upper Core	-9.320E-03	-3.047E-03	-3.057E-03	-9.023E-04	2.462E-04	3.871E-03	2.902E-03	1.524E-03
	IBZ	-2.507E-03	-1.234E-03	-3.214E-03	-6.731E-04	-5.672E-04	1.749E-04	-7.527E-05	-3.570E-04
	Lower Core	-1.357E-02	-4.251E-03	-3.596E-03	-1.437E-04	2.361E-04	4.574E-03	3.220E-03	1.626E-03
	Core	-2.539E-02	-8.165E-03	-9.760E-03	-1.145E-03	5.065E-04	9.191E-03	6.665E-03	3.437E-03
	AB	2.527E-04	1.873E-04	7.410E-04	4.852E-04	1.175E-04	3.479E-04	3.413E-04	2.153E-04
	LAR	7.503E-05	2.089E-05	4.018E-05	2.174E-05	3.671E-06	7.986E-06	8.552E-06	5.644E-06
	Sum	-2.021E-02	-7.439E-03	-7.488E-03	-5.644E-04	7.095E-04	9.845E-03	7.374E-03	3.858E-03
	Total	-1.391E-02							
SD	UAR	1.145E-07	3.280E-08	1.846E-07	4.240E-08	4.740E-07	1.325E-06	2.189E-06	4.066E-07
	Cones&Plugs	6.470E-04	2.339E-04	3.890E-04	2.516E-05	1.455E-05	1.282E-04	1.059E-04	5.785E-05
	UBS	2.737E-05	1.904E-05	2.650E-05	1.803E-05	2.061E-05	1.551E-05	1.241E-05	1.924E-05
	SP	7.430E-03	8.292E-05	1.662E-04	1.300E-04	1.232E-04	7.744E-05	1.071E-04	1.139E-04
	Upper Core	6.701E-04	4.231E-04	3.336E-03	9.227E-05	5.133E-04	4.190E-03	2.832E-03	1.231E-03
	IBZ	1.284E-04	7.721E-04	4.201E-03	1.145E-03	1.219E-03	1.820E-03	1.611E-03	1.373E-03
	Lower Core	4.757E-04	2.521E-04	4.062E-03	1.852E-04	5.705E-04	4.710E-03	3.067E-03	1.300E-03
	Core	9.847E-04	7.138E-04	9.312E-03	2.637E-04	1.189E-03	9.742E-03	6.453E-03	2.760E-03
	AB	5.842E-04	1.758E-04	2.904E-04	2.182E-04	4.667E-05	3.250E-04	2.321E-04	1.629E-04
	LAR	5.442E-05	1.301E-05	2.228E-05	2.600E-05	1.256E-06	5.468E-06	5.234E-06	4.362E-06
	Sum	7.650E-03	1.016E-03	9.251E-03	5.677E-04	1.246E-03	1.033E-02	6.940E-03	3.054E-03
	Total	2.710E-02							

* Heterogeneous calculation

TABLE 3.23. FUEL DENSITY COEFFICIENTS

(1/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
ANL	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	5.166E-02	2.379E-02	8.236E-02					
	IBZ	-3.650E-03	4.500E-03	1.560E-02					
	Lower Core	6.461E-02	2.816E-02	9.270E-02					
	Core	1.126E-01	5.645E-02	1.907E-01					
	AB	-3.019E-03	-7.786E-04	-1.247E-03					
	LAR								
	Sum	1.096E-01	5.567E-02	1.894E-01					
	Total	3.547E-01							
CEA/SA	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	5.781E-02	2.380E-02	8.636E-02					
	IBZ	-3.220E-03	4.398E-03	1.609E-02					
	Lower Core	7.490E-02	2.905E-02	1.001E-01					
	Core	1.295E-01	5.725E-02	2.025E-01					
	AB	-1.149E-03	-1.268E-04	3.096E-04					
	LAR								
	Sum	1.283E-01	5.712E-02	2.028E-01					
	Total	3.883E-01							
CIAE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	6.208E-02	2.355E-02	7.492E-02					
	IBZ	-3.867E-03	7.240E-03	2.354E-02					
	Lower Core	7.561E-02	2.981E-02	9.218E-02					
	Core	1.338E-01	6.060E-02	1.906E-01					
	AB	-1.316E-03	-1.055E-04	4.211E-04					
	LAR								
	Sum	1.325E-01	6.050E-02	1.911E-01					
	Total	3.840E-01							
FZK/IKET	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	6.266E-02	2.370E-02	7.968E-02					
	IBZ	-3.364E-03	4.456E-03	1.518E-02					
	Lower Core	8.221E-02	2.975E-02	9.513E-02					
	Core	1.415E-01	5.791E-02	1.900E-01					
	AB	-8.887E-04	9.615E-06	7.248E-04					
	LAR								
	Sum	1.406E-01	5.792E-02	1.907E-01					
	Total	3.893E-01							
IGCAR	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	5.6648E-02	2.4261E-02	8.2552E-02					
	IBZ	-3.590E-03	4.486E-03	1.538E-02					
	Lower Core	7.297E-02	2.954E-02	9.608E-02					
	Core	1.260E-01	5.829E-02	1.940E-01					
	AB	-1.599E-03	-2.066E-04	1.816E-04					
	LAR								
	Sum	1.244E-01	5.808E-02	1.942E-01					
	Total	3.767E-01							

TABLE 3.23. FUEL DENSITY COEFFICIENTS (cont.)

(2/2)

Participant	Region	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	REF
IPPE	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	6.062E-02	2.437E-02	7.909E-02					
	IBZ	-3.735E-03	4.498E-03	1.482E-02					
	Lower Core	7.923E-02	3.037E-02	9.379E-02					
	Core	1.361E-01	5.924E-02	1.877E-01					
	AB	-1.052E-03	3.261E-05	5.735E-04					
	LAR								
	Sum	1.351E-01	5.927E-02	1.883E-01					
	Total	3.826E-01							
JNC	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	6.127E-02	2.482E-02	8.066E-02					
	IBZ	-3.800E-03	4.544E-03	1.497E-02					
	Lower Core	7.642E-02	2.954E-02	9.184E-02					
	Core	1.339E-01	5.891E-02	1.875E-01					
	AB	-1.340E-03	-1.180E-04	3.795E-04					
	LAR								
	Sum	1.326E-01	5.879E-02	1.878E-01					
	Total	3.792E-01							
KAERI	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	5.681E-02	2.324E-02	8.523E-02					
	IBZ	-3.727E-03	4.527E-03	1.679E-02					
	Lower Core	7.406E-02	2.867E-02	1.008E-01					
	Core	1.271E-01	5.643E-02	2.028E-01					
	AB	-4.227E-03	-1.024E-03	-1.382E-03					
	LAR								
	Sum	1.229E-01	5.541E-02	2.014E-01					
	Total	3.798E-01							
Mean	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	5.869E-02	2.394E-02	8.136E-02					
	IBZ	-3.619E-03	4.831E-03	1.655E-02					
	Lower Core	7.500E-02	2.563E-02	8.380E-02					
	Core	1.301E-01	5.813E-02	1.932E-01					
	AB	-1.824E-03	-2.897E-04	-4.850E-06					
	LAR								
	Sum	1.283E-01	5.784E-02	1.932E-01					
	Total	3.793E-01							
SD	UAR								
	Cones&Plugs								
	UBS								
	SP								
	Upper Core	3.694E-03	5.076E-04	3.632E-03					
	IBZ	2.221E-04	9.744E-04	2.897E-03					
	Lower Core	5.144E-03	1.038E-02	3.402E-02					
	Core	8.666E-03	1.439E-03	6.175E-03					
	AB	1.175E-03	3.907E-04	8.254E-04					
	LAR								
	Sum	9.463E-03	1.740E-03	5.855E-03					
	Total	1.086E-02							

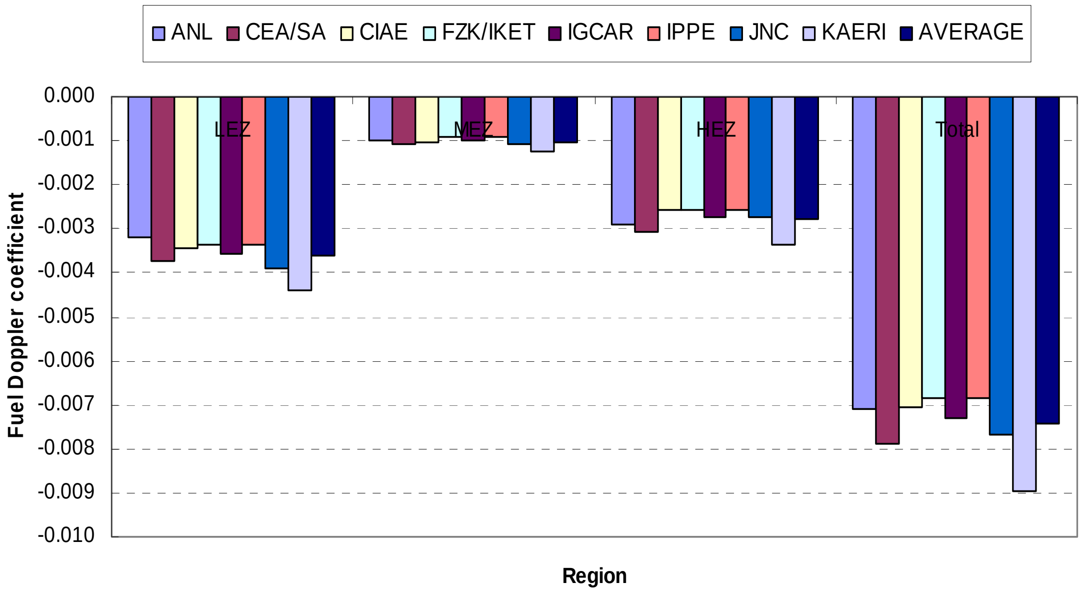


FIG. 3.7. Fuel Doppler coefficients.

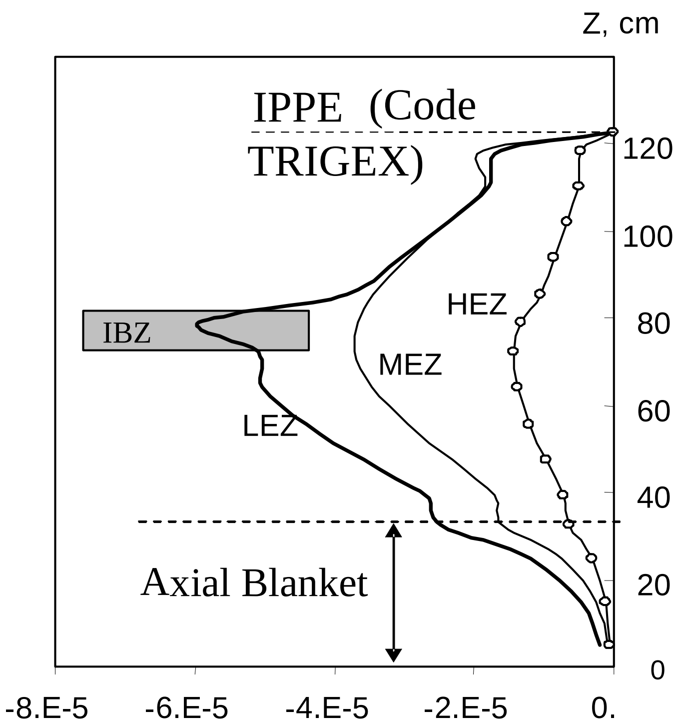


FIG. 3.8. Axial distributions of fuel Doppler coefficients (ΔZ = 1 cm) (IPPE result).

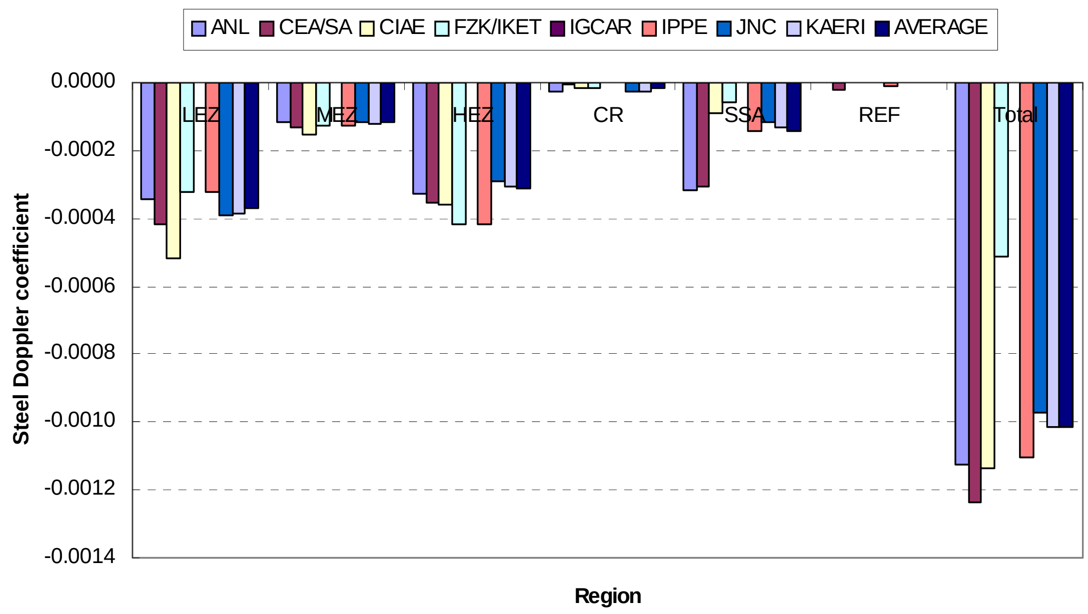


FIG. 3.9. Steel Doppler coefficients.

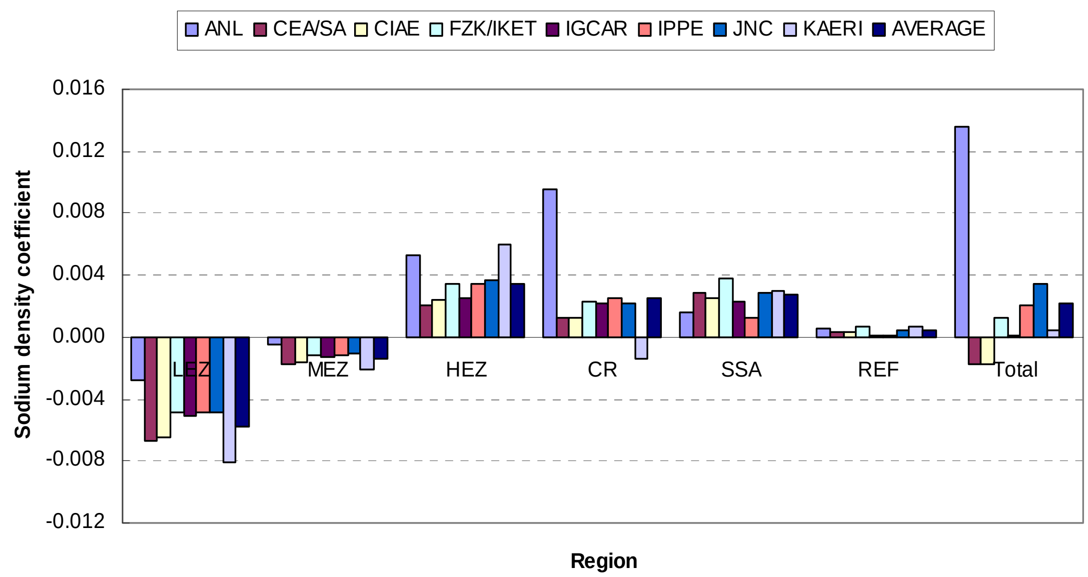


FIG. 3.10. Sodium density coefficients.

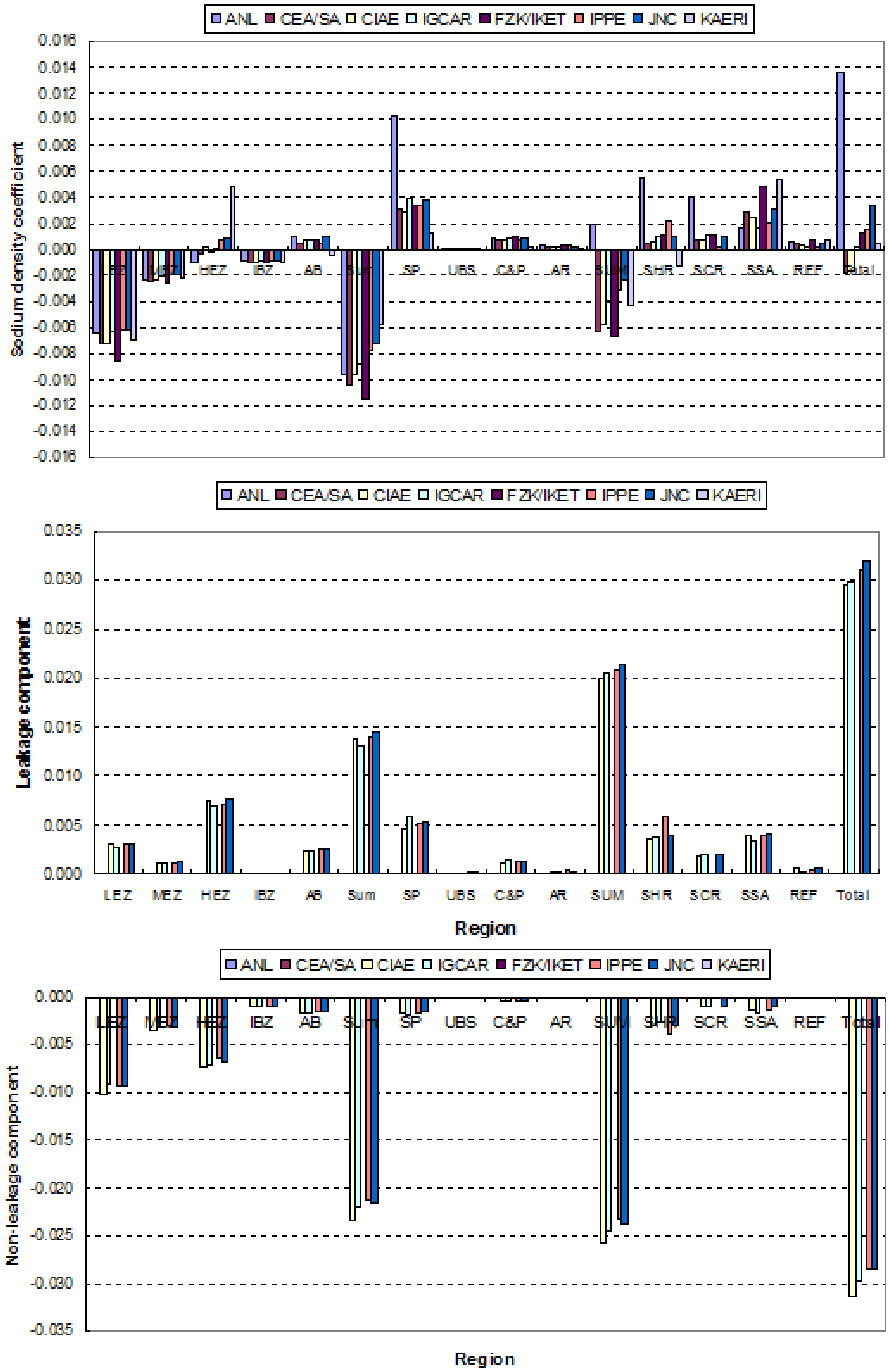


FIG. 3.11. Region-wise sodium density coefficients.

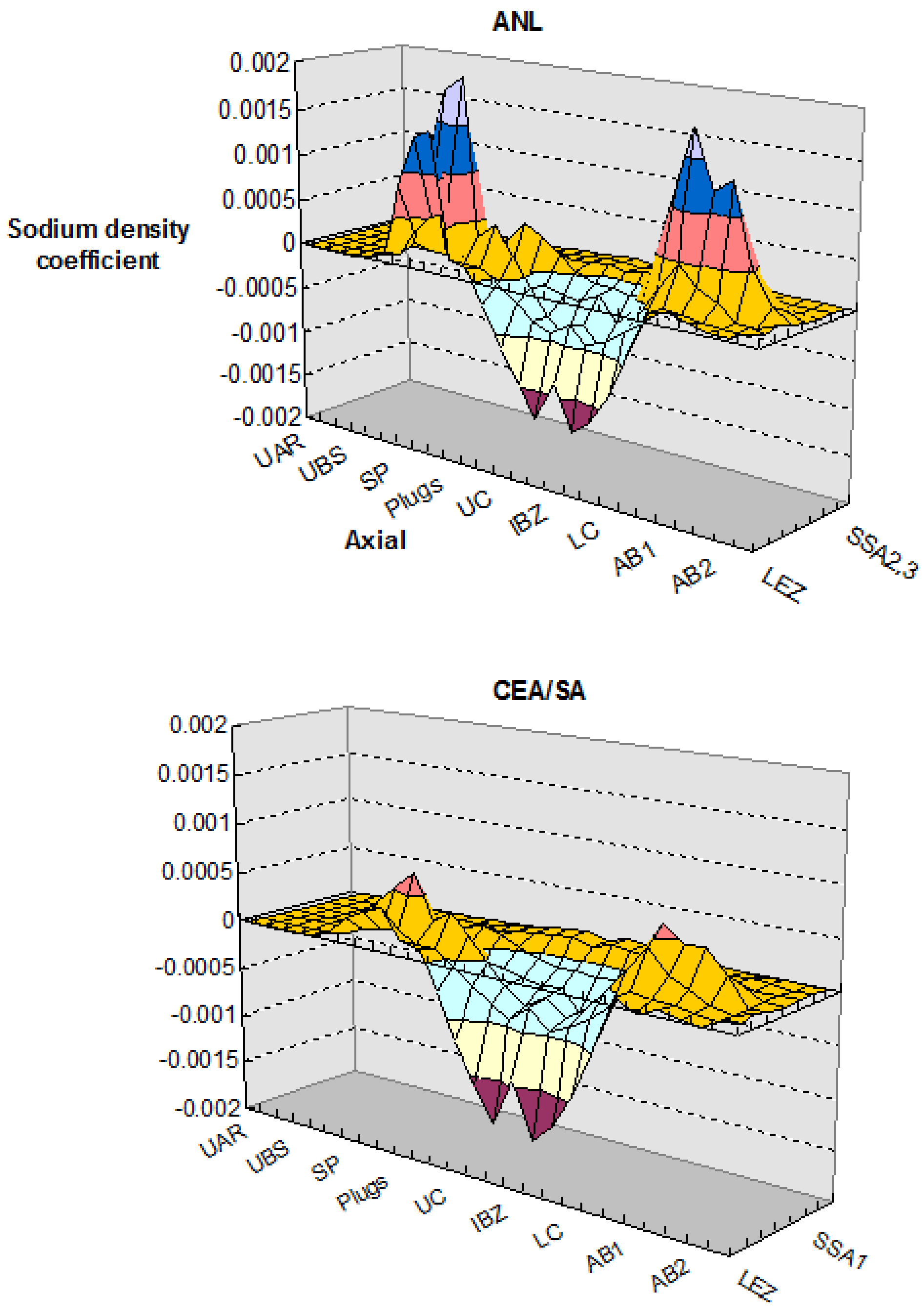
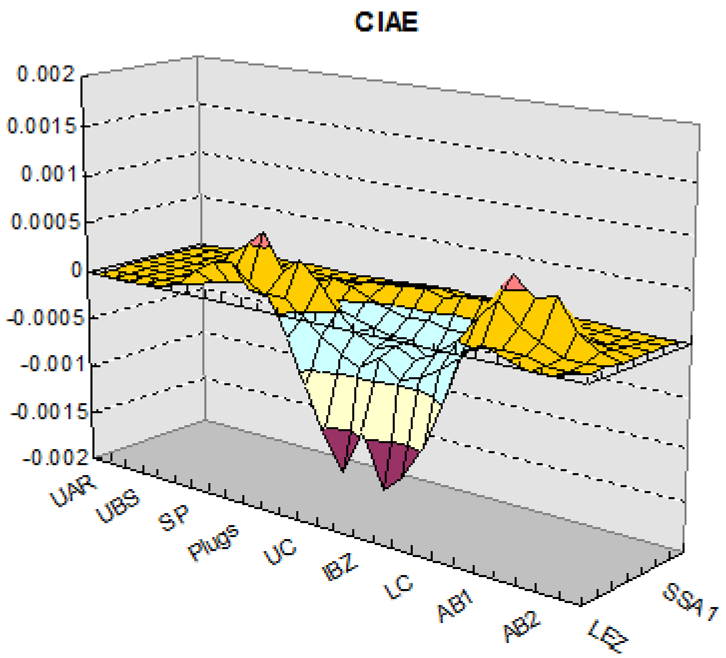


FIG. 3.12. Sodium density coefficient distributions.



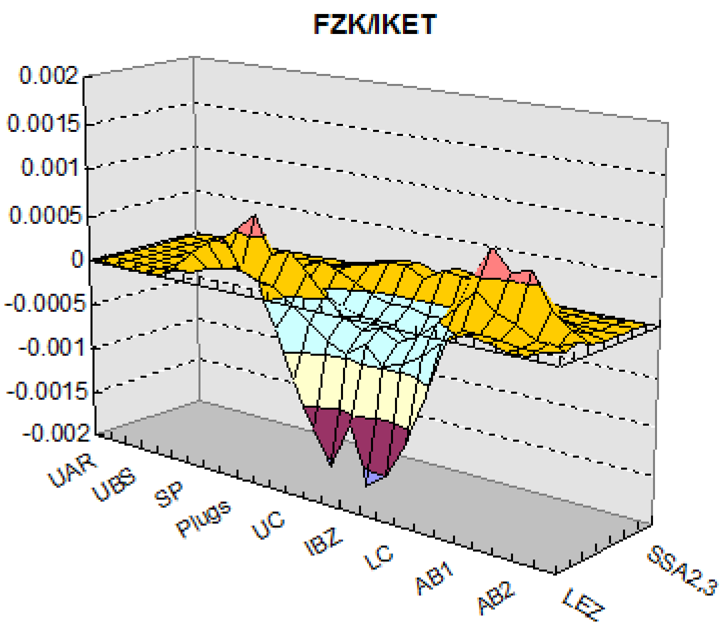


FIG. 3.12. Sodium density coefficient distributions (continued).

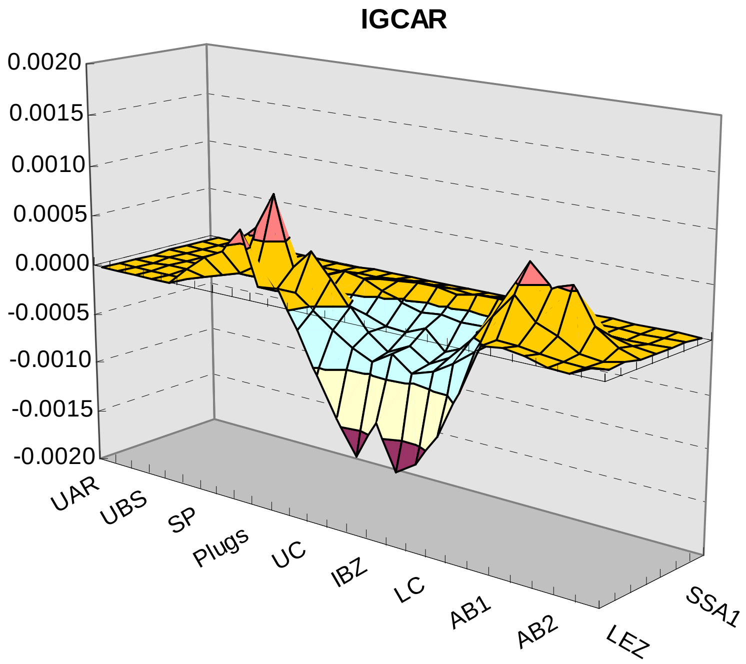
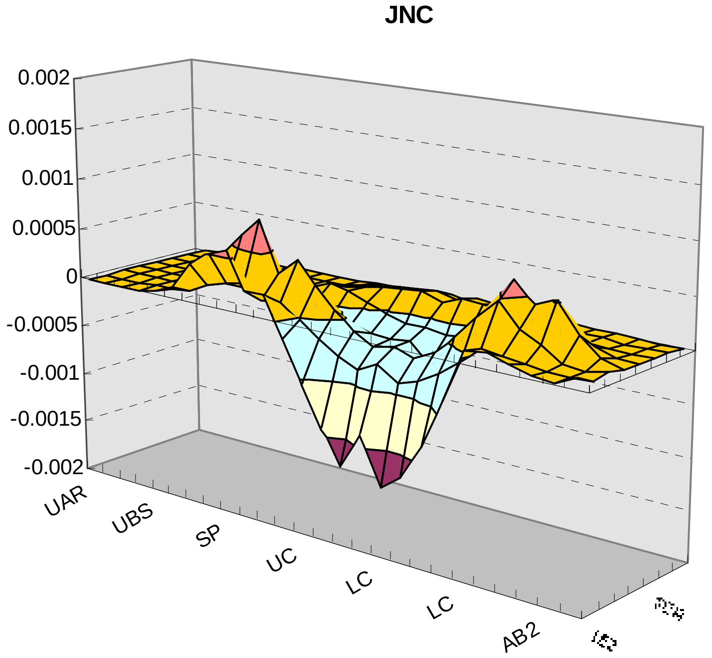


FIG. 3.12. Sodium density coefficient distributions (continued).



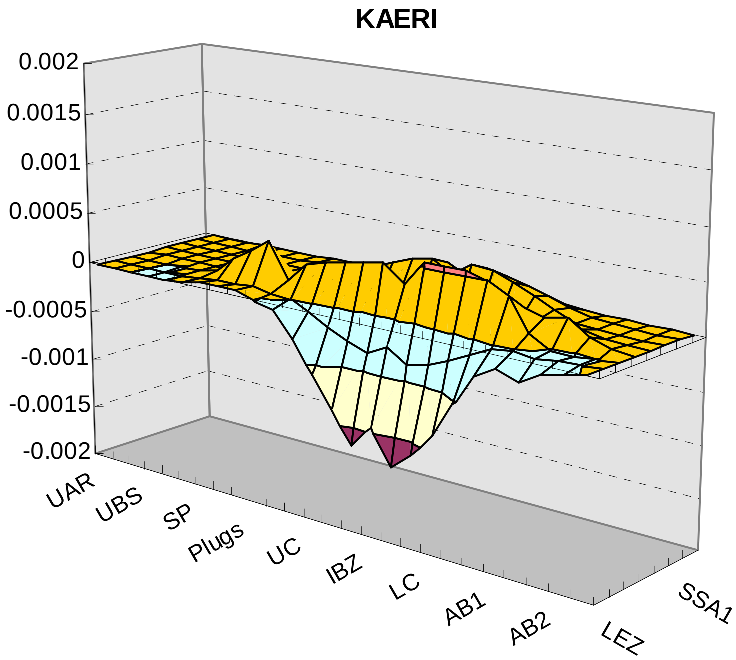


FIG. 3.12. Sodium density coefficient distributions (continued).

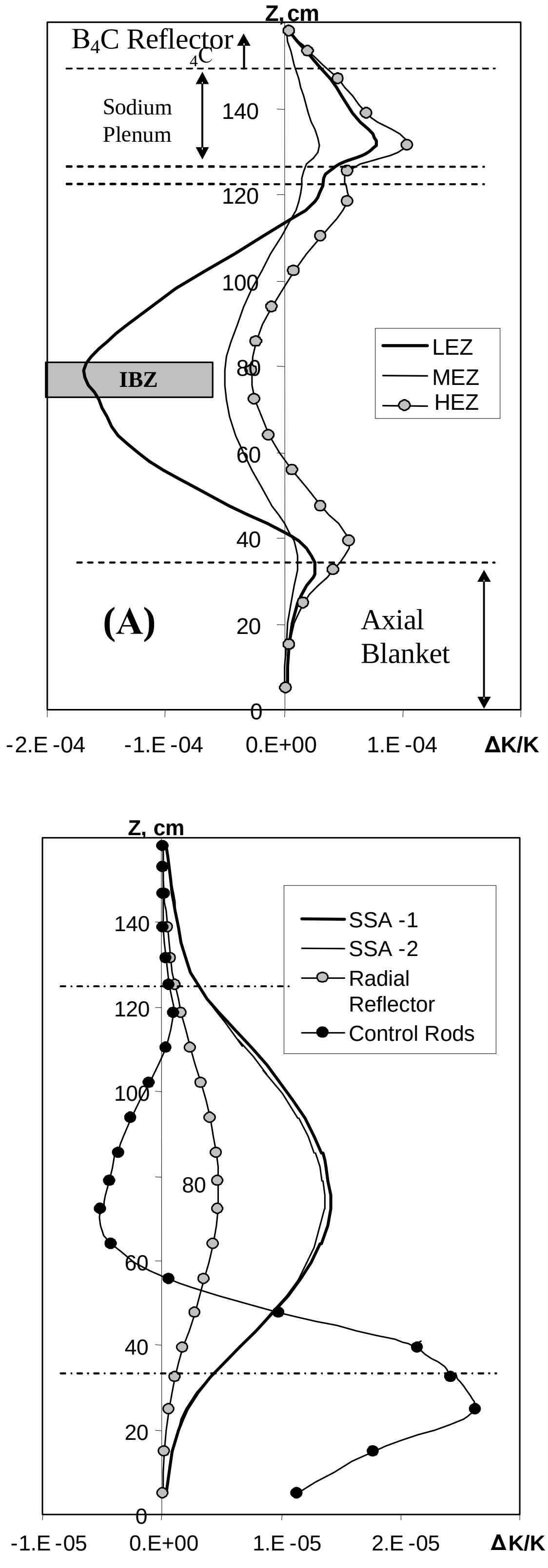


FIG. 3.13. Axial distributions of sodium density coefficients (ΔZ = 1 cm) (IPPE result).

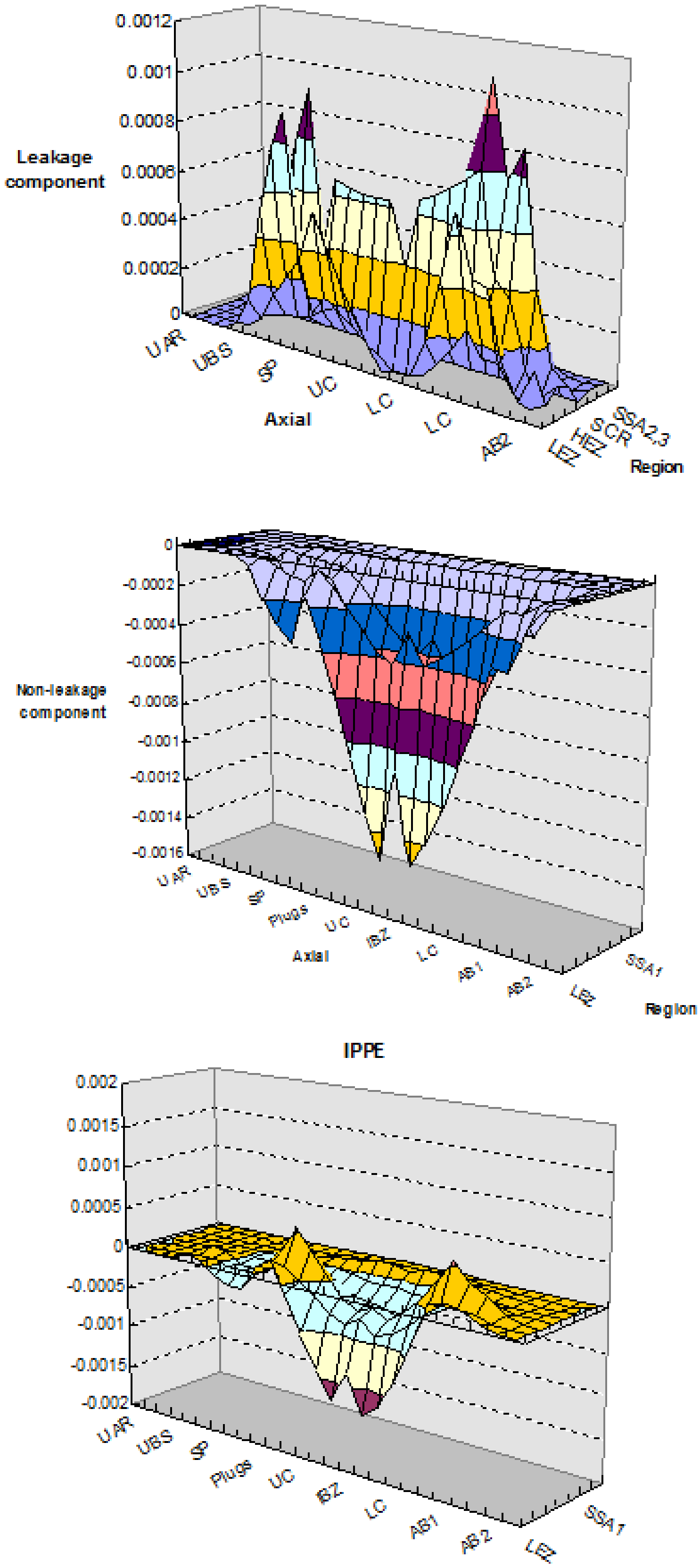
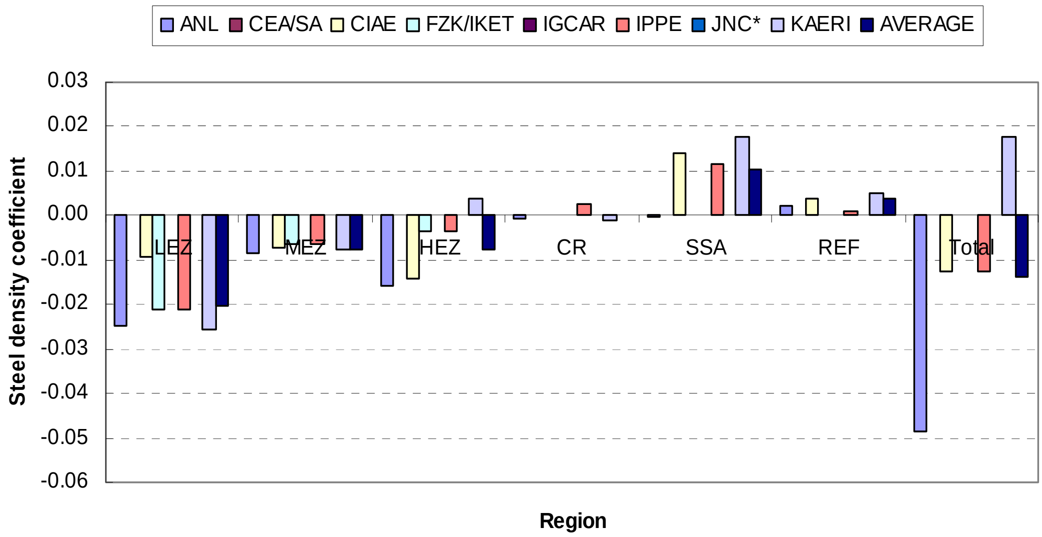


FIG. 3.14. Sodium density coefficient distributions (IPPE result).



*Heterogeneous calculation

FIG. 3.15. Steel density coefficients.

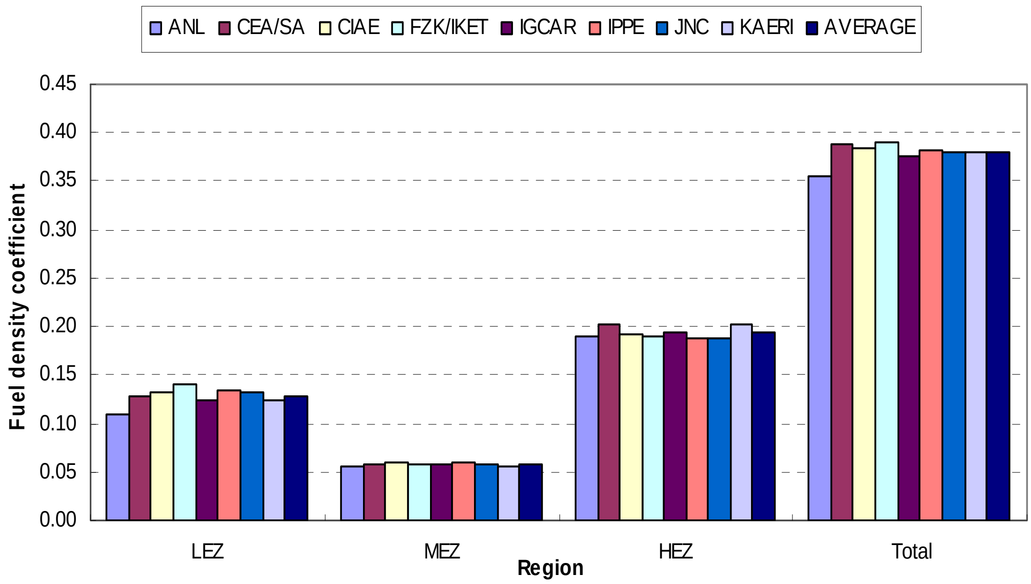


FIG. 3.16. Fuel density coefficients.

3.3.2 Heterogeneous benchmark model

Integral reactivity parameters calculated for the homogeneous and heterogeneous core models with the SHR rods insertion are compared in Tables 3.24 –3.32.

In Table 3.24 one may see that the heterogeneity effect on k_{eff} was evaluated to be an increase of 271 pcm and 288 pcm for the diffusion and transport theory calculations with relative standard deviations of 34.2% and 28.5%, respectively. These results indicate that the heterogeneity treatment gives an increased value for the core reactivity.

In Table 3.24, the JNC result for the heterogeneity effect includes the streaming effect, since the streaming effect was considered in the JNC diffusion calculations based on the heterogeneous model.

Table 3.25 shows that with the heterogeneous core model the fuel Doppler coefficient is more negative, by 5.7% and 5.2%, for the diffusion and transport theory calculations with relative standard deviations of 35.2% and 69.3% for the diffusion theory and transport theory options, respectively.

In Table 3.26 the steel Doppler coefficient appeared to be less negative in the heterogeneous core calculation. The heterogeneous core model decreases the steel Doppler coefficient by 16.8% and 12.3% in its magnitude for the diffusion and transport theory calculations. However, both results are obtained with a substantially large relative deviation. Except for the JNC results, most results show that the heterogeneity effect on the steel Doppler coefficient is small.

In Table 3.27 the heterogeneity effect on the sodium density coefficient values are shown for the diffusion and transport theory calculation options. The "heterogeneous" values appear to be higher in general. The results of opposite sign (for the homogenous and heterogeneous cases) can be seen in Table 3.26 as some "homogeneous" results (in particular, for the "transport" option) are negative. The reader should be aware that the relative values of the heterogeneous effect (%) are of opposite sign compared to the absolute ones when the coefficients are negative.

For the steel density coefficient, only one set of "heterogeneous" results is shown in Table 3.28. Similar to the sodium density coefficient, the "heterogeneous" values are higher for the steel density coefficient case. In other words, the steel coefficients are less negative and smaller by magnitude in the heterogeneous case.

As can be seen in Table 3.29, with the heterogeneous model, the fuel density coefficient is lower by ~ 2.0% for the diffusion and transport theory options, indicating only a small heterogeneity effect. The diffusion theory results for the homogeneous and heterogeneous cases are in good agreement. The same is valid for the transport theory option with respect to predicting the fuel density coefficients.

Power fractions for fuel regions calculated with the homogeneous and heterogeneous core models are given in

Table 3.30. There can be seen a small change in each fuel region. However, apparently the heterogeneity effect for the power distribution is negligibly small. The total power in HEZ is decreased in the heterogeneous core model. Due to the normalization the decreased power is compensated and is counterbalanced by the power fraction increase in LEZ and ABZ.

Tables 3.31 and 3.32 show results for the effective delayed neutron fraction and prompt neutron lifetime values, respectively. The heterogeneous core model calculations, based on the diffusion theory, increase these kinetic parameters by 0.4% and 1.1%, respectively. Thus, the heterogeneity effect for these parameters appears to be small.

A limited number of local reactivity coefficient results obtained with the heterogeneous core model have been provided by the participants. The heterogeneity effect for local sodium density coefficients should be investigated by taking into account substantially large standard deviation in the "homogeneous" results. Region-wise sodium density coefficients calculated with homogeneous and heterogeneous core models are compared in Fig. 3.17. This comparison shows that — similar to the integral values considered earlier — the region-wise sodium density coefficients become more positive for the heterogeneous core model. This observation holds for all core regions, for some results being associated with a positive value for the heterogeneous model and negative values for the homogeneous one.

TABLE 3.24. EFFECTIVE MULTIPLICATION FACTORS (k_{eff})

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (pcm)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	1.00374					
CEA/SA	1.00183	1.00946	1.00513	1.01271	329	325
CIAE	0.98834		0.98974		140	
FZK/IKET	1.00254	1.00849		1.01023		174
IGCAR	1.00164					
IPPE	1.00578	(1.00589+-0.010%)[1)]		(1.01078+-0.015%)[1)]		
JNC	0.99687	1.00196	1.00030	1.00560	343	364
KAERI	1.00976					
Mean	1.00131	1.00664	0.99839	1.00951	271	288
SD +/-	0.00599	0.00333	0.00643	0.00295	93	82
Re. SD (%)	0.60	0.33	0.64	0.29	34.21	28.48

* Heterogeneity Effect = (Hete. - Homo.) (pcm)

1) Monte Carlo calculations

TABLE 3.25. FUEL DOPPLER COEFFICIENTS (K_D^{fuel})

(Unit: abs. unit)

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect* (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	-0.00710					
CEA/SA	-0.00789	-0.00788	-0.00852	-0.00850	7.97	7.79
CIAE	-0.00683		-0.00710		4.04	
FZK/IKET	-0.00652	-0.00649		-0.00684		5.39
IGCAR	-0.00717					
IPPE	-0.00684					
JNC	-0.00770	-0.00750	-0.00810	-0.00770	5.19	2.67
KAERI	-0.00888					
Mean	-0.00737	-0.00729	-0.00755	-0.00768	5.73	5.23
SD +/-	0.00071	0.00059	0.00080	0.00068	2.02	3.62
Re. SD (%)	9.67	8.05	10.62	8.80	35.22	69.30

* Heterogeneity Effect = (Hete. - Homo.)/ Homo. x 100 (%)

TABLE 3.26. STEEL DOPPLER COEFFICIENTS (K_D^{steel})

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	-0.00113					
CEA/SA	-0.00124	-0.00126	-0.00120	-0.00120	-3.62	-4.61
CIAE	-0.00072		-0.00073		0.29	
FZK/IKET	-0.00052	-0.00052		-0.00053		1.87
IGCAR						
IPPE	-0.00110					
JNC	-0.00100	-0.00100	-0.00070	-0.00080	-30.00	-20.00
KAERI	-0.00101					
Mean	-0.00096	-0.00093	-0.00088	-0.00084	-16.81	-12.30
SD +/-	0.00023	0.00031	0.00023	0.00028	18.66	10.88
Re. SD (%)	24.48	33.17	26.21	32.81	-110.99	-88.47

TABLE 3.27. SODIUM DENSITY COEFFICIENTS (W_{NA})

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	0.01355					
CEA/SA	-0.00199	-0.00334	0.00228	-0.00039	-214.25	-88.
CIAE	-0.00099		-0.00056		-43.32	
FZK/IKET	0.00127	-0.00045		0.00059		-231.
IGCAR	0.00090					
IPPE	0.00139					
JNC	0.00084	-0.00067	0.00410	0.00040	391.02	-160.
KAERI	0.00223					
Mean	0.00046	-0.00149	0.00194	0.00197	44.48	-160.
SD +/-	0.00480	0.00131	0.00192	0.00280	312.04	36.
Re. SD (%)	1052.17	88.28	98.87	142.01	701.51	22.5

TABLE 3.28. STEEL DENSITY COEFFICIENTS (W_{STEEL})

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	-0.0484					
CEA/SA						
CIAE	-0.0177					
FZK/IKET	-0.0185					
IGCAR	-0.0185					
IPPE	-0.0126					
JNC	-0.0159	-0.0245	-0.0124	-0.0185	-22.21	-24.61
KAERI	-0.0041					
Mean	-0.0195	-0.0245	-0.0124	-0.0185		
SD +/-	0.0137					
Re. SD (%)	70.40					

TABLE 3.29. FUEL DENSITY COEFFICIENTS (W_{FUEL})

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	0.3548					
CEA/SA	0.3882	0.3788	0.3830	0.3735	-1.34	-1.40
CIAE	0.3915		0.3902		-0.32	
FZK/IKET	0.3900	0.3815		0.3802		-0.35
IGCAR	0.3790					
IPPE	0.3786					
JNC	0.3908	0.3875	0.3754	0.3698	-3.94	-4.56
KAERI	0.3722					
Mean	0.3806	0.3826	0.3829	0.3745	-1.87	-2.10
SD +/-	0.0118	0.0036	0.0060	0.0043	1.87	2.19
Re. SD (%)	3.09	0.95	1.58	1.15	-99.87	-104.38

TABLE 3.30. POWER FRACTIONS BETWEEN HOMOGENEOUS AND HETEROGENEOUS CORE MODELS

(Unit: %)
*Transport theory calculations

	Zone	Homo.	Hete.	Change
CEA/SA	LEZ	34.84	35.46	0.62
	MEZ	13.77	13.79	0.02
	HEZ	47.98	47.27	-0.71
	IBZ	1.19	1.22	0.03
	ABZ	2.19	2.25	0.06
CIAE	LEZ	35.26	35.34	0.07
	MEZ	13.88	13.88	0.00
	HEZ	47.41	47.32	-0.10
	IBZ	1.18	1.19	0.00
	ABZ	2.26	2.28	0.03
FZK/IKET*	LEZ	36.10	36.13	0.03
	MEZ	13.88	13.87	-0.01
	HEZ	46.15	46.11	-0.04
	IBZ	1.25	1.25	0.00
	ABZ	97.33	97.33	0.00
JNC	LEZ	35.80	35.93	0.13
	MEZ	13.90	13.90	0.00
	HEZ	46.94	46.80	-0.15
	IBZ	1.21	1.21	0.00
	ABZ	2.15	2.16	0.02

TABLE 3.31. EFFECTIVE DELAYED NEUTRON FRACTIONS (BEFF)

(Unit: pcm)

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	324					
CEA/SA	350		351		0.29	
CIAE	348		351		1.00	
FZK/IKET	334					
IGCAR	346					
IPPE	344					
JNC	336		336		0.00	
KAERI	342					
Mean	341		345		0.43	
SD +/-	8.18		6.63		0.51	
Re. SD (%)	2.40		1.92		119.06	

TABLE 3.32. PROMPT NEUTRON LIFETIMES

(Unit: 10^{-7} sec)

Participant	Homogeneous		Heterogeneous		Heterogeneity Effect (%)	
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport
ANL	4.107					
CEA/SA	4.365		4.413		1.12	
CIAE	4.092		4.124		0.79	
FZK/IKET	4.130					
IGCAR	4.510					
IPPE	4.530					
JNC	4.484		4.540		1.25	
KAERI	4.257					
Mean	4.309		4.359		1.12	
SD +/-	0.175		0.174		0.79	
Re. SD (%)	4.07		4.00		70.53	

(Unit: 10^{-7} sec)

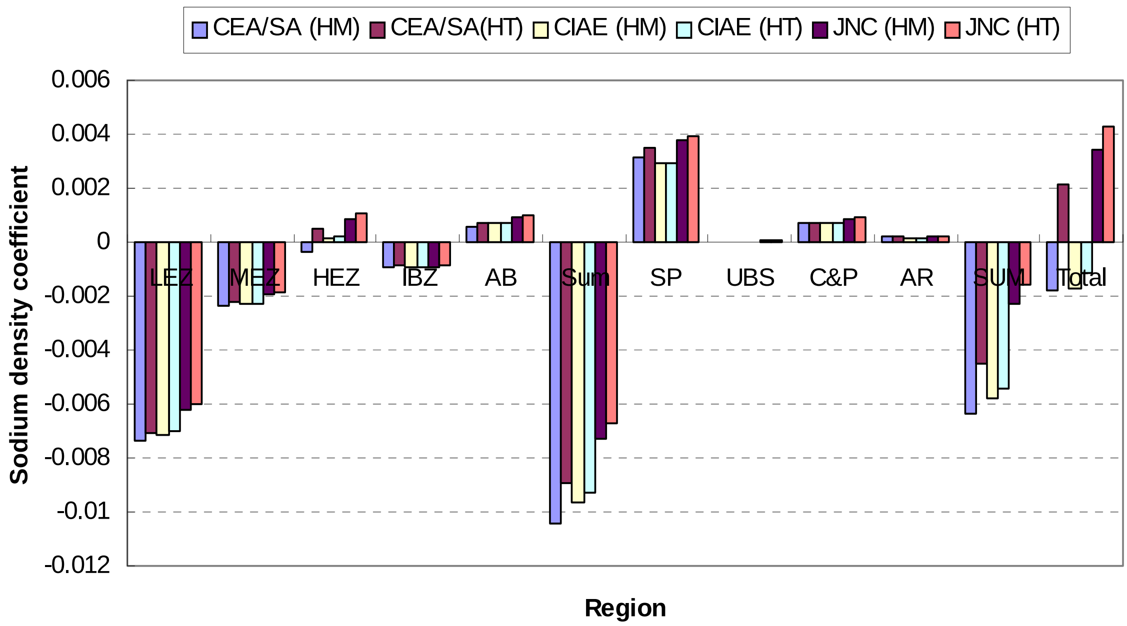


FIG. 3.17. Regionwise sodium density coefficients (homogeneous vs. heterogeneous).

3.4 SUMMARY OF BN-600 FULLY MOX FUELLED BENCHMARK (PHASE 4)

Integral reactivity coefficients and kinetics parameters for the homogeneous model of the BN-600 full MOX core are summarized in Table 3.33 with the mean values and relative standard deviations for each parameter. The comparison of the diffusion and transport results generally shows good agreement for most parameters except for the sodium density coefficient. Hex-Z diffusion and transport theory calculations predict the k_{eff} as 1.00131 and 1.00664 with corresponding relative standard deviations of 0.60% and 0.33%, respectively. Using diffusion theory, the evaluated mean effective delayed neutron fraction is β_{eff} = 0.00341 and the prompt neutron lifetime is l_p = 4.309 x 10^{-7} sec with standard deviations of 2.4% and 4.1%, respectively.

The integral sodium density coefficients show substantially large relative standard deviations for the diffusion and transport theory results. Due to a small (close to zero) integral sodium density coefficient pursued by design, there is a relatively large dispersion and even values of different sign among the diffusion theory results. For the core model of the BN-600 type fast reactor including an internal blanket zone and an above core sodium plenum, the sodium density coefficient is significantly affected by the nuclear data set used, approximations in the computation methods as well as the compensation between the positive central terms and negative leakage terms.

For such a complicated configuration under study, a low number of energy groups (e.g. 10 or less) may not be sufficient to accurately evaluate reactivity coefficients. The use of few group cross-section sets obtained by averaging with composition dependent spectra, may smooth out important spectral contributions to the reactivity coefficients. This effect may be especially important for calculations of the fuel Doppler and sodium density coefficients at the top of the core and in the sodium plenum

Integral reactivity parameters calculated for the homogeneous and heterogeneous core models with the SHR rods at mid-core insertion are compared in Table 3.33. The heterogenity effect on such parameters are reported in Table 3.34. Most parameters and corresponding heterogeneity effects are in good agreement for diffusion and transport theory results, except for the sodium density one. The heterogeneity effect on k_{eff} was evaluated to increase it by 271 pcm and 288 pcm for the diffusion and transport theory calculation options, respectively. The results are influenced by the heterogeneity treatment method, similar to the previous benchmark [2]. The heterogeneity effect on the kinetic parameters appears to be small.

The heterogeneous treatment for both diffusion and transport theory options increases in general the sodium density coefficient. However, a large standard deviation for the obtained results is observed and the heterogeneity treatment may increase an initially negative value so that it becomes positive. The mentioned large deviations are attributed to taking into account a number of rather small spatial contributions from non-fuel regions when determining the integral value for the sodium density coefficient.

TABLE 3.33. INTEGRAL REACTIVITY AND KINETICS PARAMETERS

Participant	k_{eff}		K_D^{fuel}		K_D^{steel}		W_{Na}		W_{steel}		W_{fuel}		β_{eff} (pcm)	l_p (10^{-7} sec)
	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport	Diffusion	Transport	Diffusion	Diffusion
ANL	1.00374		-0.00710		-0.00113		0.01355		-0.0484		0.3548		324	4.107
CEA/SA	1.00183	1.00946	-0.00789	-0.00788	-0.00124	-0.00126	-0.00199	-0.00334			0.3882	0.3788	350	4.365
CIAE	0.98834		-0.00683		-0.00072		-0.00099		-0.0177		0.3915		348	4.092
FZK/IKET	1.00254	1.00849	-0.00652	-0.00649	-0.00052	-0.00052	0.00127	-0.00045			0.3900	0.3815	334	4.130
IGCAR	1.00164		-0.0717				0.00090		-0.0185		0.3790		346	4.510
IPPE*	1.00578	1.00589	-0.00684	-0.00726	-0.00110	-0.00118	0.00139	-0.00723	-0.0126	-0.0135	0.3786	0.3782	344	4.530
JNC	0.99687	1.00196	-0.00770	-0.00750	-0.00100	-0.00100	0.00084	-0.00067	-0.0159	-0.0245	0.3908	0.3875	336	4.484
KAERI	1.00976		-0.00888		-0.00101		0.00223		-0.0041		0.3772		342	4.257
Mean	1.00131	1.0664	-0.00737	-0.00729	-0.00096	-0.00093	0.00046	-0.00149	-0.0195	-0.0245	0.3806	0.3826	341	4.309
SD (±) (Rel. %)	0.00599 (0.60)	0.00333 (0.33)	0.00071 (9.7)	0.00059 (8.0)	0.00023 (24.5)	0.00031 (33.2)	0.00480 (1052.2)	0.00131 (88.3)	0.0138 (70.4)		0.0118 (3.1)	0.0036 (0.9)	8.18 (2.4)	0.175 (4.1)

* Transport values for reactivity coefficient (RC) are given by $RC^{*}_{HEX,Z} = RC^{Diff}_{HEX,Z} \dfrac{RC^{Transp}_{R,Z}}{RC^{Diff}_{R,Z}}$.

TABLE 3.34. HETEROGENEITY EFFECT

Participant	k_{eff}			K_D^{fuel}			K_D^{steel}		
	Diffusion	Transport	Hete. effect (pcm)[1)]	Diffusion	Transport	Hete. effect (%)[2)]	Diffusion	Tranpsort	Hete. effect (%)
CEA/SA	1.00513 (1.00183)[3)]	1.01271 (1.00946)	329 (325)	-0.00852 (-0.00789)	-0.00850 (-0.00788)	7.97 (7.79)	-0.00120 (-0.00124)	-0.00120 (-0.00126)	-3.62 (-4.61)
CIAE	0.98974 (0.98834)		140	-0.00710 (-0.00683)		4.04	-0.00073 (-0.00072)		0.29
FZK/IKET	(1.00254)	1.01023 (1.00849)	(174)	(-0.00652)	-0.00684 (-0.00649)	(5.39)	(-0.00052)	-0.00053 (-0.00052)	(1.87)
IPPE	(1.00578)	1.01078±0.015%[3)] (1.00589±0.010%)							
JNC	1.00030 (0.99687)	1.00560 (1.00196)	343 (364)	-0.00810 (-0.00770)	-0.00770 (-0.00750)	5.19 (2.67)	-0.00810 (-0.00770)	-0.00770 (-0.00750)	-30.00 (-20.00)
Mean	0.99839	1.00951	271 (288)	-0.00755	-0.00768	5.73 (5.23)	-0.00088	-0.00084	-16.81 (-12.30)
SD (±)	0.00643	0.00295	93 (82)	0.00080	0.00068	2.02 (3.62)	0.00023	0.00028	18.66 (10.88)
Participant	W_{Na}			W_{steel}			W_{fuel}		
	Diffusion	Transport	Hete. effect (%)	Diffusion	Transport	Hete. effect (%)	Diffusion	Transport	Hete. effect (%)
CEA/SA	0.00228 (-0.00199)	-0.00039 (-0.00334)	-214.25 (-88.31)				0.3830 (0.3882)	0.3735 (0.3788)	-1.34 (-1.40)
CIAE	-0.00056 (-0.00090)		-43.20	(-0.30177)			0.3902 (0.3915)		-0.32
FZK/IKET	(0.00127)	0.00590 (-0.00045)	(-1411.11)				(0.3900)	0.3802 (0.3815)	(-0.35)
JNC	0.00410 (0.00084)	0.00040 (-0.00067)	391.02 (-159.61)	-0.0124 (-0.0159)	-0.0185 (-0.0245)	-22.21 (-24.61)	0.3754 (0.3908)	0.3698 (0.3875)	-3.94 (-4.56)
Mean	0.00194	0.00197	44.48 (-123.96)	-0.0124	-0.0185		0.3829	0.3745	-1.87 (-2.10)
SD (±)	0.00192	0.00280	312.04 (50.42)				0.0060	0.0430	1.87 (2.19)

Notes: 1) Heterogeneity effect = (Hete.–Homo.) x 10^5 (pcm) based on diffusion results, and transport results denoted by parenthesis 2) Heterogeneity effect = (Hete.–Homo.) x 100 (%) based on diffusion results, and transport results denoted in parenthesis) Values in parenthesis denote homogeneous results. 3) Monte Carlo results

3.5 INFLUENCE OF NUCLEAR DATA LIBRARIES

3.5.1 JNC studies with 70-group cross-section libraries

JNC performed the sensitivity analysis of the difference between the JENDL-3.2R and JEF-2.2R libraries for BN-600 full MOX core [25]. JENDL-3.2R is a revised version of JFS set based on JENDL-3.2, where the weighting function for generating 70-group constant was corrected in 2002. JEF-2.2R uses the newest library of ^{239}Pu compared to the JEF-2.2. Using the cross-section sensitivity coefficients calculated by the generalized perturbation theory, the nuclide-wise and reaction-wise contribution to the effect of the library change was analysed for important reactivity parameters in the sensitivity analysis.

From the sensitivity analysis, the dominant nuclides and reactions which cause the difference of the two libraries were identified for reactivity parameters. More details of the sensitivity analysis methodology and the results can be referred to the same reference [25].

The sensitivity analysis for the criticality (k_{eff}) of the BN-600 full MOX core, see Fig. 3.18, did not reproduce the results of the direct calculations. This is due to the effect of the sensitiveness and non-linearity to cross-section changes, which means some difficulty for precise design work. On the other hand, the sensitivity analysis showed good agreements with direct calculation about the sodium density and fuel Doppler reactivity, though it might be simply an accidental coincidence, especially in the case of sodium density reactivity.

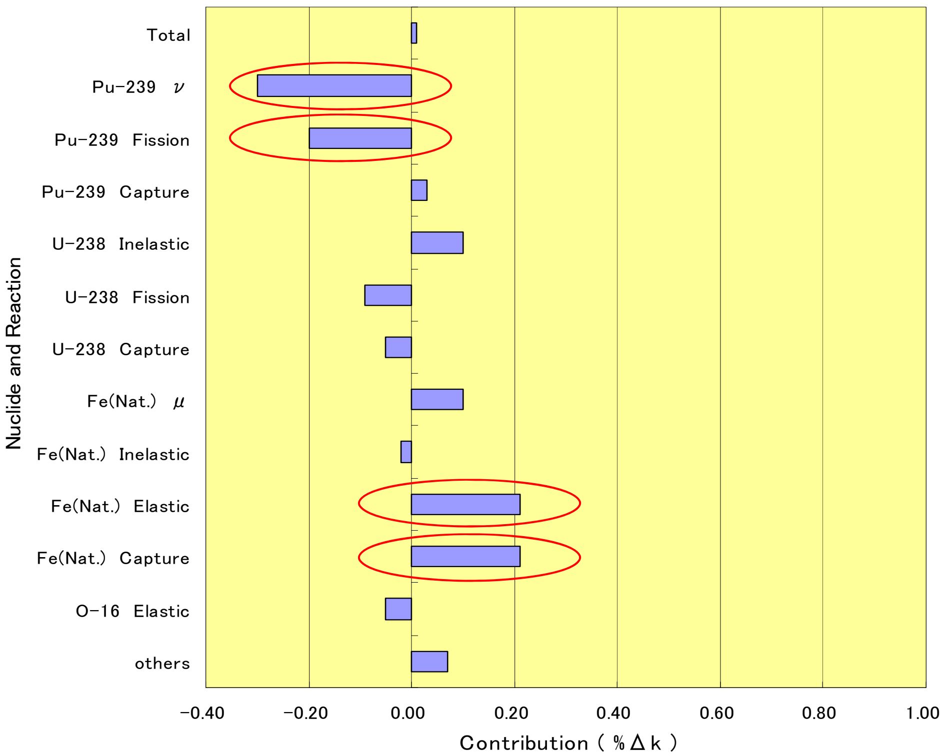


FIG. 3.18. Nuclide contributions to k_{eff} variation due to using cross-sections from JEF-2.2R instead of JENDL-3.2R.

Figure 3.19 exemplifies that the significant influence to the BN-600 full MOX core prediction is caused by the differences of ^{239}Pu fission and ν, iron capture, elastic scattering and μ between JEF and JENDL. Figure 3.19 shows the cross-section sensitivity evaluated based on JENDL-3.2R for the criticality prediction. The shielding-factors did not affect the difference of fuel Doppler reactivity between JEF and JENDL at all.

In 2002, JNC generated and released a revised version of JFS set based on JENDL-3.2, named JFS-3-J3.2R, in which a weighting function for processing group-wise constants, and the energy distribution of the secondary neutrons by the inelastic and (n,2n) scattering reaction were corrected. In the present IAEA CRP, JNC used the JFS-3-J3.2 in phases 1, 2 and 3, and changed it to JFS-3-J3.2R from Phase 4. JNC evaluated the effect of cross-section set change from JFS-3-J3.2 to JFS-3-J3.2R for the typical parameters of phases 1, 2 and 3. In the comparison of Phase 1 and Phase 2 results, the effect of cross-section change appeared to be insignificant for most reactivity parameters except for the criticality and the fuel Doppler coefficient. The effect to criticality and fuel Doppler reactivity in the Phase 3 results was almost the same as that of phases 1 and 2. The effect to criticality in the Phase 4 results was the same as for the previous cases, and the effect of control rod worth was negligible in the heterogeneous calculation. More details are addressed in Appendix.

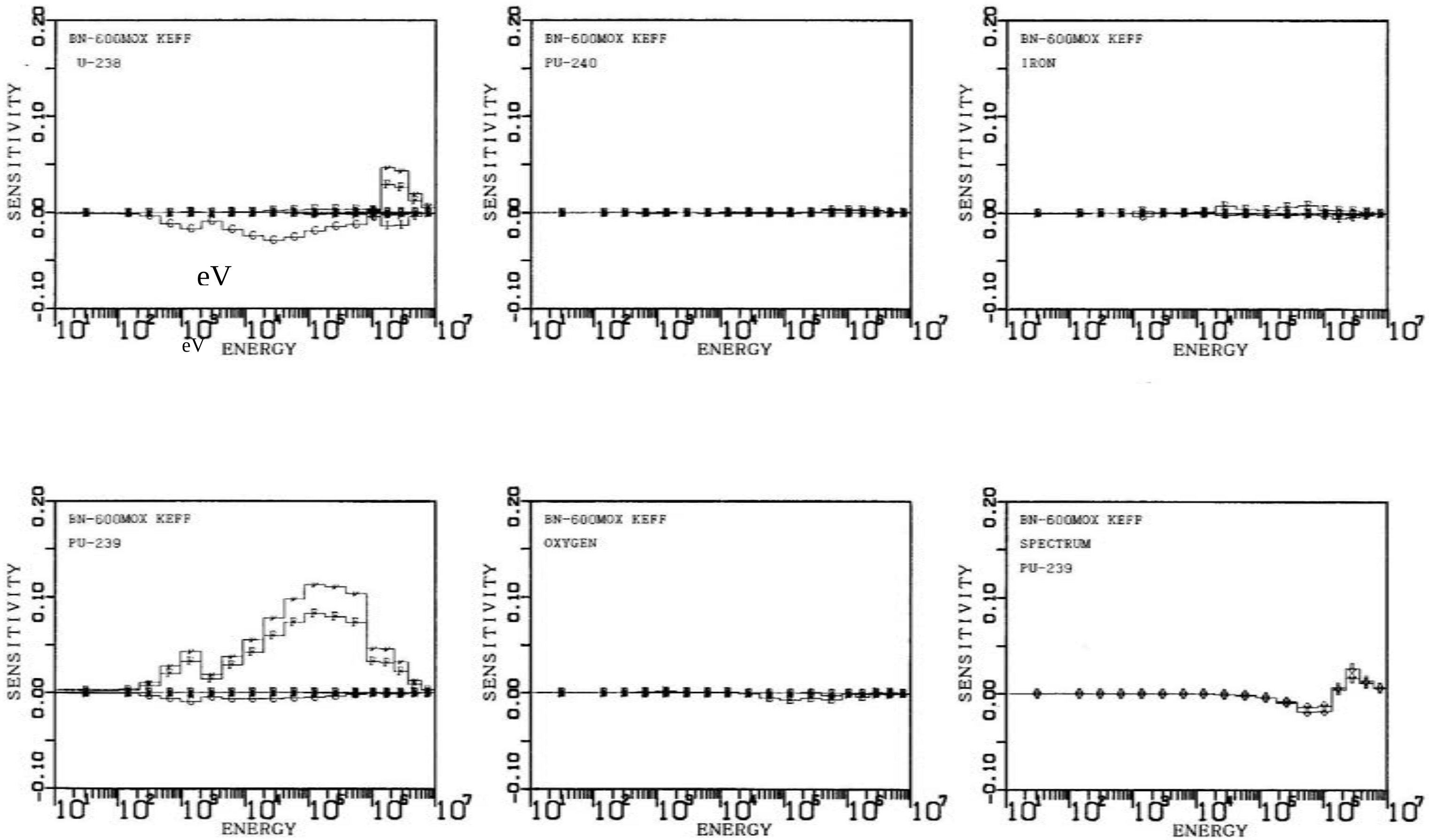


FIG. 3.19. Sensitivity coefficients of criticality (k_{eff}) based on JENDL-3.2R.

3.5.2 FZK/IKET studies with JEFF-3.0 libraries

The Doppler and kinetics parameters obtained with the FZK/IKET 11-group KFKINR-based library are lower than the mean values, that may be related to the cross-section library employed. Therefore additional calculations were done with a 30-group data library based on JEFF-3.0. Some results are provided below. They were not considered in transient analyses, but can be useful for comparing reactivity effects for Phase 4 and Phase 6 (where the 30-group library is the main option) and also for investigating the effect of employing a more recent nuclear data library with more energy groups.

The 30-group nuclear data library — employed in the calculations — is generated from a 560-group "master" library (based on JEFF-3.0 nuclear data) by employing a standard weighting function: fission spectrum at higher energies; Fermi spectrum (1/E) at "resonance" energies; Maxwellian spectrum at thermal energies. The 30-group boundaries are similar to the boundaries of the ABBN 26-group library except that 4 additional energy groups being included between ca. 0.4 and 2.5 MeV.

Effective 21-group cross-sections were computed from the 30-group library using 30-group Bondarenko f-factor tables, current weighted f-factors for transport cross-sections being employed, composition-dependent spectra being employed for averaging 30-group cross-sections into 21-group ones (similar to calculations of Phase 5), heterogeneity effects being optionally taken into account by employing Bell correction factors.

Reactor calculations were performed with 21-group cross-sections; the VARIANT nodal code was used for diffusion and P3 transport calculations in a stand-alone mode; the KIN3D extension for VARIANT and a post-processing tool (SIRENE) were employed to compute spatial distributions of reactivity coefficients on the basis of first order perturbation theory.

The criticality, Doppler and kinetics parameters for the diffusion homogeneous option obtained with the two library options are compared to the mean values provided by participants in Table 3.35.

One may observe that the Doppler constants and kinetics parameters obtained with the 30-group data library (as compared to the 11-group one) are closer to the mean values, while the deviations in criticality are lower in the 11-group case. In particular, the deviations between FZK/IKET and mean values for the steel Doppler constant are much smaller for the 30-groups case due that temperature dependence for all structure components (not only for Fe as in the 11-groups case) are taken into account.

The fuel Doppler constant computed at FZK/IKET with 30-groups still appears to be low compared to the results of participants, such as CEA/SA and JAEA, employing basic nuclear data libraries with a large number of energy groups. For evaluating uncertainties in the fuel Doppler constant, which are related to using of the 30-group library, effective 21-group cross-sections were obtained also from the 560-group library based on JEFF 3.0 (from which the 30-group library was generated). The other details in the calculations procedure are the same as in the 30-groups case. The fuel Doppler coefficient is provided in Table 3.35 (in brackets), the value being 766 pcm. This result shows that calculations with a library with a few tens of energy groups may lead to underestimation of the fuel Doppler constant by about 10%.

TABLE 3.35. DOPPLER AND KINETICS PARAMETERS, BN-600-MOX (DIFFUSION HOMOGENEOUS) WITH FZK/IKET 30-GROUP, 560-GROUP AND 11-GROUP LIBRARIES

Parameter	30 (560) group, JEFF-3.0-based, FZK/IKET	11 group KFKINR-based, FZK/IKET	Mean value (all CRP particpants)
k_{eff}	0.98961	1.00254	1.00131
Doppler fuel constant, pcm	-698 (-766)	-652	-737
Steel Doppler constant, pcm	-95	-52	-96
Beta-effective, pcm	341	317	341
Neutron generation time, s	4.18e-7	4.13e-7	4.31e-7

Spatial distributions of the fuel Doppler coefficient computed by the first order perturbation theory are given in Table 3.36 (diffusion homogeneous option) and Table 3.37 (transport heterogeneous option). Table 3.38 and Table 3.39 give the corresponding distributions for the sodium density coefficient. The fuel Doppler constant computed with the first-order perturbation theory (-715 pcm) is slightly higher by magnitude than the result obtained with the direct method (-698 pcm) when the same diffusion theory option is employed. The transport heterogeneous option gives a higher by magnitude (by about 5%) total “first order” value than the diffusion one.

TABLE 3.36. FUEL DOPPLER COEFFICIENT, BN-600-MOX (DIFFUSION HOMOGENEOUS), FZK/IKET, 30 GROUP-LIBRARY

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	-1.335E-04	-3.667E-05	-1.278E-04					
8.23	-1.597E-04	-4.290E-05	-1.372E-04					
8.23	-2.170E-04	-5.875E-05	-1.808E-04					
8.23	-2.837E-04	-7.680E-05	-2.284E-04					
8.23	-3.580E-04	-9.695E-05	-2.666E-04					
5.10	-3.467E-04	-7.237E-05	-1.769E-04					
8.23	-4.638E-04	-1.271E-04	-2.874E-04					
8.23	-4.571E-04	-1.238E-04	-2.678E-04					
8.23	-4.043E-04	-1.076E-04	-2.274E-04					
8.23	-3.256E-04	-8.508E-05	-1.768E-04					
8.23	-2.423E-04	-6.252E-05	-1.291E-04					
5.50	-1.527E-04	-4.001E-05	-8.389E-05					
9.70	-1.437E-04	-3.591E-05	-7.129E-05					
10.00	-5.821E-05	-1.351E-05	-2.495E-05					
10.00	-2.379E-05	-5.146E-06	-9.096E-06					
core	-3.392E-03	-8.906E-04	-2.206E-03					

Total: -7.151E-03

TABLE 3.37. FUEL DOPPLER COEFFICIENT, BN-600-MOX (TRANSPORT HETEROGENEOUS), FZK/IKET, 30 GROUP-LIBRARY

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	-1.350E-04	-3.847E-05	-1.359E-04					
8.23	-1.643E-04	-4.598E-05	-1.505E-04					
8.23	-2.236E-04	-6.290E-05	-1.985E-04					
8.23	-2.920E-04	-8.202E-05	-2.501E-04					
8.23	-3.678E-04	-1.032E-04	-2.915E-04					
5.10	-3.549E-04	-7.667E-05	-1.932E-04					
8.23	-4.766E-04	-1.346E-04	-3.138E-04					
8.23	-4.703E-04	-1.308E-04	-2.922E-04					
8.23	-4.161E-04	-1.135E-04	-2.480E-04					
8.23	-3.339E-04	-8.935E-05	-1.922E-04					
8.23	-2.464E-04	-6.505E-05	-1.390E-04					
5.50	-1.536E-04	-4.116E-05	-8.929E-05					
9.70	-1.444E-04	-3.698E-05	-7.652E-05					
10.00	-5.893E-05	-1.407E-05	-2.736E-05					
10.00	-2.469E-05	-5.523E-06	-1.034E-05					
core	-3.481E-03	-9.425E-04	-2.405E-03					

Total: -7.511E-03

TABLE 3.38. SODIUM DENSITY COEFFICIENT, BN-600-MOX (DIFFUSION HOMOGENEOUS), FZK/IKET, 30- GROUP LIBRARY

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.298E-07	3.645E-08	4.705E-07	2.481E-08	9.524E-09	7.151E-07	1.113E-06	9.130E-08
4.50	1.903E-08	5.804E-09	1.309E-07	3.465E-08	1.681E-08	3.971E-07	4.855E-07	8.725E-08
5.00	6.519E-08	2.105E-08	5.198E-08	3.198E-07	1.593E-07	1.149E-06	1.080E-06	2.009E-07
5.00	1.172E-06	3.572E-07	9.926E-07	1.738E-06	9.828E-07	3.012E-06	2.157E-06	4.015E-07
5.00	1.841E-05	5.475E-06	1.597E-05	6.517E-06	5.525E-06	7.771E-06	3.933E-06	7.463E-07
4.50	1.062E-04	3.216E-05	1.027E-04	3.719E-06	1.460E-05	9.544E-06	5.657E-06	1.133E-06
8.00	3.455E-04	1.083E-04	3.755E-04	-1.134E-06	1.681E-05	1.830E-05	1.630E-05	3.721E-06
8.00	4.842E-04	1.641E-04	5.688E-04	-4.941E-06	2.210E-05	2.440E-05	2.759E-05	7.181E-06
7.00	5.685E-04	2.133E-04	7.553E-04	-6.024E-06	4.554E-05	2.985E-05	3.877E-05	1.076E-05
5.30	2.558E-04	1.038E-04	3.334E-04	6.883E-06	1.004E-04	3.883E-05	4.333E-05	1.212E-05
8.23	1.984E-04	9.970E-05	4.460E-04	2.355E-06	1.882E-04	1.089E-04	1.013E-04	2.796E-05
8.23	-2.242E-04	-4.292E-05	2.570E-04	-6.131E-05	1.365E-04	1.637E-04	1.498E-04	4.155E-05
8.23	-6.932E-04	-1.991E-04	6.087E-05	-1.362E-04	5.706E-05	2.124E-04	1.991E-04	5.621E-05
8.23	-1.129E-03	-3.405E-04	-1.138E-04	-2.034E-04	-2.167E-05	2.530E-04	2.418E-04	6.943E-05
8.23	-1.470E-03	-4.369E-04	-2.348E-04	-2.194E-04	-8.139E-05	2.814E-04	2.715E-04	7.870E-05
5.10	-1.029E-03	-2.920E-04	-1.723E-04	-1.869E-04	-6.492E-05	1.819E-04	1.754E-04	5.091E-05
8.23	-1.549E-03	-4.596E-04	-2.581E-04	-3.589E-04	-1.132E-04	2.931E-04	2.803E-04	8.090E-05
8.23	-1.397E-03	-3.920E-04	-1.537E-04	-2.702E-04	-9.079E-05	2.770E-04	2.592E-04	7.362E-05
8.23	-1.023E-03	-2.619E-04	2.997E-05	-1.025E-06	-2.030E-06	2.445E-04	2.207E-04	6.101E-05
8.23	-4.756E-04	-8.915E-05	2.604E-04	3.870E-04	1.338E-04	1.995E-04	1.709E-04	4.548E-05
8.23	1.056E-04	8.483E-05	4.788E-04	7.455E-04	2.629E-04	1.458E-04	1.176E-04	3.005E-05
5.50	1.592E-04	7.310E-05	2.552E-04	5.281E-04	1.892E-04	6.209E-05	5.118E-05	1.280E-05
9.70	1.119E-04	5.333E-05	1.651E-04	5.838E-04	2.147E-04	5.504E-05	5.069E-05	1.257E-05
10.00	3.512E-05	1.625E-05	4.023E-05	2.502E-04	9.596E-05	2.081E-05	2.126E-05	5.186E-06
10.00	2.016E-05	6.916E-06	1.278E-05	8.863E-05	3.522E-05	7.234E-06	7.535E-06	1.769E-06
30.00	1.732E-04	4.093E-05	7.446E-05	2.569E-05	9.689E-06	1.207E-05	1.185E-05	8.590E-07
core	-8.687E-03	-2.330E-03	6.004E-04	-3.024E-04	4.046E-04	2.361E-03	2.188E-03	6.158E-04

Total: 3.537E-03

TABLE 3.39. SODIUM DENSITY COEFFICIENT, BN-600-MOX (TRANSPORT HETEROGENEOUS), FZK/IKET, 30- GROUP LIBRARY

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.059E-07	2.705E-08	3.382E-07	3.265E-08	1.466E-08	6.338E-07	9.648E-07	2.874E-08
4.50	1.322E-08	2.754E-09	5.983E-08	3.745E-08	2.063E-08	3.535E-07	4.675E-07	4.902E-08
5.00	8.017E-08	2.527E-08	6.476E-08	2.389E-07	1.275E-07	9.635E-07	9.895E-07	1.324E-07
5.00	1.258E-06	3.896E-07	1.081E-06	1.134E-06	6.587E-07	2.432E-06	1.925E-06	2.815E-07
5.00	1.787E-05	5.418E-06	1.606E-05	4.469E-06	3.663E-06	6.134E-06	3.397E-06	5.345E-07
4.50	1.000E-04	3.075E-05	9.815E-05	3.586E-06	1.065E-05	7.925E-06	4.801E-06	8.124E-07
8.00	3.132E-04	1.006E-04	3.356E-04	1.788E-06	1.484E-05	1.655E-05	1.360E-05	2.654E-06
8.00	4.315E-04	1.492E-04	5.021E-04	-6.774E-07	1.925E-05	2.235E-05	2.268E-05	5.101E-06
7.00	5.030E-04	1.903E-04	6.476E-04	-9.298E-07	3.249E-05	2.761E-05	3.175E-05	7.656E-06
5.30	2.418E-04	9.655E-05	3.159E-04	8.054E-06	5.466E-05	3.472E-05	3.551E-05	8.645E-06
8.23	1.940E-04	9.304E-05	4.141E-04	-5.819E-07	9.463E-05	9.411E-05	8.299E-05	2.006E-05
8.23	-2.100E-04	-4.563E-05	2.086E-04	-6.278E-05	5.921E-05	1.410E-04	1.225E-04	2.982E-05
8.23	-6.481E-04	-1.942E-04	4.260E-06	-1.336E-04	7.873E-06	1.831E-04	1.622E-04	4.019E-05
8.23	-1.052E-03	-3.283E-04	-1.766E-04	-1.967E-04	-4.299E-05	2.181E-04	1.962E-04	4.945E-05
8.23	-1.354E-03	-4.201E-04	-3.023E-04	-2.150E-04	-8.074E-05	2.427E-04	2.196E-04	5.588E-05
5.10	-9.277E-04	-2.804E-04	-2.156E-04	-1.907E-04	-6.060E-05	1.568E-04	1.418E-04	3.601E-05
8.23	-1.437E-03	-4.459E-04	-3.283E-04	-3.391E-04	-1.051E-04	2.529E-04	2.267E-04	5.738E-05
8.23	-1.327E-03	-3.831E-04	-2.213E-04	-2.788E-04	-9.305E-05	2.389E-04	2.102E-04	5.233E-05
8.23	-9.708E-04	-2.555E-04	-3.173E-05	-1.052E-04	-3.906E-05	2.106E-04	1.798E-04	4.356E-05
8.23	-4.334E-04	-8.334E-05	2.079E-04	1.405E-04	4.316E-05	1.710E-04	1.399E-04	3.272E-05
8.23	1.529E-04	9.467E-05	4.460E-04	3.659E-04	1.209E-04	1.234E-04	9.677E-05	2.181E-05
5.50	1.961E-04	8.090E-05	2.490E-04	2.694E-04	9.129E-05	5.180E-05	4.234E-05	9.340E-06
9.70	1.466E-04	5.950E-05	1.613E-04	3.020E-04	1.058E-04	4.554E-05	4.222E-05	9.254E-06
10.00	4.589E-05	1.773E-05	3.942E-05	1.333E-04	4.884E-05	1.719E-05	1.799E-05	3.820E-06
10.00	1.958E-05	6.422E-06	1.141E-05	4.788E-05	1.820E-05	6.061E-06	6.653E-06	1.277E-06
30.00	1.180E-04	2.875E-05	5.427E-05	1.763E-05	6.519E-06	9.474E-06	9.465E-06	6.709E-07
core	-8.014E-03	-2.249E-03	4.907E-06	-1.016E-03	-9.583E-05	2.033E-03	1.779E-03	4.392E-04

Total: -4.722E-05

The “diffusion homogenous” and “transport heterogeneous” local sodium density coefficients are qualitatively similar, the relative deviations being ca. 8% in the core center and several times higher at the core periphery.

3.6 SIMPLIFIED APPROACH TO ACCIDENT SIMULATION

IPPE compared the reactivity coefficients provided by the participants and investigated the effect of deviations between the results on the ULOF and UTOP transient simulation of the BN-600 full MOX benchmark core. For that purpose a simplified transient analysis model [16] was employed. If data of particular type (for a particular reactivity coefficient) were not provided by a participant, the corresponding IPPE results based on the TRIGEX HEX-Z calculations were employed.

In the previous analysis for the BN-600 hybrid core, deviations of reactivity values caused by thermal expansion of materials in radial and axial directions ranged within ~10% for both R-Z and Hex-Z geometry models regardless of diffusion/transport option employed. The reactivity balance between the radial expansion effect and other reactivity effects — computed with reactivity coefficients obtained by approximate models (e.g. diffusion homogeneous) — was similar to the balance computed with reactivity coefficients based on Monte Carlo codes and assumed to be more accurate [2].

A simple model of a truncated core is used in the following to evaluate the reactivity effect due to radial expansion. To take into account the reactivity contribution of the steel reflector in an approximate manner, the radial steel blanket assemblies (SSAs) are represented by an additional thermohydraulics channel where reactivity effects are determined only by sodium temperature (leading to related density) variations. For these calculations 1% of the core energy release is allocated to the SSAs.

3.6.1 UTOP accident

Similarly to the previous hybrid core analyses, an inadvertent withdrawal of a control rod which increases the core reactivity by 100 pcm during 7.5 sec (with a linear variation of the introduced reactivity) was assumed to be the transient initiator. Preliminary analyses did show that the maximum permissible temperature values would not be exceeded due to this reactivity variation. It appears that modelling uncertainties are the main source of deviations between the computed maximum temperatures, although the net reactivity values (the sums of the reactivity feedback components) do not differ much (the relative differences between the values are appreciable only when the values are close to zero).

Figure 3.20 shows contributions of various fuel zones to the total reactivity in the UTOP and ULOF accidents. One may conclude that, given the large contribution of LEZ, the most attention should be paid to the accuracy of calculation of reactivity coefficients in this zone, from the viewpoint of reducing the influence of modelling uncertainties.

The main conclusions resulting from the various UTOP analysis calculations are:

- Using of the transport option instead of the diffusion one for computing the coefficients for the same RZ model causes the following differences: ~17–20 MW for the maximum power (~1%) (the diffusion approximation predicts a higher level of power), and ~5 ^{o}C and ~15 ^{o}C for the sodium fuel for maximum temperatures, respectively;
- Using of a more complicated geometry model (Hex-Z instead of RZ), but with the same diffusion approximation leads to the following differences: ~60 MW for the power (3.5%), 7–10 ^{o}C for the sodium temperature and 60–65 ^{o}C for the fuel temperature. HEX-Z analyses give coefficients that predict higher, close to limits, parameters.

The modelling uncertainty (due to using of approximate geometry, e.g. RZ) is found to be higher than that of the methodological uncertainty (due to using of diffusion approximation). In other words, for accurate transient simulations one has to compute power and reactivity coefficient distributions by employing three dimensional Hex-Z models and transport (instead of diffusion) options, the first condition being more important than the second one, neglecting of one or another condition shifting the results in one or another direction. As compared to the previous hybrid core analyses, deviations between transient results for different calculation options are larger, while maximum values for power and temperature are lower in the UTOP accident. This demonstrates inherent reactor safety enhancement due to introduction of the sodium plenum above the core. The MOX fuel utilization in the BN-600 core can be then envisaged even with a penalty associated to the larger reactivity coefficient uncertainties. This is of course a consequence of the particular design with sodium plenum above the core.

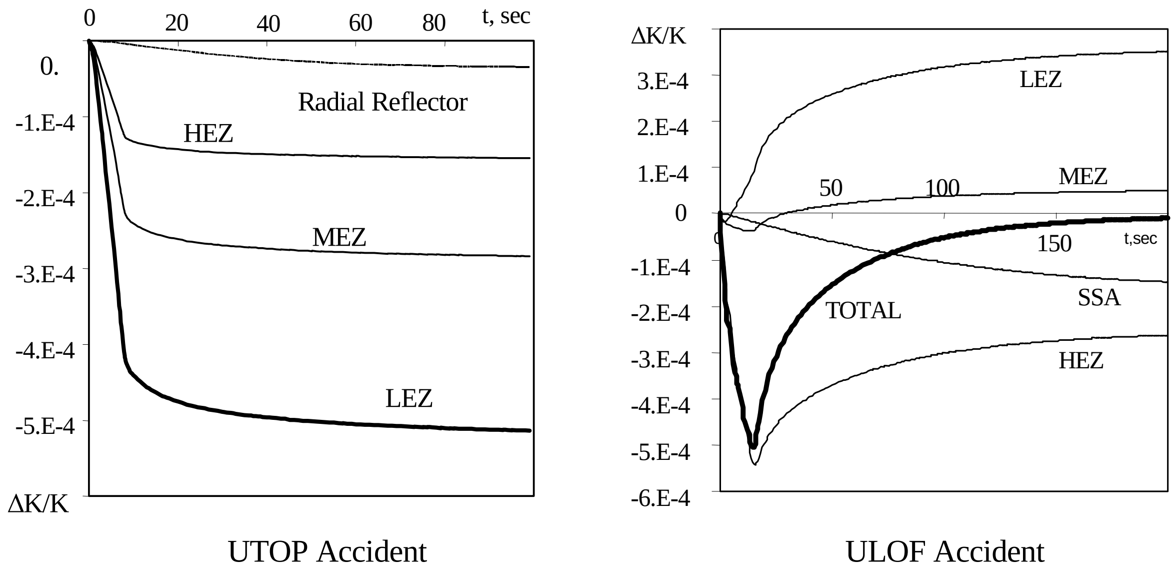


FIG. 3.20. Contributions of various fuel zones to the total reactivity (diffusion, Hex-Z model).

3.6.2 ULOF accident

For the analysis of the ULOF accident, a transient leading to the 30% flow rate (as compared to the nominal one) was considered. In Figs 3.20–3.21 one may see the results obtained with the safety parameters computed following the Hex-Z diffusion option by different participants.

In spite of similar transient temperatures and generally similar reactivity coefficients, large differences in the total reactivity feedback, with a maximum level of ~ 40 % (see Figs 3.20–3.21) are observed. According to the ANL results, the large sodium density coefficient in the sodium plenum results in an increase of the negative reactivity feedback through the temperature feedback mechanism. The maximum temperature obtained with the ANL data appears to be higher than the others due to the larger positive value of the Doppler effect, especially at the bottom part of the core. Differences in key parameters in the ULOF accident, due to differences in calculated values for the sodium density reactivity coefficient, especially in the sodium plenum, lead to differences of ~60 MW for the power, > 100 ^{o}C and ~35 ^{o}C for the maximum temperatures for the fuel and sodium, respectively (Fig. 3.22).

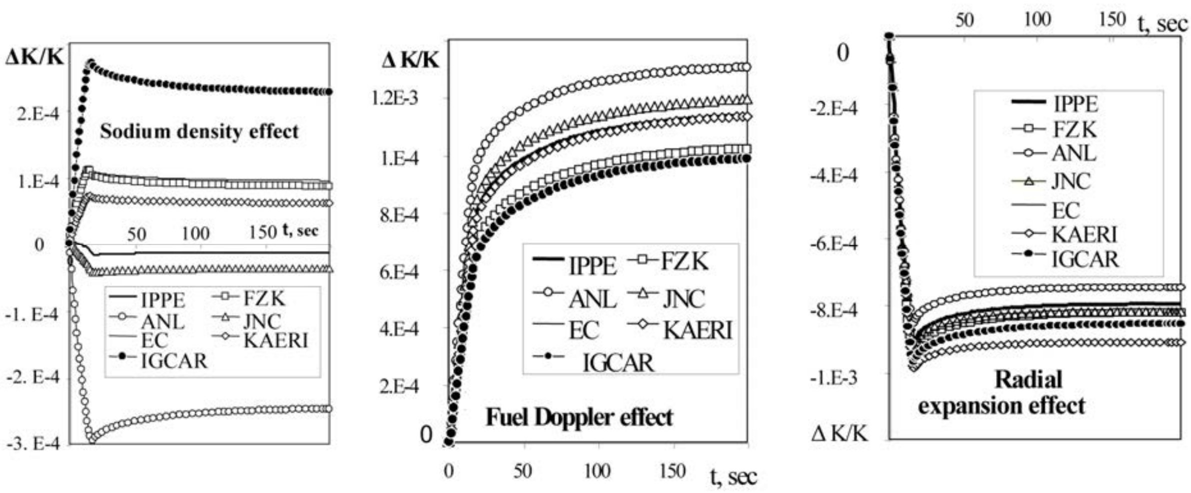


FIG. 3.21. Change of basic feedback reactivity components in ULOF accident.

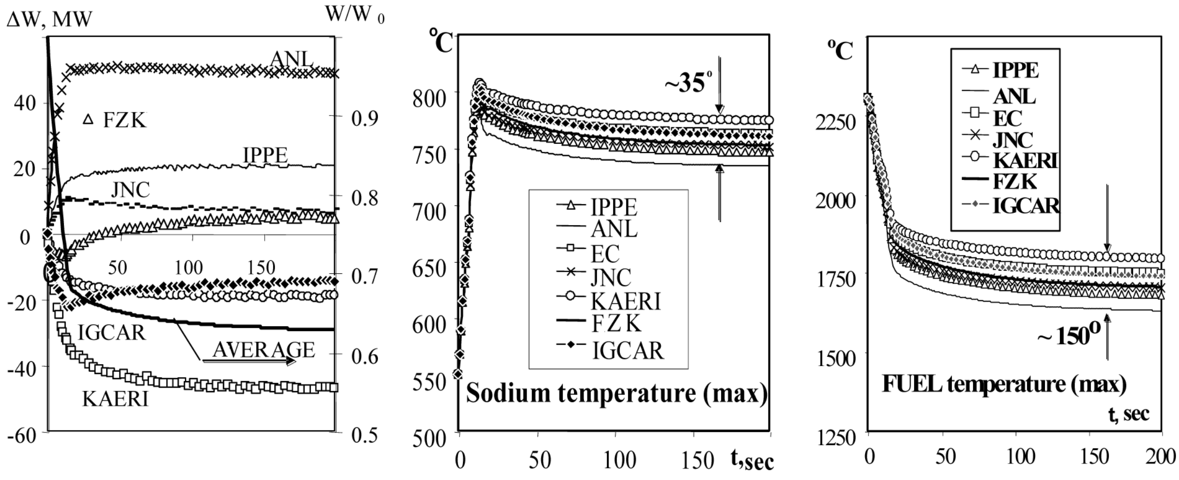


FIG. 3.22. Change of power and basic temperatures in ULOF accident.

As mentioned before, uncertainties due to approximate geometry modelling are larger than those due to using of a diffusion option instead of the transport option. One may come to this conclusion for both hybrid core full MOX cores. The differences between the maximum values of computed parameters are lower for the Hex-Z model than those for the RZ one. Taking into account heterogeneity effects reduces discrepancies between the diffusion and transport options in this study. The results also show that the heterogeneity effect evaluated using the diffusion approximation does not have any significant effect on the description of the transient behavior.

The possible influence, due to the accuracy of power distributions calculations, was investigated by using an averaged power profile obtained with the participants' data (see Table 3.23). The analyses with the safety parameters computed at FZK/IKET and JNC showed an insignificant influence of different options for computing of power distributions. The presence of a fertile zone (IBZ) deforms the axial distribution of the fuel Doppler coefficient, but leads to rather small differences in the fuel Doppler feedback under accident conditions. Differences in the

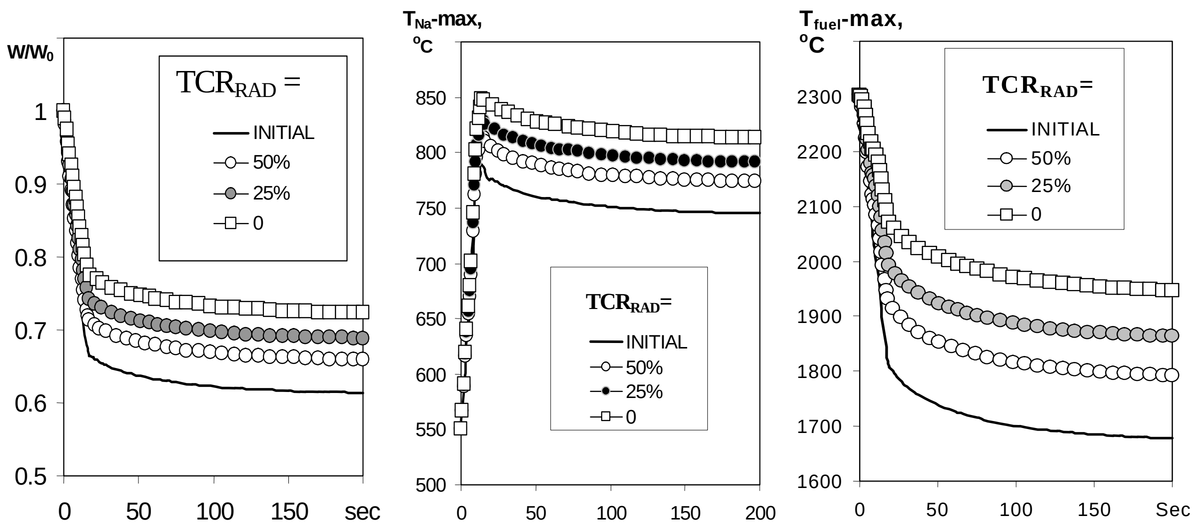


FIG. 3.23. Influence of a variation of radial expansion coefficient on calculated values for key parameters in the ULOF accident.

sodium density effect result mainly from the deviations in the local sodium density coefficient for the sodium plenum where the coolant temperature is at its maximum (see Table 3.40).

For the benchmark considered, uncertainties in basic reactivity coefficients result in the following differences in the maximum temperatures:

TABLE 3.40. RESULTS OF TRANSIENT ANALYSIS FOR PHASE 4

	Power	Max. sodium temperature	Max. fuel temperature
- Uncertainty of sodium density coefficient	< 20 MW	20 ^{o}C	50 ^{o}C
- Uncertainty of fuel Doppler coefficient	< 10 MW	10 ^{o}C	< 30 ^{o}C
- Uncertainty of material expansion coefficient (max $\rightarrow$ 0)	~ 150 MW	~ 150 ^{o}C	~ 300 ^{o}C

Differences in reactivity effects due to the thermal expansion of materials (both axial and radial) are insignificant, similar to the case of the previous hybrid core model. Figure 3.23 shows changes of key parameters in the ULOF accident, calculated with parametric variation of radial expansion coefficient, TCR_{RAD} to simulate a possible effect from SA bend. The results confirm that the uncertainty of the radial expansion feedback (if it is taken into account in a simplified manner; for accurate computation of this feedback a thermomechanical model may be required) can be the decisive and most important factor for the uncertainty of ULOF accident simulation results.

3.7 CONCLUSIONS ON ANALYSES FOR PHASE 4

Differences between the values of the reactivity coefficients obtained by the participants appear to be larger in the BN-600 full MOX core than those in a traditional arrangement for the hybrid core, mainly because of modelling uncertainties in the axial sodium plenum introduced in the full MOX core. This observation relates to both the integral values and the spatial distribution of reactivity coefficients.

The diffusion and transport theory based results for integral and local reactivity coefficients shows good agreement between most parameters except for the sodium density coefficient.

For the full MOX core, the choice of a small number of neutron energy groups may become critical in achieving an accurate evaluation of reactivity coefficients. This applies mainly for the fuel Doppler coefficient and the sodium density coefficient at the top of the core and in the sodium plenum. Since maximum sodium temperature variations take place there, the uncertainty in the computed local sodium density coefficients for these areas has the largest impact on reactor dynamics.

The increase of discrepancies between spatial distributions of reactivity coefficients has a larger effect on the prediction of maximum parameters of the UTOP and ULOF accidents in the full MOX core as compared to the hybrid core configuration. It appears that accurate transient simulation require parameters computed both with (a) three dimensional Hex-Z modelling and (b) a transport approximation, the first one being more important than the second one. The simplified options for geometry (RZ instead of Hex-Z) and neutron transport modelling (diffusion instead of transport) may lead to deviations in power (and other parameters), which are of different sign. As compared to the previously analysed hybrid core, deviations in power (and other parameters) observed with various coefficients obtained with calculation options are larger, while their maximum values are lower in the UTOP accident. The MOX fuel utilization in the BN-600 core can be envisaged given with a penalty associated with the larger reactivity coefficient uncertainties. This is of course a consequence of the particular design of this core with the sodium plenum above the core.

The results of ULOF accident analyses made with different sets of Doppler and sodium density coefficients show a considerable spread in the maximum temperature values, namely: ~ 40^{o}C for the sodium temperature and more than 100 ^{o}C for the fuel temperature. The spread in the evaluated core power distribution has a minimal effect on the maximum values of ULOF accident parameters. Nevertheless, depending on the initial power, the maximum temperature may appear in different core regions. The spread in calculated reactivity effects due to the thermal expansion of materials (both axial and radial) is insignificant, similar to the case of the previous hybrid core model analysis. The heterogeneity effect does not have any significant effect on the evolution of the accident process.

Hence, this benchmark concludes that the safety analysis of such a design would require using of three dimensional Hex-Z tools for generating power and reactivity worth distributions. Transport models are required for accurate evaluation of the sodium density coefficient in the plenum region by the direct method. Using of the diffusion approximation for computing reactivity worth distribution by the first-order perturbation theory method may give reasonable, but less accurate results. Due to the mentioned uncertainties, it is important to check the computation results by representative experiments. A side conclusion to this benchmark is that the use of MOX fuel in the BN-600 core could be envisaged given with a design penalty associated to the larger reactivity coefficient uncertainties.

4. CORE WITH MOX FUEL CONTAINING MINOR ACTINIDES (PHASE 6)

4.1 INTRODUCTION

Phases 1 to 5 addressed issues of utilization of weapons-grade plutonium in BN-600. This reactor type may also allow efficient utilization of transuranium (TRU) isotopes coming from spent nuclear fuel. This option is investigated in Phase 6 of the CRP.

The interest in this option is related to the fact that fast spectrum reactor systems have attracted more attention recently as the majority of reactor concepts chosen for GEN-IV are based on fast neutron spectra. It has been recognized that closure of the fuel cycle is essential for any sustainable future nuclear system, and that only fast spectrum systems allow the efficient incineration of Pu and other TRU isotopes and reduction of the burden of storage of nuclear wastes in repositories.

The possibility of starting the deployment of sodium cooled fast reactors and related fuel cycle facilities for managing also the spent fuel from the previous reactor generations is a challenging task which includes Plutonium and MA management.

This management should reduce the overall mass of long lived nuclear wastes accumulated over the years through the use of past generation reactors. Important international initiatives on Partitioning and Transmutation (P&T) are also aiming at reducing the overall radio-toxicity.

Several options exist to enhance nuclear long life waste transmutation/burning capabilities of sodium cooled fast systems and one of the most interesting option is the homogeneous option, in which nuclear waste is added to the fuel to be burnt (limitation exists due to the degradation of safety related coefficients, management of the fuel with added radioactive materials from spent fuel may be a problem for some fuel cycle facilities).

In this chapter the isotopic content required to study the potential of the BN-600 fast reactor for TRU management is specified following the suggestions of CEA. In addition to the plutonium management study, the impact of the addition of minor actinides (MAs) on the safety characteristics of the core is of interest.

Unlike weapons-grade plutonium, the plutonium isotopic composition of spent LWR fuel is characterized by a lower fraction of the Pu-239 isotope, but higher fractions of other plutonium isotopes, in particular Pu-240. Spent fuel may also contain an appreciable fraction of MAs, in particular of neptunium and americium isotopes. This may lead to deterioration (compared to a weapons-grade plutonium fuelled core) of core safety characteristics. At the moment, BN-600 is a sodium cooled fast reactor located in The Russian Federation and the scenario to study is associated to what is happening in The Russian Federation.

There are roughly 9 GWe VVER and 10.2 GWe RBMK reactors in the Russian Federation as compared to e.g. the nuclear capacity of 60 GWe in France. The Russian reactors are operated with UOX fuel, which produce a burnt fuel containing Plutonium and Minor Actinides. This fuel could be introduced after being reprocessed in the BN-600 reactor core. Here the plutonium fuel is NOT a weapons-grade plutonium.

The BN-600 core with MOX/MA fuel would facilitate the closure of the fuel cycle making a step to a sustainable future nuclear system with closed fuel cycle burning its own nuclear waste.

4.1.1 Plutonium isotopic composition and MA content in the MOX fuel

The two main Russian water cooled reactors, VVER and RBMK produce spent fuel not very much different from the one of Western-types PWRs.

Values for the burnt fuel are hence taken from PWR UOX burnt up to 45 GWd/t (values could be increased in the future up to 60 GWd/t) are given in Table 4.1. Masses are for the French 400 TWhe reactor park, but could be easily scaled to the values of the Russian park.

TABLE 4.1. TRU MASSES PRODUCED PER YEAR IN THE 400 TWhe REACTOR PARK, BURNUP 45 GWD/T

Isotope	Masses in kg for a 400 TWhe PWR park	Pu+Np vector	Am+Cm vector	Total vector
^{238}Pu	298	2.36%		2.24%
^{239}Pu	6540	51.77%		49.12%
^{240}Pu	2910	23.03%		21.85%
^{241}Pu	1420	11.24%		10.66%
^{242}Pu	797	6.31%		5.99%
^{237}Np	668	5.29%		5.02%
^{241}Am	443		64.91%	3.33%
^{242m}Am	0.87		0.13%	0.01%
^{243}Am	176		25.79%	1.32%
^{242}Cm	0.00995		0.00%	0.00%
^{243}Cm	0.566		0.08%	0.00%
^{244}Cm	57.2		8.38%	0.43%
^{245}Cm	4.38		0.64%	0.03%
^{246}Cm	0.485		0.07%	0.00%
^{247}Cm	0.00579		0.00%	0.00%
Total PU	11965			
Total NP	668			
Total AM	620			
Total CM	63			
Total TRU	13316	100.00%	100.00%	100.00%

The fuel will be reprocessed without making a separation between Plutonium and Minor Actinides independently from the technique used (PUREX or DRY Reprocessing). It should be in principle proliferation resistant.

For a 20% TRU content in the fuel, the Minor Actinide content in the fuel will be only 2.03%. This fuel coming from a 45GWd/t reprocessed PWR UO2 fuel has not enough Minor

Actinides for being a challenging issue for the transient behavior of the core. Therefore it can be suggested to use a 60 GWd/t reprocessed PWR UO2 fuel instead, see Table 4.2 .

TABLE 4.2. TRU MASSES PRODUCED PER YEAR IN THE 400 TWHE REACTOR PARK, BURNUP 60 GWD/T, AFTER 5 YEARS COOLING

	UO2 burnt 60 GWd/t fuel (cooled 5 years)				
Isotope	Masses in kg for a 400 TWhe PWR park	Ratio of elements	Pu + Np vector	Am+ Cm vector	Total vector
^{238}Pu	407		3.70%		3.47%
^{239}Pu	5230		47.52%		44.57%
^{240}Pu	2520		22.90%		21.48%
^{241}Pu	1260		11.45%		10.74%
^{242}Pu	850		7.72%		7.24%
^{237}Np	738		6.71%		6.29%
^{241}Am	401			54.98%	3.42%
^{242m}Am	0.939			0.13%	0.01%
^{243}Am	223			30.57%	1.90%
^{242}Cm	0.0111			0.00%	0.00%
^{243}Cm	0.777			0.11%	0.01%
^{244}Cm	93.8			12.86%	0.80%
^{245}Cm	8.64			1.18%	0.07%
^{246}Cm	1.23			0.17%	0.01%
^{247}Cm	0.019			0.00%	0.00%
Total PU	10267	87.49%			
Total NP	738	6.29%			
Total AM	625	5.33%			
Total CM	104	0.89%			
Total TRU	11734	100.00%	100.00%	100.00%	100.00%

For a 20% TRU content in the fuel, the minor actinide content in the fuel is becoming 2.50%. Again, this fuel coming from a 60GWd/t reprocessed PWR UO2 fuel may not contain enough minor actinides for being a challenging issue for the transient behavior of the core.

Furthermore, it does not correspond to a realistic scenario. At the moment, the most likely scenario will be a fast reactor deployment by the year 2035 at the earliest and spent fuel from PWR UO2 fuel will have to be cooled down for 50 years after the irradiation. It can be therefore recommended to use the 60GWd/t reprocessed PWR UO2 fuel cooled down for 50 years, see Table 4.3 (the decay of Pu-238 during the cooling time is neglected). That could be a problem to study for the BN-600 core due to higher MA content mainly because of Pu-241 decay. Furthermore, it corresponds to an envelope case of the most likely situations that could happen in the near future. As this TRU fuel differs appreciably from the weapons-grade plutonium fuel studied in previous CRP phases, a parametric study and/or a sensitivity study might well indicate the consequences the various isotopic changes could do to the reactivity coefficient and hence the transient behavior of the plant.

TABLE 4.3. TRU MASSES PRODUCED PER YEAR IN THE 400 TWHE REACTOR PARK, BURNUP 60 GWD/T, AFTER 50 YEARS COOLING

	UO2 burnt 60 GWd/t fuel				
Isotope	Masses in kg for a 400 Twhe PWR park	Ratio of elements	Pu + Np vector	Am+ Cm Vector	Total vector
^{238}Pu	407		4.12%		3.47%
^{239}Pu	5230		52.90%		44.57%
^{240}Pu	2606		26.36%		22.21%
^{241}Pu	55		0.56%		0.47%
^{242}Pu	850		8.60%		7.24%
^{237}Np	738		7.46%		6.29%
^{241}Am	1606			86.88%	13.68%
^{242m}Am	0.939			0.05%	0.01%
^{243}Am	223			12.07%	1.90%
^{242}Cm	0.011			0.00%	0.00%
^{243}Cm	0.777			0.04%	0.01%
^{244}Cm	7.807			0.42%	0.07%
^{245}Cm	8.640			0.47%	0.07%
^{246}Cm	1.230			0.07%	0.01%
^{247}Cm	0.019			0.00%	0.00%
Total PU	9148.355	77.96%			
Total NP	738.000	6.29%			
Total AM	1829.577	15.59%			
Total CM	18.484	0.16%			
Total TRU	11734.416	100.00%	100.00%	100.00%	100.00%

4.1.2 Benchmark description

Plutonium and MA isotopic compositions in spent fuel depend on its irradiation, cooling and reprocessing history. To establish an envelope case (with a TRU content deviating at most from weapons-grade plutonium while assuming no separation of plutonium and minor actinides during reprocessing) we consider a 60 GWd/t reprocessed LWR uranium fuel and allowing for a fuel storage period of 50 years before reuse. For a 25% TRU content in the fuel, the MA content there would amount to more than about 6% and may pose a quite challenging issue for the core transient behavior. For a smaller burnup (e.g. 45 GWd/t) and/or much shorter cooling time, the MA content would be appreciably smaller. According to earlier studies, safety criteria give a MA content limit from 2.5% to 5% if MAs are homogeneously mixed with other fuel components (the alternative to put MAs in special “target” subassemblies or axial blankets only is not considered here), the limit depending upon sodium cooled fast reactor design option (if a conventional, established in the past, option is considered).

Calculation of the heavy nuclei isotopic composition for the BN-600 benchmark was carried out at IPPE by using isotopic vectors for plutonium and MAs computed by CEA on the basis of the above mentioned assumptions (see Table 4.3). The TRU content in the fuel was adjusted as appropriate region by region. The employed refuelling scheme assumed reloading of a quarter of the core every 140 effective full power days (EFPDs) i.e. a four-batch reloading scheme. For the purpose of simplification, isotopic compositions for individual reloading bundles were averaged in each of three enrichment zones and then offered to the benchmark participants at a state corresponding to the beginning of an equilibrium cycle (BOC).

A 60-degree sector of the benchmark core layout in plane is shown in Fig. 3.1. The RZ layout of the core is given in Fig. 3.2. One may see there heights of reactor regions (cm). These regions are subdivided into nodes, for which spatial distributions of reactivity coefficients are computed. The core power is 1470 MW(th).

The core consists of a low enrichment MOX inner zone (LEZ), a middle enrichment MOX zone (MEZ), and a high enrichment MOX zone (HEZ). In addition, there is an internal axial breeding zone (IBZ), a region with depleted uranium of 5.1 cm height at the core mid-plane in the LEZ region. Three scram control rods (SCRs) and one shim control rod (SHR) are interspersed in the LEZ region. Beyond the HEZ outer zone there are two steel shielding zones (SSA1 and SSA2) followed by a radial reflector zone (REF). In the shim rod zone, the bottom of the absorber is parked 2.55 cm above the core mid-plane, whereas, in the scram rod zone the absorber is parked at the bottom of the upper boron shield region.

The LEZ, MEZ, and HEZ fuel subassemblies have identical geometry with a pitch of 9.902 cm, 127 fuel pins being located with a triangular pitch of 7.95 mm inside a hexagonal wrapper. A sodium plenum followed by a boron shield is located above the core to reduce the sodium void effect. All fuel isotopes are assumed to be at a uniform temperature of 1500K, and all structure and coolant isotopes are at a uniform temperature of 600K.

For this benchmark configuration, burnup for each enrichment zone is about 2%, the TRU content in different enrichment zones varying from about 26% to 30% (from about 6% to 7% being MAs and from 20% to 23% being plutonium containing ca. 61% of Pu239, 32% of Pu-240, a bit less than 5.5% of Pu-238 and small fractions of Pu-241 and Pu-242 isotopes). Thus the TRU content in the fuel was about 50% higher than that for Phase 4.The isotopic compositions specified for each cell are presented in Table 4.4, where it has been assumed that one fission produces one pseudo fission product. The arrangement of the compositions is shown in Fig. 3.2.

TABLE 4.4. ISOTOPIC DENSITIES

(Unit: 1024 nuclei /cm3)

	Fuel LEZ (1)	Fuel MEZ (2)	Fuel HEZ (3)	Fuel AB1 LEZ (4)	Fuel AB1 MEZ (5)	Fuel AB1 HEZ (6)	Fuel AB2 LEZ (7)	Fuel AB2 MEZ (8)	Fuel AB2 HEZ (9)
U235	2.068-05	2.044-05	2.016-05	3.360-05	3.397-05	3.445-05	3.217-05	3.266-05	3.347-05
U236	6.692-07	5.923-07	4.473-07	6.311-07	5.328-07	4.207-07	9.081-07	7.862-07	6.105-07
U-238	5.823-03	5.701-03	5.447-03	8.906-03	8.917-03	8.934-03	8.851-03	8.867-03	8.897-03
Pu-38	8.871-05	9.246-05	1.004-04	1.377-09	1.053-09	6.119-10	8.423-09	6.961-09	4.247-09
Pu-39	9.959-04	1.046-03	1.156-03	6.618-05	5.633-05	4.167-05	1.081-04	9.436-05	6.977-05
Pu-40	5.179-04	5.453-04	6.017-04	7.676-07	5.447-07	3.433-07	1.591-06	1.174-06	7.128-07
Pu-41	2.341-05	2.334-05	2.301-05	8.072-09	5.075-09	6.197-09	1.590-08	1.024-08	1.096-08
Pu-42	6.243-06	6.122-06	5.706-06	3.016-11	1.592-11	1.590-11	8.563-11	4.708-11	3.958-11
Np-37	1.321-04	1.408-04	1.585-04	5.386-08	4.883-08	3.495-08	2.310-07	2.227-07	1.728-07
Am-41	2.827-04	3.017-04	3.409-04	3.632-11	2.285-11	2.794-11	7.145-11	4.602-11	4.933-11
Am-2M	4.353-06	4.226-06	3.797-06	6.762-14	3.598-14	3.824-14	1.922-13	1.067-13	9.319-14
Am-43	4.118-05	4.379-05	4.894-05	1.085-13	4.811-14	5.251-14	3.957-13	1.859-13	1.564-13
Cm-42	1.494-05	1.432-05	1.252-05	2.629-13	1.395-13	1.479-13	7.529-13	4.167-13	3.623-13
Cm-43	3.617-07	3.342-07	2.922-07	1.331-23	5.884-24	4.936-24	5.054-23	2.373-23	1.609-23
Cm-44	3.895-06	3.813-06	3.727-06	8.080-16	2.980-16	3.115-16	3.810-15	1.519-15	1.119-15
Cm-45	1.511-06	1.603-06	1.816-06	1.494-20	4.643-21	4.137-21	9.657-20	3.297-20	2.026-20
Cm-46	2.645-07	2.772-07	3.010-07	2.271-23	5.968-24	4.220-24	2.354-22	6.946-23	3.255-23
Cm-47	7.442-09	7.353-09	7.338-09	3.847-26	8.435-27	4.731-27	5.451-25	1.364-25	4.966-26
Fp-39	1.654-04	1.666-04	1.395-04	7.519-06	6.313-06	4.389-06	2.089-05	1.857-05	1.301-05
O	1.658-02	1.658-02	1.658-02	1.803-02	1.803-02	1.803-02	1.803-02	1.803-02	1.803-02
Na	7.549-03	7.549-03	7.549-03	7.549-03	7.549-03	7.549-03	7.549-03	7.549-03	7.549-03
Fe	1.287-02	1.287-02	1.287-02	1.287-02	1.287-02	1.287-02	1.287-02	1.287-02	1.287-02
Cr	2.848-03	2.848-03	2.848-03	2.848-03	2.848-03	2.848-03	2.848-03	2.848-03	2.848-03
Ni	1.627-03	1.627-03	1.627-03	1.627-03	1.627-03	1.627-03	1.627-03	1.627-03	1.627-03
Mo	2.176-04	2.176-04	2.176-04	2.176-04	2.176-04	2.176-04	2.176-04	2.176-04	2.176-04
B-10									
B-11									
C									

TABLE 4.4. ISOTOPIC DENSITIES (cont.)

(Unit: 1024 nuclei / cm3)

	Plugs (10)	Sodium plenum (11)	Cones (12)	Boron shield (13)	SHR (14)	SHR follower (15)	SCR (16)	SCR follower +rod tail (17)	SCR follower (18)
U-235									
U-236									
U-238									
Pu-38									
Pu-39									
Pu-40									
Pu-41									
Pu-42									
Np-37									
Am-41									
Am-2M									
Am-43									
Cm-42									
Cm-43									
Cm-44									
Cm-45									
Cm-46									
Cm-47									
Fp-39									
O									
Na	7.549-03	2.020-02	1.380-02	6.730-03	9.653-03	1.958-02	1.126-02	1.958-02	2.027-02
Fe	3.630-02	6.810-03	2.050-02	1.020-02	1.310-02	7.111-03	1.092-02	7.111-03	5.060-03
Cr	8.890-03	1.130-03	5.860-03	2.130-03	2.799-03	1.216-03	2.250-03	1.216-03	8.655-04
Ni	6.460-03	2.160-05	2.790-03	8.980-04	1.322-03	1.212-04	9.109-04	1.212-04	1.438-05
Mo	7.320-04	7.550-05	0.	2.660-04	3.140-04	7.655-05	2.360-04	7.655-05	8.620-05
B-10				6.870-03	5.113-03		1.780-02		
B-11				2.780-02	2.045-02		4.450-03		
C				8.660-02	6.392-03		5.560-03		

TABLE 4.4. ISOTOPIC DENSITIES (cont.)

(Unit: 1024 nuclei / cm3)

	SSA1 (19)	SSA2, 3 (20)	Radial reflector (21)	Axial reflector (22)	Inner Blanket (23)
U-235					1.883E-05
U-236					1.538E-06
U-238					8.239E-03
Pu-38					3.967E-08
Pu-39					4.709E-04
Pu-40					3.685E-05
Pu-41					1.877E-06
Pu-42					7.495E-08
Np-37					6.377E-07
Am-41					2.457E-08
Am-2M					2.084E-10
Am-43					1.635E-09
Cm-42					8.005E-10
Cm-43					9.567E-12
Cm-44					5.403E-11
Cm-45					5.995E-13
Cm-46					3.433E-15
Cm-47					1.525E-17
Fp-39					2.454E-04
O					1.803E-02
Na	5.638E-03	5.875E-03	4.860E-03	1.729E-02	7.549E-03
Fe	5.252E-02	5.179E-02	4.630E-02	1.368E-02	1.287E-02
Cr	7.636E-03	7.530E-03	1.340E-02	2.344E-03	2.848E-03
Ni	7.447E-04	7.332E-04	6.280E-03	4.948E-05	1.627E-03
Mo	3.589E-04	3.550E-04		1.487E-04	2.176E-04
B-10					
B-11					
C					

4.2 BENCHMARK CALCULATIONS OF PHASE 6

The CRP participants have been asked to compute the following parameters

- K-effective;
- Beta-effective;
- Fuel Doppler coefficient;
- Steel Doppler coefficient;
- Sodium density coefficient;
- Fuel density coefficient;
- Steel density coefficient;
- Radial expansion coefficient;
- Axial expansion coefficient.

Participants have also been asked to perform burnup calculations for one cycle (140 EFPDs) as a single step (i.e. without recomputing the neutron flux and neutron cross-sections during the cycle) assuming that the control rods were at the fixed insertion depth position. The core power was normalized by assuming all power being deposited at the point of fission, energy per fission of 200 MeV and zero energy per capture for all nuclides. At the end of the cycle (EOC), the isotopic nuclear densities for reactor regions, criticality, and, optionally, the parameters mentioned above were requested.

For all reactivity coefficients, the integral values were to be obtained by direct calculations. For all reactivity coefficients, except those for radial and axial expansion, also spatial distributions were to be computed by employing first-order perturbation theory (FOPT). The density and expansion coefficients were (similar to phases 1 to 4) defined as reactivity effects due to variations in the corresponding material densities (by 1%) and dimensions (height, radius), respectively, normalized by relative variations in the corresponding (density, dimension) parameters. Fuel temperature variations from T=1500K to T=2100K and steel temperature variations from T=600K to T=900K were considered for computing the Doppler coefficients while assuming linear variations of criticality vs. ln (T).

All parameters were to be calculated by employing homogeneous representations of the material regions and the neutron diffusion theory in 3D HEX-Z geometry.

4.3 PARTICIPANTS RESULTS

4.3.1 CEA/CA

The absolute core reactivity has been calculated first with JEF 2.2 data for the homogeneous model at BOC. These values are given below :

Diffusion Theory: $k_{eff} = 0.98829$

Transport Theory: $k_{eff} = 0.99524$

The fuel Doppler coefficient has been calculated for the homogeneous core model at BOC for a change in fuel temperature from 1500 K (T1) to 2100 K (T2). Fuel consists of U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Np-237, Am-241, Am-242m, Am-243, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, O16 and FP. The fuel Doppler coefficient is defined as :

$$K_D^{fuel} = \frac{k_{eff_2} - k_{eff_1}}{k_{eff_1} k_{eff_2}} \frac{1}{\ln(T_2/T_1)}$$

The predicted values for the total fuel Doppler coefficient at BOC, based on the values for absolute core reactivity, are given below:

Diffusion Theory : K_D^{fuel} = -0.004007

Transport Theory : K_D^{fuel} = -0.003972

The steel Doppler coefficient has been calculated for the homogeneous core model at BOC for a change in steel temperature from 600 K (T_1) to 900 K (T_2). Steel isotopes consist of Fe54, Fe56, Fe57, Fe58, Cr50, Cr52, Cr53, Cr54, Ni58, Ni60, Ni61, Ni62, Ni64 and Mo. The steel Doppler coefficient is defined as :

$$K_D^{steel} = \frac{k_{eff_2} - k_{eff_1}}{k_{eff_1} k_{eff_2}} \frac{1}{\ln(T_2/T_1)}$$

The predicted values for the total steel Doppler coefficient, based on the values for absolute core reactivity, are given below :

Diffusion Theory : $K_D^{steel} = -0.000796$

Transport Theory : $K_D^{steel} = -0.000792$

The fuel density coefficient has been calculated for the homogeneous model at BOC for a 1% increase in fuel density in all zones, and is defined as :

$$W_{fuel} = \frac{\delta k}{\delta \rho_{fuel}} \frac{\rho_{fuel}}{k^2}$$

The fuel isotopes are of U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Np-237, Am-241, Am-242m, Am-243, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, O-16 and FP. The predicted values for the total fuel density coefficient, based on the values for absolute core reactivity, are given below:

Diffusion Theory : $W_{fuel} = 0.4456$

Transport Theory : $W_{fuel} = 0.4402$

The sodium density coefficient has been calculated for the homogeneous model at BOC for a 1% increase in sodium density in all zones, and is defined as :

$$W_{Na} = \frac{\delta k}{\delta \rho_{Na}} \frac{\rho_{Na}}{k^2}$$

The predicted values for the total sodium density coefficient, based on the values for absolute core reactivity, are given below :

Diffusion Theory : $W_{Na} = -0.0168$

Transport Theory : $W_{Na} = -0.0188$

The steel density coefficient has been calculated for the homogeneous model at BOC for a 1% increase in steel density in all zones, and is defined as :

$$W_{Na} = \frac{\delta k}{\delta \rho_{Steel}} \frac{\rho_{Steel}}{k^2}$$

Steel isotopes consist of Fe54, Fe56, Fe57, Fe58, Cr50, Cr52, Cr53, Cr54, Ni58, Ni60, Ni61, Ni62, Ni64 and Mo. The predicted values for the total steel density coefficient, based on the values for absolute core reactivity, are given below :

Diffusion Theory : $W_S = -0.0391$

Transport Theory : $W_S = -0.0439$

The axial expansion coefficient has been calculated for a 1% uniform axial expansion of fuel, steel and absorber within the homogeneous model at BOC. Isotope masses have been conserved except for sodium which has been kept at constant number density, as defined in Reference 1. The axial expansion coefficient is defined as :

$$R_{ax} = \frac{\delta k}{k^2} \Big/ \frac{\delta H}{H_0}$$

The value for the axial expansion coefficient, integrated over energy, isotope and space, has been determined to be 0.140427 in diffusion theory, and 0.13619 in transport theory.

The radial expansion coefficient has been calculated for a 1% uniform radial expansion of fuel, steel and absorber within the homogeneous model at BOC. Isotope masses have been conserved except for sodium which has been kept at constant number density, as defined in Reference 1. The radial expansion coefficient is defined as :

$$R_{rad} = \frac{\delta k}{k^2} \Big/ \frac{\delta R}{R_0}$$

The value for the radial expansion coefficient, integrated over energy, isotope and space, has been determined to be 0.519842 in diffusion theory, and 0.501622 in transport theory.

The summary on computed results is provided in Table 4.5. The EOC results are computed on the basis of nuclear densities shown in Table 4.6

TABLE 4.5. MAIN SAFETY PARAMETERS FOR THE BN-600-MA CORE, CEA/SA

PARAMETER	SOLUTION METHOD	BOC	EOC
k-effective	diffusion	0.988288	0.983861
	transport	0.995244	0.990493
Fuel Doppler Coefficient	diffusion	-0.004007	-0.004052
	transport	-0.003972	-0.004038
Steel Doppler Coefficient	diffusion	-0.000796	-0.000765
	transport	-0.000792	-0.000771
Sodium Density Coefficient	diffusion	-0.0168	-0.0175
	transport	-0.0188	-0.0187
Fuel Density Coefficient	diffusion	0.4456	0.3840
	transport	0.4402	0.3752
Steel Density Coefficient	diffusion	-0.0391	-0.0398
	transport	-0.0439	-0.0434
Axial Expansion Coefficient	diffusion	0.140427	0.139419
	transport	0.136190	0.136139
Radial Expansion Coefficient	diffusion	0.519842	0.518651
Beta-effective, pcm	diffusion	306.59	308.06
Prompt neutron lifetime, s	diffusion	3.0895 E-7	3.1039 E-07

Using diffusion theory, the values for the delayed neutron fraction, integrated over isotopes, have been calculated for the homogeneous model at BOC and EOC, these values being shown in Table 4.7 and Table 4.8, respectively. The value for the prompt neutron lifetime has been calculated, using diffusion theory, being 3.0895 E-7 and 3.1039 E-07 s at BOC and EOC, respectively.

The spatial distributions of the reactivity coefficients at BOC, such as fuel and steel Doppler coefficients; fuel, sodium and steel density coefficients are shown in Table 4.9 and Table 4.10; Table 4.11, and Table 4.13, respectively.

For the homogeneous models at BOC, the core power distribution has been calculated using diffusion and transport theory, a normalisation to a total power of 1470 MW being assumed. The core power has been normalised assuming all power is deposited at the point of fission using an energy per fission of 200 MeV for all nuclides and 0 MeV per capture for all nuclides. The spatial power distribution, integrated over energy (in MW(th), is shown in Table 4.14 and Table 4.15.

The spatial distributions of the reactivity coefficients at EOC, such as fuel and steel Doppler coefficients; fuel, sodium and steel density coefficients are shown in Table 4.16 and Table 4.17; Table 4.18, Table 4.19 and Table 4.20, respectively.

TABLE 4.6. ISOTOPIC COMPOSITIONS FOR FUEL AND BLANKET REGIONS OF THE BN-600-MA REACTOR AT EOC (10^{24}NUCLEI/CM^3), CEA/SA

	Fuel LEZ Region 1	Fuel MEZ Region 2	Fuel HEZ Region 3	Fuel AB2 LEZ Region 4	Fuel AB2 MEZ Region 5	Fuel AB2 HEZ Region 6	Fuel AB1 LEZ Region 7	Fuel AB1 MEZ Region 8	Fuel AB1 HEZ Region 9	Inner Blanket Region 23
U-234	2.821E-07	2.926E-07	3.158E-07	1.246E-09	1.168E-09	8.414E-10	3.743E-10	3.261E-10	2.134E-10	2.040E-09
U-235	1.780E-05	1.783E-05	1.814E-05	2.986E-05	3.068E-05	3.196E-05	3.004E-05	3.083E-05	3.207E-05	1.561E-05
U-236	1.274E-06	1.136E-06	8.840E-07	1.472E-06	1.270E-06	9.902E-07	1.416E-06	1.225E-06	9.548E-07	2.147E-06
U-238	5.703E-03	5.593E-03	5.397E-03	8.773E-03	8.802E-03	8.850E-03	8.774E-03	8.802E-03	8.849E-03	8.030E-03
Np-237	1.183E-04	1.274E-04	1.466E-04	4.315E-07	3.948E-07	2.791E-07	3.374E-07	3.126E-07	2.307E-07	1.478E-06
Np-239	2.417E-06	2.135E-06	1.591E-06	2.902E-06	2.505E-06	1.842E-06	1.777E-06	1.501E-06	1.109E-06	4.275E-06
Pu-238	1.021E-04	1.052E-04	1.121E-04	2.193E-08	1.716E-08	9.395E-09	2.320E-08	1.869E-08	1.099E-08	1.706E-07
Pu-239	9.572E-04	1.000E-03	1.106E-03	1.706E-04	1.479E-04	1.105E-04	1.708E-04	1.483E-04	1.107E-04	5.534E-04
Pu-240	5.164E-04	5.420E-04	5.992E-04	4.327E-06	3.156E-06	1.858E-06	4.384E-06	3.216E-06	1.913E-06	5.369E-05
Pu-241	3.501E-05	3.429E-05	3.300E-05	7.593E-08	4.724E-08	2.626E-08	7.553E-08	4.736E-08	2.910E-08	3.222E-06
Pu-242	1.102E-05	1.069E-05	9.711E-06	9.039E-10	4.838E-10	2.474E-10	7.506E-10	4.021E-10	2.280E-10	1.741E-07
Am-241	2.471E-04	2.667E-04	3.098E-04	6.280E-10	3.920E-10	2.715E-10	8.029E-10	5.094E-10	3.836E-10	6.375E-08
Am-242f	1.693E-07	1.646E-07	1.483E-07	3.496E-13	1.873E-13	9.750E-14	2.848E-13	1.525E-13	8.484E-14	5.461E-11
Am-242m	7.595E-06	7.458E-06	6.893E-06	3.288E-12	1.774E-12	1.115E-12	3.229E-12	1.748E-12	1.132E-12	9.953E-10
Am-243	3.707E-05	3.976E-05	4.533E-05	8.064E-12	3.687E-12	1.729E-12	6.116E-12	2.797E-12	1.437E-12	5.566E-09
Cm-242	2.365E-05	2.287E-05	2.042E-05	1.339E-11	7.184E-12	4.391E-12	1.265E-11	6.810E-12	4.295E-12	3.795E-09
Cm-243	8.590E-07	7.563E-07	5.935E-07	1.185E-13	5.422E-14	2.968E-14	9.483E-14	4.337E-14	2.352E-14	8.271E-11
Cm-244	7.421E-06	7.196E-06	6.736E-06	2.046E-13	7.990E-14	3.342E-14	1.402E-13	5.463E-14	2.445E-14	4.624E-10
Cm-245	1.438E-06	1.511E-06	1.713E-06	1.540E-15	5.122E-16	1.929E-16	9.957E-16	3.299E-16	1.301E-16	9.367E-12
Cm-246	2.843E-07	2.952E-07	3.173E-07	5.676E-18	1.603E-18	5.204E-19	3.347E-18	9.409E-19	3.072E-19	9.359E-14
Cm-247	1.006E-08	9.764E-09	9.518E-09	1.349E-20	3.221E-21	9.043E-22	7.527E-21	1.790E-21	4.886E-22	5.378E-16
Cm-248	1.656E-10	1.455E-10	1.113E-10	3.474E-23	7.079E-24	1.689E-24	1.676E-23	3.397E-24	7.584E-25	3.812E-18
FP-239	3.866E-04	3.822E-04	3.510E-04	1.845E-04	1.797E-04	1.734E-04	1.777E-04	1.745E-04	1.705E-04	3.087E-04

TABLE 4.7. DELAYED NEUTRON FRACTION FOR BN-600-MA AT BOC, HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

Delayed neutron group	Delayed neutron fraction (pcm)	Decay constant (s^{-1})
1	7.64896	0.0132658
2	61.02056	0.0304839
3	50.02566	0.1164881
4	110.93290	0.3076224
5	56.25423	0.8664110
6	20.70727	2.9513700
TOTAL	306.59	

TABLE 4.8. DELAYED NEUTRON FRACTION FOR BN-600-MA AT EOC HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

Delayed neutron group	Beta-effective(pcm)	Decay constant (s^{-1})
1	7.59991	0.0132658
2	61.42127	0.0304693
3	50.17640	0.1165260
4	111.54750	0.3079997
5	56.69056	0.8688280
6	20.62129	2.9515980
TOTAL	308.06	

TABLE 4.9. FUEL DOPPLER COEFFICIENTS FOR BN-600-MA AT BOC, HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	-7.735E-05	-2.106E-05	-7.889E-05					
8.23	-8.923E-05	-2.346E-05	-7.855E-05					
8.23	-1.201E-04	-3.172E-05	-1.017E-04					
8.23	-1.566E-04	-4.121E-05	-1.275E-04					
8.23	-1.990E-04	-5.161E-05	-1.480E-04					
5.10	-1.996E-04	-3.864E-05	-9.781E-05					
8.23	-2.567E-04	-6.727E-05	-1.583E-04					
8.23	-2.475E-04	-6.482E-05	-1.467E-04					
8.23	-2.171E-04	-5.602E-05	-1.241E-04					
8.23	-1.748E-04	-4.429E-05	-9.646E-05					
8.23	-1.332E-04	-3.332E-05	-7.203E-05					
5.50	-9.463E-05	-2.409E-05	-5.392E-05					
9.70	-8.750E-05	-2.134E-05	-4.616E-05					
20.00	-5.171E-05	-1.159E-05	-2.318E-05					
30.00								
SA SUM	-2.105E-03	-5.305E-04	-1.353E-03					
TOTAL			-3.989E-03					

TABLE 4.10. STEEL DOPPLER COEFFICIENTS FOR BN-600-MA AT BOC, HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	1.275E-10	3.062E-11	8.159E-11	1.836E-11	7.376E-12	2.292E-11	-8.436E-12	-1.728E-09
4.50	4.616E-11	1.118E-11	1.176E-10	5.560E-12	8.689E-13	-2.893E-09	-1.450E-08	-1.647E-09
5.00	9.919E-11	2.813E-11	8.990E-12	9.784E-11	1.745E-11	-8.541E-09	-3.182E-08	-3.774E-09
5.00	1.152E-09	3.293E-10	6.048E-10	7.789E-10	1.658E-10	-2.477E-08	-6.528E-08	-7.535E-09
5.00	1.704E-09	-1.198E-10	-8.148E-09	4.723E-09	1.072E-09	-8.373E-08	-1.270E-07	-1.408E-08
4.50	-1.651E-07	-5.889E-08	-3.042E-07	-3.127E-09	2.460E-10	-1.935E-07	-1.933E-07	-2.144E-08
8.00	-3.869E-07	-1.291E-07	-5.929E-07	-3.219E-08	-3.199E-09	-7.676E-07	-6.058E-07	-7.088E-08
8.00	-8.286E-07	-2.601E-07	-1.145E-06	-6.412E-08	-7.511E-09	-1.427E-06	-1.083E-06	-1.358E-07
7.00	-1.189E-06	-3.517E-07	-1.484E-06	-8.352E-08	-1.140E-08	-1.905E-06	-1.536E-06	-2.010E-07
5.30	-9.084E-06	-2.563E-06	-9.679E-06	-7.008E-08	-1.259E-08	-1.955E-06	-1.699E-06	-2.237E-07
8.23	-9.076E-06	-2.399E-06	-7.863E-06	-1.744E-07	-2.678E-08	-4.127E-06	-3.869E-06	-5.076E-07
8.23	-1.340E-05	-3.557E-06	-1.060E-05	-2.823E-07	-3.681E-08	-5.835E-06	-5.602E-06	-7.390E-07
8.23	-1.936E-05	-5.198E-06	-1.489E-05	-4.189E-07	-5.201E-08	-7.787E-06	-7.388E-06	-9.824E-07
8.23	-2.567E-05	-6.913E-06	-1.921E-05	-5.684E-07	-6.894E-08	-9.584E-06	-8.956E-06	-1.198E-06
8.23	-3.214E-05	-8.631E-06	-2.256E-05	-8.563E-07	-8.461E-08	-1.086E-05	-1.004E-05	-1.347E-06
5.10	-1.579E-05	-6.300E-06	-1.496E-05	-2.018E-07	-2.888E-08	-7.035E-06	-6.474E-06	-8.676E-07
8.23	-3.996E-05	-1.084E-05	-2.418E-05	-4.303E-07	-4.790E-08	-1.122E-05	-1.032E-05	-1.378E-06
8.23	-3.861E-05	-1.035E-05	-2.223E-05	-4.407E-07	-4.533E-08	-1.028E-05	-9.495E-06	-1.257E-06
8.23	-3.337E-05	-8.761E-06	-1.840E-05	-3.803E-07	-3.872E-08	-8.615E-06	-8.044E-06	-1.051E-06
8.23	-2.571E-05	-6.591E-06	-1.358E-05	-2.878E-07	-2.965E-08	-6.529E-06	-6.194E-06	-7.958E-07
8.23	-1.749E-05	-4.375E-06	-8.896E-06	-1.925E-07	-2.039E-08	-4.352E-06	-4.238E-06	-5.373E-07
5.50	-5.678E-06	-1.413E-06	-2.805E-06	-7.639E-08	-8.393E-09	-1.810E-06	-1.843E-06	-2.340E-07
9.70	-4.812E-06	-1.160E-06	-2.271E-06	-6.248E-08	-7.115E-09	-1.669E-06	-1.845E-06	-2.370E-07
20.00	-2.532E-06	-5.628E-07	-1.039E-06	-2.998E-08	-3.641E-09	-8.392E-07	-1.082E-06	-1.409E-07
30.00	-4.239E-07	-8.459E-08	-1.608E-07	-4.198E-08	-1.601E-08	-2.248E-08	-1.585E-08	-2.289E-08
SA SUM	-2.953E-04	-8.041E-05	-1.967E-04	-4.650E-06	-5.324E-07	-9.690E-05	-9.074E-05	-1.195E-05
TOTAL								-7.772E-04

TABLE 4.11. FUEL DENSITY COEFFICIENTS FOR BN-600-MA AT BOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	7.601E-03	4.580E-03	7.947E-03					
8.23	1.063E-02	6.025E-03	1.179E-02					
8.23	1.392E-02	8.213E-03	1.596E-02					
8.23	1.686E-02	1.058E-02	1.976E-02					
8.23	1.888E-02	1.305E-02	2.255E-02					
5.10	-1.191E-03	9.342E-03	1.474E-02					
8.23	2.079E-02	1.578E-02	2.378E-02					
8.23	2.046E-02	1.504E-02	2.217E-02					
8.23	1.851E-02	1.301E-02	1.898E-02					
8.23	1.538E-02	1.034E-02	1.479E-02					

TABLE 4.12. SODIUM DENSITY COEFFICIENTS FOR BN-600 PHASE 6 AT BOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	6.143E-08	1.728E-08	2.906E-07	1.066E-08	4.216E-09	4.267E-07	7.529E-07	3.257E-08
4.50	1.459E-08	4.468E-09	5.849E-08	8.714E-09	4.970E-09	8.906E-08	2.181E-07	3.332E-08
5.00	-1.269E-08	-1.777E-09	-2.972E-08	1.528E-07	8.030E-08	3.000E-07	4.512E-07	7.682E-08
5.00	2.997E-07	1.006E-07	2.718E-07	9.898E-07	5.527E-07	8.819E-07	8.988E-07	1.515E-07
5.00	7.663E-06	2.360E-06	7.583E-06	5.710E-06	3.774E-06	3.131E-06	1.667E-06	2.777E-07
4.50	7.052E-05	2.171E-05	7.112E-05	1.772E-06	1.179E-05	3.135E-06	2.285E-06	4.150E-07
8.00	2.386E-04	7.451E-05	2.676E-04	-4.030E-06	9.565E-06	4.288E-06	6.051E-06	1.351E-06
8.00	3.341E-04	1.107E-04	3.934E-04	-8.553E-06	1.283E-05	4.748E-06	9.734E-06	2.606E-06
7.00	4.096E-04	1.457E-04	5.130E-04	-1.204E-05	2.525E-05	4.866E-06	1.394E-05	3.963E-06
5.30	1.226E-04	5.070E-05	1.743E-04	1.036E-05	1.001E-04	1.303E-05	1.676E-05	4.538E-06
8.23	1.364E-05	1.651E-05	1.988E-04	-1.631E-05	1.417E-04	3.957E-05	4.123E-05	1.061E-05
8.23	-5.149E-04	-1.639E-04	-1.380E-04	-9.010E-05	7.329E-05	5.815E-05	6.143E-05	1.582E-05
8.23	-1.085E-03	-3.581E-04	-4.868E-04	-1.715E-04	-1.149E-05	7.412E-05	8.063E-05	2.130E-05
8.23	-1.590E-03	-5.326E-04	-7.959E-04	-2.435E-04	-9.019E-05	8.716E-05	9.660E-05	2.613E-05
8.23	-1.931E-03	-6.539E-04	-1.013E-03	-2.792E-04	-1.457E-04	9.630E-05	1.075E-04	2.946E-05
5.10	-1.245E-03	-4.341E-04	-6.799E-04	-3.099E-04	-1.002E-04	6.215E-05	6.921E-05	1.900E-05
8.23	-2.088E-03	-6.982E-04	-1.075E-03	-5.576E-04	-1.716E-04	1.005E-04	1.109E-04	3.017E-05
8.23	-1.982E-03	-6.233E-04	-9.110E-04	-4.804E-04	-1.526E-04	9.577E-05	1.034E-04	2.749E-05
8.23	-1.553E-03	-4.642E-04	-6.090E-04	-2.264E-04	-6.902E-05	8.563E-05	8.950E-05	2.288E-05
8.23	-8.895E-04	-2.477E-04	-2.190E-04	1.440E-04	5.971E-05	7.079E-05	7.063E-05	1.718E-05
8.23	-1.613E-04	-2.315E-05	1.772E-04	5.051E-04	1.877E-04	5.172E-05	4.919E-05	1.143E-05
5.50	-1.065E-05	3.222E-05	1.463E-04	3.910E-04	1.448E-04	2.078E-05	2.125E-05	4.892E-06
9.70	1.661E-05	1.896E-05	7.858E-05	4.056E-04	1.542E-04	1.532E-05	2.054E-05	4.836E-06
20.00	1.277E-05	8.882E-06	2.175E-05	2.269E-04	9.076E-05	6.147E-06	1.127E-05	2.665E-06
30.00	1.243E-04	2.903E-05	5.345E-05	1.500E-05	5.626E-06	8.472E-06	8.851E-06	3.650E-07
SA SUM	-1.182E-02	-3.717E-03	-3.877E-03	-7.080E-04	2.753E-04	8.990E-04	9.860E-04	2.573E-04
TOTAL								-1.771E-02

TABLE 4.13. STEEL DENSITY COEFFICIENTS FOR BN-600-MA AT BOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	7.487E-08	2.162E-08	2.734E-07	1.188E-08	4.730E-09	3.739E-07	6.553E-07	3.567E-07
4.50	6.660E-08	1.965E-08	2.020E-07	1.983E-08	8.039E-09	7.068E-07	1.163E-06	3.532E-07
5.00	4.209E-08	1.622E-08	3.857E-08	3.067E-07	1.179E-07	2.320E-06	2.431E-06	7.998E-07
5.00	1.357E-06	4.245E-07	1.271E-06	2.019E-06	8.246E-07	6.736E-06	4.827E-06	1.553E-06
5.00	2.292E-05	6.904E-06	2.161E-05	1.190E-05	5.797E-06	2.346E-05	8.901E-06	2.808E-06
4.50	1.922E-04	5.911E-05	1.999E-04	5.669E-06	6.561E-06	2.499E-05	1.211E-05	4.148E-06
8.00	1.225E-04	3.792E-05	1.254E-04	-1.394E-06	5.722E-06	3.303E-05	3.136E-05	1.327E-05
8.00	1.745E-04	5.604E-05	1.743E-04	-5.901E-06	7.470E-06	3.483E-05	4.888E-05	2.509E-05
7.00	2.153E-04	7.323E-05	2.179E-04	-8.655E-06	1.311E-05	3.356E-05	6.797E-05	3.747E-05
5.30	9.963E-04	3.878E-04	1.174E-03	3.694E-05	4.580E-05	8.457E-05	8.026E-05	4.233E-05
8.23	-6.873E-06	3.650E-05	3.487E-04	2.553E-06	6.486E-05	2.521E-04	1.945E-04	9.770E-05
8.23	-1.283E-03	-3.858E-04	-4.695E-04	-1.249E-04	3.508E-05	3.677E-04	2.865E-04	1.442E-04
8.23	-2.640E-03	-8.356E-04	-1.327E-03	-2.616E-04	-3.322E-06	4.673E-04	3.738E-04	1.929E-04
8.23	-3.842E-03	-1.241E-03	-2.088E-03	-3.814E-04	-3.926E-05	5.484E-04	4.463E-04	2.359E-04
8.23	-4.670E-03	-1.539E-03	-2.630E-03	-4.506E-04	-6.465E-05	6.054E-04	4.957E-04	2.655E-04
5.10	-3.041E-03	-1.044E-03	-1.765E-03	-1.193E-04	-3.161E-05	3.907E-04	3.191E-04	1.711E-04
8.23	-5.248E-03	-1.709E-03	-2.808E-03	-2.423E-04	-5.521E-05	6.327E-04	5.115E-04	2.718E-04
8.23	-5.086E-03	-1.550E-03	-2.417E-03	-2.162E-04	-4.958E-05	6.049E-04	4.784E-04	2.481E-04
8.23	-4.063E-03	-1.175E-03	-1.680E-03	-1.018E-04	-2.221E-05	5.442E-04	4.161E-04	2.072E-04
8.23	-2.431E-03	-6.539E-04	-7.157E-04	6.854E-05	2.023E-05	4.557E-04	3.318E-04	1.565E-04
8.23	-5.900E-04	-9.775E-05	2.956E-04	2.347E-04	6.216E-05	3.439E-04	2.354E-04	1.053E-04
5.50	1.213E-04	7.640E-05	3.430E-04	1.835E-04	4.842E-05	1.464E-04	1.040E-04	4.567E-05
9.70	1.584E-04	7.917E-05	2.697E-04	1.962E-04	5.322E-05	1.149E-04	1.029E-04	4.593E-05
20.00	1.154E-04	4.470E-05	1.065E-04	1.117E-04	3.188E-05	5.140E-05	5.850E-05	2.622E-05
30.00	1.091E-04	2.553E-05	4.766E-05	1.301E-05	4.867E-06	7.510E-06	7.700E-06	3.695E-06
SA SUM	-3.078E-02	-9.372E-03	-1.262E-02	-1.060E-03	1.354E-04	5.770E-03	4.613E-03	2.342E-03
TOTAL								-4.097E-02

TABLE 4.14. POWER DISTRIBUTION FOR BN-600-MA AT BOC, HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	3.344E+01	1.139E+01	4.218E+01					
8.23	4.237E+01	1.461E+01	5.263E+01					
8.23	5.073E+01	1.761E+01	6.278E+01					
8.23	5.747E+01	2.005E+01	7.087E+01					
8.23	6.210E+01	2.187E+01	7.628E+01					
5.10	1.961E+01	1.418E+01	4.865E+01					
8.23	6.675E+01	2.323E+01	7.836E+01					
8.23	6.633E+01	2.259E+01	7.511E+01					
8.23	6.195E+01	2.078E+01	6.840E+01					
8.23	5.426E+01	1.794E+01	5.856E+01					
8.23	4.393E+01	1.428E+01	4.627E+01					
5.50	4.374E+00	1.315E+00	3.646E+00					
9.70	5.862E+00	1.671E+00	4.349E+00					
20.00	5.953E+00	1.607E+00	4.095E+00					
30.00								
SA SUM	5.751E+02	2.031E+02	6.922E+02					
TOTAL			1.470E+03					

TABLE 4.15. POWER DISTRIBUTION FOR BN-600-MA AT BOC, HOMOGENEOUS — TRANSPORT THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	3.334E+01	1.135E+01	4.206E+01					
8.23	4.225E+01	1.456E+01	5.248E+01					
8.23	5.057E+01	1.755E+01	6.259E+01					
8.23	5.730E+01	1.999E+01	7.065E+01					
8.23	6.191E+01	2.180E+01	7.605E+01					
5.10	1.956E+01	1.414E+01	4.850E+01					
8.23	6.655E+01	2.316E+01	7.813E+01					
8.23	6.613E+01	2.253E+01	7.489E+01					
8.23	6.177E+01	2.072E+01	6.820E+01					
8.23	5.409E+01	1.789E+01	5.839E+01					
8.23	4.380E+01	1.789E+01	4.613E+01					
5.50	4.361E+00	1.311E+00	3.635E+00					
9.70	5.845E+00	1.666E+00	4.336E+00					
20.00	5.935E+00	1.602E+00	4.082E+00					
30.00								
SA SUM	5.734E+02	2.062E+02	6.901E+02					
TOTAL			1.470E+03					

TABLE 4.16. FUEL DOPPLER COEFFICIENTS FOR BN-600-MA AT EOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	-7.637E-05	-1.993E-05	-7.197E-05					
8.23	-9.026E-05	-2.279E-05	-7.395E-05					
8.23	-1.227E-04	-3.104E-05	-9.663E-05					
8.23	-1.609E-04	-4.053E-05	-1.217E-04					
8.23	-2.057E-04	-5.101E-05	-1.420E-04					
5.10	-2.052E-04	-3.837E-05	-9.421E-05					
8.23	-2.673E-04	-6.712E-05	-1.532E-04					
8.23	-2.590E-04	-6.506E-05	-1.428E-04					
8.23	-2.286E-04	-5.658E-05	-1.215E-04					
8.23	-1.849E-04	-4.497E-05	-9.492E-05					
8.23	-1.410E-04	-3.384E-05	-7.091E-05					
5.50	-1.026E-04	-2.496E-05	-5.392E-05					
9.70	-9.946E-05	-2.315E-05	-4.824E-05					
20.00	-6.267E-05	-1.348E-05	-2.609E-05					
30.00								
SA SUM	-2.207E-03	-5.328E-04	-1.312E-03					
TOTAL			-4.051E-03					

TABLE 4.17. STEEL DOPPLER COEFFICIENTS FOR BN-600 PHASE 6 AT EOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	1.197E-10	2.851E-11	1.045E-10	1.719E-11	6.941E-12	7.612E-11	1.064E-10	-1.348E-09
4.50	4.442E-11	1.078E-11	1.153E-10	5.289E-12	8.497E-13	-2.356E-09	-1.211E-08	-1.305E-09
5.00	9.536E-11	2.615E-11	1.511E-11	9.279E-11	1.684E-11	-7.017E-09	-2.661E-08	-2.996E-09
5.00	1.126E-09	3.112E-10	5.963E-10	7.458E-10	1.609E-10	-2.051E-08	-5.470E-08	-5.991E-09
5.00	2.783E-09	2.995E-10	-5.396E-09	4.606E-09	1.066E-09	-6.983E-08	-1.065E-07	-1.121E-08
4.50	-1.418E-07	-4.829E-08	-2.463E-07	-2.622E-09	2.443E-10	-1.590E-07	-1.616E-07	-1.712E-08
8.00	-3.509E-07	-1.114E-07	-4.934E-07	-2.921E-08	-2.977E-09	-6.292E-07	-5.049E-07	-5.688E-08
8.00	-7.724E-07	-2.308E-07	-9.767E-07	-5.935E-08	-7.141E-09	-1.185E-06	-9.061E-07	-1.099E-07
7.00	-1.133E-06	-3.196E-07	-1.294E-06	-7.889E-08	-1.107E-08	-1.608E-06	-1.297E-06	-1.644E-07
5.30	-8.958E-06	-2.414E-06	-8.774E-06	-6.765E-08	-1.245E-08	-1.684E-06	-1.450E-06	-1.845E-07
8.23	-8.874E-06	-2.319E-06	-7.401E-06	-1.739E-07	-2.743E-08	-3.655E-06	-3.336E-06	-4.222E-07
8.23	-1.317E-05	-3.493E-06	-1.016E-05	-2.852E-07	-3.849E-08	-5.241E-06	-4.873E-06	-6.193E-07
8.23	-1.910E-05	-5.133E-06	-1.435E-05	-4.261E-07	-5.486E-08	-7.042E-06	-6.461E-06	-8.277E-07
8.23	-2.550E-05	-6.859E-06	-1.859E-05	-5.819E-07	-7.313E-08	-8.710E-06	-7.863E-06	-1.013E-06
8.23	-3.226E-05	-8.610E-06	-2.194E-05	-8.842E-07	-9.021E-08	-9.914E-06	-8.849E-06	-1.144E-06
5.10	-1.678E-05	-6.318E-06	-1.460E-05	-2.130E-07	-3.067E-08	-6.443E-06	-5.722E-06	-7.392E-07
8.23	-4.073E-05	-1.092E-05	-2.371E-05	-4.564E-07	-5.106E-08	-1.031E-05	-9.148E-06	-1.178E-06
8.23	-3.958E-05	-1.049E-05	-2.193E-05	-4.702E-07	-4.860E-08	-9.488E-06	-8.457E-06	-1.080E-06
8.23	-3.447E-05	-8.948E-06	-1.829E-05	-4.091E-07	-4.183E-08	-7.996E-06	-7.202E-06	-9.079E-07
8.23	-2.686E-05	-6.793E-06	-1.362E-05	-3.129E-07	-3.233E-08	-6.097E-06	-5.582E-06	-6.922E-07
8.23	-1.858E-05	-4.561E-06	-9.006E-06	-2.118E-07	-2.243E-08	-4.098E-06	-3.854E-06	-4.717E-07
5.50	-6.426E-06	-1.524E-06	-2.916E-06	-8.633E-08	-9.454E-09	-1.719E-06	-1.696E-06	-2.077E-07
9.70	-5.647E-06	-1.296E-06	-2.440E-06	-7.491E-08	-8.473E-09	-1.613E-06	-1.723E-06	-2.133E-07
20.00	-3.186E-06	-6.762E-07	-1.197E-06	-3.928E-08	-4.694E-09	-8.433E-07	-1.041E-06	-1.311E-07
30.00	-5.398E-07	-1.033E-07	-1.854E-07	-5.282E-08	-2.018E-08	-2.291E-08	-1.535E-08	-2.273E-08
SA SUM	-3.025E-04	-8.106E-05	-1.919E-04	-4.857E-06	-5.658E-07	-8.853E-05	-8.033E-05	-1.020E-05
TOTAL								-7.600E-04

TABLE 4.18. FUEL DENSITY COEFFICIENTS FOR BN-600 PHASE 6 AT EOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00								
4.50								
5.00								
5.00								
5.00								
4.50								
8.00								
8.00								
7.00								
5.30								
8.23	7.749E-03	2.429E-03	7.212E-03					
8.23	1.083E-02	3.460E-03	1.068E-02					
8.23	1.424E-02	4.610E-03	1.447E-02					
8.23	1.738E-02	5.695E-03	1.795E-02					
8.23	1.962E-02	6.549E-03	2.057E-02					
5.10	4.534E-04	4.310E-03	1.348E-02					
8.23	2.173E-02	7.071E-03	2.184E-02					
8.23	2.140E-02	6.774E-03	2.048E-02					
8.23	1.943E-02	5.989E-03	1.765E-02					
8.23	1.621E-02	4.869E-03	1.387E-02					
8.23	1.258E-02	3.665E-03	9.943E-03					
5.50	-1.545E-04	2.738E-05	3.298E-04					
9.70	-1.852E-04	7.160E-06	1.242E-04					
20.00	8.232E-05	4.166E-05	6.961E-05					
30.00								
SA SUM	1.614E-01	5.550E-02	1.687E-01					
TOTAL			3.855E-01					

TABLE 4.19. SODIUM DENSITY COEFFICIENTS FOR BN-600 PHASE 6 AT EOC : HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	5.72E-08	1.54E-08	2.44E-07	9.93E-09	3.99E-09	3.62E-07	6.36E-07	2.65E-08
4.50	1.37E-08	4.16E-09	4.83E-08	8.18E-09	4.85E-09	7.62E-08	1.84E-07	2.76E-08
5.00	-1.24E-08	-1.75E-09	-2.74E-08	1.44E-07	7.86E-08	2.60E-07	3.82E-07	6.40E-08
5.00	2.85E-07	9.14E-08	2.39E-07	9.37E-07	5.45E-07	7.76E-07	7.66E-07	1.27E-07
5.00	7.38E-06	2.18E-06	6.81E-06	5.45E-06	3.74E-06	2.80E-06	1.43E-06	2.33E-07
4.50	6.71E-05	1.98E-05	6.26E-05	1.66E-06	1.10E-05	2.77E-06	1.96E-06	3.50E-07
8.00	2.35E-04	6.96E-05	2.44E-04	-4.05E-06	9.08E-06	3.65E-06	5.18E-06	1.14E-06
8.00	3.35E-04	1.05E-04	3.64E-04	-8.55E-06	1.24E-05	3.91E-06	8.35E-06	2.22E-06
7.00	4.19E-04	1.39E-04	4.81E-04	-1.20E-05	2.50E-05	3.94E-06	1.21E-05	3.41E-06
5.30	1.27E-04	4.86E-05	1.63E-04	1.03E-05	9.94E-05	1.16E-05	1.47E-05	3.93E-06
8.23	1.00E-04	1.64E-05	1.90E-04	-1.57E-05	1.42E-04	3.62E-05	3.65E-05	9.24E-06
8.23	-4.60E-04	-1.58E-04	-1.25E-04	-8.87E-05	7.58E-05	5.36E-05	5.47E-05	1.39E-05
8.23	-1.04E-03	-3.48E-04	-4.55E-04	-1.70E-04	-6.95E-06	6.86E-05	7.21E-05	1.87E-05
8.23	-1.56E-03	-5.21E-04	-7.52E-04	-2.43E-04	-8.54E-05	8.08E-05	8.66E-05	2.31E-05
8.23	-1.91E-03	-6.43E-04	-9.63E-04	-2.81E-04	-1.43E-04	8.96E-05	9.67E-05	2.61E-05
5.10	-1.29E-03	-4.29E-04	-6.50E-04	-3.05E-04	-1.04E-04	5.79E-05	6.24E-05	1.69E-05
8.23	-2.10E-03	-6.93E-04	-1.03E-03	-5.55E-04	-1.79E-04	9.40E-05	1.00E-04	2.69E-05
8.23	-2.02E-03	-6.23E-04	-8.83E-04	-4.85E-04	-1.61E-04	8.99E-05	9.40E-05	2.47E-05
8.23	-1.59E-03	-4.70E-04	-6.00E-04	-2.43E-04	-7.81E-05	8.08E-05	8.17E-05	2.06E-05
8.23	-9.05E-04	-2.59E-04	-2.29E-04	1.15E-04	5.17E-05	6.72E-05	6.49E-05	1.56E-05
8.23	-1.26E-04	-3.68E-05	1.53E-04	4.70E-04	1.83E-04	4.94E-05	4.55E-05	1.05E-05
5.50	3.12E-05	2.71E-05	1.36E-04	3.78E-04	1.47E-04	2.01E-05	1.98E-05	4.51E-06
9.70	6.97E-06	1.72E-05	7.62E-05	4.08E-04	1.62E-04	1.51E-05	1.94E-05	4.51E-06
20.00	1.84E-05	1.06E-05	2.51E-05	2.47E-04	1.03E-04	6.36E-06	1.09E-05	2.55E-06
30.00	1.68E-04	3.73E-05	6.64E-05	1.96E-05	7.40E-06	9.59E-06	9.47E-06	3.74E-07
SA SUM	-1.166E-02	-3.727E-03	-3.786E-03	-7.757E-04	2.681E-04	8.397E-04	8.911E-04	2.293E-04
TOTAL								-1.772E-02

TABLE 4.20. STEEL DENSITY COEFFICIENTS FOR BN-600 PHASE 6 AT EOC :HOMOGENEOUS — DIFFUSION THEORY, CEA/SA

dz (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RAD REF
30.00	6.75E-08	1.87E-08	2.24E-07	1.07E-08	4.30E-09	3.08E-07	5.39E-07	3.03E-07
4.50	6.30E-08	1.82E-08	1.72E-07	1.88E-08	7.66E-09	6.10E-07	1.00E-06	3.03E-07
5.00	3.97E-08	1.47E-08	3.32E-08	2.91E-07	1.13E-07	2.02E-06	2.12E-06	6.90E-07
5.00	1.30E-06	3.88E-07	1.13E-06	1.93E-06	7.93E-07	5.93E-06	4.24E-06	1.35E-06
5.00	2.21E-05	6.39E-06	1.95E-05	1.15E-05	5.61E-06	2.09E-05	7.88E-06	2.44E-06
4.50	1.85E-04	5.41E-05	1.75E-04	5.45E-06	6.24E-06	2.22E-05	1.08E-05	3.62E-06
8.00	1.20E-04	3.53E-05	1.14E-04	-1.44E-06	5.60E-06	3.03E-05	2.83E-05	1.17E-05
8.00	1.75E-04	5.30E-05	1.63E-04	-5.87E-06	7.52E-06	3.30E-05	4.46E-05	2.22E-05
7.00	2.20E-04	7.00E-05	2.08E-04	-8.52E-06	1.34E-05	3.26E-05	6.27E-05	3.34E-05
5.30	1.05E-03	3.78E-04	1.12E-03	3.73E-05	4.70E-05	8.10E-05	7.46E-05	3.79E-05
8.23	1.03E-04	3.85E-05	3.39E-04	4.29E-06	6.68E-05	2.41E-04	1.82E-04	8.79E-05
8.23	-1.19E-03	-3.63E-04	-4.16E-04	-1.22E-04	3.73E-05	3.51E-04	2.69E-04	1.30E-04
8.23	-2.56E-03	-7.94E-04	-1.21E-03	-2.59E-04	-1.15E-06	4.47E-04	3.52E-04	1.75E-04
8.23	-3.78E-03	-1.19E-03	-1.93E-03	-3.81E-04	-3.79E-05	5.27E-04	4.22E-04	2.15E-04
8.23	-4.65E-03	-1.49E-03	-2.45E-03	-4.54E-04	-6.50E-05	5.83E-04	4.70E-04	2.43E-04
5.10	-3.12E-03	-1.01E-03	-1.65E-03	-1.20E-04	-3.26E-05	3.78E-04	3.03E-04	1.57E-04
8.23	-5.30E-03	-1.67E-03	-2.64E-03	-2.47E-04	-5.74E-05	6.13E-04	4.88E-04	2.50E-04
8.23	-5.18E-03	-1.52E-03	-2.29E-03	-2.23E-04	-5.21E-05	5.87E-04	4.58E-04	2.30E-04
8.23	-4.17E-03	-1.17E-03	-1.62E-03	-1.12E-04	-2.50E-05	5.29E-04	3.99E-04	1.93E-04
8.23	-2.52E-03	-6.67E-04	-7.15E-04	5.68E-05	1.75E-05	4.44E-04	3.19E-04	1.46E-04
8.23	-6.33E-04	-1.27E-04	2.43E-04	2.25E-04	6.05E-05	3.36E-04	2.28E-04	9.93E-05
5.50	6.59E-05	6.19E-05	3.14E-04	1.83E-04	4.88E-05	1.43E-04	1.01E-04	4.34E-05
9.70	1.25E-04	7.15E-05	2.55E-04	2.02E-04	5.55E-05	1.14E-04	1.01E-04	4.41E-05
20.00	1.25E-04	4.72E-05	1.11E-04	1.24E-04	3.58E-05	5.30E-05	5.82E-05	2.58E-05
30.00	1.39E-04	3.10E-05	5.60E-05	1.61E-05	6.07E-06	8.11E-06	7.87E-06	3.86E-06
SA SUM	-3.092E-02	-9.179E-03	-1.187E-02	-1.081E-03	1.375E-04	5.576E-03	4.386E-03	2.155E-03
TOTAL								**-4.079E-02**

4.3.2 FZK/IKET

4.3.2.1 Introduction

The 30-group nuclear JEFF-3.0-based data library — the same as employed in Phase 4 (as an additional option) and Phase 5 — is employed as the main calculation option. For evaluating the uncertainty of the fuel Doppler coefficient, only the 560-group JEFF-3.0-based library was employed.

3-D calculations were performed with 21-group cross-sections computed from 30-group and 560-group libraries by employing composition-dependent spectra. The VARIANT nodal code was used for diffusion and P3 transport calculations in a stand-alone mode; the KIN3D extension for VARIANT and a post-processing tool (SIRENE) were employed to compute spatial distributions of reactivity coefficients on the basis of first order perturbation theory.

4.3.2.2 Information on burnup chain for Phase 6 calculations

The burnup chain takes into account the following neutron induced reactions (fission being omitted hereafter, isomT means isomeric transformation):

```
U-234    capt U-235
U-235     n2n U-234  capt U-236
U-236     n3n U-234  capt U-237   n2n U-235
U-237     n2n U-236  capt U-238   n3n U-235
U-238     n2n U-237   n3n U-236  capt Np239
Np237    capt Np238
Np238     n2n Np237  capt Np239
Np239     n2n Np238   n3n Np237
Pu238    capt Pu239
Pu239     n2n Pu238  capt Pu240
Pu240     n2n Pu239   n3n Pu238  capt Pu241
Pu241     n2n Pu240   n3n Pu239  capt Pu242
Pu242     n2n Pu241   n3n Pu240  capt Pu243
Am241    capt Am242  capt Am242m
Am242     n2n Am241  capt Am243
Am242m    n2n Am241  capt Am243
Am243     n3n Am241  capt Am244  capt Am244m  n2n Am242   n2n Am242m
Cm242    capt Cm243
Cm243     n2n Cm242  capt Cm244
Cm244     n2n Cm243   n3n Cm242  capt Cm245
Cm245     n2n Cm244   n3n Cm243  capt Cm246
Cm246     n2n Cm245   n3n Cm244  capt Cm247
Cm247     n2n Cm246   n3n Cm245  capt Cm248
Cm248     n2n Cm247   n3n Cm246
```

and the following decay options:

```
U-237   beta- Np237
U-239   beta- Np239
Np238   beta- Pu238
Np239   beta- Pu239
Pu238   alpha U-234
Pu240   alpha U-236
Pu241   beta- Am241   alpha U-237
Pu242   alpha U-238
Pu243   beta- Am243
Am241   alpha Np237
Am242   beta- Cm242   beta+ Pu242
Am242m  isomT Am242   alpha Np238
Am243   alpha Np239
Am244   beta- Cm244
Am244m  beta- Cm244
Cm242   alpha Pu238
Cm243   beta+ Am243   alpha Pu239
Cm244   alpha Pu240
Cm245   alpha Pu241
Cm246   alpha Pu242
```

The isomeric branching ratio for Am-241 capture ((to Am-242 ground/(Am-242 ground and Am-242 metastable)) was computed from the JEFF-3.1 activation files (as well as all parameters, such as decay constants, which are not present in the general purpose JEFF-3.0 file). Though this ratio is energy dependent and the spectra in different core sub-regions differ, this ratio remains in the range from 0.915 to 0.916 for all considered core sub-regions. Note, that the branching ratio in the JEFF-3.1 activation file is 0.919 at 1.e-5 eV, about 0.916 at 100 keV, about 0.889 at 1 MeV; while the capture cross-section in this file is 3.2e4 barn at 1.e-5 eV, about 1.74 barn at 100 keV, about 0.37 barn at 1 MeV. The decay constants for the Am-242 beta- and beta+ decay options are about 9.98 e-6 and 2.02e-6 (1/s), the beta- option contributing to 83.2% of decay events.

4.3.2.3 Beta-effective calculations for BN-600 core with MAs

JENDL-3.3 delayed neutron data (delayed neutron yields and spectra) were employed for computing the beta-effective value. For a few nuclides of minor importance delayed spectra are absent in the JENDL-3.3 library. While computing the beta-effective value, spectra for these nuclides were assumed to be the same as the spectra of “similar” nuclides, which are present in the library. The results are provided in Table 4.21.

TABLE 4.21. BETA-EFFECTIVE VALUES IN THE BN-600 CORE WITH MAS AT BOC, FZK/IKET

Nuclide	Absolute contribution to beta-effective	Relative contribution to beta-effective
U-235	6.2564E-05	2.0981E-02
U-236	1.6319E-07	5.4725E-05
U-238	1.3844E-03	4.6425E-01
Pu-238	5.0520E-05	1.6942E-02
Pu-239	1.0832E-03	3.6323E-01
Pu-240	1.9418E-04	6.5118E-02
P u-241	8.1782E-05	2.7425E-02
P u-242	3.2078E-06	1.0757E-03
Np-237	5.7348E-05	1.9232E-02
Am-241	4.3482E-05	1.4582E-02
Am-242M	7.3160E-06	2.4534E-03
Am-243	8.5843E-06	2.8787E-03
Cm-242	1.8012E-06	6.0402E-04
Cm-243	2.7870E-07	9.3461E-05
Cm-244	7.3371E-07	2.4605E-04
Cm-245	2.3844E-06	7.9959E-04
Cm-246	7.7182E-08	2.5883E-05
Cm-247	2.0002E-08	6.7075E-06
TOTAL	2.9820E-03	1.0

One may see that U-238 and Pu-239 provide the largest contributions (ca. 46% and 36%) to the total beta-effective, similar to conventional fast breeder reactors.

4.3.2.4 Results of calculations (30-group library based on JEFF-3.0) for the BN-600 with MAs

The main core parameters at BOC and EOC are given in Table 4.22. Sodium and steel density coefficients were computed by varying corresponding nuclear densities by 1% and 10%, the latter values being in brackets. Similarly to Phase 4, the effect of using a finer group cross-section library for fuel Doppler constant calculations was also investigated, giving a higher by ca. 10% value of the constant of -379 pcm (instead of -351 pcm with the 30-group library).

The nuclear densities at EOC are shown in Table 4.23. The spatial distributions of reactivity coefficients, such as fuel and steel Doppler coefficient, fuel, sodium and steel density coefficients at BOC are given in Tables 4.24–4.28. The spatial distributions of reactivity coefficients, such as fuel and steel Doppler coefficient, fuel, sodium and steel density coefficients at EOC are given in Tables 4.29–4.33.

All spatial distributions of reactivity coefficients are computed by employing the first-order perturbation theory option.

TABLE 4.22. k_{eff} AND MAJOR SAFETY PARAMETERS AT BOC AND EOC CONDITIONS, FZK/IKET

Value	Beginning of cycle (BOC), 30 gr/560gr	End of cycle (EOC)
k_{eff}	0.99069	0.98489
Beta-effective (pcm)	298	300
Fuel Doppler Coefficient (pcm)	-351/-379	-361
Steel Doppler Coefficient (pcm)	-61	-63
Sodium Density Coefficient (pcm)	-1124 (-1150)	-1099 (-1158)
Fuel Density Coefficient (pcm)	37807	36093
Steel Density Coefficient (pcm)	-3496 (-3533)	-3477 (-3622)
Radial expansion coefficient (pcm)	-5317	-5298
Axial expansion coefficient (pcm)	-1485	-1469

TABLE 4.23. NUCLEAR DENSITIES IN BN-600-MA AT EOC CONDITIONS (AFTER 140 EFPDS AT 1470 MW(th), FZK/IKET

	Fuel LEZ	Fuel MEZ	Fuel HEZ	Fuel AB2 LEZ	Fuel AB2 MEZ	Fuel AB2 HEZ	Fuel AB1 LEZ	Fuel AB1 MEZ	Fuel AB1 HEZ	Inner Blanket
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 23
U-234	2.805E-07	2.911E-07	3.144E-07	3.613E-10	3.082E-10	1.953E-10	1.341E-09	1.231E-09	8.756E-10	2.190E-09
U-235	1.768E-05	1.779E-05	1.819E-05	3.100E-05	3.180E-05	3.286E-05	2.834E-05	2.936E-05	3.103E-05	1.547E-05
U-236	1.315E-06	1.158E-06	8.820E-07	1.314E-06	1.103E-06	8.496E-07	1.805E-06	1.558E-06	1.194E-06	2.208E-06
U-237	5.344E-08	5.186E-08	3.783E-08	1.002E-08	8.186E-09	5.047E-09	3.555E-08	3.156E-08	2.156E-08	8.517E-08
U-238	5.699E-03	5.592E-03	5.399E-03	8.825E-03	8.850E-03	8.888E-03	8.712E-03	8.749E-03	8.814E-03	8.025E-03
Np-237	1.180E-04	1.273E-04	1.470E-04	1.759E-07	1.499E-07	9.802E-08	6.580E-07	6.072E-07	4.408E-07	1.616E-06
Np-238	2.477E-07	2.318E-07	1.988E-07	2.295E-10	1.600E-10	7.691E-11	1.222E-09	9.412E-10	4.940E-10	4.231E-09
Np-239	2.499E-06	2.151E-06	1.529E-06	1.866E-06	1.535E-06	1.076E-06	3.024E-06	2.548E-06	1.793E-06	4.352E-06
Pu-238	1.015E-04	1.045E-04	1.113E-04	8.084E-09	5.832E-09	2.970E-09	4.516E-08	3.579E-08	1.979E-08	1.796E-07
Pu-239	9.562E-04	9.999E-04	1.108E-03	1.341E-04	1.131E-04	8.228E-05	2.120E-04	1.839E-04	1.350E-04	5.537E-04
Pu-240	5.172E-04	5.425E-04	5.994E-04	3.112E-06	2.167E-06	1.236E-06	6.349E-06	4.610E-06	2.586E-06	5.356E-05
Pu-241	3.366E-05	3.286E-05	3.133E-05	5.146E-08	3.030E-08	1.866E-08	1.208E-07	7.469E-08	4.031E-08	3.073E-06
Pu-242	1.153E-05	1.105E-05	9.847E-06	4.708E-10	2.318E-10	1.336E-10	1.561E-09	8.178E-10	3.913E-10	1.612E-07
Am-241	2.458E-04	2.664E-04	3.109E-04	4.887E-10	2.945E-10	2.303E-10	1.090E-09	6.852E-10	4.558E-10	6.244E-08
Am-242	1.875E-07	1.780E-07	1.530E-07	2.052E-13	1.014E-13	5.759E-14	7.095E-13	3.641E-13	1.735E-13	5.971E-11
Am-242M	5.830E-06	5.711E-06	5.237E-06	1.130E-12	5.714E-13	3.930E-13	3.620E-12	1.943E-12	1.113E-12	6.357E-10
Am-243	3.688E-05	3.968E-05	4.542E-05	3.792E-12	1.562E-12	8.346E-13	1.633E-11	7.238E-12	3.070E-12	5.478E-09
Cm-242	2.514E-05	2.392E-05	2.068E-05	8.517E-12	4.264E-12	2.812E-12	2.768E-11	1.470E-11	8.072E-12	4.098E-09
Cm-243	8.295E-07	7.181E-07	5.458E-07	5.567E-14	2.320E-14	1.328E-14	2.454E-13	1.083E-13	4.840E-14	8.233E-11
Cm-244	7.554E-06	7.228E-06	6.617E-06	7.712E-14	2.585E-14	1.227E-14	4.590E-13	1.714E-13	6.206E-14	4.771E-10
Cm-245	1.424E-06	1.501E-06	1.706E-06	4.168E-16	1.163E-16	4.827E-17	3.331E-15	1.028E-15	3.186E-16	9.225E-12
Cm-246	2.817E-07	2.930E-07	3.147E-07	1.021E-18	2.380E-19	8.437E-20	1.183E-17	3.158E-18	7.908E-19	9.811E-14
Cm-247	1.424E-08	1.357E-08	1.248E-08	1.057E-20	6.762E-21	4.021E-21	7.995E-20	3.682E-20	1.991E-20	1.188E-15
Cm-248	3.232E-10	2.753E-10	1.907E-10	9.963E-16	9.969E-16	9.979E-16	9.894E-16	9.906E-16	9.934E-16	9.877E-16
FP239	3.405E-04	3.354E-04	2.755E-04	1.803E-05	1.442E-05	9.298E-06	5.049E-05	4.286E-05	2.819E-05	3.558E-04

TABLE 4.24. FUEL DOPPLER COEFFICIENT IN BN-600-MA AT BOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	-7.288E-05	-1.865E-05	-6.028E-05	0.000E+00				
8.23	-8.055E-05	-2.028E-05	-5.876E-05	0.000E+00				
8.23	-1.091E-04	-2.774E-05	-7.706E-05	0.000E+00				
8.23	-1.436E-04	-3.628E-05	-9.732E-05	0.000E+00				
8.23	-1.864E-04	-4.570E-05	-1.135E-04	0.000E+00				
5.10	-2.204E-04	-3.397E-05	-7.513E-05	0.000E+00				
8.23	-2.360E-04	-5.875E-05	-1.217E-04	0.000E+00				
8.23	-2.225E-04	-5.636E-05	-1.130E-04	0.000E+00				
8.23	-1.942E-04	-4.868E-05	-9.562E-05	0.000E+00				
8.23	-1.576E-04	-3.877E-05	-7.462E-05	0.000E+00				
8.23	-1.263E-04	-3.054E-05	-5.819E-05	0.000E+00				
5.50	-1.064E-04	-2.580E-05	-5.198E-05	0.000E+00				
9.70	-1.076E-04	-2.496E-05	-4.769E-05	0.000E+00				
10.00	-4.636E-05	-1.008E-05	-1.798E-05	0.000E+00				
10.00	-1.958E-05	-4.010E-06	-6.865E-06	0.000E+00				
Core	-1.750E-03	-4.157E-04	-9.451E-04	0.000E+00				

(Total: -3.580E-03)

TABLE 4.25. STEEL DOPPLER COEFFICIENT IN BN-600-MA AT BOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.363E-10	4.198E-11	8.599E-10	2.280E-11	7.579E-12	1.366E-09	2.168E-09	7.753E-10
4.50	2.263E-11	4.956E-12	3.710E-10	4.551E-11	1.316E-11	6.941E-09	1.046E-08	7.309E-10
5.00	1.900E-10	5.060E-11	1.566E-10	4.643E-10	1.554E-10	1.933E-08	2.529E-08	1.650E-09
5.00	2.507E-09	6.715E-10	1.672E-09	2.839E-09	1.158E-09	4.356E-08	5.021E-08	3.208E-09
5.00	2.070E-08	5.137E-09	9.188E-09	1.050E-08	6.473E-09	7.487E-08	8.802E-08	5.793E-09
4.50	-2.380E-07	-7.066E-08	-2.875E-07	-1.586E-09	8.969E-10	3.616E-08	1.214E-07	8.583E-09
8.00	-5.331E-07	-1.513E-07	-5.283E-07	-4.626E-08	-2.004E-08	-1.297E-07	3.417E-07	2.736E-08
8.00	-1.052E-06	-2.872E-07	-9.782E-07	-9.371E-08	-4.610E-08	-4.191E-07	5.471E-07	5.132E-08
7.00	-1.443E-06	-3.790E-07	-1.246E-06	-1.249E-07	-6.523E-08	-7.121E-07	6.675E-07	7.497E-08
5.30	-1.188E-05	-3.098E-06	-9.674E-06	-1.136E-07	-6.534E-08	-9.190E-07	6.112E-07	8.284E-08
8.23	-8.218E-06	-2.131E-06	-5.970E-06	-3.152E-07	-1.592E-07	-2.634E-06	1.101E-06	1.880E-07
8.23	-1.295E-05	-3.449E-06	-8.993E-06	-5.948E-07	-2.885E-07	-4.351E-06	1.317E-06	2.770E-07
8.23	-1.903E-05	-5.149E-06	-1.304E-05	-9.289E-07	-4.601E-07	-6.191E-06	1.587E-06	3.746E-07
8.23	-2.529E-05	-6.867E-06	-1.695E-05	-1.273E-06	-6.362E-07	-7.848E-06	1.858E-06	4.636E-07
8.23	-3.162E-05	-8.534E-06	-1.997E-05	-1.831E-06	-7.920E-07	-9.031E-06	2.053E-06	5.260E-07
5.10	-2.265E-05	-6.116E-06	-1.325E-05	-1.251E-06	-7.974E-08	-5.892E-06	1.313E-06	3.402E-07
8.23	-3.850E-05	-1.041E-05	-2.143E-05	-2.437E-06	-1.402E-07	-9.422E-06	2.072E-06	5.397E-07
8.23	-3.692E-05	-9.887E-06	-1.973E-05	-2.430E-06	-1.366E-07	-8.632E-06	1.881E-06	4.895E-07
8.23	-3.187E-05	-8.362E-06	-1.636E-05	-2.042E-06	-9.733E-08	-7.189E-06	1.581E-06	4.037E-07
8.23	-2.454E-05	-6.280E-06	-1.206E-05	-1.456E-06	-3.035E-08	-5.296E-06	1.267E-06	2.998E-07
8.23	-1.671E-05	-4.156E-06	-7.866E-06	-8.583E-07	3.034E-08	-3.122E-06	1.026E-06	1.986E-07
5.50	-7.227E-06	-1.756E-06	-3.299E-06	-3.105E-07	3.151E-08	-9.277E-07	5.772E-07	8.552E-08
9.70	-6.584E-06	-1.532E-06	-2.771E-06	-2.509E-07	4.517E-08	-4.412E-07	7.500E-07	8.562E-08
10.00	-2.503E-06	-5.454E-07	-9.340E-07	-7.940E-08	2.689E-08	-1.249E-08	3.967E-07	3.634E-08
10.00	-8.767E-07	-1.785E-07	-2.959E-07	-2.550E-08	1.175E-08	6.839E-09	1.358E-07	1.215E-08
30.00	-4.278E-07	-7.853E-08	-1.246E-07	-3.684E-08	-1.428E-08	-3.404E-09	5.579E-09	4.260E-09
core	-2.683E-04	-7.134E-05	-1.556E-04	-1.542E-05	-2.790E-06	-6.961E-05	1.706E-05	4.101E-06

(Total: -6.225E-04)

TABLE 4.26. FUEL DENSITY COEFFICIENT IN BN-600-MA AT BOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	7.815E-03	2.511E-03	7.105E-03	0.000E+00				
8.23	1.090E-02	3.584E-03	1.056E-02	0.000E+00				
8.23	1.428E-02	4.783E-03	1.434E-02	0.000E+00				
8.23	1.730E-02	5.904E-03	1.781E-02	0.000E+00				
8.23	1.936E-02	6.775E-03	2.038E-02	0.000E+00				
5.10	-1.582E-03	4.458E-03	1.335E-02	0.000E+00				
8.23	2.135E-02	7.297E-03	2.156E-02	0.000E+00				
8.23	2.103E-02	6.965E-03	2.014E-02	0.000E+00				
8.23	1.904E-02	6.124E-03	1.725E-02	0.000E+00				
8.23	1.581E-02	4.940E-03	1.342E-02	0.000E+00				
8.23	1.222E-02	3.688E-03	9.456E-03	0.000E+00				
5.50	-2.811E-04	1.116E-05	3.489E-04	0.000E+00				
9.70	-5.028E-04	-4.963E-05	9.204E-05	0.000E+00				
10.00	-1.466E-04	-9.350E-06	1.124E-05	0.000E+00				
10.00	1.274E-05	1.067E-05	1.810E-05	0.000E+00				
Core	1.575E-01	5.703E-02	1.654E-01	0.000E+00				

(Total: 3.794E-01)

TABLE 4.27. SODIUM DENSITY COEFFICIENT IN BN-600-MA AT BOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.158E-07	2.999E-08	3.438E-07	2.175E-08	8.625E-09	5.218E-07	8.116E-07	6.706E-08
4.50	1.810E-08	5.352E-09	9.481E-08	3.063E-08	1.541E-08	2.889E-07	3.511E-07	6.425E-08
5.00	5.739E-08	1.699E-08	3.916E-08	2.806E-07	1.442E-07	8.407E-07	7.819E-07	1.480E-07
5.00	1.025E-06	2.856E-07	7.591E-07	1.513E-06	8.776E-07	2.214E-06	1.565E-06	2.959E-07
5.00	1.586E-05	4.315E-06	1.202E-05	5.627E-06	4.815E-06	5.752E-06	2.857E-06	5.503E-07
4.50	9.023E-05	2.490E-05	7.589E-05	3.069E-06	1.236E-05	7.055E-06	4.112E-06	8.360E-07
8.00	2.974E-04	8.423E-05	2.804E-04	-1.692E-06	1.437E-05	1.343E-05	1.183E-05	2.744E-06
8.00	4.240E-04	1.283E-04	4.261E-04	-5.746E-06	1.931E-05	1.774E-05	1.999E-05	5.295E-06
7.00	5.048E-04	1.675E-04	5.707E-04	-7.390E-06	4.133E-05	2.144E-05	2.804E-05	7.934E-06
5.30	2.252E-04	7.999E-05	2.465E-04	4.925E-06	9.426E-05	2.780E-05	3.135E-05	8.941E-06
8.23	9.381E-05	3.661E-05	2.217E-04	-9.001E-06	1.710E-04	7.863E-05	7.344E-05	2.065E-05
8.23	-4.624E-04	-1.449E-04	-7.889E-05	-8.386E-05	1.072E-04	1.183E-04	1.090E-04	3.075E-05
8.23	-1.063E-03	-3.415E-04	-3.945E-04	-1.700E-04	1.655E-05	1.534E-04	1.452E-04	4.169E-05
8.23	-1.594E-03	-5.180E-04	-6.767E-04	-2.460E-04	-6.907E-05	1.824E-04	1.766E-04	5.157E-05
8.23	-1.946E-03	-6.393E-04	-8.764E-04	-2.744E-04	-1.284E-04	2.026E-04	1.984E-04	5.849E-05
5.10	-1.442E-03	-4.251E-04	-5.920E-04	-2.846E-04	-9.447E-05	1.308E-04	1.281E-04	3.784E-05
8.23	-2.107E-03	-6.845E-04	-9.368E-04	-5.152E-04	-1.632E-04	2.108E-04	2.046E-04	6.008E-05
8.23	-2.006E-03	-6.104E-04	-7.878E-04	-4.303E-04	-1.419E-04	1.992E-04	1.889E-04	5.459E-05
8.23	-1.558E-03	-4.506E-04	-5.085E-04	-1.556E-04	-4.957E-05	1.761E-04	1.606E-04	4.514E-05
8.23	-8.617E-04	-2.319E-04	-1.410E-04	2.443E-04	9.225E-05	1.441E-04	1.242E-04	3.357E-05
8.23	-9.275E-05	-3.038E-06	2.437E-04	6.226E-04	2.294E-04	1.059E-04	8.527E-05	2.213E-05
5.50	1.032E-04	4.693E-05	1.775E-04	4.610E-04	1.708E-04	4.516E-05	3.706E-05	9.415E-06
9.70	7.659E-05	3.636E-05	1.157E-04	5.034E-04	1.904E-04	3.994E-05	3.665E-05	9.237E-06
10.00	2.686E-05	1.197E-05	2.903E-05	2.128E-04	8.348E-05	1.511E-05	1.537E-05	3.815E-06
10.00	1.703E-05	5.441E-06	9.597E-06	7.494E-05	3.031E-05	5.259E-06	5.457E-06	1.305E-06
30.00	1.476E-04	3.316E-05	5.825E-05	2.160E-05	8.239E-06	9.032E-06	8.781E-06	6.372E-07
core	-1.304E-02	-4.013E-03	-4.527E-03	-1.302E-03	-3.027E-05	1.702E-03	1.594E-03	4.565E-04

(Total: -1.218E-02)

TABLE 4.28. STEEL DENSITY COEFFICIENT IN BN-600-MA AT BOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	9.464E-08	2.558E-08	2.760E-07	1.681E-08	6.849E-09	3.888E-07	5.959E-07	4.929E-07
4.50	3.981E-08	1.231E-08	1.905E-07	4.509E-08	1.745E-08	1.042E-06	1.149E-06	4.686E-07
5.00	9.512E-09	6.312E-09	-2.648E-08	4.158E-07	1.607E-07	3.046E-06	2.503E-06	1.083E-06
5.00	1.038E-06	3.057E-07	8.253E-07	2.298E-06	1.001E-06	8.181E-06	4.976E-06	2.170E-06
5.00	2.161E-05	6.027E-06	1.811E-05	8.850E-06	5.923E-06	2.223E-05	9.044E-06	4.036E-06
4.50	1.780E-04	4.923E-05	1.537E-04	5.212E-06	5.677E-06	2.676E-05	1.290E-05	6.128E-06
8.00	1.177E-04	3.300E-05	1.068E-04	-1.501E-06	6.299E-06	4.414E-05	3.622E-05	2.005E-05
8.00	1.636E-04	4.833E-05	1.512E-04	-6.639E-06	7.946E-06	5.196E-05	6.008E-05	3.846E-05
7.00	1.918E-04	6.165E-05	1.933E-04	-7.124E-06	1.618E-05	5.968E-05	8.487E-05	5.726E-05
5.30	9.645E-04	3.525E-04	1.018E-03	1.177E-05	3.555E-05	8.726E-05	9.701E-05	6.426E-05
8.23	2.866E-05	1.950E-05	2.543E-04	-1.938E-05	6.406E-05	2.806E-04	2.337E-04	1.479E-04
8.23	-1.257E-03	-3.996E-04	-4.792E-04	-1.547E-04	3.918E-05	4.301E-04	3.518E-04	2.195E-04
8.23	-2.639E-03	-8.533E-04	-1.272E-03	-3.040E-04	2.036E-06	5.564E-04	4.702E-04	2.969E-04
8.23	-3.866E-03	-1.263E-03	-1.983E-03	-4.358E-04	-3.329E-05	6.589E-04	5.719E-04	3.668E-04
8.23	-4.716E-03	-1.561E-03	-2.493E-03	-4.953E-04	-5.795E-05	7.303E-04	6.422E-04	4.158E-04
5.10	-3.238E-03	-1.054E-03	-1.675E-03	-1.132E-04	-2.917E-05	4.717E-04	4.149E-04	2.689E-04
8.23	-5.277E-03	-1.721E-03	-2.669E-03	-2.242E-04	-5.070E-05	7.619E-04	6.632E-04	4.271E-04
8.23	-5.096E-03	-1.560E-03	-2.310E-03	-1.954E-04	-4.496E-05	7.244E-04	6.140E-04	3.883E-04
8.23	-4.067E-03	-1.189E-03	-1.625E-03	-8.438E-05	-1.808E-05	6.463E-04	5.240E-04	3.215E-04
8.23	-2.436E-03	-6.742E-04	-7.168E-04	7.936E-05	2.360E-05	5.346E-04	4.061E-04	2.396E-04
8.23	-6.084E-04	-1.277E-04	2.440E-04	2.350E-04	6.391E-05	3.945E-04	2.779E-04	1.584E-04
5.50	1.113E-04	6.996E-05	3.066E-04	1.781E-04	4.829E-05	1.625E-04	1.191E-04	6.758E-05
9.70	1.269E-04	6.871E-05	2.306E-04	1.977E-04	5.478E-05	1.347E-04	1.152E-04	6.655E-05
10.00	6.357E-05	2.814E-05	7.023E-05	8.470E-05	2.438E-05	4.842E-05	4.724E-05	2.764E-05
10.00	3.632E-05	1.223E-05	2.295E-05	2.952E-05	8.740E-06	1.708E-05	1.675E-05	9.533E-06
30.00	1.123E-04	2.529E-05	4.516E-05	1.607E-05	6.130E-06	6.935E-06	6.481E-06	4.874E-06
core	-3.317E-02	-1.038E-02	-1.472E-02	-1.712E-03	-4.135E-05	6.190E-03	5.170E-03	3.251E-03

(Total: -3.781E-02)

TABLE 4.29. FUEL DOPPLER COEFFICIENT IN BN-600-MA AT EOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	-7.286E-05	-1.802E-05	-5.763E-05					
8.23	-8.120E-05	-1.965E-05	-5.624E-05					
8.23	-1.108E-04	-2.700E-05	-7.405E-05					
8.23	-1.464E-04	-3.546E-05	-9.389E-05					
8.23	-1.903E-04	-4.488E-05	-1.099E-04					
5.10	-2.215E-04	-3.351E-05	-7.308E-05					
8.23	-2.430E-04	-5.829E-05	-1.189E-04					
8.23	-2.313E-04	-5.632E-05	-1.110E-04					
8.23	-2.035E-04	-4.902E-05	-9.465E-05					
8.23	-1.664E-04	-3.935E-05	-7.457E-05					
8.23	-1.341E-04	-3.121E-05	-5.884E-05					
5.50	-1.168E-04	-2.729E-05	-5.405E-05					
9.70	-1.288E-04	-2.869E-05	-5.381E-05					
10.00	-6.116E-05	-1.282E-05	-2.257E-05					
10.00	-2.791E-05	-5.538E-06	-9.388E-06					
core	-1.801E-03	-4.127E-04	-9.228E-04					

(Total: -3.686E-03)

TABLE 4.30. STEEL DOPPLER COEFFICIENT IN BN-600-MA AT EOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.346E-10	4.046E-11	8.169E-10	2.240E-11	7.498E-12	1.300E-09	2.063E-09	7.350E-10
4.50	2.282E-11	4.958E-12	3.523E-10	4.492E-11	1.309E-11	6.610E-09	9.970E-09	6.932E-10
5.00	1.888E-10	4.901E-11	1.496E-10	4.583E-10	1.544E-10	1.844E-08	2.412E-08	1.565E-09
5.00	2.500E-09	6.521E-10	1.605E-09	2.807E-09	1.152E-09	4.160E-08	4.795E-08	3.043E-09
5.00	2.081E-08	5.042E-09	8.984E-09	1.041E-08	6.450E-09	7.174E-08	8.417E-08	5.494E-09
4.50	-2.331E-07	-6.762E-08	-2.737E-07	-1.517E-09	9.240E-10	3.520E-08	1.163E-07	8.139E-09
8.00	-5.294E-07	-1.466E-07	-5.073E-07	-4.567E-08	-1.985E-08	-1.211E-07	3.280E-07	2.594E-08
8.00	-1.047E-06	-2.789E-07	-9.404E-07	-9.275E-08	-4.581E-08	-3.945E-07	5.266E-07	4.862E-08
7.00	-1.440E-06	-3.687E-07	-1.199E-06	-1.239E-07	-6.495E-08	-6.711E-07	6.450E-07	7.100E-08
5.30	-1.197E-05	-3.033E-06	-9.347E-06	-1.130E-07	-6.515E-08	-8.683E-07	5.931E-07	7.844E-08
8.23	-8.374E-06	-2.103E-06	-5.794E-06	-3.154E-07	-1.606E-07	-2.498E-06	1.076E-06	1.780E-07
8.23	-1.331E-05	-3.419E-06	-8.756E-06	-5.990E-07	-2.941E-07	-4.135E-06	1.297E-06	2.627E-07
8.23	-1.967E-05	-5.123E-06	-1.273E-05	-9.408E-07	-4.721E-07	-5.896E-06	1.573E-06	3.558E-07
8.23	-2.629E-05	-6.861E-06	-1.661E-05	-1.298E-06	-6.569E-07	-7.493E-06	1.850E-06	4.413E-07
8.23	-3.305E-05	-8.570E-06	-1.964E-05	-1.883E-06	-8.226E-07	-8.652E-06	2.053E-06	5.022E-07
5.10	-2.357E-05	-6.172E-06	-1.308E-05	-1.293E-06	-9.210E-08	-5.663E-06	1.317E-06	3.258E-07
8.23	-4.063E-05	-1.056E-05	-2.126E-05	-2.536E-06	-1.648E-07	-9.089E-06	2.087E-06	5.186E-07
8.23	-3.923E-05	-1.010E-05	-1.970E-05	-2.549E-06	-1.635E-07	-8.372E-06	1.903E-06	4.726E-07
8.23	-3.414E-05	-8.615E-06	-1.646E-05	-2.166E-06	-1.224E-07	-7.023E-06	1.605E-06	3.921E-07
8.23	-2.660E-05	-6.545E-06	-1.228E-05	-1.574E-06	-5.049E-08	-5.236E-06	1.280E-06	2.933E-07
8.23	-1.845E-05	-4.411E-06	-8.148E-06	-9.625E-07	2.025E-08	-3.177E-06	1.015E-06	1.958E-07
5.50	-8.299E-06	-1.926E-06	-3.525E-06	-3.708E-07	3.290E-08	-1.020E-06	5.566E-07	8.496E-08
9.70	-8.037E-06	-1.784E-06	-3.146E-06	-3.315E-07	5.530E-08	-6.108E-07	7.104E-07	8.580E-08
10.00	-3.349E-06	-6.970E-07	-1.168E-06	-1.242E-07	3.664E-08	-1.187E-07	3.724E-07	3.692E-08
10.00	-1.272E-06	-2.490E-07	-4.060E-07	-4.484E-08	1.730E-08	-3.733E-08	1.256E-07	1.243E-08
30.00	-6.993E-07	-1.256E-07	-2.006E-07	-6.193E-08	-2.386E-08	-1.025E-08	2.007E-09	3.968E-09
core	-2.833E-04	-7.248E-05	-1.545E-04	-1.612E-05	-2.979E-06	-6.723E-05	1.706E-05	3.938E-06

(Total: -6.422E-04)

TABLE 4.31. FUEL DENSITY COEFFICIENT IN BN-600-MA AT EOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
8.23	7.884E-03	2.409E-03	6.822E-03					
8.23	1.103E-02	3.435E-03	1.014E-02					
8.23	1.452E-02	4.590E-03	1.382E-02					
8.23	1.771E-02	5.687E-03	1.723E-02					
8.23	1.997E-02	6.559E-03	1.980E-02					
5.10	-1.191E-04	4.333E-03	1.301E-02					
8.23	2.218E-02	7.119E-03	2.109E-02					
8.23	2.189E-02	6.827E-03	1.980E-02					
8.23	1.988E-02	6.039E-03	1.705E-02					
8.23	1.659E-02	4.907E-03	1.337E-02					
8.23	1.286E-02	3.691E-03	9.509E-03					
5.50	1.529E-04	1.040E-04	4.747E-04					
9.70	-3.115E-04	-6.881E-06	1.499E-04					
10.00	-5.709E-05	1.070E-05	3.787E-05					
10.00	6.903E-05	2.215E-05	3.266E-05					
Core	1.644E-01	5.560E-02	1.616E-01					

(Total:3.823E-01)

TABLE 4.32. SODIUM DENSITY COEFFICIENT IN BN-600-MA AT EOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	1.146E-07	2.900E-08	3.260E-07	2.140E-08	8.539E-09	4.952E-07	7.703E-07	6.361E-08
4.50	1.817E-08	5.259E-09	8.979E-08	3.019E-08	1.529E-08	2.748E-07	3.338E-07	6.097E-08
5.00	5.717E-08	1.642E-08	3.736E-08	2.766E-07	1.430E-07	8.002E-07	7.438E-07	1.405E-07
5.00	1.020E-06	2.766E-07	7.268E-07	1.494E-06	8.718E-07	2.111E-06	1.489E-06	2.810E-07
5.00	1.583E-05	4.194E-06	1.157E-05	5.566E-06	4.792E-06	5.494E-06	2.721E-06	5.226E-07
4.50	9.015E-05	2.421E-05	7.302E-05	3.040E-06	1.232E-05	6.746E-06	3.916E-06	7.940E-07
8.00	2.988E-04	8.195E-05	2.696E-04	-1.673E-06	1.439E-05	1.284E-05	1.127E-05	2.606E-06
8.00	4.288E-04	1.247E-04	4.084E-04	-5.682E-06	1.951E-05	1.692E-05	1.902E-05	5.028E-06
7.00	5.142E-04	1.625E-04	5.455E-04	-7.295E-06	4.201E-05	2.039E-05	2.668E-05	7.532E-06
5.30	2.299E-04	7.723E-05	2.340E-04	5.019E-06	9.597E-05	2.636E-05	2.982E-05	8.489E-06
8.23	1.003E-04	3.764E-05	2.341E-04	-8.041E-06	1.760E-04	7.471E-05	6.990E-05	1.961E-05
8.23	-4.551E-04	-1.349E-04	-3.565E-05	-8.213E-05	1.141E-04	1.127E-04	1.039E-04	2.924E-05
8.23	-1.062E-03	-3.237E-04	-3.216E-04	-1.685E-04	2.382E-05	1.465E-04	1.387E-04	3.971E-05
8.23	-1.611E-03	-4.955E-04	-5.797E-04	-2.460E-04	-6.337E-05	1.747E-04	1.691E-04	4.925E-05
8.23	-1.988E-03	-6.160E-04	-7.651E-04	-2.756E-04	-1.264E-04	1.946E-04	1.905E-04	5.603E-05
5.10	-1.398E-03	-4.119E-04	-5.213E-04	-2.829E-04	-9.537E-05	1.260E-04	1.234E-04	3.635E-05
8.23	-2.182E-03	-6.662E-04	-8.291E-04	-5.204E-04	-1.670E-04	2.036E-04	1.976E-04	5.792E-05
8.23	-2.089E-03	-5.982E-04	-6.992E-04	-4.427E-04	-1.474E-04	1.931E-04	1.833E-04	5.289E-05
8.23	-1.646E-03	-4.472E-04	-4.500E-04	-1.749E-04	-5.671E-05	1.713E-04	1.566E-04	4.402E-05
8.23	-9.465E-04	-2.376E-04	-1.192E-04	2.212E-04	8.460E-05	1.408E-04	1.219E-04	3.300E-05
8.23	-1.627E-04	-1.504E-05	2.291E-04	6.042E-04	2.242E-04	1.040E-04	8.439E-05	2.200E-05
5.50	7.971E-05	4.129E-05	1.676E-04	4.599E-04	1.716E-04	4.480E-05	3.706E-05	9.474E-06
9.70	7.127E-05	3.566E-05	1.157E-04	5.223E-04	1.991E-04	4.040E-05	3.719E-05	9.446E-06
10.00	3.285E-05	1.372E-05	3.245E-05	2.357E-04	9.320E-05	1.579E-05	1.599E-05	4.010E-06
10.00	2.579E-05	7.347E-06	1.249E-05	9.085E-05	3.704E-05	5.724E-06	5.861E-06	1.422E-06
30.00	2.172E-04	4.620E-05	7.897E-05	2.988E-05	1.144E-05	1.119E-05	1.042E-05	7.338E-07
core	-1.344E-02	-3.909E-03	-3.858E-03	-1.376E-03	-3.355E-05	1.642E-03	1.539E-03	4.400E-04

(Total: -1.191E-02)

TABLE 4.33. STEEL DENSITY COEFFICIENT IN BN-600-MA AT EOC, FZK/IKET

DZ	LEZ	MEZ	HEZ	SHR	SCR	SAS1	SAS23	RR
30.00	9.367E-08	2.473E-08	2.620E-07	1.653E-08	6.779E-09	3.694E-07	5.661E-07	4.679E-07
4.50	3.982E-08	1.202E-08	1.808E-07	4.444E-08	1.730E-08	9.905E-07	1.092E-06	4.451E-07
5.00	9.911E-09	6.084E-09	-2.527E-08	4.099E-07	1.594E-07	2.899E-06	2.381E-06	1.029E-06
5.00	1.034E-06	2.956E-07	7.900E-07	2.269E-06	9.942E-07	7.800E-06	4.734E-06	2.062E-06
5.00	2.156E-05	5.853E-06	1.742E-05	8.755E-06	5.895E-06	2.124E-05	8.609E-06	3.837E-06
4.50	1.780E-04	4.796E-05	1.482E-04	5.165E-06	5.657E-06	2.558E-05	1.228E-05	5.828E-06
8.00	1.183E-04	3.212E-05	1.028E-04	-1.478E-06	6.310E-06	4.213E-05	3.446E-05	1.907E-05
8.00	1.655E-04	4.700E-05	1.452E-04	-6.548E-06	8.027E-06	4.942E-05	5.710E-05	3.657E-05
7.00	1.953E-04	5.985E-05	1.850E-04	-6.980E-06	1.646E-05	5.650E-05	8.058E-05	5.446E-05
5.30	9.912E-04	3.407E-04	9.666E-04	1.198E-05	3.622E-05	8.238E-05	9.208E-05	6.112E-05
8.23	4.611E-05	2.502E-05	2.955E-04	-1.734E-05	6.598E-05	2.658E-04	2.219E-04	1.407E-04
8.23	-1.235E-03	-3.734E-04	-3.666E-04	-1.508E-04	4.189E-05	4.088E-04	3.347E-04	2.092E-04
8.23	-2.631E-03	-8.090E-04	-1.088E-03	-2.999E-04	4.959E-06	5.303E-04	4.481E-04	2.835E-04
8.23	-3.897E-03	-1.208E-03	-1.741E-03	-4.339E-04	-3.102E-05	6.297E-04	5.463E-04	3.511E-04
8.23	-4.815E-03	-1.504E-03	-2.218E-03	-4.959E-04	-5.728E-05	6.999E-04	6.151E-04	3.992E-04
5.10	-3.217E-03	-1.022E-03	-1.501E-03	-1.122E-04	-2.952E-05	4.532E-04	3.985E-04	2.589E-04
8.23	-5.459E-03	-1.676E-03	-2.404E-03	-2.263E-04	-5.187E-05	7.339E-04	6.389E-04	4.126E-04
8.23	-5.290E-03	-1.530E-03	-2.091E-03	-2.005E-04	-4.661E-05	7.002E-04	5.941E-04	3.770E-04
8.23	-4.272E-03	-1.180E-03	-1.477E-03	-9.245E-05	-2.021E-05	6.269E-04	5.095E-04	3.142E-04
8.23	-2.638E-03	-6.861E-04	-6.539E-04	6.952E-05	2.128E-05	5.206E-04	3.974E-04	2.360E-04
8.23	-7.832E-04	-1.550E-04	2.261E-04	2.274E-04	6.244E-05	3.860E-04	2.744E-04	1.578E-04
5.50	4.487E-05	5.569E-05	2.837E-04	1.776E-04	4.857E-05	1.605E-04	1.189E-04	6.818E-05
9.70	8.336E-05	6.125E-05	2.206E-04	2.044E-04	5.714E-05	1.358E-04	1.169E-04	6.825E-05
10.00	5.767E-05	2.827E-05	7.149E-05	9.330E-05	2.707E-05	5.056E-05	4.927E-05	2.916E-05
10.00	4.592E-05	1.463E-05	2.639E-05	3.550E-05	1.057E-05	1.864E-05	1.801E-05	1.044E-05
30.00	1.618E-04	3.465E-05	6.015E-05	2.196E-05	8.405E-06	8.511E-06	7.657E-06	5.675E-06
core	-3.419E-02	-1.012E-02	-1.302E-02	-1.732E-03	-3.995E-05	5.955E-03	4.979E-03	3.140E-03

(Total: -3.755E-02)

4.3.3 IGCAR results

4.3.3.1 Analytical methods

The core model used in the analysis is based on the 60° sector layout provided by the IPPE for BOC. The nuclear data are taken from XSET-98, a 26-group dataset with ABBN type self-shielding f-factor tables. The homogeneous core model was employed for core calculations with the 3DB code based on the diffusion theory. The reactivity coefficient distributions were computed with 3DPERT. The delayed neutron data for 235-U, 238-U, 239–242-Pu are those given by Tuttle (1979), for other actinides the delayed data are taken from XSET-98. The power distribution is calculated assuming 200 MeV per fission energy release at the point of fission, no energy release by neutron capture.

Igcar results of phase-6 are pertaining to the BOC condition only: k_{EFF}, βeff and prompt neutron life time, fuel Doppler coefficient, na-density coefficient, steel density coefficient. The multiplication factor and prompt neutron lifetime are given in Table 4.34. The delayed neutron parameters are given in Table 4.35. The spatial distribution of the fuel Doppler coefficient (node-wise) is given in Table 4.36, the zone-wise distributions fuel Doppler coefficient of the sodium density coefficient (including the leakage and non-leakage components) of the steel coefficient in Table 4.37, Table 4.38 and Table 4.39. The power density distribution is given in: Table 4.40 and Fig. 4.1.

TABLE 4.34. MULTIPLICATION FACTOR AND PROMPT NEUTRON LIFETIME, IGCAR

k_{eff}	1.00238
Prompt Neutron Life Time	3.178×10^{-7}s

TABLE 4.35. DELAYED NEUTRON PARAMETERS, IGCAR

Delayed Neutron Group	Delayed Neutron Fraction	Decay Constant (s-1)
1	7.4390	0.01298
2	62.688	0.03138
3	55.3203	0.13470
4	107.2847	0.34300
5	49.0038	1.35600
6	15.5902	3.75300
Total Delayed Neutron Fraction = 297.33 pcm		

TABLE 4.36. FUEL DOPPLER COEFFICIENT, IGCAR

Region	DZ (Total)	DZ (cm)	LEZ	MEZ	HEZ
CORE	41.15 cm	8.23	-7.383E-05	-2.019E-05	-6.914E-05
		8.23	-8.100E-05	-2.157E-05	-6.840E-05
		8.23	-1.097E-04	-2.947E-05	-9.034E-05
		8.23	-1.437E-04	-3.849E-05	-1.142E-04
		8.23	-1.844E-04	-4.806E-05	-1.327E-04
IBZ	5.1 cm	5.1	-2.166E-04	-3.524E-05	-8.753E-05
CORE	41.15 cm	8.23	-2.291E-04	-6.034E-05	-1.416E-04
		8.23	-2.168E-04	-5.783E-05	-1.313E-04
		8.23	-1.893E-04	-4.984E-05	-1.107E-04
		8.23	-1.527E-04	-3.943E-05	-8.579E-05
		8.23	-1.201E-04	-3.059E-05	-6.602E-05
AB-1	5.5 cm	5.5	-1.004E-04	-2.600E-05	-5.839E-05
AB-2	29.7 cm	9.7	-9.991E-05	-2.463E-05	-5.192E-05
		10.0	-4.369E-05	-1.005E-05	-1.965E-05
		10.0	-1.935E-05	-4.184E-06	-7.774E-06
REFL	30.0 cm	30.0	0.0	0.0	0.0

TABLE 4.37. FUEL DOPPLER COEFFICIENT

LEZ	- 1.981E-03
MEZ	- 4.959E-04
HEZ	- 1.235E-03
TOTAL	- 3.712E-03

TABLE 4.38. SODIUM DENSITY COEFFICIENT (TOTAL)

	Total= Leakage+Non-leakage	Leakage	Non-leakage
LEZ	-9.929E-03	6.668E-03	-1.660E-02
MEZ	-2.997E-03	2.216E-03	-5.213E-03
HEZ	-2.684E-03	9.600E-03	-1.229E-02
SHR	-3.781E-05	3.471E-03	-3.509E-03
SCR	6.263E-04	1.896E-03	-1.269E-03
SAS-1	6.829E-04	1.563E-03	-8.800E-04
SAS-2,3	3.482E-04	1.052E-03	-7.035E-04
RR	7.505E-05	1.767E-04	-1.016E-04
TOTAL	-1.392E-02	2.664E-02	-4.056E-02

TABLE 4.39. STEEL DENSITY COEFFICIENT

LEZ	-2.676E-02
MEZ	-8.330E-03
HEZ	-1.130E-02
SHR	-7.543E-04
SCR	2.052E-04
SAS-1	6.973E-03
SAS-2,3	4.794E-03
RR	1.501E-03
TOTAL	-3.368E-02

TABLE 4.40. POWER DISTRIBUTION BOC, W

Material	DZ Total (cm)	DZ (cm)	LEZ	MEZ	HEZ
Core	41.15	8.23	3.304E+07	1.118E+07	4.147E+07
		8.23	4.192E+07	1.439E+07	5.188E+07
		8.23	5.052E+07	1.748E+07	6.240E+07
		8.23	5.745E+07	1.999E+07	7.077E+07
		8.23	6.234E+07	2.182E+07	7.630E+07
IBZ (Core)	5.1	5.1	1.933E+07	1.414E+07	4.871E+07
Core	41.15	8.23	6.683E+07	2.313E+07	7.855E+07
		8.23	6.616E+07	2.251E+07	7.541E+07
		8.23	6.174E+07	2.070E+07	6.864E+07
		8.23	5.403E+07	1.786E+07	5.871E+07
		8.23	4.400E+07	1.430E+07	4.665E+07
AB-1	5.5	5.5	5.659E+06	1.692E+06	4.048E+06
AB-2	29.7	9.7	5.822E+06	1.689E+06	4.560E+06
		10	3.675E+06	1.023E+06	2.703E+06
		10	2.408E+06	6.479E+05	1.704E+06
		Sum	5.749E+08	2.026E+08	6.925E+08
		Total	1.47E+09		

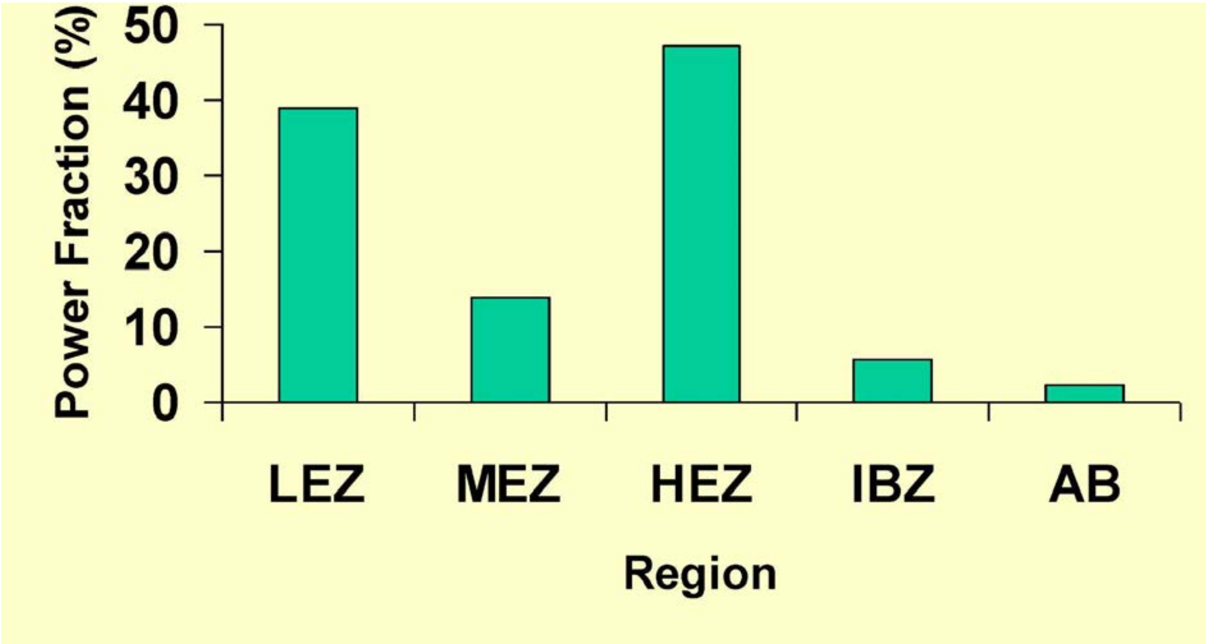


FIG. 4.1. Region-wise power distribution.

4.3.3.2 Comparison of IGCAR Results (Diffusion Theory) for Phase 4 and Phase 6

Table 4.41 compares reactivity coefficients of Phase 4 and Phase 6. A less negative fuel Doppler constant and more negative sodium density coefficient is observed, similar to the results of other CRP partners.

TABLE 4.41. COMPARISON OF REACTIVITY COEFFICIENTS FOR PHASE 4 AND PHASE 6, IGCAR

Parameter	Phase-6	Phase-4
KD -fuel	- 0.00371	- 0.00732
Na-Density coefficient (total)	- 0.01392	- 0.00015
Na-Density coefficient (L)	0.02664	0.02989
Na-Density coefficient (Non-L)	- 0.04056	- 0.02974
Steel Density coefficient	- 0.03368	–
Fuel Density coefficient	0.37057	0.37670

4.3.4 IPPE result

The IPPE performed calculations of the safety parameters and also transient analyses (ULOF simulations, see section 4.6.) Neutronics results are presented in this section. The calculation procedure is described in section 2.2.6.

4.3.4.1 Effective fraction of delayed neutrons

Effective fractions of delayed neutrons are presented in the Table 4.42 and Table 4.43.

TABLE 4.42. EFFECTIVES FRACTION OF DELAYED NEUTRONS 6 GROUP AT BOC, IPPE

	1 group	2 group	3 group	4 group	5 group	6 group	Total
βeff	7.450E-05	6.240E-04	5.560E-04	1.080E-03	4.930E-04	1.640E-04	2.99E-03

TABLE 4.43. EFFECTIVE FRACTIONS OF DELAYED NEUTRONS FOR 6 GROUPS AT EOC, IPPE

	1 group	2 group	3 group	4 group	5 group	6 group	Total
βeff	7.43E-05	6.43E-04	5.47E-04	1.11E-03	5.02E-04	1.60E-04	3.04E-03

4.3.4.2 Doppler constant for steel

Doppler constants for steel are presented in Tables 4.44 and 4.45.

TABLE 4.44. DOPPLER CONSTANT FOR STEEL AT BOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
	30.00	3.29E-11	-8.03E-12	-1.57E-10	-8.62E-12	-1.69E-13	-9.68E-10	-1.89E-09	-4.24E-10
cones	4.50	-2.98E-11	-1.02E-11	-1.34E-10	-4.39E-13	-2.48E-11	-1.17E-09	-2.27E-09	-4.42E-10
	5.00	3.45E-11	1.52E-11	8.83E-10	-1.41E-11	-1.81E-11	-3.48E-09	-4.48E-09	-9.78E-10
Upper boron shield	5.00	9.27E-11	5.35E-11	1.54E-09	-9.70E-11	-3.62E-11	-9.19E-09	-9.94E-09	-1.92E-09
	5.00	-4.52E-09	-1.20E-09	-3.03E-10	-5.40E-10	-3.76E-10	-2.55E-08	-2.26E-08	-3.62E-09
cones	4.50	-2.76E-07	-8.04E-08	-2.80E-07	2.42E-09	-3.20E-09	-6.45E-08	-3.61E-08	-5.56E-09
	8.00	-2.82E-07	-8.27E-08	-3.03E-07	-6.49E-09	-1.22E-08	-2.44E-07	-1.20E-07	-1.80E-08
Sodium plenum	8.00	-5.23E-07	-1.45E-07	-5.17E-07	-2.85E-08	-2.24E-08	-4.31E-07	-2.26E-07	-3.47E-08
	7.00	-7.01E-07	-2.06E-07	-6.88E-07	-2.98E-08	-3.57E-08	-6.07E-07	-3.15E-07	-5.26E-08
Plugs	5.30	-4.51E-06	-1.19E-06	-3.61E-06	-1.65E-08	-4.28E-08	-9.10E-07	-3.60E-07	-5.99E-08
	8.23	-3.62E-06	-9.88E-07	-2.82E-06	-4.18E-08	-9.32E-08	-1.48E-06	-8.44E-07	-1.38E-07
	8.23	-5.40E-06	-1.53E-06	-4.23E-06	-1.06E-07	-1.42E-07	-2.24E-06	-1.27E-06	-2.03E-07
	8.23	-7.70E-06	-2.19E-06	-5.93E-06	-1.72E-07	-2.01E-07	-3.06E-06	-1.71E-06	-2.67E-07
	8.23	-9.97E-06	-2.86E-06	-7.59E-06	-2.36E-07	-2.58E-07	-3.80E-06	-2.12E-06	-3.30E-07
	8.23	-1.21E-05	-3.46E-06	-8.86E-06	-4.46E-07	-2.11E-07	-4.33E-06	-2.34E-06	-3.73E-07
IBZ	5.10	-8.51E-06	-2.47E-06	-5.83E-06	-4.57E-07	-1.45E-07	-2.82E-06	-1.62E-06	-2.41E-07
	8.23	-1.46E-05	-4.15E-06	-9.48E-06	-9.04E-07	-2.33E-07	-4.48E-06	-2.61E-06	-3.85E-07
	8.23	-1.41E-05	-3.96E-06	-8.77E-06	-9.32E-07	-2.22E-07	-4.09E-06	-2.40E-06	-3.53E-07
	8.23	-1.23E-05	-3.39E-06	-7.40E-06	-8.31E-07	-1.93E-07	-3.38E-06	-1.98E-06	-2.94E-07
	8.23	-9.68E-06	-2.61E-06	-5.58E-06	-6.54E-07	-1.52E-07	-2.55E-06	-1.41E-06	-2.21E-07
	8.23	-6.84E-06	-1.80E-06	-3.73E-06	-4.61E-07	-1.08E-07	-1.65E-06	-9.21E-07	-1.47E-07
Axial blanket 1	5.50	-2.79E-06	-7.19E-07	-1.48E-06	-2.03E-07	-4.91E-08	-7.11E-07	-3.72E-07	-6.23E-08
	9.70	-2.33E-06	-5.78E-07	-1.13E-06	-1.84E-07	-4.67E-08	-5.45E-07	-3.49E-07	-5.92E-08
Axial blanket 2	10.00	-8.68E-07	-2.01E-07	-3.74E-07	-7.03E-08	-1.92E-08	-1.84E-07	-1.41E-07	-2.31E-08
	10.00	-2.69E-07	-5.88E-08	-9.76E-08	-2.39E-08	-1.54E-08	-1.91E-08	-5.15E-08	-1.02E-08
Reflector	30.00	-1.86E-07	-3.88E-08	-5.53E-06	-2.01E-08	-7.53E-09	-1.60E-08	-1.13E-08	-6.77E-09
SUM									-3.05E-04

TABLE 4.45. DOPPLER CONSTANT FOR STEEL AT EOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	-3.56E-11	-1.28E-11	-2.06E-10	-4.52E-12	-1.26E-12	-1.09E-09	-2.06E-09	-5.46E-10
cones	4.50	-3.81E-11	-1.18E-11	-1.76E-10	-4.68E-12	3.05E-13	-1.32E-09	-2.42E-09	-5.84E-10
	5.00	-2.24E-11	-5.26E-12	-3.70E-12	-2.49E-11	-7.06E-12	-3.52E-09	-4.73E-09	-1.16E-09
Upper boron shield	5.00	-3.87E-10	-1.04E-10	-2.56E-10	-1.52E-10	-5.18E-11	-9.14E-09	-9.81E-09	-2.11E-09
	5.00	-7.62E-09	-2.16E-09	-6.89E-09	-8.44E-10	-4.03E-10	-2.52E-08	-2.22E-08	-3.90E-09
cones	4.50	-2.84E-07	-8.07E-08	-2.81E-07	-2.61E-09	-3.46E-09	-6.14E-08	-3.54E-08	-5.77E-09
	8.00	-3.12E-07	-8.88E-08	-3.19E-07	-1.41E-08	-1.27E-08	-2.41E-07	-1.17E-07	-1.80E-08
Sodium plenum	8.00	-5.23E-07	-1.48E-07	-5.20E-07	-2.59E-08	-2.34E-08	-4.40E-07	-2.24E-07	-3.37E-08
	7.00	-7.25E-07	-2.01E-07	-6.75E-07	-3.28E-08	-3.62E-08	-5.99E-07	-3.13E-07	-4.99E-08
Plugs	5.30	-4.53E-06	-1.22E-06	-3.67E-06	-3.35E-08	-4.42E-08	-6.13E-07	-3.51E-07	-5.64E-08
	8.23	-3.56E-06	-9.88E-07	-2.80E-06	-9.33E-08	-9.77E-08	-1.44E-06	-8.02E-07	-1.37E-07
	8.23	-5.62E-06	-1.53E-06	-4.16E-06	-1.73E-07	-1.47E-07	-2.17E-06	-1.24E-06	-2.01E-07
	8.23	-8.02E-06	-2.20E-06	-5.85E-06	-2.64E-07	-2.07E-07	-2.98E-06	-1.67E-06	-2.68E-07
	8.23	-1.05E-05	-2.87E-06	-7.47E-06	-3.57E-07	-2.68E-07	-3.71E-06	-2.06E-06	-3.29E-07
	8.23	-1.28E-05	-3.50E-06	-8.74E-06	-5.63E-07	-2.22E-07	-4.21E-06	-2.34E-06	-3.71E-07
IBZ	5.10	-9.04E-06	-2.51E-06	-5.80E-06	-4.73E-07	-1.51E-07	-2.74E-06	-1.49E-06	-2.41E-07
	8.23	-1.55E-05	-4.22E-06	-9.41E-06	-9.41E-07	-2.46E-07	-4.36E-06	-2.71E-06	-3.71E-07
	8.23	-1.50E-05	-4.05E-06	-8.76E-06	-9.79E-07	-2.36E-07	-3.97E-06	-2.31E-06	-3.49E-07
	8.23	-1.33E-05	-3.50E-06	-7.45E-06	-8.77E-07	-2.07E-07	-3.43E-06	-1.94E-06	-2.92E-07
	8.23	-1.05E-05	-2.72E-06	-5.70E-06	-6.99E-07	-1.65E-07	-2.56E-06	-1.40E-06	-2.22E-07
	8.23	-7.48E-06	-1.88E-06	-3.89E-06	-4.96E-07	-1.19E-07	-1.69E-06	-9.33E-07	-1.50E-07
Axial blanket 1	5.50	-3.20E-06	-7.89E-07	-1.59E-06	-2.26E-07	-5.50E-08	-7.28E-07	-3.87E-07	-6.48E-08
	9.70	-2.90E-06	-6.84E-07	-1.31E-06	-2.17E-07	-5.47E-08	-6.23E-07	-3.75E-07	-6.36E-08
Axial blanket 2	10.00	-1.14E-06	-2.51E-07	-4.53E-07	-8.78E-08	-2.37E-08	-2.16E-07	-1.58E-07	-2.81E-08
	10.00	-3.76E-07	-7.89E-08	-1.36E-07	-3.06E-08	-2.07E-08	-2.41E-08	-6.27E-08	-1.19E-08
Reflector	30.00	-2.60E-07	-5.22E-08	-9.76E-08	-2.79E-08	-1.02E-08	-1.33E-08	-1.15E-08	-8.42E-09
Sum									-3.08E-04

4.3.4.3 Doppler constant for the fuel

Doppler constants for the fuel are presented in Tables 4.46 and 4.47.

TABLE 4.46. DOPPLER CONSTANT FOR THE FUEL AT BOC, IPPE

Russian Federation (IPPE)					0.	0.	0.	0.	0.
		LEZ	MEZ	HEZ	0.	0.	0.	0.	0.
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-7.668E-05	-2.027E-05	-7.192E-05	0.	0.	0.	0.	0.
	8.23	-7.727E-05	-1.920E-05	-6.330E-05	0.	0.	0.	0.	0.
	8.23	-1.022E-04	-2.541E-05	-8.054E-05	0.	0.	0.	0.	0.
	8.23	-1.334E-04	-3.299E-05	-1.008E-04	0.	0.	0.	0.	0.
	8.23	-1.700E-04	-4.131E-05	-1.168E-04	0.	0.	0.	0.	0.
IBZ	5.10	-1.997E-04	-3.150E-05	-7.757E-05	0.	0.	0.	0.	0.
	8.23	-2.140E-04	-5.320E-05	-1.251E-04	0.	0.	0.	0.	0.
	8.23	-2.039E-04	-5.112E-05	-1.162E-04	0.	0.	0.	0.	0.
	8.23	-1.789E-04	-4.428E-05	-9.867E-05	0.	0.	0.	0.	0.
	8.23	-1.456E-04	-3.566E-05	-7.787E-05	0.	0.	0.	0.	0.
	8.23	-1.159E-04	-2.812E-05	-6.122E-05	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-9.362E-05	-2.318E-05	-5.142E-05	0.	0.	0.	0.	0.
	9.70	-8.916E-05	-2.098E-05	-4.399E-05	0.	0.	0.	0.	0.
Axial blanket 2	10.00	-3.745E-05	-8.292E-06	-1.644E-05	0.	0.	0.	0.	0.
	10.00	-1.563E-05	-3.299E-06	-6.449E-06	0.	0.	0.	0.	0.
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
SUM									-3.401E-03

TABLE 4.47. DOPPLER CONSTANT FOR FUEL AT EOC, IPPE

Russian Federation (IPPE)					0.	0.	0.	0.	0.
		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-7.698E-05	-1.973E-05	-6.984E-05	0.	0.	0.	0.	0.
	8.23	-7.876E-05	-1.899E-05	-6.152E-05	0.	0.	0.	0.	0.
	8.23	-1.043E-04	-2.517E-05	-7.846E-05	0.	0.	0.	0.	0.
	8.23	-1.364E-04	-3.269E-05	-9.808E-05	0.	0.	0.	0.	0.
	8.23	-1.745E-04	-4.072E-05	-1.138E-04	0.	0.	0.	0.	0.
IBZ	5.10	-2.033E-04	-3.121E-05	-7.549E-05	0.	0.	0.	0.	0.
	8.23	-2.208E-04	-5.320E-05	-1.227E-04	0.	0.	0.	0.	0.
	8.23	-2.116E-04	-5.142E-05	-1.147E-04	0.	0.	0.	0.	0.
	8.23	-1.863E-04	-4.458E-05	-9.867E-05	0.	0.	0.	0.	0.
	8.23	-1.531E-04	-3.626E-05	-7.787E-05	0.	0.	0.	0.	0.
	8.23	-1.213E-04	-2.809E-05	-6.033E-05	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-1.046E-04	-2.491E-05	-5.409E-05	0.	0.	0.	0.	0.
	9.70	-1.109E-04	-2.499E-05	-5.112E-05	0.	0.	0.	0.	0.
Axial blanket 2	10.00	-5.112E-05	-1.088E-05	-2.101E-05	0.	0.	0.	0.	0.
	10.00	-2.214E-05	-4.488E-06	-8.530E-06	0.	0.	0.	0.	0.
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
SUM									-3.510E-03

4.3.4.4 Fuel worth (fuel density coefficient)

Values for fuel worth are presented in Tables 4.48 and 4.49.

TABLE 4.48. FUEL WORTH AT BOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
..	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	7.42E-03	2.44E-03	7.18E-03	0.	0.	0.	0.	0.
	8.23	1.04E-02	3.48E-03	1.07E-02	0.	0.	0.	0.	0.
	8.23	1.36E-02	4.63E-03	1.46E-02	0.	0.	0.	0.	0.
	8.23	1.65E-02	5.71E-03	1.81E-02	0.	0.	0.	0.	0.
	8.23	1.83E-02	6.53E-03	2.07E-02	0.	0.	0.	0.	0.
IBZ	5.10	-1.92E-03	4.26E-03	1.36E-02	0.	0.	0.	0.	0.
	8.23	2.03E-02	7.00E-03	2.20E-02	0.	0.	0.	0.	0.
	8.23	2.00E-02	6.70E-03	2.05E-02	0.	0.	0.	0.	0.
	8.23	1.82E-02	5.91E-03	1.77E-02	0.	0.	0.	0.	0.
	8.23	1.51E-02	4.79E-03	1.38E-02	0.	0.	0.	0.	0.
	8.23	1.17E-02	3.58E-03	9.81E-03	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-3.34E-04	1.59E-06	3.00E-04	0.	0.	0.	0.	0.
	9.70	-3.42E-04	5.75E-06	1.85E-04	0.	0.	0.	0.	0.
Axial blanket 2	10.00	-5.48E-05	2.01E-05	6.33E-05	0.	0.	0.	0.	0.
	10.00	5.75E-05	2.36E-05	3.67E-05	0.	0.	0.	0.	0.
Reflector	30.00	0.	0.	0.	0.	0.	0.	0.	0.
Sum									0.37E+00

TABLE 4.49. FUEL WORTH AT EOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cones	4.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Upper boron shield	5.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cones	4.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium plenum	8.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plugs	5.30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	7.64E-03	2.40E-03	6.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.06E-02	3.40E-03	1.03E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.39E-02	4.49E-03	1.39E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.68E-02	5.52E-03	1.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.89E-02	6.31E-03	1.97E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IBZ	5.10	-5.00E-04	4.13E-03	1.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	2.09E-02	6.80E-03	2.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	2.07E-02	6.55E-03	1.98E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.89E-02	5.84E-03	1.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.59E-02	4.80E-03	1.36E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8.23	1.24E-02	3.65E-03	9.84E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Axial blanket 1	5.50	6.82E-06	7.90E-05	4.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9.70	-9.82E-05	6.13E-05	2.66E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Axial blanket 2	10.00	1.45E-05	3.66E-05	8.56E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10.00	9.16E-05	3.12E-05	4.59E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Reflector	30.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUM									3.73E-01

4.3.4.5 Sodium worth (sodium density coefficient)

Values of sodium worth are presented in Tables 4.50 and 4.51.

TABLE 4.50. SODIUM WORTH AT BOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	1.51E-07	4.17E-08	4.27E-07	5.24E-08	2.51E-08	2.35E-07	3.29E-07	3.76E-08
cones	4.50	-3.77E-09	-1.32E-09	1.11E-07	5.22E-08	3.46E-08	2.60E-07	1.98E-07	2.26E-08
	5.00	1.66E-07	4.75E-08	1.61E-07	3.10E-07	2.15E-07	7.29E-07	4.36E-07	4.89E-08
Upper boron shield	5.00	2.00E-06	5.72E-07	1.65E-06	1.34E-06	1.12E-06	1.79E-06	8.19E-07	9.49E-08
	5.00	2.32E-05	6.52E-06	1.87E-05	3.81E-06	5.71E-06	3.64E-06	1.40E-06	1.76E-07
cones	4.50	7.00E-05	2.08E-05	6.72E-05	3.48E-06	1.16E-05	5.39E-06	2.01E-06	2.69E-07
	8.00	2.63E-04	8.18E-05	2.73E-04	-2.18E-06	1.65E-05	9.14E-06	5.15E-06	8.47E-07
Sodium plenum	8.00	3.97E-04	1.31E-04	4.24E-04	-8.62E-06	2.23E-05	9.30E-06	7.29E-06	1.57E-06
	7.00	4.78E-04	1.70E-04	5.62E-04	-9.97E-06	4.94E-05	1.08E-05	9.45E-06	2.34E-06
Plugs	5.30	1.76E-04	6.55E-05	2.07E-04	-8.58E-06	7.55E-05	1.19E-05	1.07E-05	2.72E-06
	8.23	1.04E-04	5.09E-05	2.54E-04	-3.37E-05	1.47E-04	4.31E-05	2.71E-05	6.40E-06
	8.23	-3.87E-04	-1.07E-04	-2.19E-05	-9.72E-05	1.03E-04	7.05E-05	4.20E-05	9.69E-06
	8.23	-9.18E-04	-2.77E-04	-3.07E-04	-1.77E-04	2.35E-05	9.24E-05	5.58E-05	1.32E-05
	8.23	-1.40E-03	-4.32E-04	-5.60E-04	-2.53E-04	-5.52E-05	1.10E-04	6.70E-05	1.62E-05
	8.23	-1.73E-03	-5.45E-04	-7.38E-04	-2.85E-04	-1.16E-04	1.22E-04	7.46E-05	1.84E-05
IBZ	5.10	-1.14E-03	-3.70E-04	-5.01E-04	-2.42E-04	-8.89E-05	7.91E-05	4.84E-05	1.19E-05
	8.23	-1.90E-03	-5.97E-04	-7.91E-04	-4.56E-04	-1.46E-04	1.28E-04	7.82E-05	1.90E-05
	8.23	-1.81E-03	-5.33E-04	-6.60E-04	-3.79E-04	-1.23E-04	1.23E-04	7.41E-05	1.74E-05
	8.23	-1.41E-03	-3.94E-04	-4.17E-04	-1.24E-04	-3.67E-05	1.11E-04	6.53E-05	1.46E-05
	8.23	-8.02E-04	-2.04E-04	-1.00E-04	2.44E-04	9.38E-05	9.22E-05	5.24E-05	1.10E-05
	8.23	-1.25E-04	-6.86E-06	2.13E-04	5.86E-04	2.18E-04	6.79E-05	3.69E-05	7.24E-06
Axial blanket 1	5.50	9.77E-05	4.47E-05	1.65E-04	4.27E-04	1.59E-04	2.56E-05	1.55E-05	3.01E-06
	9.70	9.66E-05	4.27E-05	1.24E-04	5.06E-04	1.90E-04	2.15E-05	1.42E-05	2.71E-06
Axial blanket 2	10.00	4.14E-05	1.62E-05	3.64E-05	2.31E-04	8.55E-05	9.81E-06	6.00E-06	1.06E-06
	10.00	2.65E-05	7.97E-06	1.33E-05	8.11E-05	2.41E-05	1.41E-05	2.70E-06	3.62E-07
Reflector	30.00	1.32E-04	3.11E-05	5.74E-05	2.94E-05	9.96E-06	1.36E-05	1.16E-05	3.17E-07
SUM									-1.14E-02

TABLE 4.51. SODIUM WORTH AT EOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	1.53E-07	4.14E-08	4.15E-07	5.28E-08	3.65E-08	3.65E-08	3.65E-08	3.65E-08
cones	4.50	-3.62E-09	-1.27E-09	1.07E-07	5.26E-08	2.19E-08	2.19E-08	2.19E-08	2.19E-08
	5.00	1.68E-07	4.70E-08	1.57E-07	3.13E-07	4.74E-08	4.74E-08	4.74E-08	4.74E-08
Upper boron shield	5.00	2.04E-06	5.67E-07	1.61E-06	1.35E-06	9.19E-08	9.19E-08	9.19E-08	9.19E-08
	5.00	2.36E-05	6.47E-06	1.83E-05	3.85E-06	1.70E-07	1.70E-07	1.70E-07	1.70E-07
cones	4.50	7.14E-05	2.06E-05	6.59E-05	3.51E-06	2.60E-07	2.60E-07	2.60E-07	2.60E-07
	8.00	2.70E-04	8.10E-05	2.67E-04	-2.17E-06	8.19E-07	8.19E-07	8.19E-07	8.19E-07
Sodium plenum	8.00	4.09E-04	1.29E-04	4.13E-04	-8.63E-06	1.51E-06	1.51E-06	1.51E-06	1.51E-06
	7.00	4.96E-04	1.68E-04	5.47E-04	-9.96E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06
Plugs	5.30	1.83E-04	6.44E-05	2.00E-04	-8.56E-06	2.61E-06	2.61E-06	2.61E-06	2.61E-06
	8.23	1.13E-04	4.96E-05	2.45E-04	-3.37E-05	6.13E-06	6.13E-06	6.13E-06	6.13E-06
	8.23	-3.86E-04	-1.05E-04	-2.17E-05	-9.77E-05	9.26E-06	9.26E-06	9.26E-06	9.26E-06
	8.23	-9.23E-04	-2.72E-04	-2.94E-04	-1.78E-04	1.26E-05	1.26E-05	1.26E-05	1.26E-05
	8.23	-1.41E-03	-4.23E-04	-5.34E-04	-2.55E-04	1.55E-05	1.55E-05	1.55E-05	1.55E-05
	8.23	-1.76E-03	-5.34E-04	-7.04E-04	-2.87E-04	1.75E-05	1.75E-05	1.75E-05	1.75E-05
IBZ	5.10	-1.16E-03	-3.63E-04	-4.79E-04	-2.41E-04	1.14E-05	1.14E-05	1.14E-05	1.14E-05
	8.23	-1.95E-03	-5.88E-04	-7.60E-04	-4.61E-04	1.82E-05	1.82E-05	1.82E-05	1.82E-05
	8.23	-1.87E-03	-5.29E-04	-6.42E-04	-3.92E-04	1.68E-05	1.68E-05	1.68E-05	1.68E-05
	8.23	-1.48E-03	-3.98E-04	-4.16E-04	-1.47E-04	1.41E-05	1.41E-05	1.41E-05	1.41E-05
	8.23	-8.75E-04	-2.15E-04	-1.18E-04	2.16E-04	1.08E-05	1.08E-05	1.08E-05	1.08E-05
	8.23	-1.84E-04	-2.01E-05	1.92E-04	5.67E-04	7.20E-06	7.20E-06	7.20E-06	7.20E-06
Axial blanket 1	5.50	8.12E-05	4.04E-05	1.58E-04	4.26E-04	3.04E-06	3.04E-06	3.04E-06	3.04E-06
	9.70	9.90E-05	4.33E-05	1.26E-04	5.25E-04	2.81E-06	2.81E-06	2.81E-06	2.81E-06
Axial blanket 2	10.00	5.32E-05	1.91E-05	4.18E-05	2.56E-04	1.13E-06	1.13E-06	1.13E-06	1.13E-06
	10.00	3.71E-05	1.03E-05	1.68E-05	9.63E-05	4.06E-07	4.06E-07	4.06E-07	4.06E-07
Reflector	30.00	1.87E-04	4.18E-05	7.53E-05	3.84E-05	3.75E-07	3.75E-07	3.75E-07	3.75E-07
SUM									-1.37E-02

4.3.4.6 *Steel worth (steel density coefficient)*

TABLE 4.52. STEEL WORTH AT BOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	1.59E-07	4.52E-08	4.12E-07	4.77E-08	2.28E-08	1.53E-06	2.11E-06	5.45E-07
cones	4.50	3.52E-08	9.94E-09	2.92E-07	9.60E-08	4.39E-08	1.70E-06	1.39E-06	3.93E-07
	5.00	3.94E-07	1.13E-07	4.32E-07	5.66E-07	2.72E-07	4.82E-06	3.02E-06	8.06E-07
Upper boron shield	5.00	4.78E-06	1.37E-06	4.06E-06	2.47E-06	1.44E-06	1.20E-05	5.64E-06	1.49E-06
	5.00	5.85E-05	1.66E-05	5.01E-05	7.31E-06	7.97E-06	2.52E-05	9.66E-06	2.64E-06
cones	4.50	1.77E-04	5.18E-05	1.60E-04	9.52E-06	5.41E-06	3.62E-05	1.37E-05	3.90E-06
	8.00	1.28E-04	3.90E-05	1.15E-04	1.20E-05	7.87E-06	6.10E-05	3.53E-05	1.19E-05
Sodium plenum	8.00	1.86E-04	5.90E-05	1.66E-04	1.00E-05	1.02E-05	5.93E-05	5.04E-05	2.14E-05
	7.00	2.15E-04	7.34E-05	2.09E-04	1.43E-05	2.10E-05	6.53E-05	6.40E-05	3.06E-05
Plugs	5.30	1.02E-03	3.74E-04	1.04E-03	4.82E-06	3.04E-05	6.65E-05	7.00E-05	3.43E-05
	8.23	1.71E-04	9.17E-05	4.46E-04	-1.93E-05	5.93E-05	2.50E-04	1.69E-04	7.80E-05
	8.23	-1.05E-03	-2.99E-04	-2.74E-04	-1.22E-04	4.05E-05	4.33E-04	2.55E-04	1.15E-04
	8.23	-2.36E-03	-7.22E-04	-1.04E-03	-2.46E-04	5.34E-06	5.80E-04	3.38E-04	1.54E-04
	8.23	-3.54E-03	-1.11E-03	-1.72E-03	-3.60E-04	-2.96E-05	6.96E-04	4.05E-04	1.88E-04
	8.23	-4.37E-03	-1.40E-03	-2.22E-03	-3.97E-04	-3.97E-05	7.78E-04	4.52E-04	2.12E-04
IBZ	5.10	-2.90E-03	-9.76E-04	-1.50E-03	-9.73E-05	-2.98E-05	5.07E-04	2.93E-04	1.37E-04
	8.23	-4.99E-03	-1.60E-03	-2.39E-03	-2.11E-04	-4.95E-05	8.21E-04	4.72E-04	2.19E-04
	8.23	-4.85E-03	-1.45E-03	-2.04E-03	-1.87E-04	-4.31E-05	7.85E-04	4.47E-04	2.01E-04
	8.23	-3.87E-03	-1.10E-03	-1.39E-03	-7.67E-05	-1.65E-05	7.04E-04	3.93E-04	1.69E-04
	8.23	-2.30E-03	-6.05E-04	-5.35E-04	8.69E-05	2.44E-05	5.83E-04	3.17E-04	1.28E-04
	8.23	-5.10E-04	-7.88E-05	3.55E-04	2.42E-04	6.36E-05	4.29E-04	2.26E-04	8.65E-05
Axial blanket 1	5.50	2.24E-04	1.04E-04	3.83E-04	1.81E-04	4.75E-05	1.58E-04	9.81E-05	3.71E-05
	9.70	3.13E-04	1.25E-04	3.46E-04	2.19E-04	5.78E-05	1.40E-04	9.41E-05	3.54E-05
Axial blanket 2	10.00	1.50E-04	5.24E-05	1.17E-04	1.01E-04	2.63E-05	6.62E-05	4.09E-05	1.48E-05
	10.00	7.65E-05	2.26E-05	3.95E-05	3.53E-05	2.01E-05	1.18E-05	1.77E-05	5.29E-06
Reflector	30.00	1.16E-04	2.74E-05	5.13E-05	2.47E-05	8.35E-06	1.18E-05	1.01E-05	4.13E-06
Sum									-0.32E-01

TABLE 4.53. STEEL WORTH AT EOC, IPPE

		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	1.61E-07	4.48E-08	4.01E-07	4.81E-08	2.32E-08	1.48E-06	2.05E-06	5.28E-07
cones	4.50	3.62E-08	9.91E-09	2.82E-07	9.68E-08	4.45E-08	1.65E-06	1.35E-06	3.81E-07
	5.00	4.01E-07	1.12E-07	4.22E-07	5.71E-07	2.76E-07	4.68E-06	2.93E-06	7.81E-07
Upper boron shield	5.00	4.87E-06	1.35E-06	3.97E-06	2.49E-06	1.46E-06	1.16E-05	5.47E-06	1.44E-06
	5.00	5.96E-05	1.65E-05	4.92E-05	7.38E-06	8.09E-06	2.46E-05	9.36E-06	2.56E-06
cones	4.50	1.80E-04	5.13E-05	1.57E-04	9.61E-06	5.49E-06	3.53E-05	1.33E-05	3.77E-06
	8.00	1.31E-04	3.86E-05	1.12E-04	1.22E-05	8.02E-06	5.95E-05	3.42E-05	1.15E-05
Sodium plenum	8.00	1.91E-04	5.83E-05	1.62E-04	1.02E-05	1.04E-05	5.77E-05	4.87E-05	2.06E-05
	7.00	2.22E-04	7.24E-05	2.03E-04	1.46E-05	2.16E-05	6.31E-05	6.17E-05	2.95E-05
Plugs	5.30	1.06E-03	3.67E-04	1.01E-03	5.06E-06	3.13E-05	6.39E-05	6.72E-05	3.29E-05
	8.23	1.88E-04	8.91E-05	4.28E-04	-1.89E-05	6.11E-05	2.40E-04	1.62E-04	7.49E-05
	8.23	-1.05E-03	-2.94E-04	-2.65E-04	-1.22E-04	4.24E-05	4.14E-04	2.44E-04	1.10E-04
	8.23	-2.37E-03	-7.05E-04	-9.94E-04	-2.46E-04	7.16E-06	5.52E-04	3.22E-04	1.47E-04
	8.23	-3.57E-03	-1.08E-03	-1.64E-03	-3.60E-04	-2.82E-05	6.62E-04	3.87E-04	1.80E-04
	8.23	-4.45E-03	-1.37E-03	-2.11E-03	-3.97E-04	-3.95E-05	7.39E-04	4.31E-04	2.03E-04
IBZ	5.10	-2.98E-03	-9.56E-04	-1.43E-03	-9.65E-05	-3.02E-05	4.82E-04	2.80E-04	1.32E-04
	8.23	-5.13E-03	-1.57E-03	-2.28E-03	-2.13E-04	-5.07E-05	7.82E-04	4.52E-04	2.10E-04
	8.23	-5.01E-03	-1.44E-03	-1.98E-03	-1.93E-04	-4.50E-05	7.52E-04	4.30E-04	1.94E-04
	8.23	-4.06E-03	-1.11E-03	-1.38E-03	-8.69E-05	-1.91E-05	6.79E-04	3.80E-04	1.64E-04
	8.23	-2.50E-03	-6.34E-04	-5.70E-04	7.42E-05	2.14E-05	5.67E-04	3.09E-04	1.26E-04
	8.23	-6.78E-04	-1.14E-04	2.99E-04	2.33E-04	6.17E-05	4.21E-04	2.22E-04	8.59E-05
Axial blanket 1	5.50	1.62E-04	8.90E-05	3.59E-04	1.80E-04	4.76E-05	1.57E-04	9.73E-05	3.74E-05
	9.70	2.86E-04	1.19E-04	3.39E-04	2.26E-04	6.01E-05	1.41E-04	9.46E-05	3.63E-05
Axial blanket 2	10.00	1.65E-04	5.65E-05	1.25E-04	1.11E-04	2.91E-05	6.84E-05	4.18E-05	1.56E-05
	10.00	9.75E-05	2.72E-05	4.62E-05	4.16E-05	2.39E-05	1.26E-05	1.87E-05	5.74E-06
Reflector	30.00	1.62E-04	3.63E-05	6.63E-05	3.20E-05	1.10E-05	1.39E-05	1.17E-05	4.76E-06
SUM									-3.40E-02

4.3.5 JAEA results

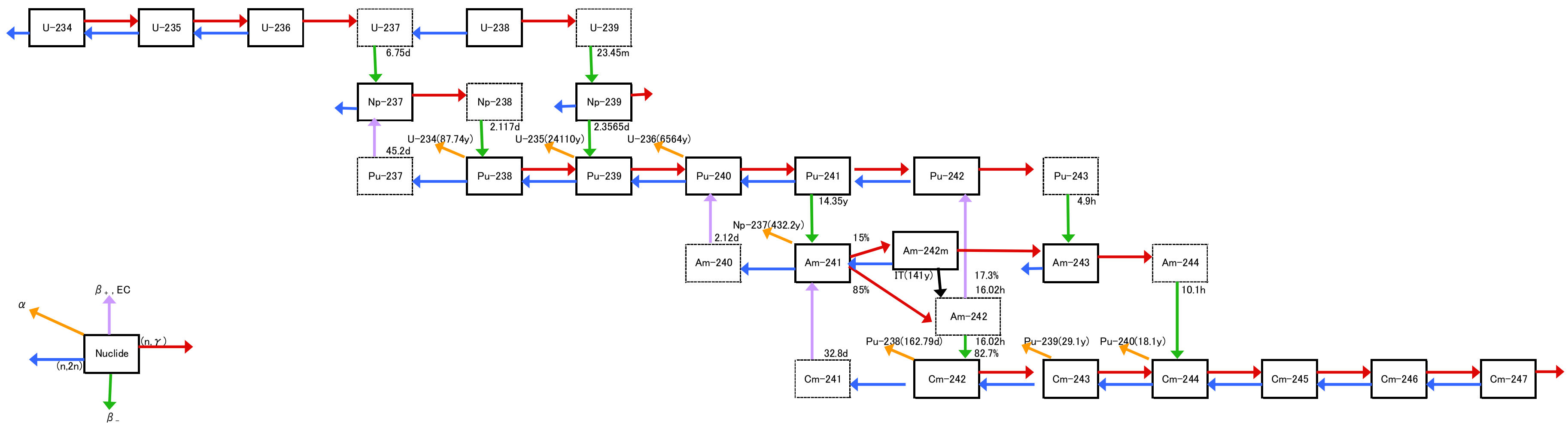
This section shows JAEA results, delivered in May 2006. They are based on using an extended burnup chain (this chain is more detailed compared to that used earlier in the CRP studies) that is described in the following.

4.3.5.1 Analytical method

The main calculation assumptions are as following:

- Nuclear Data Library: JENDL-3.2, Group Constant Set JFS-3-J3.2R: 70-group, ABBN-type self-shielding factor table;
- Effective Cross-section: Current weighted transport cross-section;
- Cell model for fuel SA and for control rods: Homogeneous Model;
- Diffusion Calculation: 18-group and three dimensional Hex-Z model (CITATION code), in which region dependent fission spectra;
- Reactivity maps are calculated by the diffusion based first-order perturbation theory (PERKY code);
- Transport theory and mesh size correction: Not applied according to the benchmark specification;
- The generated thermal power per fission was fixed as 200MeV per fission, and 0 MeV per capture for all nuclides;
- Delayed Neutron Yield: Tuttle (79) or Brady & England (89), Yield Fraction and Decay constant: Keepin (65), Delayed Neutron Spectrum: Saphier (77) were used, the detail of which can be found in Table 4.54;
- Burnup Chain Model: A new detailed model explained in the following was used, where the branching ratio from Am-241 to Am-242g is 0.85, and that from Am-242g to Pu-242 is 0.173 as shown in Fig. 4.2. This assumption is based on an experimental evidence of the branching ratio [26].

Detailed model used by JAEA



Simplified model used previously

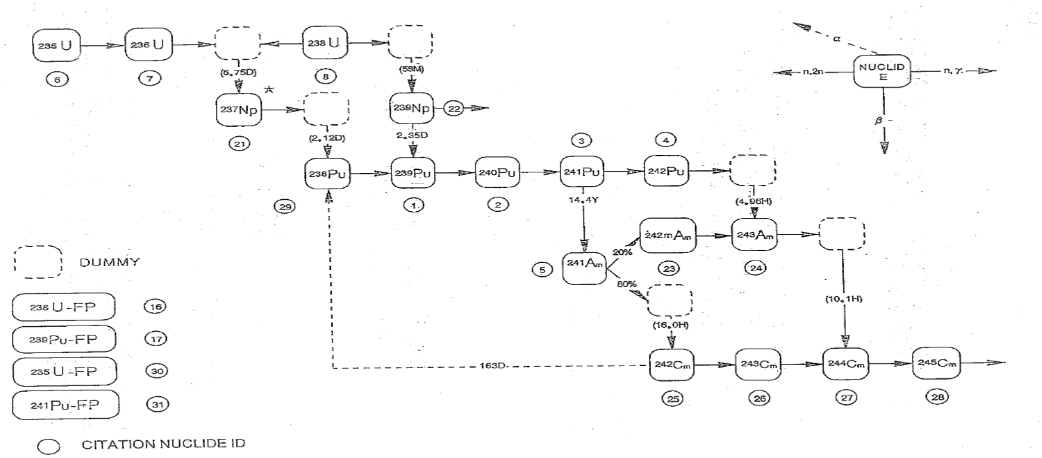


FIG. 4.2. Comparison of detailed and simplified burnup chain models.

4.3.5.2 Results

The following core parameters before and after burnup are summarized in Table 4.55

- k_{eff} (the detailed burnup chain, gives a higher reactivity loss, 541 pcm instead of 387 pcm)
- Fuel Doppler coefficient;
- Steel Doppler coefficient;
- Sodium density coefficient;
- Fuel density coefficient;
- Steel density coefficient;
- Radial expansion coefficient;
- Axial expansion coefficient;
- Beta effective;
- Prompt neutron life time.

The region-wise compositions at the end of cycle are summarized in Table 4.56

The following reactivity maps are calculated:

- Table 4.57: Fuel Doppler coefficients at BOC;
- Table 4.58: Fuel Doppler coefficients at EOC;
- Table 4.59 : Steel Doppler coefficients at BOC;
- Table 4.60: Steel Doppler coefficients at EOC;
- Table 4.61: Fuel density coefficients at BOC;
- Table 4.62: Fuel density coefficients at EOC;
- Table 4.63: Sodium density coefficients at BOC;
- Table 4.64: Sodium density coefficients at EOC;
- Table 4.65: Steel density coefficients at BOC;
- Table 4.66: Steel density coefficients at EOC;
- Table 4.67: Effective delayed neutron fraction of each family and each isotope.

(Note: In these tables "sum core" includes the internal breeding zone.)

TABLE 4.54. FAMILY-WISE DELAYED NEUTRON YIELD (N_D) AND SPECTRUM(X_D) OF EACH ISOTOP USED IN JAEA CALCULATION

Isotope and reference \ Family		No.1	No.2	No.3	No.4	No.5	No.6	Total	Delayed neutron spectrum
U-235	Tuttle	6.36E-04	3.56E-03	3.15E-03	6.81E-03	2.14E-03	4.35E-04	1.673E-02	U-235 data by Saphier et al.
U-236	Brady& England	7.01E-04	4.00E-03	3.76E-03	8.91E-03	4.12E-03	1.72E-03	2.321E-02	(same with U-235)
U-238	Tuttle	5.71E-04	6.01E-03	7.11E-03	1.70E-02	9.88E-03	3.29E-03	4.386E-02	U-238 data by Saphier et al.
Pu-238	Brady& England	2.98E-04	1.89E-03	1.25E-03	2.81E-03	1.26E-03	3.98E-04	7.906E-03	(same with Pu-239)
Pu-239	Tuttle	2.39E-04	1.76E-03	1.36E-03	2.07E-03	6.49E-04	2.21E-04	6.299E-03	Pu-239 data by Saphier et al.
Pu-240	Tuttle	2.66E-04	2.59E-03	1.82E-03	3.33E-03	1.22E-03	2.76E-04	9.502E-03	(same with Pu-239)
Pu-241	Tuttle	1.52E-04	3.48E-03	2.63E-03	5.93E-03	2.77E-03	2.43E-04	1.521E-02	(same with Pu-239)
Pu-242	Tuttle	8.84E-05	4.31E-03	3.56E-03	9.11E-03	4.82E-03	2.21E-04	2.211E-02	(same with Pu-239)
Np-237	Brady& England	4.56E-04	2.46E-03	1.78E-03	4.14E-03	1.89E-03	6.71E-04	1.140E-02	(same with Pu-239)
Am-241	Brady& England	1.81E-04	1.30E-03	7.97E-04	1.72E-03	8.79E-04	2.32E-04	5.109E-03	(same with Pu-239)
Am-242m	Brady& England	1.93E-04	2.07E-03	1.18E-03	2.60E-03	1.37E-03	3.81E-04	7.794E-03	(same with Pu-239)
Am-243	Brady& England	1.87E-04	2.36E-03	1.23E-03	2.52E-03	1.32E-03	3.84E-04	8.001E-03	(same with Pu-239)
Cm-242	Brady& England	1.07E-04	3.99E-04	1.99E-04	3.97E-04	2.47E-04	5.25E-05	1.402E-03	(same with Pu-239)
Cm-243	(same with Cm-242)	1.07E-04	3.99E-04	1.99E-04	3.97E-04	2.47E-04	5.25E-05	1.402E-03	(same with Pu-239)
Cm-244	(same with Cm-245)	1.42E-04	1.14E-03	1.07E-03	2.37E-03	1.31E-03	3.58E-04	6.390E-03	(same with Pu-239)
Cm-245	Brady& England	1.42E-04	1.14E-03	1.07E-03	2.37E-03	1.31E-03	3.58E-04	6.390E-03	(same with Pu-239)

TABLE 4.55. MAIN INTEGRAL RESULTS FOR BN-600-MA, JAEA

Item	BOC	EOC
k_{eff}	0.99194	0.98664
Bunup Reactivity Loss (pcm)	541	
Fuel Doppler coefficient		
k_{eff} (Fuel_2100K)	0.99071	0.98539
Coefficient (Δk/kk'/ΔlnK) (pcm)	-371	-383
Steel Doppler coefficient		
k_{eff} (Steel_900K)	0.99169	0.98639
Coefficient (Δk/kk'/ΔlnK) (pcm)	-63	-65
Sodium density coefficient		
k_{eff} (Sodium dens.*1.01)	0.99178	0.98649
Coefficient (Δk/kk'/Δρ/ρ) (pcm)	-1571	-1611
Sodium density coefficient		
k_{eff} (Sodium dens.*1.1)	0.99034	0.98503
Coefficient (Δk/kk'/Δρ/ρ) (pcm)	-1622	-1659
Fuel density coefficient		
k_{eff} (Fuel dens.*1.01)	0.99566	0.99032
Coefficient (Δk/kk'/Δρ/ρ) (pcm)	37698	37670
Steel density coefficient		
k_{eff} (Steel dens.*1.01)	0.99158	0.98627
Coefficient (Δk/kk'/Δρ/ρ) (pcm)	-3673	-3787
Steel density coefficient		
k_{eff} (Steel dens.*1.1)	0.98821	0.98284
Coefficient (Δk/kk'/Δρ/ρ) (pcm)	-3806	-3923
Radial expansion coefficient		
k_{eff} (Radial length *1.01)	0.98676	0.98154
Coefficient (Δk/kk'/Δcm/cm) (pcm)	-52873	-52739
Axial expansion coefficient		
k_{eff} (Axial length *1.01)	0.99047	0.98521
Coefficient (Δk/kk'/Δcm/cm) (pcm)	-14885	-14726
βeff (Total) (pcm)	299	301
Prompt Life Time (sec)	3.12E-07	3.20E-07

TABLE 4.56. REGION-WISE COMPOSITION AT THE END OF CYCLE, JAEA

Nuclide	Fuel LEZ (1)	Fuel MEZ (2)	Fuel HEZ (3)	Fuel AB2 LEZ (4)	Fuel AB2 MEZ (5)	Fuel AB2 HEZ (6)	Fuel AB1 LEZ (7)	Fuel AB1 MEZ (8)	Fuel AB1 HEZ (9)	Inner Blanket (23)	Fuel AB1 HEZ (9)
U-234	2.815E-07	2.919E-07	3.150E-07	2.668E-10	2.317E-10	1.562E-10	9.763E-10	9.069E-10	6.714E-10	1.679E-09	6.714E-10
U-235	1.774E-05	1.780E-05	1.817E-05	3.116E-05	3.190E-05	3.290E-05	2.852E-05	2.946E-05	3.105E-05	1.553E-05	3.105E-05
U-236	1.292E-06	1.150E-06	8.795E-07	1.225E-06	1.038E-06	8.099E-07	1.724E-06	1.502E-06	1.164E-06	2.181E-06	1.164E-06
U-238	5.701E-03	5.592E-03	5.398E-03	8.827E-03	8.851E-03	8.887E-03	8.717E-03	8.752E-03	8.814E-03	8.030E-03	8.814E-03
Np-237	1.171E-04	1.264E-04	1.461E-04	1.331E-07	1.149E-07	7.868E-08	4.875E-07	4.557E-07	3.426E-07	1.221E-06	3.426E-07
Np-239	2.457E-06	2.148E-06	1.543E-06	1.833E-06	1.531E-06	1.098E-06	2.934E-06	2.513E-06	1.804E-06	4.280E-06	1.804E-06
Pu-238	1.014E-04	1.044E-04	1.112E-04	7.265E-09	5.353E-09	2.876E-09	4.050E-08	3.277E-08	1.893E-08	1.624E-07	1.893E-08
Pu-239	9.559E-04	9.991E-04	1.106E-03	1.331E-04	1.130E-04	8.310E-05	2.089E-04	1.825E-04	1.352E-04	5.512E-04	1.352E-04
Pu-240	5.160E-04	5.416E-04	5.984E-04	3.030E-06	2.141E-06	1.255E-06	6.247E-06	4.609E-06	2.650E-06	5.381E-05	2.650E-06
Pu-241	3.561E-05	3.476E-05	3.297E-05	5.332E-08	3.243E-08	2.384E-08	1.310E-07	8.294E-08	5.123E-08	3.302E-06	5.123E-08
Pu-242	1.092E-05	1.051E-05	9.426E-06	4.738E-10	2.415E-10	1.585E-10	1.636E-09	8.832E-10	4.697E-10	1.650E-07	4.697E-10
Am-241	2.491E-04	2.693E-04	3.129E-04	5.036E-10	3.101E-10	2.677E-10	1.169E-09	7.458E-10	5.346E-10	6.496E-08	5.346E-10
Am-242m	7.273E-06	7.076E-06	6.460E-06	2.003E-12	1.037E-12	7.776E-13	6.305E-12	3.444E-12	2.108E-12	9.458E-10	2.108E-12
Am-243	3.732E-05	4.004E-05	4.568E-05	3.608E-12	1.551E-12	1.004E-12	1.647E-11	7.589E-12	3.764E-12	5.593E-09	3.764E-12
Cm-242	2.213E-05	2.112E-05	1.848E-05	7.953E-12	4.095E-12	3.000E-12	2.558E-11	1.388E-11	8.278E-12	3.571E-09	8.278E-12
Cm-243	8.292E-07	7.286E-07	5.576E-07	5.586E-14	2.407E-14	1.503E-14	2.328E-13	1.077E-13	5.411E-14	7.988E-11	5.411E-14
Cm-244	7.164E-06	6.909E-06	6.388E-06	6.896E-14	2.489E-14	1.454E-14	4.342E-13	1.706E-13	7.312E-14	4.435E-10	7.312E-14
Cm-245	1.469E-06	1.538E-06	1.733E-06	5.201E-16	1.570E-16	8.114E-17	4.358E-15	1.459E-15	5.351E-16	1.113E-11	5.351E-16
Cm-246	2.853E-07	2.966E-07	3.177E-07	1.411E-18	3.561E-19	1.493E-19	1.766E-17	5.062E-18	1.476E-18	1.196E-13	1.476E-18
Cm-247	1.148E-08	1.108E-08	1.049E-08	3.895E-21	8.168E-22	2.736E-22	6.567E-20	1.595E-20	3.669E-21	9.823E-16	3.669E-21
U-235FP	2.326E-06	2.105E-06	1.584E-06	1.828E-06	1.549E-06	1.157E-06	2.798E-06	2.457E-06	1.849E-06	2.596E-06	1.849E-06
U-238FP	2.909E-05	2.885E-05	2.259E-05	3.214E-06	2.758E-06	1.821E-06	1.165E-05	1.062E-05	7.618E-06	2.914E-05	7.618E-06
Pu-239FP	2.790E-04	2.768E-04	2.316E-04	1.232E-05	9.724E-06	6.256E-06	3.405E-05	2.851E-05	1.839E-05	3.190E-04	1.839E-05
Pu-241FP	2.717E-05	2.725E-05	2.246E-05	1.026E-08	5.996E-09	2.640E-09	5.512E-08	3.553E-08	1.508E-08	1.890E-06	1.508E-08

TABLE 4.57. FUEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 HYBRID CORE (BOC), ΔK/KK'/ (LN (T2/T1)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00								
Cones	4.50								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Cones	4.50								
Sodium Plenum	8.00								
Sodium Plenum	8.00								
Sodium Plenum	7.00								
Plugs	5.30								
Core	8.23	-9.641E-05	-2.508E-05	-7.576E-05					
Core	8.23	-9.313E-05	-2.345E-05	-6.742E-05					
Core	8.23	-1.222E-04	-3.113E-05	-8.670E-05					
Core	8.23	-1.577E-04	-4.021E-05	-1.085E-04					
Core	8.23	-1.973E-04	-4.929E-05	-1.254E-04					
Internal Breeding Zone	5.10	-2.245E-04	-3.544E-05	-8.260E-05					
Core	8.23	-2.352E-04	-5.929E-05	-1.326E-04					
Core	8.23	-2.211E-04	-5.623E-05	-1.221E-04					
Core	8.23	-1.920E-04	-4.818E-05	-1.026E-04					
Core	8.23	-1.535E-04	-3.780E-05	-7.910E-05					
Core	8.23	-1.188E-04	-2.885E-05	-6.025E-05					
Axial Blanket 1	5.50	-9.664E-05	-2.384E-05	-5.101E-05					
Axial Blanket 2	9.70	-9.518E-05	-2.241E-05	-4.514E-05					
Axial Blanket 2	10.00	-4.034E-05	-8.862E-06	-1.657E-05					
Axial Blanket 2	10.00	-1.801E-05	-3.716E-06	-6.661E-06					
Reflector	30.00	0	0	0					
sum Core		-1.587E-03	-3.995E-04	-9.605E-04					
sum Axial Blanket		-2.502E-04	-5.883E-05	-1.194E-04					

TABLE 4.58. FUEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 HYBRID CORE (EOC), ΔK/KK'/ (LN (T2/T1)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	0	0	0	0	0	0	0	0
Cones	4.50	0	0	0	0	0	0	0	0
Upper Boron Shield	5.00	0	0	0	0	0	0	0	0
Upper Boron Shield	5.00	0	0	0	0	0	0	0	0
Upper Boron Shield	5.00	0	0	0	0	0	0	0	0
Cones	4.50	0	0	0	0	0	0	0	0
Sodium Plenum	8.00	0	0	0	0	0	0	0	0
Sodium Plenum	8.00	0	0	0	0	0	0	0	0
Sodium Plenum	7.00	0	0	0	0	0	0	0	0
Plugs	5.30	0	0	0	0	0	0	0	0
Core	8.23	-9.632E-05	-2.422E-05	-7.242E-05	0	0	0	0	0
Core	8.23	-9.389E-05	-2.279E-05	-6.475E-05	0	0	0	0	0
Core	8.23	-1.241E-04	-3.038E-05	-8.356E-05	0	0	0	0	0
Core	8.23	-1.609E-04	-3.941E-05	-1.049E-04	0	0	0	0	0
Core	8.23	-2.019E-04	-4.851E-05	-1.218E-04	0	0	0	0	0
Internal Breeding Zone	5.10	-2.277E-04	-3.501E-05	-8.048E-05	0	0	0	0	0
Core	8.23	-2.429E-04	-5.889E-05	-1.298E-04	0	0	0	0	0
Core	8.23	-2.303E-04	-5.624E-05	-1.202E-04	0	0	0	0	0
Core	8.23	-2.016E-04	-4.857E-05	-1.017E-04	0	0	0	0	0
Core	8.23	-1.625E-04	-3.844E-05	-7.911E-05	0	0	0	0	0
Core	8.23	-1.268E-04	-2.957E-05	-6.069E-05	0	0	0	0	0
Axial Blanket 1	5.50	-1.086E-04	-2.568E-05	-5.370E-05	0	0	0	0	0
Axial Blanket 2	9.70	-1.172E-04	-2.641E-05	-5.211E-05	0	0	0	0	0
Axial Blanket 2	10.00	-5.513E-05	-1.165E-05	-2.154E-05	0	0	0	0	0
Axial Blanket 2	10.00	-2.668E-05	-5.340E-06	-9.535E-06	0	0	0	0	0
Reflector	30.00	0	0	0	0	0	0	0	0
sum Core		-1.641E-03	-3.970E-04	-9.389E-04	0	0	0	0	0
sum Axial Blanket		-3.076E-04	-6.909E-05	-1.369E-04	0	0	0	0	0

TABLE 4.59. STEEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC)

	DZ (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	1.251E-10	1.329E-11	-1.632E-10	2.157E-11	6.267E-11	2.099E-10	1.890E-10	7.107E-10
Cones	4.50	1.995E-11	-4.314E-12	-1.143E-10	4.512E-11	1.695E-10	2.247E-09	4.091E-10	4.750E-10
Upper Boron Shield	5.00	3.807E-10	1.025E-10	3.101E-10	2.776E-10	7.966E-10	2.117E-09	-1.616E-09	1.097E-09
Upper Boron Shield	5.00	4.172E-09	1.140E-09	3.057E-09	1.455E-09	2.926E-09	-1.720E-09	-7.751E-09	2.020E-09
Upper Boron Shield	5.00	4.147E-08	1.107E-08	2.837E-08	7.030E-09	6.681E-09	-2.669E-08	-2.224E-08	3.464E-09
Cones	4.50	-8.103E-07	-2.204E-07	-7.085E-07	-4.997E-09	5.254E-09	-1.033E-07	-4.378E-08	4.963E-09
Sodium Plenum	8.00	-1.127E-06	-3.073E-07	-1.003E-06	-3.393E-08	-1.328E-08	-5.216E-07	-1.728E-07	1.515E-08
Sodium Plenum	8.00	-1.854E-06	-4.987E-07	-1.606E-06	-6.530E-08	-3.529E-08	-9.967E-07	-3.429E-07	2.771E-08
Sodium Plenum	7.00	-2.379E-06	-6.320E-07	-1.972E-06	-8.508E-08	-4.895E-08	-1.323E-06	-4.901E-07	4.081E-08
Plugs	5.30	-1.381E-05	-3.605E-06	-1.072E-05	-9.127E-08	-5.057E-08	-1.334E-06	-5.250E-07	4.568E-08
Core	8.23	-8.083E-06	-2.100E-06	-5.641E-06	-2.086E-07	-1.541E-07	-2.772E-06	-1.153E-06	1.070E-07
Core	8.23	-1.286E-05	-3.502E-06	-9.012E-06	-3.362E-07	-3.248E-07	-3.963E-06	-1.656E-06	1.611E-07
Core	8.23	-1.865E-05	-5.179E-06	-1.303E-05	-5.026E-07	-5.308E-07	-5.393E-06	-2.215E-06	2.190E-07
Core	8.23	-2.441E-05	-6.831E-06	-1.684E-05	-6.707E-07	-7.460E-07	-6.730E-06	-2.728E-06	2.703E-07
Core	8.23	-2.968E-05	-8.284E-06	-1.969E-05	-8.084E-07	-1.120E-06	-7.672E-06	-3.087E-06	3.054E-07
Internal Breeding Zone	5.10	-2.059E-05	-5.764E-06	-1.299E-05	-3.649E-07	-1.075E-06	-4.974E-06	-1.994E-06	1.973E-07
Core	8.23	-3.442E-05	-9.563E-06	-2.084E-05	-5.995E-07	-2.264E-06	-7.865E-06	-3.150E-06	3.116E-07
Core	8.23	-3.280E-05	-8.986E-06	-1.903E-05	-5.625E-07	-2.319E-06	-7.093E-06	-2.845E-06	2.819E-07
Core	8.23	-2.813E-05	-7.533E-06	-1.563E-05	-4.692E-07	-1.969E-06	-5.786E-06	-2.333E-06	2.319E-07
Core	8.23	-2.138E-05	-5.573E-06	-1.136E-05	-3.394E-07	-1.416E-06	-4.194E-06	-1.712E-06	1.714E-07
Core	8.23	-1.412E-05	-3.562E-06	-7.158E-06	-2.046E-07	-8.313E-07	-2.608E-06	-1.098E-06	1.124E-07

TABLE 4.59. STEEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC) (cont.)

Axial Blanket 1	5.50	-5.818E-06	-1.432E-06	-2.787E-06	-7.334E-08	-2.865E-07	-1.028E-06	-4.475E-07	4.754E-08
Axial Blanket 2	9.70	-5.401E-06	-1.276E-06	-2.401E-06	-5.817E-08	-2.186E-07	-8.951E-07	-4.098E-07	4.721E-08
Axial Blanket 2	10.00	-2.037E-06	-4.488E-07	-8.023E-07	-1.929E-08	-6.836E-08	-3.146E-07	-1.529E-07	1.976E-08
Axial Blanket 2	10.00	-7.170E-07	-1.473E-07	-2.580E-07	-7.755E-09	-2.513E-08	-9.477E-08	-5.030E-08	5.750E-09
Reflector	30.00	-5.674E-07	-1.091E-07	-1.944E-07	-1.936E-08	-5.045E-08	-2.141E-08	-1.284E-08	2.466E-09
sum Upper Boron Shield		4.603E-08	1.231E-08	3.174E-08	8.762E-09	1.040E-08	-2.629E-08	-3.161E-08	6.581E-09
sum Sodium Plenum		-5.360E-06	-1.438E-06	-4.581E-06	-1.843E-07	-9.752E-08	-2.841E-06	-1.006E-06	8.368E-08
sum Core		-2.245E-04	-6.111E-05	-1.382E-04	-4.702E-06	-1.168E-05	-5.408E-05	-2.198E-05	2.172E-06
sum Axial Blanket		-1.397E-05	-3.303E-06	-6.249E-06	-1.586E-07	-5.986E-07	-2.333E-06	-1.060E-06	1.203E-07

TABLE 4.60. STEEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC)

	DZ (cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	1.232E-10	1.277E-11	-1.564E-10	2.139E-11	6.180E-11	1.993E-10	1.802E-10	6.772E-10
Cones	4.50	2.018E-11	-3.952E-12	-1.103E-10	4.509E-11	1.683E-10	2.128E-09	3.858E-10	4.519E-10
Upper Boron Shield	5.00	3.753E-10	9.824E-11	2.936E-10	2.774E-10	7.915E-10	2.008E-09	-1.532E-09	1.043E-09
Upper Boron Shield	5.00	4.149E-09	1.101E-09	2.918E-09	1.455E-09	2.911E-09	-1.636E-09	-7.350E-09	1.921E-09
Upper Boron Shield	5.00	4.166E-08	1.080E-08	2.740E-08	7.038E-09	6.665E-09	-2.541E-08	-2.111E-08	3.295E-09
Cones	4.50	-8.092E-07	-2.142E-07	-6.806E-07	-4.921E-09	5.305E-09	-9.840E-08	-4.155E-08	4.722E-09
Sodium Plenum	8.00	-1.128E-06	-2.994E-07	-9.655E-07	-3.369E-08	-1.293E-08	-4.976E-07	-1.641E-07	1.441E-08
Sodium Plenum	8.00	-1.859E-06	-4.865E-07	-1.548E-06	-6.502E-08	-3.464E-08	-9.510E-07	-3.257E-07	2.633E-08
Sodium Plenum	7.00	-2.394E-06	-6.177E-07	-1.903E-06	-8.485E-08	-4.809E-08	-1.262E-06	-4.654E-07	3.873E-08
Plugs	5.30	-1.394E-05	-3.531E-06	-1.036E-05	-9.139E-08	-4.962E-08	-1.273E-06	-4.986E-07	4.332E-08
Core	8.23	-8.242E-06	-2.076E-06	-5.491E-06	-2.107E-07	-1.520E-07	-2.650E-06	-1.096E-06	1.015E-07
Core	8.23	-1.319E-05	-3.469E-06	-8.780E-06	-3.426E-07	-3.229E-07	-3.794E-06	-1.577E-06	1.528E-07
Core	8.23	-1.924E-05	-5.146E-06	-1.272E-05	-5.156E-07	-5.315E-07	-5.172E-06	-2.113E-06	2.080E-07
Core	8.23	-2.534E-05	-6.816E-06	-1.649E-05	-6.927E-07	-7.530E-07	-6.470E-06	-2.609E-06	2.573E-07
Core	8.23	-3.100E-05	-8.308E-06	-1.935E-05	-8.409E-07	-1.142E-06	-7.399E-06	-2.961E-06	2.916E-07
Internal Breeding Zone	5.10	-2.173E-05	-5.808E-06	-1.282E-05	-3.835E-07	-1.120E-06	-4.813E-06	-1.919E-06	1.889E-07
Core	8.23	-3.631E-05	-9.683E-06	-2.065E-05	-6.327E-07	-2.369E-06	-7.640E-06	-3.043E-06	2.992E-07
Core	8.23	-3.480E-05	-9.160E-06	-1.899E-05	-5.976E-07	-2.444E-06	-6.933E-06	-2.766E-06	2.719E-07
Core	8.23	-3.010E-05	-7.747E-06	-1.573E-05	-5.038E-07	-2.099E-06	-5.704E-06	-2.289E-06	2.248E-07
Core	8.23	-2.317E-05	-5.805E-06	-1.157E-05	-3.711E-07	-1.538E-06	-4.190E-06	-1.705E-06	1.668E-07

TABLE 4.60. STEEL DOPPLER COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC) (cont.)

Core	8.23	-1.566E-05	-3.794E-06	-7.440E-06	-2.316E-07	-9.371E-07	-2.674E-06	-1.124E-06	1.095E-07
Axial Blanket 1	5.50	-6.858E-06	-1.604E-06	-3.020E-06	-8.858E-08	-3.464E-07	-1.104E-06	-4.776E-07	4.611E-08
Axial Blanket 2	9.70	-6.771E-06	-1.532E-06	-2.802E-06	-7.779E-08	-2.946E-07	-1.027E-06	-4.654E-07	4.534E-08
Axial Blanket 2	10.00	-2.820E-06	-5.967E-07	-1.040E-06	-3.045E-08	-1.103E-07	-4.033E-07	-1.942E-07	1.852E-08
Axial Blanket 2	10.00	-1.074E-06	-2.134E-07	-3.652E-07	-1.322E-08	-4.457E-08	-1.372E-07	-7.343E-08	4.818E-09
Reflector	30.00	-9.027E-07	-1.685E-07	-2.965E-07	-3.135E-08	-8.221E-08	-3.291E-08	-2.050E-08	1.394E-09
sum Upper Boron Shield		4.619E-08	1.200E-08	3.061E-08	8.770E-09	1.037E-08	-2.504E-08	-2.999E-08	6.260E-09
sum Sodium Plenum		-5.381E-06	-1.404E-06	-4.416E-06	-1.836E-07	-9.566E-08	-2.710E-06	-9.551E-07	7.947E-08
sum Core		-2.370E-04	-6.200E-05	-1.372E-04	-4.939E-06	-1.229E-05	-5.263E-05	-2.128E-05	2.083E-06
sum Axial Blanket		-1.752E-05	-3.946E-06	-7.227E-06	-2.100E-07	-7.959E-07	-2.671E-06	-1.211E-06	1.148E-07

TABLE 4.61. FUEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00								
Cones	4.50								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Cones	4.50								
Sodium Plenum	8.00								
Sodium Plenum	8.00								
Sodium Plenum	7.00								
Plugs	5.30								
Core	8.23	7.715E-03	2.511E-03	7.443E-03					
Core	8.23	1.076E-02	3.580E-03	1.108E-02					
Core	8.23	1.399E-02	4.745E-03	1.499E-02					
Core	8.23	1.679E-02	5.812E-03	1.850E-02					
Core	8.23	1.851E-02	6.593E-03	2.104E-02					
Internal Breeding Zone	5.10	-1.849E-03	4.302E-03	1.374E-02					
Core	8.23	2.015E-02	7.001E-03	2.204E-02					
Core	8.23	1.981E-02	6.648E-03	2.048E-02					
Core	8.23	1.786E-02	5.822E-03	1.746E-02					
Core	8.23	1.478E-02	4.684E-03	1.355E-02					
Core	8.23	1.135E-02	3.487E-03	9.559E-03					
Axial Blanket 1	5.50	-2.665E-04	1.280E-05	3.342E-04					
Axial Blanket 2	9.70	-5.178E-04	-5.612E-05	6.513E-05					
Axial Blanket 2	10.00	-1.646E-04	-1.231E-05	4.247E-07					
Axial Blanket 2	10.00	-1.396E-05	6.121E-06	6.623E-06					
Reflector	30.00	0	0	0					
sum Core		1.517E-01	5.088E-02	1.562E-01					
sum Axial Blanket		-9.630E-04	-4.952E-05	4.064E-04					

TABLE 4.62. FUEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00								
Cones	4.50								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Upper Boron Shield	5.00								
Cones	4.50								
Sodium Plenum	8.00								
Sodium Plenum	8.00								
Sodium Plenum	7.00								
Plugs	5.30								
Core	8.23	7.819E-03	2.416E-03	7.027E-03					
Core	8.23	1.094E-02	3.443E-03	1.046E-02					
Core	8.23	1.429E-02	4.571E-03	1.417E-02					
Core	8.23	1.725E-02	5.617E-03	1.753E-02					
Core	8.23	1.917E-02	6.400E-03	2.001E-02					
Internal Breeding Zone	5.10	-3.054E-04	4.192E-03	1.311E-02					
Core	8.23	2.102E-02	6.849E-03	2.111E-02					
Core	8.23	2.070E-02	6.537E-03	1.972E-02					
Core	8.23	1.874E-02	5.759E-03	1.692E-02					
Core	8.23	1.558E-02	4.667E-03	1.324E-02					
Core	8.23	1.201E-02	3.500E-03	9.416E-03					
Axial Blanket 1	5.50	1.074E-04	9.690E-05	4.524E-04					
Axial Blanket 2	9.70	-3.693E-04	-1.925E-05	1.140E-04					
Axial Blanket 2	10.00	-1.039E-04	3.188E-06	1.987E-05					
Axial Blanket 2	10.00	2.372E-05	1.470E-05	1.613E-05					
Reflector	30.00	0	0	0					
sum Core		1.575E-01	4.976E-02	1.496E-01					
sum Axial Blanket		-3.421E-04	9.554E-05	6.024E-04					

TABLE 4.63. SODIUM DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	7.335E-08	1.891E-08	3.247E-07	1.818E-08	4.651E-08	8.217E-07	1.063E-06	5.791E-08
Cones	4.50	-1.033E-08	-3.074E-09	6.469E-08	4.162E-08	8.311E-08	3.069E-07	2.375E-07	4.339E-08
Upper Boron Shield	5.00	1.729E-07	4.797E-08	1.389E-07	2.282E-07	3.844E-07	6.820E-07	4.764E-07	9.980E-08
Upper Boron Shield	5.00	2.203E-06	6.079E-07	1.655E-06	1.108E-06	1.404E-06	1.524E-06	8.685E-07	1.957E-07
Upper Boron Shield	5.00	2.627E-05	7.157E-06	1.981E-05	5.510E-06	3.401E-06	3.080E-06	1.535E-06	3.594E-07
Cones	4.50	8.460E-05	2.370E-05	7.333E-05	1.247E-05	4.664E-06	4.930E-06	2.279E-06	5.426E-07
Sodium Plenum	8.00	2.980E-04	8.702E-05	2.911E-04	1.727E-05	3.190E-06	9.629E-06	6.278E-06	1.732E-06
Sodium Plenum	8.00	4.233E-04	1.327E-04	4.395E-04	2.279E-05	-6.021E-07	1.102E-05	9.800E-06	3.203E-06
Sodium Plenum	7.00	4.901E-04	1.693E-04	5.779E-04	5.130E-05	-1.394E-06	1.300E-05	1.318E-05	4.651E-06
Plugs	5.30	1.954E-04	7.124E-05	2.176E-04	7.865E-05	3.470E-07	1.385E-05	1.454E-05	5.132E-06
Core	8.23	8.509E-05	4.587E-05	2.527E-04	1.399E-04	-1.196E-05	4.895E-05	3.630E-05	1.181E-05
Core	8.23	-4.588E-04	-1.261E-04	-5.627E-05	8.860E-05	-6.917E-05	7.829E-05	5.560E-05	1.748E-05
Core	8.23	-1.025E-03	-3.069E-04	-3.671E-04	7.643E-06	-1.371E-04	1.032E-04	7.448E-05	2.351E-05
Core	8.23	-1.518E-03	-4.679E-04	-6.389E-04	-6.914E-05	-1.995E-04	1.233E-04	9.029E-05	2.885E-05
Core	8.23	-1.851E-03	-5.861E-04	-8.281E-04	-1.221E-04	-2.258E-04	1.371E-04	1.010E-04	3.252E-05
Internal Breeding Zone	5.10	-1.200E-03	-3.963E-04	-5.584E-04	-9.253E-05	-2.452E-04	8.876E-05	6.527E-05	2.100E-05
Core	8.23	-2.019E-03	-6.386E-04	-8.770E-04	-1.521E-04	-4.794E-04	1.425E-04	1.040E-04	3.319E-05
Core	8.23	-1.919E-03	-5.674E-04	-7.293E-04	-1.251E-04	-3.925E-04	1.344E-04	9.641E-05	3.012E-05
Core	8.23	-1.491E-03	-4.169E-04	-4.620E-04	-4.055E-05	-1.389E-04	1.182E-04	8.239E-05	2.493E-05
Core	8.23	-8.356E-04	-2.133E-04	-1.191E-04	8.292E-05	2.113E-04	9.521E-05	6.373E-05	1.855E-05
Core	8.23	-1.130E-04	-1.069E-06	2.304E-04	1.944E-04	5.197E-04	6.687E-05	4.298E-05	1.221E-05
Axial Blanket 1	5.50	1.136E-04	4.923E-05	1.820E-04	1.419E-04	3.785E-04	2.458E-05	1.762E-05	5.137E-06
Axial Blanket 2	9.70	7.283E-05	3.490E-05	1.135E-04	1.721E-04	4.511E-04	2.064E-05	1.659E-05	5.011E-06
Axial Blanket 2	10.00	2.428E-05	1.146E-05	2.786E-05	8.011E-05	2.034E-04	7.331E-06	6.646E-06	2.065E-06
Axial Blanket 2	10.00	1.528E-05	5.233E-06	8.682E-06	2.843E-05	7.029E-05	2.483E-06	2.356E-06	7.013E-07
Reflector	30.00	1.028E-04	2.443E-05	4.407E-05	8.322E-06	2.174E-05	7.771E-06	7.795E-06	4.565E-07
sum Upper Boron Shield		2.864E-05	7.813E-06	2.161E-05	6.846E-06	5.189E-06	5.286E-06	2.880E-06	6.549E-07
sum Sodium Plenum		1.211E-03	3.890E-04	1.308E-03	9.136E-05	1.194E-06	3.365E-05	2.926E-05	9.587E-06
sum Core		-1.115E-02	-3.278E-03	-3.595E-03	4.501E-06	-9.232E-04	1.048E-03	7.472E-04	2.332E-04
sum Axial Blanket		2.260E-04	1.008E-04	3.320E-04	4.226E-04	1.103E-03	5.503E-05	4.321E-05	1.291E-05

TABLE 4.64. SODIUM DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	7.428E-08	1.861E-08	3.089E-07	1.819E-08	4.621E-08	7.813E-07	1.011E-06	5.494E-08
Cones	4.50	-1.022E-08	-2.965E-09	6.056E-08	4.153E-08	8.232E-08	2.912E-07	2.250E-07	4.112E-08
Upper Boron Shield	5.00	1.728E-07	4.652E-08	1.325E-07	2.278E-07	3.809E-07	6.479E-07	4.515E-07	9.459E-08
Upper Boron Shield	5.00	2.205E-06	5.905E-07	1.587E-06	1.107E-06	1.393E-06	1.449E-06	8.236E-07	1.856E-07
Upper Boron Shield	5.00	2.634E-05	6.970E-06	1.906E-05	5.510E-06	3.377E-06	2.933E-06	1.456E-06	3.407E-07
Cones	4.50	8.484E-05	2.303E-05	7.041E-05	1.248E-05	4.636E-06	4.700E-06	2.163E-06	5.144E-07
Sodium Plenum	8.00	3.008E-04	8.471E-05	2.794E-04	1.738E-05	3.191E-06	9.172E-06	5.955E-06	1.642E-06
Sodium Plenum	8.00	4.307E-04	1.290E-04	4.204E-04	2.317E-05	-5.447E-07	1.046E-05	9.278E-06	3.034E-06
Sodium Plenum	7.00	5.032E-04	1.644E-04	5.512E-04	5.252E-05	-1.271E-06	1.228E-05	1.245E-05	4.403E-06
Plugs	5.30	2.004E-04	6.860E-05	2.054E-04	8.072E-05	5.414E-07	1.302E-05	1.372E-05	4.857E-06
Core	8.23	9.738E-05	4.498E-05	2.407E-04	1.451E-04	-1.116E-05	4.610E-05	3.428E-05	1.118E-05
Core	8.23	-4.463E-04	-1.201E-04	-4.863E-05	9.504E-05	-6.786E-05	7.391E-05	5.257E-05	1.656E-05
Core	8.23	-1.019E-03	-2.953E-04	-3.417E-04	1.395E-05	-1.361E-04	9.764E-05	7.054E-05	2.231E-05
Core	8.23	-1.529E-03	-4.533E-04	-6.003E-04	-6.476E-05	-1.998E-04	1.170E-04	8.572E-05	2.745E-05
Core	8.23	-1.887E-03	-5.718E-04	-7.834E-04	-1.212E-04	-2.264E-04	1.305E-04	9.616E-05	3.103E-05
Internal Breeding Zone	5.10	-1.234E-03	-3.891E-04	-5.310E-04	-9.372E-05	-2.443E-04	8.466E-05	6.230E-05	2.009E-05
Core	8.23	-2.086E-03	-6.295E-04	-8.392E-04	-1.562E-04	-4.862E-04	1.363E-04	9.961E-05	3.187E-05
Core	8.23	-1.993E-03	-5.636E-04	-7.052E-04	-1.309E-04	-4.061E-04	1.291E-04	9.271E-05	2.908E-05
Core	8.23	-1.569E-03	-4.201E-04	-4.560E-04	-4.739E-05	-1.580E-04	1.140E-04	7.966E-05	2.422E-05
Core	8.23	-9.111E-04	-2.233E-04	-1.315E-04	7.626E-05	1.901E-04	9.239E-05	6.207E-05	1.819E-05
Core	8.23	-1.739E-04	-1.492E-05	2.050E-04	1.907E-04	5.044E-04	6.549E-05	4.233E-05	1.212E-05
Axial Blanket 1	5.50	9.614E-05	4.408E-05	1.714E-04	1.429E-04	3.774E-04	2.454E-05	1.763E-05	5.176E-06
Axial Blanket 2	9.70	7.241E-05	3.490E-05	1.137E-04	1.794E-04	4.657E-04	2.116E-05	1.695E-05	5.148E-06
Axial Blanket 2	10.00	3.168E-05	1.348E-05	3.170E-05	8.852E-05	2.226E-04	7.880E-06	7.035E-06	2.193E-06
Axial Blanket 2	10.00	2.407E-05	7.218E-06	1.176E-05	3.400E-05	8.331E-05	2.800E-06	2.592E-06	7.799E-07
Reflector	30.00	1.601E-04	3.585E-05	6.364E-05	1.145E-05	2.983E-05	1.008E-05	9.647E-06	5.517E-07
sum Upper Boron Shield		2.872E-05	7.607E-06	2.078E-05	6.845E-06	5.150E-06	5.030E-06	2.731E-06	6.209E-07
sum Sodium Plenum		1.235E-03	3.782E-04	1.251E-03	9.306E-05	1.375E-06	3.192E-05	2.769E-05	9.080E-06
sum Core		-1.152E-02	-3.247E-03	-3.460E-03	6.172E-07	-9.972E-04	1.002E-03	7.156E-04	2.240E-04
sum Axial Blanket		2.243E-04	9.967E-05	3.285E-04	4.448E-04	1.149E-03	5.638E-05	4.421E-05	1.330E-05

TABLE 4.65. STEEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	1.032E-07	2.924E-08	3.600E-07	1.712E-08	4.319E-08	7.354E-07	9.563E-07	6.714E-07
Cones	4.50	3.476E-08	9.307E-09	2.156E-07	5.248E-08	1.447E-07	2.140E-06	1.637E-06	4.984E-07
Upper Boron Shield	5.00	4.162E-07	1.151E-07	3.712E-07	2.900E-07	6.835E-07	4.785E-06	3.258E-06	1.133E-06
Upper Boron Shield	5.00	5.205E-06	1.434E-06	3.996E-06	1.447E-06	2.576E-06	1.073E-05	5.893E-06	2.208E-06
Upper Boron Shield	5.00	6.800E-05	1.861E-05	5.321E-05	8.083E-06	6.656E-06	2.184E-05	1.030E-05	4.035E-06
Cones	4.50	2.108E-04	5.867E-05	1.766E-04	5.834E-06	1.143E-05	3.387E-05	1.517E-05	6.069E-06
Sodium Plenum	8.00	1.309E-04	3.758E-05	1.178E-04	7.955E-06	1.839E-05	6.306E-05	4.148E-05	1.928E-05
Sodium Plenum	8.00	1.777E-04	5.424E-05	1.662E-04	9.802E-06	1.858E-05	6.679E-05	6.404E-05	3.536E-05
Sodium Plenum	7.00	1.974E-04	6.621E-05	2.085E-04	2.071E-05	2.200E-05	7.593E-05	8.492E-05	5.091E-05
Plugs	5.30	1.199E-03	4.396E-04	1.241E-03	3.086E-05	1.889E-05	7.748E-05	9.236E-05	5.581E-05
Core	8.23	6.034E-05	6.156E-05	4.035E-04	5.452E-05	1.500E-05	3.023E-04	2.283E-04	1.276E-04
Core	8.23	-1.246E-03	-3.514E-04	-3.745E-04	3.331E-05	-7.159E-05	5.006E-04	3.476E-04	1.878E-04
Core	8.23	-2.615E-03	-7.896E-04	-1.182E-03	-1.398E-06	-1.703E-04	6.696E-04	4.649E-04	2.517E-04
Core	8.23	-3.808E-03	-1.182E-03	-1.893E-03	-3.474E-05	-2.597E-04	8.057E-04	5.635E-04	3.084E-04
Core	8.23	-4.617E-03	-1.479E-03	-2.393E-03	-5.779E-05	-2.966E-04	8.991E-04	6.305E-04	3.473E-04
Internal Breeding Zone	5.10	-2.981E-03	-1.009E-03	-1.606E-03	-3.025E-05	-9.490E-05	5.828E-04	4.074E-04	2.242E-04
Core	8.23	-5.136E-03	-1.640E-03	-2.536E-03	-5.024E-05	-2.127E-04	9.363E-04	6.493E-04	3.545E-04
Core	8.23	-4.946E-03	-1.475E-03	-2.158E-03	-4.236E-05	-1.848E-04	8.823E-04	6.015E-04	3.219E-04
Core	8.23	-3.913E-03	-1.107E-03	-1.466E-03	-1.660E-05	-7.712E-05	7.738E-04	5.141E-04	2.667E-04
Core	8.23	-2.297E-03	-6.024E-04	-5.710E-04	2.115E-05	7.494E-05	6.210E-04	3.986E-04	1.991E-04
Core	8.23	-4.858E-04	-6.814E-05	3.575E-04	5.549E-05	2.108E-04	4.352E-04	2.709E-04	1.317E-04
Axial Blanket 1	5.50	2.468E-04	1.097E-04	4.045E-04	4.163E-05	1.582E-04	1.589E-04	1.126E-04	5.579E-05
Axial Blanket 2	9.70	2.396E-04	1.012E-04	3.071E-04	5.144E-05	1.921E-04	1.363E-04	1.084E-04	5.489E-05

TABLE 4.65. STEEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (BOC) (cont.)

Axial Blanket 2	10.00	1.039E-04	3.987E-05	9.388E-05	2.433E-05	8.808E-05	5.024E-05	4.488E-05	2.293E-05
Axial Blanket 2	10.00	4.892E-05	1.598E-05	2.848E-05	8.609E-06	3.038E-05	1.748E-05	1.621E-05	7.934E-06
Reflector	30.00	9.378E-05	2.235E-05	4.125E-05	7.205E-06	1.888E-05	7.281E-06	7.191E-06	5.342E-06
sum Upper Boron Shield		7.362E-05	2.016E-05	5.758E-05	9.820E-06	9.916E-06	3.736E-05	1.946E-05	7.376E-06
sum Sodium Plenum		5.060E-04	1.580E-04	4.926E-04	3.847E-05	5.897E-05	2.058E-04	1.904E-04	1.055E-04
sum Core		-2.900E-02	-8.633E-03	-1.181E-02	-3.866E-05	-9.720E-04	6.826E-03	4.669E-03	2.497E-03
sum Axial Blanket		6.393E-04	2.667E-04	8.340E-04	1.260E-04	4.688E-04	3.630E-04	2.821E-04	1.415E-04

TABLE 4.66. STEEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC)

	DZ(cm)	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	RR
Reflector	30.00	1.031E-07	2.843E-08	3.421E-07	1.708E-08	4.276E-08	6.984E-07	9.080E-07	6.373E-07
Cones	4.50	3.487E-08	9.086E-09	2.038E-07	5.236E-08	1.433E-07	2.032E-06	1.553E-06	4.727E-07
Upper Boron Shield	5.00	4.160E-07	1.117E-07	3.543E-07	2.894E-07	6.773E-07	4.549E-06	3.091E-06	1.075E-06
Upper Boron Shield	5.00	5.210E-06	1.393E-06	3.831E-06	1.446E-06	2.555E-06	1.022E-05	5.595E-06	2.095E-06
Upper Boron Shield	5.00	6.817E-05	1.813E-05	5.122E-05	8.082E-06	6.610E-06	2.082E-05	9.788E-06	3.828E-06
Cones	4.50	2.116E-04	5.713E-05	1.700E-04	5.840E-06	1.137E-05	3.234E-05	1.442E-05	5.759E-06
Sodium Plenum	8.00	1.322E-04	3.666E-05	1.134E-04	8.012E-06	1.832E-05	6.021E-05	3.941E-05	1.829E-05
Sodium Plenum	8.00	1.810E-04	5.287E-05	1.594E-04	9.979E-06	1.860E-05	6.358E-05	6.075E-05	3.353E-05
Sodium Plenum	7.00	2.028E-04	6.447E-05	1.992E-04	2.124E-05	2.216E-05	7.193E-05	8.042E-05	4.824E-05
Plugs	5.30	1.235E-03	4.240E-04	1.171E-03	3.172E-05	1.926E-05	7.284E-05	8.735E-05	5.287E-05
Core	8.23	8.943E-05	6.212E-05	3.872E-04	5.661E-05	1.676E-05	2.845E-04	2.159E-04	1.209E-04
Core	8.23	-1.217E-03	-3.338E-04	-3.407E-04	3.598E-05	-6.825E-05	4.721E-04	3.290E-04	1.781E-04
Core	8.23	-2.602E-03	-7.576E-04	-1.102E-03	1.207E-06	-1.666E-04	6.328E-04	4.408E-04	2.391E-04
Core	8.23	-3.836E-03	-1.142E-03	-1.778E-03	-3.301E-05	-2.572E-04	7.633E-04	5.356E-04	2.937E-04
Core	8.23	-4.714E-03	-1.440E-03	-2.261E-03	-5.766E-05	-2.937E-04	8.543E-04	6.009E-04	3.317E-04
Internal Breeding Zone	5.10	-3.085E-03	-9.889E-04	-1.525E-03	-3.080E-05	-9.410E-05	5.552E-04	3.894E-04	2.147E-04
Core	8.23	-5.314E-03	-1.614E-03	-2.422E-03	-5.172E-05	-2.156E-04	8.946E-04	6.224E-04	3.407E-04
Core	8.23	-5.137E-03	-1.462E-03	-2.081E-03	-4.431E-05	-1.909E-04	8.464E-04	5.791E-04	3.110E-04
Core	8.23	-4.113E-03	-1.111E-03	-1.437E-03	-1.889E-05	-8.580E-05	7.457E-04	4.975E-04	2.594E-04
Core	8.23	-2.492E-03	-6.252E-04	-5.921E-04	1.892E-05	6.524E-05	6.017E-04	3.882E-04	1.954E-04
Core	8.23	-6.496E-04	-1.022E-04	2.985E-04	5.419E-05	2.036E-04	4.246E-04	2.662E-04	1.308E-04
Axial Blanket 1	5.50	1.835E-04	9.311E-05	3.721E-04	4.175E-05	1.571E-04	1.563E-04	1.120E-04	5.622E-05
Axial Blanket 2	9.70	2.054E-04	9.366E-05	2.928E-04	5.332E-05	1.972E-04	1.361E-04	1.095E-04	5.637E-05

TABLE 4.66. STEEL DENSITY COEFFICIENT DISTRIBUTION OF EACH REGION IN BN-600 PHASE 6 CORE (EOC) (cont.)

Axial Blanket 2	10.00	1.045E-04	4.093E-05	9.591E-05	2.664E-05	9.551E-05	5.162E-05	4.656E-05	2.434E-05
Axial Blanket 2	10.00	6.184E-05	1.912E-05	3.294E-05	1.015E-05	3.552E-05	1.870E-05	1.729E-05	8.798E-06
Reflector	30.00	1.407E-04	3.177E-05	5.754E-05	9.756E-06	2.549E-05	9.243E-06	8.807E-06	6.460E-06
sum Upper Boron Shield		7.379E-05	1.963E-05	5.541E-05	9.817E-06	9.843E-06	3.558E-05	1.847E-05	6.997E-06
sum Sodium Plenum		5.160E-04	1.540E-04	4.720E-04	3.923E-05	5.908E-05	1.957E-04	1.806E-04	1.001E-04
sum Core		-2.999E-02	-8.526E-03	-1.133E-02	-3.868E-05	-9.924E-04	6.520E-03	4.476E-03	2.401E-03
sum Axial Blanket		5.553E-04	2.468E-04	7.938E-04	1.319E-04	4.854E-04	3.627E-04	2.853E-04	1.457E-04

TABLE 4.67. EFFECTIVE DELAYED NEUTRON FRACTION OF EACH FAMILY AND EACH ISOTOPE IN BN-600 PHASE 6 CORE

	Family no.1		Family no.2		Family no.3		Family no.4		Family no.5		Family no.6	
	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC
U-235	2.301-06	2.077-06	1.397-05	1.260-05	1.213-05	1.094-05	2.655-05	2.394-05	8.214-06	7.409-06	1.689-06	1.523-06
U-236	4.732-09	9.174-09	2.922-08	5.661-08	2.697-08	5.226-08	6.468-08	1.253-07	2.945-08	5.708-08	1.244-08	2.410-08
U-238	1.616-05	1.611-05	1.847-04	1.839-04	2.135-04	2.127-04	5.144-04	5.124-04	2.950-04	2.940-04	9.973-05	9.936-05
Pu-238	2.783-06	3.178-06	1.923-05	2.195-05	1.236-05	1.411-05	2.804-05	3.200-05	1.236-05	1.411-05	3.978-06	4.540-06
Pu-239	3.947-05	3.875-05	3.166-04	3.107-04	2.378-04	2.334-04	3.653-04	3.584-04	1.126-04	1.105-04	3.906-05	3.833-05
Pu-240	5.358-06	5.383-06	5.681-05	5.705-05	3.880-05	3.897-05	7.165-05	7.196-05	2.581-05	2.593-05	5.947-06	5.973-06
Pu-241	7.367-07	1.117-06	1.838-05	2.785-05	1.350-05	2.046-05	3.071-05	4.654-05	1.411-05	2.138-05	1.261-06	1.910-06
Pu-242	1.382-08	2.390-08	7.343-07	1.269-06	5.894-07	1.019-06	1.522-06	2.631-06	7.919-07	1.369-06	3.698-08	6.391-08
Np-237	2.166-06	1.968-06	1.272-05	1.156-05	8.946-06	8.129-06	2.100-05	1.908-05	9.428-06	8.567-06	3.409-06	3.097-06
Am-241	1.547-06	1.397-06	1.210-05	1.092-05	7.208-06	6.508-06	1.570-05	1.417-05	7.890-06	7.123-06	2.121-06	1.914-06
Am-242m	2.028-07	3.481-07	2.370-06	4.067-06	1.313-06	2.253-06	2.920-06	5.010-06	1.513-06	2.596-06	4.285-07	7.353-07
Am-243	1.706-07	1.576-07	2.345-06	2.165-06	1.188-06	1.097-06	2.456-06	2.267-06	1.265-06	1.168-06	3.748-07	3.460-07
Cm-242	9.958-08	1.495-07	4.046-07	6.071-07	1.961-07	2.943-07	3.948-07	5.924-07	2.415-07	3.625-07	5.229-08	7.847-08
Cm-243	8.757-09	1.932-08	3.560-08	7.847-08	1.725-08	3.804-08	3.473-08	7.657-08	2.125-08	4.685-08	4.600-09	1.014-08
Cm-244	2.227-08	4.029-08	1.948-07	3.522-07	1.776-07	3.213-07	3.971-07	7.182-07	2.158-07	3.904-07	6.008-08	1.087-07
Cm-245	5.046-08	4.941-08	4.413-07	4.319-07	4.025-07	3.940-07	8.998-07	8.807-07	4.891-07	4.788-07	1.361-07	1.332-07
Total	7.110-05	7.078-05	6.411-04	6.456-04	5.481-04	5.506-04	1.082-03	1.091-03	4.900-04	4.955-04	1.583-04	1.581-04

TABLE 4.67. EFFECTIVE DELAYED NEUTRON FRACTION OF EACH FAMILY AND EACH ISOTOPE IN BN-600 PHASE 6 CORE (cont.)

Total (Family no.1~no.6)	U-235	U-236	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Total
BOC	6.486E-05	1.675E-07	1.323E-03	7.875E-05	1.111E-03	2.044E-04	7.869E-05	3.689E-06	
EOC	5.849E-05	3.245E-07	1.318E-03	8.989E-05	1.090E-03	2.053E-04	1.193E-04	6.375E-06	
Total (Family no.1~no.6)	Np-237	Am-241	Am-242m	Am-243	Cm-242	Cm-243	Cm-244	Cm-245	
BOC	5.767E-05	4.656E-05	8.747E-06	7.800E-06	1.389E-06	1.222E-07	1.068E-06	2.419E-06	2.991E-03
EOC	5.240E-05	4.203E-05	1.501E-05	7.200E-06	2.084E-06	2.694E-07	1.931E-06	2.368E-06	3.012E-03

4.3.6 KAERI results

4.3.6.1 Introduction

The calculation procedure is explained in Section 2.2.8. Results are presented in Tables 4.70–4.83. Depletion calculation is performed as a single stage calculation for one cycle (140 effective full power days) with no recalculation of the flux or resonance self-shielding in sub time steps. The benchmark results are shown in the following.

- K-effective;
- Beta effective;
- Fuel Doppler coefficient;
- Steel Doppler coefficient;
- Sodium density coefficient;
- Fuel density coefficient;
- Steel density coefficient;
- Radial expansion coefficient;
- Axial expansion coefficient.

The definition of the above coefficients conforms to those in previous phases of CRP. At the end of cycle (140 EFPDs), also the same parameters including the isotopes number densities are provided. In the depletion calculation, “DUMP’ pseudo isotopes are provided for the non-treatable isotopes in the chain reactions such as U-234 from the alpha-decay of Pu-238 or Cm-247 from the (n, gamma) reaction of Cm-246.

In Table 4.68 and Table 4.69, the integral fuel and sodium density coefficients for the core are calculated by homogeneous diffusion model by employing two cross-section generation options: JEFF-3.1-based 150-group library cross-section condensed to 25 groups and JEFF-2.2-based 80-group library cross-sections condensed to 9 groups (similar to the procedure used for Phase 4). The integral parameters are computed by the direct method. The spatial distribution of reactivity coefficients given in the following are computed with the first order perturbation theory by employing the JEFF-3.1-based 150-group cross-sections condensed to 25 groups, density reduction of 1% was assumed for computing density coefficients, microscopic cross-section being not affected by that.

4.3.6.2 Eigenvalues and whole core coefficients by diffusion theory calculation

TABLE 4.68. EIGENVALUES AND WHOLE CORE COEFFICIENTS AT BOC, KAERI, JEFF-3.1, 25 GROUPS

Case.	Item	Keff	Coefficients	
1	Reference Value (Fuel: 1500K, Steel: 600K)	1.0065791		
2	Fuel Doppler (Fuel: 2100K, Steel: 600K)	1.005136	-4.239E-03	(Δk/kk'/ΔlnK)
3	Steel Doppler (Fuel: 1500K, Steel: 900K)	1.0063134	-6.469E-04	(Δk/kk'/ΔlnK)
4	Fuel Density 0.99 Change (Fuel Density*0.99)	1.0028135	3.731E-01	(Δk/kk'/Δρ/ρ)
5	Steel Density 0.99 Change (Fe, Cr, Ni, Mo Density*0.99)	1.0068737	-2.907E-02	(Δk/kk'/Δρ/ρ)
6	Sodium Density 0.99 Change (Sodium Density*0.99)	1.006694	-1.133E-02	(Δk/kk'/Δρ/ρ)
7	Axial Expansion 1.01 Change (Atom Density*0.99)	1.0051347	-1.428E-01	(Δk/kk'/ΔH/H)
8	Radial Expansion 1.01 Change (Atom Density*0.99*0.99)	1.0012871	-5.251E-01	(Δk/kk'/ΔR/R)

TABLE 4.68. EIGENVALUES AND WHOLE CORE COEFFICIENTS AT BOC, KAERI, JEF 2.2, 9 GROUPS (cont.)

Case.	Item	Keff	Coefficients	
1	Reference Value (Fuel: 1500K, Steel: 600K)	0.9902232		
2	Fuel Doppler (Fuel: 2100K, Steel: 600K)	0.9887806	-4.379E-03	(Δk/kk'/ΔlnK)
3	Steel Doppler (Fuel: 1500K, Steel: 900K)	0.989942	-7.077E-04	(Δk/kk'/ΔlnK)
4	Fuel Density 0.99 Change (Fuel Density*0.99)	0.9865285	3.782E-01	(Δk/kk'/Δρ/ρ)
5	Steel Density 0.99 Change (Fe, Cr, Ni, Mo Density*0.99)	0.9905032	-2.854E-02	(Δk/kk'/Δρ/ρ)
6	Sodium Density 0.99 Change (Sodium Density*0.99)	0.990353	-1.324E-02	(Δk/kk'/Δρ/ρ)
7	Axial Expansion 1.01 Change (Atom Density*0.99)	0.9887989	-1.455E-01	(Δk/kk'/ΔH/H)
8	Radial Expansion 1.01 Change (Atom Density*0.99*0.99)	0.9850043	-5.351E-01	(Δk/kk'/ΔR/R)

TABLE 4.69. EIGENVALUES AND WHOLE CORE COEFFICIENTS AT EOC, KAERI, JEFF-3.1, 25 GROUPS

Case.	Item	Keff	Coefficients	
1	Reference Value (Fuel: 1500K, Steel: 600K)	1.010054		
2	Fuel Doppler (Fuel: 2100K, Steel: 600K)	1.008488	-4.571E-03	(Δk/kk'/ΔlnK)
3	Steel Doppler (Fuel: 1500K, Steel: 900K)	1.009773	-6.799E-04	(Δk/kk'/ΔlnK)
4	Fuel Density 0.99 Change (Fuel Density*0.99)	1.006286	3.708E-01	(Δk/kk'/Δρ/ρ)
5	Steel Density 0.99 Change (Fe, Cr, Ni, Mo Density*0.99)	1.010351	-2.913E-02	(Δk/kk'/Δρ/ρ)
6	Sodium Density 0.99 Change (Sodium Density*0.99)	1.010162	-1.062E-02	(Δk/kk'/Δρ/ρ)
7	Axial Expansion 1.01 Change (Atom Density*0.99)	1.008625	-1.403E-01	(Δk/kk'/ΔH/H)
8	Radial Expansion 1.01 Change (Atom Density*0.99*0.99)	1.004763	-5.213E-01	(Δk/kk'/ΔR/R)

TABLE 4.69. EIGENVALUES AND WHOLE CORE COEFFICIENTS AT EOC, KAERI, KAERI, JEF 2.2, 9 GROUPS (cont.)

Case.	Item	Keff	Coefficients	
1	Reference Value (Fuel: 1500K, Steel: 600K)	0.993238		
2	Fuel Doppler (Fuel: 2100K, Steel: 600K)	0.991673	-4.721E-03	(Δk/kk'/ΔlnK)
3	Steel Doppler (Fuel: 1500K, Steel: 900K)	0.992942	-7.404E-04	(Δk/kk'/ΔlnK)
4	Fuel Density 0.99 Change (Fuel Density*0.99)	0.989539	3.763E-01	(Δk/kk'/Δρ/ρ)
5	Steel Density 0.99 Change (Fe, Cr, Ni, Mo Density*0.99)	0.993523	-2.895E-02	(Δk/kk'/Δρ/ρ)
6	Sodium Density 0.99 Change (Sodium Density*0.99)	0.993363	-1.269E-02	(Δk/kk'/Δρ/ρ)
7	Axial Expansion 1.01 Change (Atom Density*0.99)	0.991828	-1.431E-01	(Δk/kk'/ΔH/H)
8	Radial Expansion 1.01 Change (Atom Density*0.99*0.99)	0.988022	-5.315E-01	(Δk/kk'/ΔR/R)

4.3.6.3 Fuel Doppler coefficients

TABLE 4.70. FUEL DOPPLER COEFFICIENTS AT BOC, ΔK/KK')/ (LN (T2/T1), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Reflector 8
Reflector	234.90	30.00								
Cones	204.90	4.50								
Upper Boron Shield	200.40	5.00								
	195.40	5.00								
	190.40	5.00								
(sum of UBS)										
Cones	185.40	4.50								
Sodium Plenum	180.90	8.00								
	172.90	8.00								
	164.90	7.00								
(sum of SP)										
Plugs	157.90	5.30								
Core	152.60	8.23	-8.746E-05	-2.234E-05	-7.455E-05					
	144.37	8.23	-9.936E-05	-2.460E-05	-7.499E-05					
	136.14	8.23	-1.337E-04	-3.331E-05	-9.771E-05					
	127.91	8.23	-1.751E-04	-4.349E-05	-1.231E-04					
	119.68	8.23	-2.244E-04	-5.479E-05	-1.434E-04					
Internal Breeding Zone	111.45	5.10	-2.586E-04	-4.075E-05	-9.488E-05					
Core	106.35	8.23	-2.822E-04	-7.036E-05	-1.532E-04					
	98.12	8.23	-2.692E-04	-6.761E-05	-1.420E-04					
	89.89	8.23	-2.354E-04	-5.835E-05	-1.200E-04					
	81.66	8.23	-1.892E-04	-4.609E-05	-9.317E-05					
	73.43	8.23	-1.447E-04	-3.481E-05	-7.015E-05					
(sum of Core)			-2.099E-03	-4.965E-04	-1.187E-03					
Axial Blanket 1	65.20	5.50	-1.145E-04	-2.818E-05	-5.936E-05					
Axial Blanket 2	59.70	9.70	-1.113E-04	-2.631E-05	-5.233E-05					
	50.00	10.00	-4.671E-05	-1.036E-05	-1.925E-05					
	40.00	10.00	-2.019E-05	-4.245E-06	-7.577E-06					
(sum of AB2)			-1.782E-04	-4.092E-05	-7.916E-05					
Reflector	30.00	30.00								
(sum)			-2.392E-03	-5.656E-04	-1.326E-03					
Total Sum			-4.283E-03							

TABLE 4.71.FUEL DOPPLER COEFFICIENTS AT 140 EFPD, ΔK/KK'/LN (T2/T1)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00								
Cones	204.90	4.50								
Upper Boron Shield	200.40	5.00								
	195.40	5.00								
	190.40	5.00								
(sum of UBS)										
Cones	185.40	4.50								
Sodium Plenum	180.90	8.00								
	172.90	8.00								
	164.90	7.00								
(sum of SP)										
Plugs	157.90	5.30								
Core	152.60	8.23	-9.230E-05	-2.246E-05	-7.382E-05					
	144.37	8.23	-1.059E-04	-2.490E-05	-7.457E-05					
	136.14	8.23	-1.430E-04	-3.373E-05	-9.712E-05					
	127.91	8.23	-1.880E-04	-4.414E-05	-1.226E-04					
	119.68	8.23	-2.420E-04	-5.587E-05	-1.432E-04					
Internal Breeding Zone	111.45	5.10	-2.766E-04	-4.178E-05	-9.514E-05					
Core	106.35	8.23	-3.075E-04	-7.262E-05	-1.543E-04					
	98.12	8.23	-2.958E-04	-7.038E-05	-1.441E-04					
	89.89	8.23	-2.610E-04	-6.131E-05	-1.229E-04					
	81.66	8.23	-2.120E-04	-4.895E-05	-9.643E-05					
	73.43	8.23	-1.636E-04	-3.729E-05	-7.331E-05					
(sum of Core)			-2.288E-03	-5.134E-04	-1.198E-03					
Axial Blanket 1	65.20	5.50	-1.351E-04	-3.139E-05	-6.369E-05					
Axial Blanket 2	59.70	9.70	-1.427E-04	-3.182E-05	-6.117E-05					
	50.00	10.00	-6.640E-05	-1.396E-05	-2.522E-05					
	40.00	10.00	-3.110E-05	-6.230E-06	-1.087E-05					
(sum of AB2)			-2.402E-04	-5.201E-05	-9.725E-05					
Reflector	30.00	30.00								
(sum)			-2.663E-03	-5.968E-04	-1.358E-03					
Total Sum			-4.618E-03							

4.3.6.4 Steel Doppler coefficients

TABLE 4.72. STEEL DOPPLER COEFFICIENTS AT BOC, ΔK/KK'/LN(T2/T1)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00	-2.288E-08	-2.293E-08	-2.278E-08	-2.291E-08	-2.293E-08	-2.256E-08	-2.227E-08	-2.232E-08
Cones	204.90	4.50	-2.291E-08	-2.293E-08	-2.274E-08	-2.288E-08	-2.291E-08	-2.183E-08	-2.242E-08	-2.239E-08
Upper Boron Shield	200.40	5.00	-2.264E-08	-2.283E-08	-2.269E-08	-2.247E-08	-2.278E-08	-2.123E-08	-2.359E-08	-2.174E-08
	195.40	5.00	-1.969E-08	-2.203E-08	-2.059E-08	-2.013E-08	-2.179E-08	-2.208E-08	-2.780E-08	-2.076E-08
	190.40	5.00	1.448E-08	-1.249E-08	8.227E-09	-1.385E-08	-1.672E-08	-4.060E-08	-3.951E-08	-1.925E-08
(sum of UBS)			-2.785E-08	-5.735E-08	-3.505E-08	-5.645E-08	-6.129E-08	-8.391E-08	-9.089E-08	-6.175E-08
Cones	185.40	4.50	-2.714E-07	-9.985E-08	-3.629E-07	-2.271E-08	-2.203E-08	-1.234E-07	-5.708E-08	-1.777E-08
Sodium Plenum	180.90	8.00	-5.090E-07	-1.694E-07	-6.326E-07	-6.229E-08	-4.657E-08	-5.707E-07	-1.638E-07	-7.181E-09
	172.90	8.00	-9.983E-07	-3.046E-07	-1.148E-06	-1.041E-07	-7.731E-08	-1.105E-06	-3.287E-07	5.818E-09
	164.90	7.00	-1.396E-06	-4.017E-07	-1.466E-06	-1.292E-07	-9.929E-08	-1.499E-06	-4.963E-07	1.862E-08
(sum of SP)			-2.903E-06	-8.757E-07	-3.247E-06	-2.956E-07	-2.232E-07	-3.174E-06	-9.887E-07	1.726E-08
Plugs	157.90	5.30	-1.236E-05	-3.340E-06	-1.120E-05	-1.158E-07	-1.000E-07	-1.538E-06	-5.636E-07	2.269E-08
Core	152.60	8.23	-8.499E-06	-2.258E-06	-6.905E-06	-2.832E-07	-1.822E-07	-3.242E-06	-1.272E-06	8.006E-08
	144.37	8.23	-1.209E-05	-3.270E-06	-9.077E-06	-5.347E-07	-2.682E-07	-4.628E-06	-1.881E-06	1.276E-07
	136.14	8.23	-1.732E-05	-4.753E-06	-1.272E-05	-8.375E-07	-3.988E-07	-6.279E-06	-2.547E-06	1.789E-07
	127.91	8.23	-2.301E-05	-6.325E-06	-1.643E-05	-1.142E-06	-5.416E-07	-7.833E-06	-3.157E-06	2.249E-07
	119.68	8.23	-2.905E-05	-7.894E-06	-1.932E-05	-1.591E-06	-6.663E-07	-8.947E-06	-3.588E-06	2.568E-07
Internal Breeding Zone	111.45	5.10	-2.099E-05	-5.689E-06	-1.280E-05	-1.023E-06	-3.293E-07	-5.822E-06	-2.334E-06	1.573E-07
Core	106.35	8.23	-3.541E-05	-9.677E-06	-2.065E-05	-2.049E-06	-5.272E-07	-9.244E-06	-3.691E-06	2.625E-07
	98.12	8.23	-3.387E-05	-9.207E-06	-1.898E-05	-2.056E-06	-4.943E-07	-8.406E-06	-3.353E-06	2.357E-07
	89.89	8.23	-2.925E-05	-7.795E-06	-1.571E-05	-1.728E-06	-4.127E-07	-6.945E-06	-2.771E-06	1.908E-07
	81.66	8.23	-2.262E-05	-5.886E-06	-1.164E-05	-1.236E-06	-3.005E-07	-5.140E-06	-2.050E-06	1.370E-07
	73.43	8.23	-1.568E-05	-3.983E-06	-7.841E-06	-7.369E-07	-1.882E-07	-3.298E-06	-1.327E-06	8.454E-08
(sum of Core)			-2.478E-04	-6.674E-05	-1.521E-04	-1.322E-05	-4.309E-06	-6.978E-05	-2.797E-05	1.936E-06
Axial Blanket 1	65.20	5.50	-6.144E-06	-1.520E-06	-2.899E-06	-2.699E-07	-8.125E-08	-1.315E-06	-5.537E-07	2.427E-08
Axial Blanket 2	59.70	9.70	-5.232E-06	-1.238E-06	-2.295E-06	-2.092E-07	-6.748E-08	-1.135E-06	-5.046E-07	2.563E-08
	50.00	10.00	-2.054E-06	-4.666E-07	-8.196E-07	-8.551E-08	-3.846E-08	-4.142E-07	-2.010E-07	-1.728E-09
	40.00	10.00	-8.108E-07	-1.852E-07	-3.097E-07	-5.319E-08	-3.135E-08	-1.478E-07	-8.344E-08	-1.655E-08
(sum of AB2)			-8.097E-06	-1.890E-06	-3.424E-06	-3.479E-07	-1.373E-07	-1.697E-06	-7.890E-07	7.351E-09
Reflector	30.00	30.00	-5.683E-07	-1.279E-07	-2.146E-07	-7.171E-08	-4.158E-08	-4.343E-08	-3.352E-08	-2.232E-08
(sum)			-2.782E-04	-7.469E-05	-1.735E-04	-1.444E-05	-5.022E-06	-7.780E-05	-3.109E-05	1.861E-06
Total Sum			-6.529E-04							

TABLE 4.73. STEEL DOPPLER COEFFICIENTS AT EOC, ΔK/KK'/LN(T2/T1)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00	2.417E-11	0.000E+00	1.450E-10	0.000E+00	0.000E+00	3.384E-10	6.285E-10	5.802E-10
Cones	204.90	4.50	2.417E-11	0.000E+00	1.692E-10	4.835E-11	0.000E+00	1.015E-09	4.835E-10	4.835E-10
Upper Boron Shield	200.40	5.00	2.901E-10	7.252E-11	2.176E-10	4.593E-10	1.450E-10	1.596E-09	-6.769E-10	1.136E-09
	195.40	5.00	3.288E-09	8.703E-10	2.248E-09	2.828E-09	1.160E-09	7.011E-10	-4.762E-09	2.055E-09
	190.40	5.00	3.815E-08	1.023E-08	3.015E-08	9.138E-09	6.310E-09	-1.738E-08	-1.615E-08	3.457E-09
(sum of UBS)			4.173E-08	1.117E-08	3.261E-08	1.243E-08	7.615E-09	-1.508E-08	-2.159E-08	6.648E-09
Cones	185.40	4.50	-2.578E-07	-7.663E-08	-3.328E-07	1.692E-10	8.703E-10	-9.757E-08	-3.312E-08	4.883E-09
Sodium Plenum	180.90	8.00	-5.027E-07	-1.457E-07	-5.972E-07	-3.998E-08	-2.439E-08	-5.307E-07	-1.363E-07	1.484E-08
	172.90	8.00	-1.010E-06	-2.805E-07	-1.103E-06	-8.253E-08	-5.621E-08	-1.047E-06	-2.954E-07	2.700E-08
	164.90	7.00	-1.424E-06	-3.778E-07	-1.415E-06	-1.082E-07	-7.924E-08	-1.427E-06	-4.568E-07	3.892E-08
(sum of SP)			-2.936E-06	-8.040E-07	-3.116E-06	-2.307E-07	-1.598E-07	-3.005E-06	-8.886E-07	8.077E-08
Plugs	157.90	5.30	-1.290E-05	-3.318E-06	-1.097E-05	-9.498E-08	-8.089E-08	-1.465E-06	-5.216E-07	4.264E-08
Core	152.60	8.23	-9.013E-06	-2.264E-06	-6.810E-06	-2.675E-07	-1.695E-07	-3.116E-06	-1.204E-06	9.612E-08
	144.37	8.23	-1.288E-05	-3.280E-06	-8.946E-06	-5.245E-07	-2.614E-07	-4.457E-06	-1.792E-06	1.403E-07
	136.14	8.23	-1.849E-05	-4.772E-06	-1.252E-05	-8.356E-07	-4.001E-07	-6.055E-06	-2.436E-06	1.882E-07
	127.91	8.23	-2.468E-05	-6.372E-06	-1.619E-05	-1.153E-06	-5.535E-07	-7.569E-06	-3.029E-06	2.315E-07
	119.68	8.23	-3.134E-05	-7.999E-06	-1.910E-05	-1.634E-06	-6.907E-07	-8.672E-06	-3.455E-06	2.619E-07
Internal Breeding										
Zone	111.45	5.10	-2.278E-05	-5.795E-06	-1.270E-05	-1.061E-06	-3.314E-07	-5.652E-06	-2.247E-06	1.692E-07
Core	106.35	8.23	-3.865E-05	-9.939E-06	-2.061E-05	-2.168E-06	-5.482E-07	-9.025E-06	-3.580E-06	2.688E-07
	98.12	8.23	-3.726E-05	-9.538E-06	-1.909E-05	-2.197E-06	-5.168E-07	-8.259E-06	-3.272E-06	2.448E-07
	89.89	8.23	-3.249E-05	-8.161E-06	-1.597E-05	-1.871E-06	-4.336E-07	-6.881E-06	-2.725E-06	2.034E-07
	81.66	8.23	-2.548E-05	-6.249E-06	-1.199E-05	-1.366E-06	-3.167E-07	-5.153E-06	-2.040E-06	1.529E-07
	73.43	8.23	-1.802E-05	-4.309E-06	-8.220E-06	-8.409E-07	-1.971E-07	-3.372E-06	-1.345E-06	1.031E-07
(sum of Core)			-2.711E-04	-6.868E-05	-1.521E-04	-1.392E-05	-4.419E-06	-6.821E-05	-2.713E-05	2.060E-06
Axial Blanket 1	65.20	5.50	-7.358E-06	-1.697E-06	-3.182E-06	-3.144E-07	-7.494E-08	-1.383E-06	-5.665E-07	4.535E-08
Axial Blanket 2	59.70	9.70	-6.726E-06	-1.478E-06	-2.701E-06	-2.699E-07	-6.527E-08	-1.265E-06	-5.428E-07	4.658E-08
	50.00	10.00	-2.900E-06	-5.994E-07	-1.058E-06	-1.091E-07	-2.734E-08	-4.932E-07	-2.217E-07	2.016E-08
	40.00	10.00	-1.222E-06	-2.402E-07	-4.194E-07	-5.434E-08	-1.492E-08	-1.750E-07	-8.509E-08	5.560E-09
(sum of AB2)			-1.085E-05	-2.317E-06	-4.178E-06	-4.334E-07	-1.075E-07	-1.933E-06	-8.496E-07	7.231E-08
Reflector	30.00	30.00	-8.911E-07	-1.652E-07	-2.951E-07	-8.055E-08	-3.073E-08	-3.191E-08	-1.774E-08	-1.040E-09
(sum)			-3.062E-04	-7.704E-05	-1.742E-04	-1.506E-05	-4.864E-06	-7.614E-05	-3.002E-05	2.313E-06
Total Sum			-6.812E-04							

4.3.6.5 Fuel density coefficients by the first order perturbation theory

TABLE 4.74. FUEL DENSITY COEFFICIENTS AT BOC, ΔK/KK'/(ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00								
Cones	204.90	4.50								
Upper Boron Shield	200.40	5.00								
	195.40	5.00								
	190.40	5.00								
(sum of UBS)										
Cones	185.40	4.50								
Sodium Plenum	180.90	8.00								
	172.90	8.00								
	164.90	7.00								
(sum of SP)										
Plugs	157.90	5.30								
Core	152.60	8.23	6.342E-03	2.059E-03	6.727E-03					
	144.37	8.23	9.624E-03	3.207E-03	1.102E-02					
	136.14	8.23	1.324E-02	4.486E-03	1.571E-02					
	127.91	8.23	1.648E-02	5.678E-03	2.000E-02					
	119.68	8.23	1.864E-02	6.579E-03	2.320E-02					
Internal Breeding Zone	111.45	5.10	-1.937E-03	4.326E-03	1.524E-02					
Core	106.35	8.23	2.054E-02	7.106E-03	2.466E-02					
	98.12	8.23	2.017E-02	6.739E-03	2.286E-02					
	89.89	8.23	1.787E-02	5.801E-03	1.919E-02					
	81.66	8.23	1.418E-02	4.478E-03	1.433E-02					
	73.43	8.23	1.010E-02	3.092E-03	9.323E-03					
(sum of Core)			1.452E-01	5.355E-02	1.823E-01					
Axial Blanket 1	65.20	5.50	-1.514E-03	-3.425E-04	-2.751E-04					
Axial Blanket 2	59.70	9.70	-1.618E-03	-3.503E-04	-4.779E-04					
	50.00	10.00	-5.498E-04	-1.082E-04	-1.797E-04					
	40.00	10.00	-1.375E-04	-2.313E-05	-4.570E-05					
(sum of AB2)			-2.305E-03	-4.816E-04	-7.033E-04					
Reflector	30.00	30.00								
(sum)			1.414E-01	5.273E-02	1.813E-01					
Total Sum			3.754E-01							

TABLE 4.75. FUEL DENSITY COEFFICIENTS AT EOC, ΔK/KK'/(ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA 2,3 7	R. Refletor 8
Reflector	234.90	30.00								
Cones	204.90	4.50								
Upper Boron Shield	200.40	5.00								
	195.40	5.00								
	190.40	5.00								
(sum of UBS)										
Cones	185.40	4.50								
Sodium Plenum	180.90	8.00								
	172.90	8.00								
	164.90	7.00								
(sum of SP)										
Plugs	157.90	5.30								
Core	152.60	8.23	4.997E-03	4.874E-04	4.782E-03					
	144.37	8.23	8.360E-03	1.574E-03	8.743E-03					
	136.14	8.23	1.210E-02	2.795E-03	1.309E-02					
	127.91	8.23	1.553E-02	3.946E-03	1.711E-02					
	119.68	8.23	1.791E-02	4.839E-03	2.016E-02					
Internal Breeding Zone	111.45	5.10	-1.717E-03	2.695E-03	1.280E-02					
Core	106.35	8.23	2.006E-02	5.419E-03	2.173E-02					
	98.12	8.23	1.973E-02	5.108E-03	2.018E-02					
	89.89	8.23	1.742E-02	4.239E-03	1.687E-02					
	81.66	8.23	1.365E-02	2.984E-03	1.237E-02					
	73.43	8.23	9.399E-03	1.643E-03	7.670E-03					
(sum of Core)			1.375E-01	3.573E-02	1.555E-01					
Axial Blanket 1	65.20	5.50	-2.626E-03	-1.728E-03	-1.584E-03					
Axial Blanket 2	59.70	9.70	-3.031E-03	-1.795E-03	-1.881E-03					
	50.00	10.00	-2.028E-03	-1.580E-03	-1.641E-03					
	40.00	10.00	-1.614E-03	-1.501E-03	-1.522E-03					
(sum of AB2)			-6.672E-03	-4.876E-03	-5.045E-03					
Reflector	30.00	30.00								
(sum)			1.282E-01	2.913E-02	1.489E-01					
Total Sum			3.062E-01							

4.3.6.6 Sodium density coefficients by the first order perturbation theory

TABLE 4.76. SODIUM DENSITY COEFFICIENTS AT BOC, ΔK/KK'/ (ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00	-4.185E-08	-1.220E-08	1.917E-07	-2.080E-09	-7.511E-10	1.361E-07	3.253E-07	6.957E-08
Cones	204.90	4.50	-4.977E-09	1.614E-09	1.512E-07	1.248E-08	4.539E-09	7.403E-08	7.323E-08	5.955E-08
Upper Boron Shield	200.40	5.00	-4.531E-08	-1.101E-08	-2.976E-08	9.925E-08	4.495E-08	1.572E-07	1.931E-07	1.441E-07
	195.40	5.00	-3.515E-07	-9.266E-08	-2.342E-07	5.053E-07	2.790E-07	3.786E-07	4.998E-07	2.925E-07
	190.40	5.00	-7.438E-07	-1.128E-07	5.814E-07	1.442E-06	1.444E-06	1.081E-06	1.190E-06	5.499E-07
(sum of UBS)			-1.141E-06	-2.165E-07	3.174E-07	2.047E-06	1.768E-06	1.616E-06	1.883E-06	9.866E-07
Cones	185.40	4.50	1.756E-05	6.026E-06	3.074E-05	8.271E-07	5.112E-06	3.170E-06	2.003E-06	8.461E-07
Sodium Plenum	180.90	8.00	5.933E-05	2.344E-05	1.633E-04	-2.500E-06	3.830E-06	8.566E-06	7.417E-06	2.832E-06
	172.90	8.00	6.019E-05	3.044E-05	2.592E-04	-6.343E-06	3.272E-06	1.291E-05	1.456E-05	5.616E-06
	164.90	7.00	4.880E-05	3.359E-05	3.813E-04	-8.794E-06	1.311E-05	1.682E-05	2.252E-05	8.604E-06
(sum of SP)			1.683E-04	8.748E-05	8.038E-04	-1.764E-05	2.021E-05	3.830E-05	4.449E-05	1.705E-05
Plugs	157.90	5.30	-1.921E-05	1.962E-06	6.851E-05	-1.401E-05	3.447E-05	2.032E-05	2.767E-05	9.811E-06
Core	152.60	8.23	-1.467E-04	-3.398E-05	1.623E-04	-5.081E-05	5.757E-05	8.048E-05	7.034E-05	2.289E-05
	144.37	8.23	-5.356E-04	-1.594E-04	1.090E-04	-1.259E-04	1.457E-05	1.515E-04	1.155E-04	3.439E-05
	136.14	8.23	-9.740E-04	-3.009E-04	4.008E-05	-2.091E-04	-4.516E-05	2.229E-04	1.642E-04	4.692E-05
	127.91	8.23	-1.368E-03	-4.299E-04	-1.771E-05	-2.846E-04	-1.019E-04	2.854E-04	2.076E-04	5.824E-05
	119.68	8.23	-1.673E-03	-5.288E-04	-4.842E-05	-3.325E-04	-1.427E-04	3.299E-04	2.379E-04	6.614E-05
Internal Breeding Zone	111.45	5.10	-1.199E-03	-3.600E-04	-3.444E-05	-3.328E-04	-1.014E-04	2.162E-04	1.549E-04	4.279E-05
Core	106.35	8.23	-1.851E-03	-5.696E-04	-2.359E-05	-5.532E-04	-1.719E-04	3.458E-04	2.464E-04	6.782E-05
	98.12	8.23	-1.750E-03	-5.099E-04	3.096E-05	-4.851E-04	-1.580E-04	3.168E-04	2.241E-04	6.144E-05
	89.89	8.23	-1.423E-03	-3.939E-04	1.027E-04	-3.111E-04	-1.020E-04	2.614E-04	1.839E-04	5.053E-05
	81.66	8.23	-9.232E-04	-2.393E-04	1.789E-04	-6.180E-05	-1.592E-05	1.880E-04	1.328E-04	3.725E-05
	73.43	8.23	-3.946E-04	-8.418E-05	2.308E-04	1.800E-04	6.939E-05	1.083E-04	8.083E-05	2.427E-05
(sum of Core)			-1.224E-02	-3.610E-03	7.306E-04	-2.567E-03	-6.975E-04	2.507E-03	1.818E-03	5.127E-04
Axial Blanket 1	65.20	5.50	-1.369E-04	-2.149E-05	6.300E-05	1.782E-04	6.638E-05	3.100E-05	3.053E-05	1.020E-05
Axial Blanket 2	59.70	9.70	-1.748E-04	-3.007E-05	-7.296E-06	2.087E-04	7.837E-05	1.745E-05	2.511E-05	9.865E-06
	50.00	10.00	-6.943E-05	-1.124E-05	-1.442E-05	8.691E-05	3.366E-05	3.319E-06	8.004E-06	3.975E-06
	40.00	10.00	-1.790E-05	-2.273E-06	-4.397E-06	2.910E-05	1.160E-05	5.989E-07	2.123E-06	1.317E-06
(sum of AB2)			-2.621E-04	-4.359E-05	-2.611E-05	3.247E-04	1.236E-04	2.137E-05	3.523E-05	1.516E-05
Reflector	30.00	30.00	1.352E-05	7.774E-06	1.610E-05	5.173E-06	1.789E-06	3.860E-06	6.796E-06	7.433E-07
(sum)			-1.246E-02	-3.572E-03	1.687E-03	-2.088E-03	-4.441E-04	2.627E-03	1.967E-03	5.676E-04
Total Sum			-1.171E-02							

TABLE 4.77. SODIUM DENSITY COEFFICIENTS AT EOC, ΔK/KK'/(ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00	-7.417E-05	-7.414E-05	-7.394E-05	-7.413E-05	-7.413E-05	-7.400E-05	-7.381E-05	-7.406E-05
Cones	204.90	4.50	-7.413E-05	-7.412E-05	-7.398E-05	-7.411E-05	-7.412E-05	-7.405E-05	-7.406E-05	-7.407E-05
Upper Boron Shield	200.40	5.00	-7.417E-05	-7.414E-05	-7.415E-05	-7.403E-05	-7.408E-05	-7.398E-05	-7.394E-05	-7.399E-05
	195.40	5.00	-7.448E-05	-7.422E-05	-7.435E-05	-7.362E-05	-7.384E-05	-7.376E-05	-7.365E-05	-7.385E-05
	190.40	5.00	-7.484E-05	-7.423E-05	-7.354E-05	-7.267E-05	-7.265E-05	-7.309E-05	-7.299E-05	-7.360E-05
(sum of UBS)			-2.235E-04	-2.226E-04	-2.220E-04	-2.203E-04	-2.206E-04	-2.208E-04	-2.206E-04	-2.214E-04
Cones	185.40	4.50	-5.562E-05	-6.813E-05	-4.405E-05	-7.325E-05	-6.888E-05	-7.108E-05	-7.221E-05	-7.332E-05
Sodium Plenum	180.90	8.00	-8.916E-06	-5.029E-05	8.643E-05	-7.646E-05	-7.007E-05	-6.588E-05	-6.704E-05	-7.143E-05
	172.90	8.00	-2.575E-06	-4.260E-05	1.805E-04	-8.015E-05	-7.046E-05	-6.172E-05	-6.025E-05	-6.879E-05
	164.90	7.00	-7.458E-06	-3.847E-05	2.991E-04	-8.240E-05	-6.010E-05	-5.803E-05	-5.274E-05	-6.597E-05
(sum of SP)			-1.895E-05	-1.314E-04	5.660E-04	-2.390E-04	-2.006E-04	-1.856E-04	-1.800E-04	-2.062E-04
Plugs	157.90	5.30	-8.810E-05	-7.182E-05	-8.526E-06	-8.776E-05	-3.806E-05	-5.485E-05	-4.791E-05	-6.483E-05
Core	152.60	8.23	-2.031E-04	-1.041E-04	8.761E-05	-1.236E-04	-1.314E-05	1.754E-06	-7.650E-06	-5.247E-05
	144.37	8.23	-5.836E-04	-2.218E-04	4.869E-05	-1.979E-04	-5.483E-05	6.820E-05	3.483E-05	-4.160E-05
	136.14	8.23	-1.019E-03	-3.557E-04	-4.788E-06	-2.807E-04	-1.137E-04	1.352E-04	8.087E-05	-2.972E-05
	127.91	8.23	-1.417E-03	-4.790E-04	-4.854E-05	-3.571E-04	-1.707E-04	1.943E-04	1.220E-04	-1.892E-05
	119.68	8.23	-1.733E-03	-5.748E-04	-6.858E-05	-4.067E-04	-2.131E-04	2.371E-04	1.513E-04	-1.127E-05
Internal Breeding Zone	111.45	5.10	-1.267E-03	-4.159E-04	-7.179E-05	-4.014E-04	-1.743E-04	1.305E-04	7.306E-05	-3.334E-05
Core	106.35	8.23	-1.930E-03	-6.137E-04	-3.868E-05	-6.189E-04	-2.451E-04	2.545E-04	1.610E-04	-9.247E-06
	98.12	8.23	-1.836E-03	-5.579E-04	9.623E-06	-5.536E-04	-2.323E-04	2.288E-04	1.409E-04	-1.502E-05
	89.89	8.23	-1.518E-03	-4.501E-04	6.900E-05	-3.860E-04	-1.779E-04	1.779E-04	1.038E-04	-2.515E-05
	81.66	8.23	-1.025E-03	-3.052E-04	1.298E-04	-1.435E-04	-9.323E-05	1.094E-04	5.582E-05	-3.766E-05
	73.43	8.23	-4.952E-04	-1.573E-04	1.684E-04	9.736E-05	-7.324E-06	3.383E-05	6.253E-06	-5.005E-05
(sum of core)			-1.303E-02	-4.236E-03	2.808E-04	-3.372E-03	-1.496E-03	1.571E-03	9.222E-04	-3.245E-04
Axial Blanket 1	65.20	5.50	-2.188E-04	-9.461E-05	-4.417E-06	1.044E-04	-7.031E-06	-4.210E-05	-4.315E-05	-6.386E-05
Axial Blanket 2	59.70	9.70	-2.535E-04	-1.013E-04	-6.976E-05	1.456E-04	9.136E-06	-5.497E-05	-4.794E-05	-6.402E-05
	50.00	10.00	-1.446E-04	-8.365E-05	-8.312E-05	2.467E-05	-3.551E-05	-6.995E-05	-6.535E-05	-6.992E-05
	40.00	10.00	-9.093E-05	-7.546E-05	-7.656E-05	-3.750E-05	-5.940E-05	-7.323E-05	-7.166E-05	-7.267E-05
(sum of AB2)			-4.891E-04	-2.604E-04	-2.294E-04	1.328E-04	-8.577E-05	-1.982E-04	-1.849E-04	-2.066E-04
Reflector	30.00	30.00	-4.211E-05	-6.057E-05	-4.628E-05	-6.599E-05	-7.128E-05	-6.846E-05	-6.548E-05	-7.324E-05
(sum)			-1.431E-02	-5.293E-03	1.441E-04	-3.969E-03	-2.336E-03	5.822E-04	-3.994E-05	-1.382E-03
Total Sum			-2.661E-02							

4.3.6.7 *Steel density coefficients by the first order perturbation theory*

TABLE 4.78. STEEL DENSITY COEFFICIENTS AT BOC, ΔK/KK'/(ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height	dZ	LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2,3	R. Refletor
	(cm)	(cm)	1	2	3	4	5	6	7	8
Reflector	234.90	30.00	-1.757E-08	-3.503E-09	2.229E-07	2.659E-10	7.445E-12	1.726E-07	3.460E-07	7.949E-07
Cones	204.90	4.50	-9.516E-11	5.937E-09	3.323E-07	2.132E-08	5.541E-09	6.547E-07	6.746E-07	6.703E-07
Upper Boron Shield	200.40	5.00	-5.435E-08	-1.068E-08	1.594E-08	1.772E-07	5.607E-08	1.490E-06	1.709E-06	1.616E-06
	195.40	5.00	-2.754E-10	2.107E-08	1.894E-07	9.761E-07	3.755E-07	3.626E-06	4.161E-06	3.274E-06
	190.40	5.00	5.927E-06	1.772E-06	6.059E-06	3.252E-06	2.118E-06	9.815E-06	9.442E-06	6.139E-06
(sum of UBS)			5.873E-06	1.782E-06	6.265E-06	4.405E-06	2.550E-06	1.493E-05	1.531E-05	1.103E-05
Cones	185.40	4.50	6.509E-05	1.981E-05	7.834E-05	3.133E-06	2.285E-06	2.617E-05	1.551E-05	9.410E-06
Sodium Plenum	180.90	8.00	4.301E-05	1.401E-05	6.765E-05	-5.018E-07	2.070E-06	7.005E-05	5.568E-05	3.131E-05
	172.90	8.00	5.345E-05	1.892E-05	1.012E-04	-4.864E-06	2.024E-06	1.013E-04	1.060E-04	6.145E-05
	164.90	7.00	5.726E-05	2.210E-05	1.429E-04	-6.958E-06	6.133E-06	1.259E-04	1.588E-04	9.317E-05
(sum of SP)			1.537E-04	5.503E-05	3.118E-04	-1.232E-05	1.023E-05	2.973E-04	3.205E-04	1.859E-04
Plugs	157.90	5.30	-9.158E-05	1.680E-05	3.446E-04	-8.742E-06	1.473E-05	1.450E-04	1.909E-04	1.054E-04
Core	152.60	8.23	-4.486E-04	-1.162E-04	2.009E-04	-4.958E-05	2.272E-05	5.790E-04	4.757E-04	2.442E-04
	144.37	8.23	-1.456E-03	-4.388E-04	-7.984E-05	-1.530E-04	3.489E-06	1.081E-03	7.711E-04	3.646E-04
	136.14	8.23	-2.536E-03	-7.873E-04	-3.731E-04	-2.651E-04	-2.164E-05	1.590E-03	1.091E-03	4.957E-04
	127.91	8.23	-3.501E-03	-1.106E-03	-6.276E-04	-3.647E-04	-4.511E-05	2.037E-03	1.375E-03	6.142E-04
	119.68	8.23	-4.213E-03	-1.358E-03	-7.905E-04	-4.393E-04	-6.157E-05	2.355E-03	1.574E-03	6.968E-04
Internal Breeding Zone	111.45	5.10	-2.881E-03	-9.290E-04	-5.234E-04	-1.245E-04	-3.022E-05	1.543E-03	1.024E-03	4.506E-04
Core	106.35	8.23	-4.779E-03	-1.502E-03	-7.795E-04	-2.278E-04	-5.153E-05	2.469E-03	1.630E-03	7.145E-04
	98.12	8.23	-4.633E-03	-1.369E-03	-6.046E-04	-2.088E-04	-4.810E-05	2.262E-03	1.483E-03	6.476E-04
	89.89	8.23	-3.831E-03	-1.080E-03	-3.350E-04	-1.390E-04	-3.209E-05	1.867E-03	1.220E-03	5.336E-04
	81.66	8.23	-2.569E-03	-6.856E-04	-1.540E-05	-3.507E-05	-6.952E-06	1.346E-03	8.868E-04	3.946E-04
	73.43	8.23	-1.152E-03	-2.678E-04	2.963E-04	6.889E-05	1.871E-05	7.861E-04	5.473E-04	2.585E-04
(sum of Core)			-3.200E-02	-9.639E-03	-3.632E-03	-1.938E-03	-2.523E-04	1.792E-02	1.208E-02	5.415E-03
Axial Blanket 1	65.20	5.50	-2.512E-04	-3.442E-05	1.654E-04	7.311E-05	1.911E-05	2.339E-04	2.113E-04	1.093E-04
Axial Blanket 2	59.70	9.70	-2.133E-04	-2.016E-05	8.520E-05	8.888E-05	2.341E-05	1.450E-04	1.798E-04	1.065E-04
	50.00	10.00	-6.788E-05	-2.545E-06	1.489E-05	3.837E-05	1.039E-05	3.496E-05	6.112E-05	4.346E-05
	40.00	10.00	-1.207E-05	1.855E-06	3.895E-06	1.301E-05	3.621E-06	8.448E-06	1.738E-05	1.463E-05
(sum of AB2)			-2.932E-04	-2.085E-05	1.040E-04	1.403E-04	3.742E-05	1.884E-04	2.583E-04	1.646E-04
Reflector	30.00	30.00	2.386E-05	9.324E-06	1.946E-05	5.548E-06	1.968E-06	4.256E-06	6.394E-06	8.600E-06
(sum)			-3.239E-02	-9.592E-03	-2.601E-03	-1.733E-03	-1.640E-04	1.883E-02	1.310E-02	6.011E-03
Total Sum			-8.543E-03							

TABLE 4.78. STEEL DENSITY COEFFICIENTS AT BOC, ΔK/KK'/(ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS (cont.)

	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
UAR	-1.757E-08	-3.503E-09	2.229E-07	2.659E-10	7.445E-12	1.726E-07	3.460E-07	7.949E-07
Cones&Plugs	-2.649E-05	3.661E-05	4.233E-04	-5.588E-06	1.702E-05	1.718E-04	2.071E-04	1.155E-04
UBS	5.873E-06	1.782E-06	6.265E-06	4.405E-06	2.550E-06	1.493E-05	1.531E-05	1.103E-05
SP	1.537E-04	5.503E-05	3.118E-04	-1.232E-05	1.023E-05	2.973E-04	3.205E-04	1.859E-04
Upper Core	-1.215E-02	-3.807E-03	-1.670E-03	-1.272E-03	-1.021E-04	7.642E-03	5.286E-03	2.416E-03
IBZ	-2.881E-03	-9.290E-04	-5.234E-04	-1.245E-04	-3.022E-05	1.543E-03	1.024E-03	4.506E-04
Lower Core	-1.696E-02	-4.904E-03	-1.438E-03	-5.418E-04	-1.200E-04	8.730E-03	5.767E-03	2.549E-03
Core	-3.200E-02	-9.639E-03	-3.632E-03	-1.938E-03	-2.523E-04	1.792E-02	1.208E-02	5.415E-03
AB	-5.444E-04	-5.526E-05	2.694E-04	2.134E-04	5.654E-05	4.223E-04	4.696E-04	2.740E-04
LAR	2.386E-05	9.324E-06	1.946E-05	5.548E-06	1.968E-06	4.256E-06	6.394E-06	8.600E-06
(sum)	-3.239E-02	-9.592E-03	-2.601E-03	-1.733E-03	-1.640E-04	1.883E-02	1.310E-02	6.011E-03
Total Sum	-8.543E-03							

	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
UAR	-1.608E-08	-3.316E-09	3.094E-07	5.894E-10	1.568E-10	2.378E-07	4.624E-07	9.944E-07
Cones&Plugs	1.233E-04	1.174E-04	6.661E-04	5.125E-07	1.994E-05	2.193E-04	2.745E-04	1.550E-04
UBS	7.680E-06	2.618E-06	9.486E-06	5.016E-06	2.898E-06	2.007E-05	1.990E-05	1.424E-05
SP	2.010E-04	8.229E-05	4.111E-04	-4.294E-06	1.222E-05	3.774E-04	4.220E-04	2.477E-04
Upper Core	-9.390E-03	-2.997E-03	7.656E-04	-9.933E-04	-5.475E-05	9.522E-03	6.993E-03	3.273E-03
IBZ	-2.455E-03	-8.005E-04	-4.931E-05	-9.674E-05	-2.529E-05	1.911E-03	1.349E-03	6.105E-04
Lower Core	-1.376E-02	-4.157E-03	1.468E-03	-3.750E-04	-8.188E-05	1.089E-02	7.628E-03	3.453E-03
Core	-2.560E-02	-7.954E-03	2.185E-03	-1.465E-03	-1.619E-04	2.233E-02	1.597E-02	7.337E-03
AB	-4.841E-04	-3.036E-05	4.278E-04	2.575E-04	6.708E-05	5.524E-04	6.223E-04	3.652E-04
LAR	2.730E-05	1.100E-05	2.412E-05	6.485E-06	2.292E-06	5.677E-06	8.516E-06	1.103E-05
(sum)	-2.573E-02	-7.772E-03	3.723E-03	-1.200E-03	-5.749E-05	2.350E-02	1.732E-02	8.131E-03
Total Sum	1.792E-02							

TABLE 4.79. STEEL DENSITY COEFFICIENTS AT EOC, ΔK/KK'/ (ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00	-2.965E-04	-2.965E-04	-2.963E-04	-2.965E-04	-2.965E-04	-2.963E-04	-2.962E-04	-2.957E-04
Cones	204.90	4.50	-2.965E-04	-2.965E-04	-2.962E-04	-2.965E-04	-2.965E-04	-2.959E-04	-2.959E-04	-2.959E-04
Upper Boron Shield	200.40	5.00	-2.966E-04	-2.965E-04	-2.965E-04	-2.963E-04	-2.964E-04	-2.951E-04	-2.949E-04	-2.950E-04
	195.40	5.00	-2.965E-04	-2.965E-04	-2.963E-04	-2.955E-04	-2.961E-04	-2.930E-04	-2.925E-04	-2.934E-04
	190.40	5.00	-2.904E-04	-2.947E-04	-2.906E-04	-2.932E-04	-2.943E-04	-2.871E-04	-2.875E-04	-2.906E-04
(sum of UBS)			-8.834E-04	-8.877E-04	-8.834E-04	-8.851E-04	-8.869E-04	-8.752E-04	-8.749E-04	-8.790E-04
Cones	185.40	4.50	-2.291E-04	-2.769E-04	-2.200E-04	-2.933E-04	-2.942E-04	-2.713E-04	-2.817E-04	-2.875E-04
Sodium Plenum	180.90	8.00	-2.511E-04	-2.825E-04	-2.302E-04	-2.967E-04	-2.943E-04	-2.291E-04	-2.433E-04	-2.667E-04
	172.90	8.00	-2.386E-04	-2.774E-04	-1.974E-04	-3.009E-04	-2.943E-04	-1.992E-04	-1.954E-04	-2.381E-04
	164.90	7.00	-2.326E-04	-2.740E-04	-1.569E-04	-3.027E-04	-2.900E-04	-1.761E-04	-1.455E-04	-2.080E-04
(sum of SP)			-7.223E-04	-8.338E-04	-5.844E-04	-9.004E-04	-8.787E-04	-6.044E-04	-5.843E-04	-7.128E-04
Plugs	157.90	5.30	-3.590E-04	-2.781E-04	3.199E-05	-3.045E-04	-2.812E-04	-1.591E-04	-1.155E-04	-1.965E-04
Core	152.60	8.23	-7.196E-04	-4.043E-04	-9.100E-05	-3.434E-04	-2.726E-04	2.491E-04	1.534E-04	-6.514E-05
	144.37	8.23	-1.721E-03	-7.099E-04	-3.338E-04	-4.449E-04	-2.915E-04	7.181E-04	4.317E-04	4.885E-05
	136.14	8.23	-2.806E-03	-1.042E-03	-5.880E-04	-5.555E-04	-3.165E-04	1.195E-03	7.334E-04	1.733E-04
	127.91	8.23	-3.796E-03	-1.349E-03	-8.081E-04	-6.554E-04	-3.404E-04	1.618E-03	1.004E-03	2.865E-04
	119.68	8.23	-4.560E-03	-1.596E-03	-9.465E-04	-7.329E-04	-3.578E-04	1.924E-03	1.196E-03	3.666E-04
Internal Breeding Zone	111.45	5.10	-3.242E-03	-1.189E-03	-7.264E-04	-4.200E-04	-3.270E-04	1.163E-03	6.773E-04	1.336E-04
Core	106.35	8.23	-5.192E-03	-1.741E-03	-9.288E-04	-5.238E-04	-3.488E-04	2.049E-03	1.260E-03	3.879E-04
	98.12	8.23	-5.055E-03	-1.617E-03	-7.733E-04	-5.062E-04	-3.457E-04	1.865E-03	1.128E-03	3.274E-04
	89.89	8.23	-4.264E-03	-1.346E-03	-5.375E-04	-4.387E-04	-3.300E-04	1.503E-03	8.849E-04	2.214E-04
	81.66	8.23	-3.005E-03	-9.736E-04	-2.586E-04	-3.371E-04	-3.051E-04	1.017E-03	5.713E-04	9.028E-05
	73.43	8.23	-1.574E-03	-5.727E-04	1.507E-05	-2.332E-04	-2.791E-04	4.853E-04	2.475E-04	-3.984E-05
(sum of Core)			-3.594E-02	-1.254E-02	-5.977E-03	-5.191E-03	-3.515E-03	1.379E-02	8.287E-03	1.931E-03
Axial Blanket 1	65.20	5.50	-6.088E-04	-3.382E-04	-1.331E-04	-2.246E-04	-2.776E-04	-5.707E-05	-8.265E-05	-1.864E-04
Axial Blanket 2	59.70	9.70	-5.673E-04	-3.211E-04	-2.065E-04	-2.048E-04	-2.722E-04	-1.419E-04	-1.099E-04	-1.871E-04
	50.00	10.00	-3.865E-04	-2.996E-04	-2.777E-04	-2.541E-04	-2.849E-04	-2.565E-04	-2.304E-04	-2.504E-04
	40.00	10.00	-3.117E-04	-2.937E-04	-2.903E-04	-2.807E-04	-2.921E-04	-2.863E-04	-2.768E-04	-2.803E-04
(sum of AB2)			-1.266E-03	-9.144E-04	-7.745E-04	-7.395E-04	-8.491E-04	-6.847E-04	-6.171E-04	-7.178E-04
Reflector	30.00	30.00	-2.578E-04	-2.824E-04	-2.673E-04	-2.886E-04	-2.937E-04	-2.907E-04	-2.885E-04	-2.862E-04
(sum)			-4.085E-02	-1.695E-02	-9.400E-03	-9.420E-03	-7.869E-03	1.025E-02	4.851E-03	-1.927E-03
Total Sum			-7.131E-02							

TABLE 4.79. STEEL DENSITY COEFFICIENTS AT EOC, ΔK/KK'/ (ΔP/P)), KAERI, JEFF-3.1, 25 GROUPS (cont.)

	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
UAR	-2.965E-04	-2.965E-04	-2.963E-04	-2.965E-04	-2.965E-04	-2.963E-04	-2.962E-04	-2.957E-04
Cones&Plugs	-8.846E-04	-8.514E-04	-4.842E-04	-8.943E-04	-8.718E-04	-7.263E-04	-6.930E-04	-7.799E-04
UBS	-8.834E-04	-8.877E-04	-8.834E-04	-8.851E-04	-8.869E-04	-8.752E-04	-8.749E-04	-8.790E-04
SP	-7.223E-04	-8.338E-04	-5.844E-04	-9.004E-04	-8.787E-04	-6.044E-04	-5.843E-04	-7.128E-04
Upper Core	-1.360E-02	-5.102E-03	-2.767E-03	-2.732E-03	-1.579E-03	5.704E-03	3.519E-03	8.101E-04
IBZ	-3.242E-03	-1.189E-03	-7.264E-04	-4.200E-04	-3.270E-04	1.163E-03	6.773E-04	1.336E-04
Lower Core	-1.909E-02	-6.250E-03	-2.483E-03	-2.039E-03	-1.609E-03	6.919E-03	4.091E-03	9.872E-04
Core	-3.594E-02	-1.254E-02	-5.977E-03	-5.191E-03	-3.515E-03	1.379E-02	8.287E-03	1.931E-03
AB	-1.874E-03	-1.253E-03	-9.076E-04	-9.641E-04	-1.127E-03	-7.417E-04	-6.998E-04	-9.042E-04
LAR	-2.578E-04	-2.824E-04	-2.673E-04	-2.886E-04	-2.937E-04	-2.907E-04	-2.885E-04	-2.862E-04
(sum)	-4.085E-02	-1.695E-02	-9.400E-03	-9.420E-03	-7.869E-03	1.025E-02	4.851E-03	-1.927E-03
Total Sum	-7.131E-02							

4.3.6.8 Power distribution for fuel and non-fuelled regions

TABLE 4.80. POWER DISTRIBUTION AT BOC, W, KAERI

	Height (cm)	dZ (cm)	LEZ 1	MEZ 2	HEZ 3	SHR 4	SCR 5	SSA1 6	SSA2,3 7	R. Refletor 8
Reflector	234.90	30.00								
Cones	204.90	4.50								
Upper Boron Shield	200.40	5.00								
	195.40	5.00								
	190.40	5.00								
(sum of UBS)										
Cones	185.40	4.50								
Sodium Plenum	180.90	8.00								
	172.90	8.00								
	164.90	7.00								
(sum of SP)										
Plugs	157.90	5.30								
Core	152.60	8.23	3.449E+07	1.131E+07	4.036E+07					
	144.37	8.23	4.356E+07	1.449E+07	5.011E+07					
	136.14	8.23	5.237E+07	1.755E+07	6.004E+07					
	127.91	8.23	5.956E+07	2.006E+07	6.802E+07					
	119.68	8.23	6.481E+07	2.194E+07	7.340E+07					
Internal Breeding Zone	111.45	5.10	2.083E+07	1.425E+07	4.688E+07					
Core	106.35	8.23	6.954E+07	2.331E+07	7.558E+07					
	98.12	8.23	6.868E+07	2.266E+07	7.248E+07					
	89.89	8.23	6.405E+07	2.083E+07	6.600E+07					
	81.66	8.23	5.605E+07	1.798E+07	5.650E+07					
	73.43	8.23	4.571E+07	1.443E+07	4.505E+07					
(sum of Core)			5.796E+08	1.988E+08	6.544E+08					
Axial Blanket 1	65.20	5.50	5.886E+06	1.708E+06	4.536E+06					
Axial Blanket 2	59.70	9.70	6.139E+06	1.734E+06	4.596E+06					
	50.00	10.00	3.867E+06	1.051E+06	2.748E+06					
	40.00	10.00	2.487E+06	6.549E+05	1.724E+06					
(sum of AB2)			1.249E+07	3.440E+06	9.067E+06					
Reflector	30.00	30.00								
(sum)			5.980E+08	2.039E+08	6.680E+08					
Total Power			1.470E+09							

4.3.6.9 Beta-effective and prompt neutron lifetime

TABLE 4.81. BETA-EFFECTIVE AND PROMPT NEUTRON LIFETIME AT BOC, KAERI

Item	value
Effective delayed neutron fraction	3.0151E-03
Neutron lifetime (sec)	3.0850E-07

Fraction of delayed neutron groups

delayed neutron group	1	2	3	4	5	6
Beta_group/B_eff (%)	2.463	18.236	15.007	35.875	20.810	7.609

TABLE 4.82. BETA-EFFECTIVE AND PROMPT NEUTRON LIFETIME EOC, KAERI

Item	value
Effective delayed neutron fraction	3.0427E-03
Neutron lifetime (sec)	3.2140E-07

Fraction of delayed neutron groups

delayed neutron group	1	2	3	4	5	6
Beta_group/B_eff (%)	2.416	18.016	14.970	35.908	20.980	7.710

4.3.6.10 Isotopic densities at EOC

TABLE 4.83. ISOTOPIC DENSITIES AT EOC, KAERI

(Unit: 1024 nuclei / cm3)

	Fuel LEZ (1)	Fuel MEZ (2)	Fuel HEZ (3)	Fuel AB2 LEZ (4)	Fuel AB2 MEZ (5)	Fuel AB2 HEZ (6)	Fuel AB1 LEZ (7)	Fuel AB1 MEZ (8)	Fuel AB1 HEZ (9)
U-235	1.7706E-05	1.7789E-05	1.8144E-05	3.0980E-05	3.1767E-05	3.2776E-05	2.8377E-05	2.9368E-05	3.0966E-05
U-236	1.2944E-06	1.1389E-06	8.7113E-07	1.3247E-06	1.1166E-06	8.7625E-07	1.8041E-06	1.5612E-06	1.2156E-06
U-238	5.7013E-03	5.5933E-03	5.3987E-03	8.8252E-03	8.8500E-03	8.8861E-03	8.7149E-03	8.7509E-03	8.8137E-03
Pu-38	1.0082E-04	1.0380E-04	1.1081E-04	9.0383E-09	6.5982E-09	3.5498E-09	4.7289E-08	3.7704E-08	2.1821E-08
Pu-39	9.5880E-04	1.0022E-03	1.1087E-03	1.3598E-04	1.1511E-04	8.4674E-05	2.1329E-04	1.8558E-04	1.3752E-04
Pu-40	5.1843E-04	5.4370E-04	6.0047E-04	3.2591E-06	2.2878E-06	1.3635E-06	6.4079E-06	4.6753E-06	2.7213E-06
Pu-41	3.3055E-05	3.2298E-05	3.1095E-05	5.6982E-08	3.4822E-08	2.9432E-08	1.1963E-07	7.4681E-08	5.1933E-08
Pu-42	1.0827E-05	1.0409E-05	9.4049E-06	5.3624E-10	2.7274E-10	1.9791E-10	1.5523E-09	8.2241E-10	4.8624E-10
Np-37	1.1789E-04	1.2722E-04	1.4659E-04	1.6994E-07	1.4575E-07	9.6952E-08	6.4851E-07	6.0277E-07	4.4319E-07
Am-41	2.4834E-04	2.6863E-04	3.1213E-04	5.1252E-10	3.1705E-10	2.9951E-10	1.0584E-09	6.6961E-10	5.2687E-10
Am-2M	8.7478E-06	8.4895E-06	7.7476E-06	2.7479E-12	1.4226E-12	1.1664E-12	7.8489E-12	4.2385E-12	2.8203E-12
Am-43	3.7187E-05	3.9936E-05	4.5543E-05	4.3921E-12	1.8835E-12	1.3908E-12	1.6117E-11	7.2532E-12	4.0585E-12
Cm-42	2.1821E-05	2.0809E-05	1.8332E-05	7.7865E-12	4.0094E-12	3.2371E-12	2.2550E-11	1.2094E-11	7.8929E-12
Cm-43	7.8700E-07	6.8535E-07	5.3473E-07	5.7610E-14	2.4658E-14	1.6396E-14	2.0474E-13	9.2604E-14	5.0102E-14
Cm-44	7.2423E-06	6.9697E-06	6.4997E-06	9.2987E-14	3.3407E-14	2.1966E-14	4.4838E-13	1.7112E-13	8.2744E-14
Cm-45	1.5020E-06	1.5651E-06	1.7521E-06	9.0241E-16	2.7208E-16	1.6055E-16	5.4785E-15	1.7756E-15	7.4867E-16
Cm-46	2.9902E-07	3.0885E-07	3.2835E-07	4.4350E-18	1.1156E-18	5.0910E-19	3.5847E-17	9.8227E-18	3.2661E-18
Cm-47	1.4587E-08	1.3878E-08	1.2874E-08	2.1077E-20	4.4042E-21	1.6000E-21	2.0777E-19	4.7824E-20	1.2810E-20
Fp-39	3.3683E-04	3.3322E-04	2.7671E-04	1.7827E-05	1.4305E-05	9.4079E-06	4.9283E-05	4.2034E-05	2.8086E-05
O	1.6580E-02	1.6580E-02	1.6580E-02	1.8030E-02	1.8030E-02	1.8030E-02	1.8030E-02	1.8030E-02	1.8030E-02
Na	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03	7.5490E-03
Fe	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02	1.2870E-02
Cr	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03	2.8480E-03
Ni	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03	1.6270E-03
MO	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04	2.1760E-04
B-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
B-11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
C	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
DUMP	2.8895E-07	2.9922E-07	3.2140E-07	1.3941E-11	1.0308E-11	5.6383E-12	7.8583E-11	6.3422E-11	3.7067E-11

TABLE 4.83. ISOTOPIC DENSITIES AT EOC, KAERI (cont.)

(Unit: 1024 nuclei/cm3)

	Plugs (10)	Sodium plenum (11)	Cones (12)	Boron shield (13)	SHR (14)	SHR follower (15)	SCR (16)	SCR follower +rod tail (17)	SCR follower (18)
U-235	0.	0.	0.	0.	0.	0.	0.	0.	0.
U-236	0.	0.	0.	0.	0.	0.	0.	0.	0.
U-238	0.	0.	0.	0.	0.	0.	0.	0.	0.
Pu-38	0.	0.	0.	0.	0.	0.	0.	0.	0.
Pu-39	0.	0.	0.	0.	0.	0.	0.	0.	0.
Pu-40	0.	0.	0.	0.	0.	0.	0.	0.	0.
Pu-41	0.	0.	0.	0.	0.	0.	0.	0.	0.
Pu-42	0.	0.	0.	0.	0.	0.	0.	0.	0.
Np-37	0.	0.	0.	0.	0.	0.	0.	0.	0.
Am-41	0.	0.	0.	0.	0.	0.	0.	0.	0.
Am-2M	0.	0.	0.	0.	0.	0.	0.	0.	0.
Am-43	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-42	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-43	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-44	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-45	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-46	0.	0.	0.	0.	0.	0.	0.	0.	0.
Cm-47	0.	0.	0.	0.	0.	0.	0.	0.	0.
Fp-39	0.	0.	0.	0.	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.	0.	0.	0.	0.
Na	7.549E-03	2.020E-02	1.380E-02	6.730E-03	9.653E-03	1.958E-02	1.126E-02	1.958E-02	2.027E-02
Fe	3.630E-02	6.810E-03	2.050E-02	1.020E-02	1.310E-02	7.111E-03	1.092E-02	7.111E-03	5.060E-03
Cr	8.890E-03	1.130E-03	5.860E-03	2.130E-03	2.799E-03	1.216E-03	2.250E-03	1.216E-03	8.655E-04
Ni	6.460E-03	2.160E-05	2.790E-03	8.980E-04	1.322E-03	1.212E-04	9.109E-04	1.212E-04	1.438E-05
MO	7.320E-04	7.550E-05	0.	2.660E-04	3.140E-04	7.655E-05	2.360E-04	7.655E-05	8.620E-05
B-10	0.	0.	0.	6.870E-03	5.113E-03	0.	1.780E-02	0.	0.
B-11	0.	0.	0.	2.780E-02	2.045E-02	0.	4.450E-03	0.	0.
C	0.	0.	0.	8.660E-02	6.392E-03	0.	5.560E-03	0.	0.
DUMP									

TABLE 4.83. ISOTOPIC DENSITIES AT EOC, KAERI (cont.)

(Unit: 1024 nuclei / cm3)

	SSA1 (19)	SSA2, 3 (20)	Radial reflector (21)	Axial reflector (22)	Inner Blanket (23)
U-235	0.	0.	0.	0.	1.5509E-05
U-236	0.	0.	0.	0.	2.2026E-06
U-238	0.	0.	0.	0.	8.0304E-03
Pu-38	0.	0.	0.	0.	1.8485E-07
Pu-39	0.	0.	0.	0.	5.5567E-04
Pu-40	0.	0.	0.	0.	5.3731E-05
Pu-41	0.	0.	0.	0.	3.0109E-06
Pu-42	0.	0.	0.	0.	1.5962E-07
Np-37	0.	0.	0.	0.	1.6114E-06
Am-41	0.	0.	0.	0.	6.1383E-08
Am-2M	0.	0.	0.	0.	1.2046E-09
Am-43	0.	0.	0.	0.	5.4650E-09
Cm-42	0.	0.	0.	0.	3.3608E-09
Cm-43	0.	0.	0.	0.	7.1297E-11
Cm-44	0.	0.	0.	0.	4.4749E-10
Cm-45	0.	0.	0.	0.	1.3521E-11
Cm-46	0.	0.	0.	0.	2.1506E-13
Cm-47	0.	0.	0.	0.	2.5858E-15
Fp-39	0.	0.	0.	0.	3.5262E-04
O	0.	0.	0.	0.	1.8030E-02
Na	5.638E-03	5.875E-03	4.860E-03	1.729E-02	7.5490E-03
Fe	5.252E-02	5.179E-02	4.630E-02	1.368E-02	1.2870E-02
Cr	7.636E-03	7.530E-03	1.340E-02	2.344E-03	2.8480E-03
Ni	7.447E-04	7.332E-04	6.280E-03	4.948E-05	1.6270E-03
MO	3.589E-04	3.550E-04	0.	1.487E-04	2.1760E-04
B-10	0.	0.	0.	0.	0.0000E+00
B-11	0.	0.	0.	0.	0.0000E+00
C	0.	0.	0.	0.	0.0000E+00
DUMP					3.3533E-10

4.4 SUMMARY AND COMPARISON OF PHASE 6 RESULTS

The main results on criticality, integral reactivity coefficients and other parameters obtained by benchmark participants at BOC are summarized in Table 4.84.

The first column shows the parameters delivered as a combined contribution of CEA/SA by employing two fine-group (1968 groups) cross-section libraries: (1) based on JEF-2.2 (for all benchmark parameters: these results were presented originally and described in this report) and (2) on JEFF-3.1 (for a restricted set of parameters, the results being provided more recently). For the core calculations, the fine-group effective (i.e. after taking self-shielding effects into account) cross-sections were condensed to 33 groups by using fine-group spectra calculated for homogeneous cell models. For example, the k_{eff} values — obtained with the JEF-2.2 and JEFF-3.1 data — are 0.98829 and 1.00386, respectively.Some reactivity coefficients are provided for both Phase 4 and Phase 6 benchmark models, the values in brackets showing the Phase 4 results. For example, the fuel Doppler constant for Phase 6 (-401 and -408 pcm for the JEF-2.2 and JEFF-3.1 data options, respectively) is about 50% lower compared to that for Phase 4 (-789 and -794 pcm for the JEF-2.2 and JEFF-3.1 data options, respectively). For the fuel density, steel density, radial expansion and axial expansion coefficients and for the kinetics parameters, only results obtained with JEF-2.2 are given. The sodium density coefficient increased appreciably by magnitude compared to Phase 4 (to -1680 and -1489 pcm for the JEF-2.2 and JEFF-3.1 data options, respectively, compared to -199 pcm for the JEF-2.2 option in Phase 4). That means a much higher positive coolant void effect. The kinetics parameters are smaller as compared to those for Phase 4. Thus the reactor physics parameters for this core are less favorable (compared to those for the core studied in Phase 4) as concerns reactor safety. This is in line with results of the other benchmark participants discussed in the following. CEA performed also studies to analyse energy and nuclide contributions to computed parameters, some results of which are discussed later.

TABLE 4.84. REACTOR PHYSICS PARAMETERS OF BN-600 MODEL WITH MOX CONTAINING MAS AT BOC

	CEA& SA, JEF-2.2/ JEFF3.1 1968→ 33 gr. (Phase 4)	FZK/IKET, JEFF-3.0, 30→21gr. / 560→21 gr. (Phase 4)	IPPE, ABBN-93 26→18gr. /FOPT (Phase 4)	IGCAR, XSET 98, 26 gr. (Phase 4)	JAEA, JENDL-3.2, 70→18 gr. (Phase 4)	KAERI, JEFF3.1 150→25gr. / JEF-2.2 80→9 gr. (Phase 4)
k_{eff}	0.98829/ 1.00386	0.99069	0.99517	1.00238 (1.00164)	0.99194	1.00658/ 0.99022
Fuel Doppler coefficient (pcm)	-401/-408 (-789/-794)	-351/-379 (-698/ -766)	-337/ -341 (-684)	-371 (-732)	-371 (-770)	-424/-438 (/888)
Steel Doppler coefficient (pcm)	-80 (-124)	-61			-63 (-100)	-65/-71 (-101)
Sodium density coefficient (pcm)	-1680/ -1489 (-199)	-1124	/-1140 (139)	-1392 (+15)	-1571 (84)	-1133/ -1324 (223)
Fuel density coefficient (pcm)	44560 (38820)	37807	/37000 (37860)	37057 (37670)	37698 (39080)	37305/ 37820 (37220)
Steel density coefficient (pcm)	-3910	-3496	/-3200 (-126)	-3368 (-185)	-3673 (-159)	-2907/ -2854 (-41)
Radial expansion coefficient (pcm)	-5198	-5317			-5287	-5251/ 5351
Axial expansion coefficient (pcm)	-1404	-1485			-1489	-1428/ 1455
Beta-effective (pcm)	307 (350)	298	299 (344)	297 (346)	299 (336)	302 (342)
Prompt neutron lifetime time, μs	0.309 (0.436)	0.296		0.318 (0.451)	0.312 (0.448)	0.309 (0.426)

The FZK/IKET results are given in the second column. They were obtained by employing two JEFF-3.0-based multigroup libraries: a 30-group library and a 560-group one. In both cases, the effective cross-sections were condensed to 21 groups with cell-wise spectra, the 21-group cross-sections being employed for the core analyses. Initially a full set of benchmark parameters was obtained with the 30-group library, but the fuel Doppler constant appeared to be low by magnitude compared to those of some participants. One of the possible reasons was assumed to be the insufficient number of energy groups in the employed data library. Therefore the fuel Doppler calculations were performed in addition with the 560-group data condensed with cell-wise spectra to 21-group cross-sections. That resulted in a higher absolute value of the constant by ca. 30 pcm or by about 10%. Calculations with the fine-group library performed for the Phase 4 model, did lead to the same relative (but higher absolute) variation from -698 to -766 pcm (due to using of the 560-group library instead of the 30-group one) as shown in the above Table.

Column three shows the IPPE results obtained with a 26-group library, ABBN-93. The 26-group effective cross-sections were condensed to 18 groups and employed for the core calculations. The fuel Doppler constant parameters, computed directly and by FOPT are -337 and -341 pcm, respectively. The IPPE results are in line with those of the other participants as regards ratios of the fuel Doppler constants for Phase 4 and Phase 6. All density coefficients for Phase 4 (unlike those shown for Phase 4) are obtained by employing the FOPT option.

The IGCAR results (column four) were obtained with 26-group effective cross-sections generated from a library of the ABBN-type, XSET 98. The results shown in Table 4.84 for Phase 4 deviate slightly from those given in the Phase 4 part of this report due to modifications in the employed calculation procedure. The leakage and non-leakage components of the sodium density coefficient were evaluated by IGCAR as 2664 pcm and – 4056 pcm, respectively, for Phase 6, while as 2989 pcm and -2974 pcm, respectively, for Phase 4. One may observe relatively minor variations in the leakage component as the core geometry is the same, but strong variations in the non-leakage component due to the higher content of Pu^{240} and MAs.

Column five shows the JAEA results. JAEA employed the same computation procedure for all CRP stages by employing a basic 70-group library based on JENDL-3.2 and condensing the effective cross-sections to 18 energy groups with cell-wise spectra. Variations in the computed parameters between Phase 4 and Phase 6 are similar to the average (of all participants) ones. As for earlier phases, JAEA performed a broad scope of sensitivity studies described in the following.

The KAERI results are given in the last column. Results for two cross-section generation options are shown: (1) a 150-group library based on JEFF-3.1, the effective 150-group cross-sections being condensed to 25 groups and (2) an 80-group library based on JEF-2.2 and condensing the data to 9 groups (the latter option was used also for Phase 4). The fine group (150-group and 80-group) spectra used for condensation were computed for a 2D RZ core model by employing a neutron transport model.

The highest criticality values were obtained with JEFF-3.1 data, the lowest ones with JEF-2.2. The effect of using JEFF-3.1 instead of JEF-2.2 is predicted similarly by CEA/SA and KAERI: by a value between 1550 pcm and 1850 pcm (the criticality values being higher in the KAERI case). For Phase 4, the effect of using JEFF-3.1 instead of JEF-2.2 was much smaller, about 200 pcm (a result of CEA). This may be seen as indication of larger uncertainties in reactor physics parameters while employing fuels with higher content of MAs.

The lowest by magnitude fuel Doppler coefficients were obtained by FZK/IKET (in case of using the 30-group library) and IPPE. This may be related to a relatively low number of energy groups in the basic data library, this conclusion being confirmed in the FZK case (as explained above). The highest coefficient was computed by KAERI, similar to Phase 4, probably reflecting specific features of the employed computation procedure.

The lowest by magnitude sodium density coefficients were obtained by FZK/IKET, IPPE and KAERI (with JEFF-3.1), the highest values being provided by CEA/SA (JEF-2.2) and JAEA. One may partly associate this observation with newly evaluated Na cross-sections (as concerns the contributions of elastic and inelastic scattering to the total neutron scattering) available from JEFF-3.0 and JEFF-3.1. Using of JEFF-3.1 data as compared to JEF-2.2 yields a lower by ca. 200 pcm absolute value of the density coefficient.

The highest values for the fuel density and (by magnitude) for the steel density coefficients were obtained by CEA/SA, exceeding the results of the other participants by about 10% or more. Further analyses are needed to understand whether using of a much finer (as compared to other participants) basic data library is the reason for the observed deviations.

The expansion coefficients do not show a large spread prompting a conclusion that their uncertainties due to nuclear data and computation options are not too high, especially taking into account existing uncertainties in modelling of the core thermal expansion during the transient. The kinetics parameters are in reasonable agreement.

4.4.1 Burnup modelling

The burnup analyses and reactivity coefficients for EOC were delivered by CEA/SA, FZK/IKET, JAEA and KAERI by employing the JEF-2.2 based data, 30-group JEFF-3.0 based data, JENDL-3.2 based data and JEFF-3.1 based data, respectively. The burnup reactivity loss values after 140 EFPDs are compared in Table 4.85.

TABLE 4.85. REACTIVITY LOSS AFTER 140 EFPDS

	CEA/SA	FZK/IKET	JAEA
Reactivity loss, pcm	456	594	541

The average (of the participants) variations of the nuclear density of the main fuel isotopes in the LEZ region and the ratios (of the results of the participants) to the average values are given in Table 4.86.

TABLE 4.86. NUCLEAR DENSITY VARIATIONS IN THE LEZ REGION AFTER 140 EFPDS

	Nuclear density at BOC, at/barn/cm	Average variation after 140 EFPDs, at/barn/cm	Ratio to the average by CEA	Ratio to the average by FZK/IKET	Ratio to the average by JAEA	Ratio to the average by KAERI
U-238	5.823E-03	-0.000122	0.98	1.02	1.00	1.00
Np-237	1.321E-04	-0.000014	0.97	0.99	1.05	1.00
Pu-238	8.871E-05	0.000013	1.05	1.00	1.00	0.95
Pu-239	9.959E-04	-0.000039	1.00	1.02	1.03	0.95
Pu-240	5.179E-04	-0.000001	1.68	0.78	2.13	-0.59
Pu-241	2.341E-05	0.000011	1.06	0.94	1.12	0.88
Pu-242	6.243E-06	0.000005	0.99	1.09	0.97	0.95
Am-241	2.827E-04	-0.000035	1.01	1.05	0.96	0.98
Am-242m	4.353E-06	0.000003	1.08	0.49	0.97	1.46
Am-243	4.118E-05	-0.000004	1.01	1.06	0.95	0.98
Cm-242	1.494E-05	0.000008	1.06	1.24	0.87	0.83

The results of the participants are in general agreement. Relatively strong deviations of the ratios from unity for Pu-240 are partly due to a very small absolute variation of the Pu-240 nuclear density. The ratios for Am-242m (anti-) correlate to the reactivity loss. One should note that different branching ratios for the Am-241 capture cross-section were employed by different participants. CEA/SA and JAEA employed a value of 0.85 (that means probabilities of 85% and 15% to get Am-242 and Am-242m nuclei, respectively, after a neutron capture by an Am241 nucleus), while FZK employed energy-dependent probabilities from the JEFF-3.1 activation file, effectively yielding a value near 0.90 for the considered composition. It was observed in earlier analyses that a higher branching ratio leads to a higher reactivity loss for MA-bearing fuels. This observation was supported by analyses performed by JAEA for Phase 6, in which a simplified burnup chain and a lower branching ratio of 0.8 were employed, resulting in a reactivity loss of 387 pcm (instead of 541 pcm, see Table 4.85).

Deviations between the reactivity coefficients provided by CEA, FZK/IKET, JAEA and KAERI at EOC are similar to those at BOC.

The transport and heterogeneity effects were not addressed in Phase 6. They were evaluated before, in particular for Phase 4. The results of Phase 4 have shown that criticality values provided by transport theory were higher by a value near 600 pcm (a similar value was obtained by CEA for Phase 6); while the integral sodium density coefficient (opposite to the void one) was lower by a value near 200 pcm if the transport theory was employed. Heterogeneity treatment resulted in higher by about 300 pcm criticalities and in variations of the sodium coefficient that were similar by magnitude, but opposite by sign to those due to using of the transport approach instead of the diffusion theory.

4.4.2 Kinetics parameters

Computed (with diffusion theory) values for the effective delayed neutron fractions are shown in Table 4.87. In Table 4.88 the values for delayed groups (families) are given. The standard deviations are lower at EOC as only a part of participants provided values computed at EOC.

In the following, CEA/SERCO results are denoted as France/UK ones. Results are also shown in Figs 4.3 and 4.4. Values of prompt neutron lifetime are reported in Table 4.89.

TABLE 4.87. BETA-EFFECTIVE (PCM)

Participant	BOC	EOC
IPPE	299.0	304.0
France/UK	307.0	308.0
FZK/IKET	298.0	300.0
IGCAR	297.3	-
JAEA	299.0	301.0
KAERI	301.5	304.3
Average	300.3	303.5
Std Dev.	3.6	3.1

TABLE 4.88. BETA-EFFECTIVE BY GROUPS (PCM)

BOC						
	1 group	2 group	3 group	4 group	5 group	6 group
JAEA	7.11	64.11	54.81	108.20	49.00	15.83
KAERI	7.43	54.98	45.25	108.20	62.74	22.94
IPPE	7.45	62.40	55.60	108.00	49.30	16.40
France/UK	7.65	61.02	50.03	110.93	56.25	20.71
Average	*7.41*	*60.63*	*51.42*	*108.83*	*54.32*	*18.97*
Maximum Deviation	4%	10%	12%	2%	14%	21%
EOC						
	1 group	2 group	3 group	4 group	5 group	6 group
JAEA	7.08	64.56	55.06	109.09	49.55	15.81
KAERI	7.35	54.82	45.55	109.30	63.84	23.46
IPPE	7.43	64.30	54.70	111.00	50.20	16.00
France/UK	7.60	61.42	50.18	111.55	56.69	20.62
Average	7.36	61.28	51.37	110.23	55.07	18.97
Maximum Deviation	3%	11%	11%	1%	16%	24%

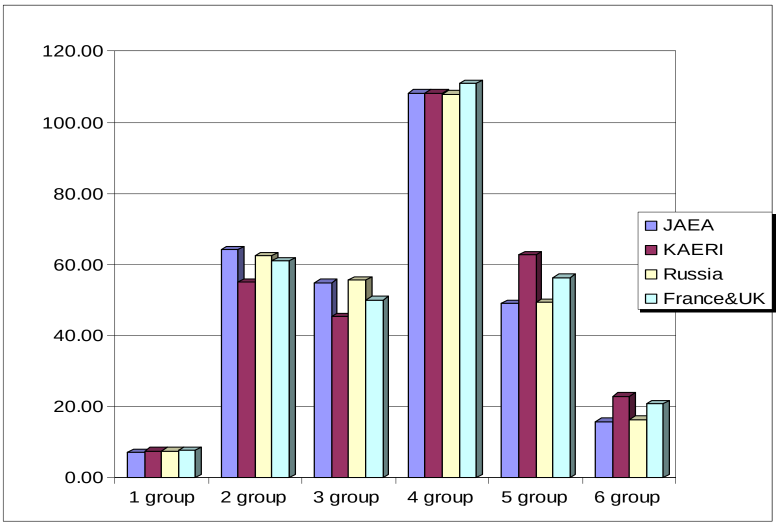


FIG. 4.3. Beta-effective by groups (pcm) at BOC.

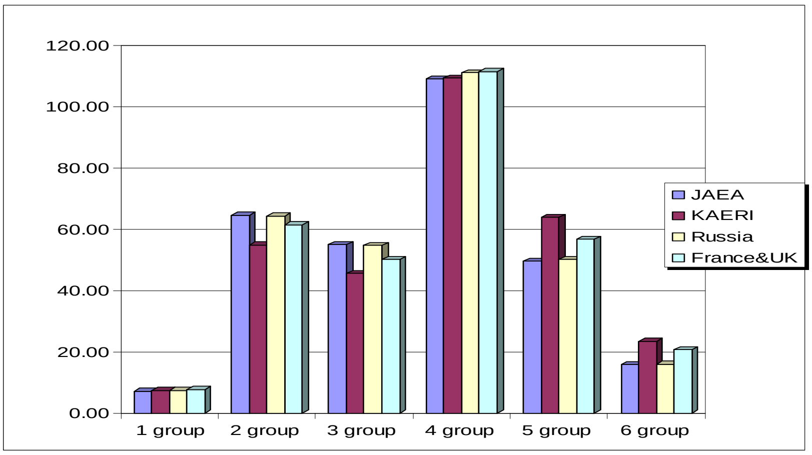


FIG. 4.4. Beta-effective by groups (pcm) at EOC.

TABLE 4.89. PROMPT NEUTRON LIFETIME (SEC X 10^{-7})

Participant	BOC	EOC
IPPE	-	-
France/UK	3.090	3.104
FZK/IKET	2.964	3.047
IGCAR	3.178	-
JAEA		-
KAERI	3.085	3.214
Average	3.079	3.122
Std Dev.	0.088	0.085

4.4.3 Doppler constant for fuel temperature

Values of fuel doppler coefficients are reported in Table 4.90.

TABLE 4.90. FUEL DOPPLER COEFFICIENT (PCM).

	Diffusion Theory		Transport Theory		Transport Effect	
Participant	BOC	EOC	BOC	EOC	BOC	EOC
France/UK	-401	-405	-397	-404	4	1
FZK/IKET	-351	-361				
IGCAR	-371	-				
JAEA	-420	-430				
KAERI	-424	-457				
IPPE	-340	-351				
Average	-384	-401				
Std Dev.	35.7	45.0				

The average (mean) values for spatial distributions of reactivity coefficients provided in the following were obtained by taking into account only a part of results provided by the CRP participants. Values of local fuel doppler constants at BOC and EOC are reported in Tables 4.91–4.92.

TABLE 4.91. LOCAL FUEL DOPPLER CONSTANT AT BOC

Mean JAEA, KAERI, IPPE, IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-8.577E-05	-2.255E-05	-7.438E-05	0.	0.	0.	0.	0.
	8.23	-9.093E-05	-2.310E-05	-7.079E-05	0.	0.	0.	0.	0.
	8.23	-1.216E-04	-3.114E-05	-9.206E-05	0.	0.	0.	0.	0.
	8.23	-1.585E-04	-4.052E-05	-1.158E-04	0.	0.	0.	0.	0.
	8.23	-2.013E-04	-5.044E-05	-1.344E-04	0.	0.	0.	0.	0.
IBZ	5.10	-2.297E-04	-3.718E-05	-8.884E-05	0.	0.	0.	0.	0.
	8.23	-2.486E-04	-6.319E-05	-1.433E-04	0.	0.	0.	0.	0.
	8.23	-2.358E-04	-6.044E-05	-1.326E-04	0.	0.	0.	0.	0.
	8.23	-2.058E-04	-5.205E-05	-1.118E-04	0.	0.	0.	0.	0.
	8.23	-1.655E-04	-4.115E-05	-8.680E-05	0.	0.	0.	0.	0.
	8.23	-1.284E-04	-3.150E-05	-6.620E-05	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-1.026E-04	-2.564E-05	-5.570E-05	0.	0.	0.	0.	0.
	9.70	-1.000E-04	-2.386E-05	-4.888E-05	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-4.245E-05	-9.482E-06	-1.814E-05	0.	0.	0.	0.	0.
	10.0	-1.843E-05	-3.889E-06	-7.165E-06	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM									-3.895E-03

The average (mean) values for spatial distribution of reactivity coefficients provided in the following were obtained by taking into account only a part of results provided by the CRP participants.

TABLE 4.91. LOCAL FUEL DOPPLER CONSTANT AT BOC (cont.)

Relative standard deviation JAEA, KAERI, IPPE, IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-17%	-15%	-7%	0.	0.	0.	0.	0.
	8.23	-15%	-15%	-9%	0.	0.	0.	0.	0.
	8.23	-15%	-15%	-9%	0.	0.	0.	0.	0.
	8.23	-15%	-15%	-10%	0.	0.	0.	0.	0.
	8.23	-14%	-14%	-10%	0.	0.	0.	0.	0.
IBZ	5.10	-12%	-13%	-9%	0.	0.	0.	0.	0.
	8.23	-13%	-13%	-9%	0.	0.	0.	0.	0.
	8.23	-13%	-12%	-9%	0.	0.	0.	0.	0.
	8.23	-13%	-12%	-9%	0.	0.	0.	0.	0.
	8.23	-12%	-11%	-8%	0.	0.	0.	0.	0.
	8.23	-10%	-9%	-6%	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-8%	-8%	-7%	0.	0.	0.	0.	0.
	9.70	-9%	-9%	-8%	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-9%	-10%	-9%	0.	0.	0.	0.	0.
	10.0	-11%	-11%	-9%	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM		0.	0.	0.	0.	0.	0.	0.	-11%

TABLE 4.92. LOCAL FUEL DOPPLER CONSTANT AT EOC

Mean JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-9.213E-05	-2.306E-05	-7.446E-05	0.	0.	0.	0.	0.
	8.23	-9.789E-05	-2.355E-05	-7.027E-05	0.	0.	0.	0.	0.
	8.23	-1.309E-04	-3.165E-05	-9.103E-05	0.	0.	0.	0.	0.
	8.23	-1.711E-04	-4.123E-05	-1.145E-04	0.	0.	0.	0.	0.
	8.23	-2.176E-04	-5.139E-05	-1.332E-04	0.	0.	0.	0.	0.
IBZ	5.10	-2.444E-04	-3.813E-05	-8.831E-05	0.	0.	0.	0.	0.
	8.23	-2.706E-04	-6.512E-05	-1.430E-04	0.	0.	0.	0.	0.
	8.23	-2.588E-04	-6.271E-05	-1.332E-04	0.	0.	0.	0.	0.
	8.23	-2.275E-04	-5.436E-05	-1.135E-04	0.	0.	0.	0.	0.
	8.23	-1.847E-04	-4.342E-05	-8.880E-05	0.	0.	0.	0.	0.
	8.23	-1.438E-04	-3.323E-05	-6.785E-05	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-1.197E-04	-2.816E-05	-5.878E-05	0.	0.	0.	0.	0.
	9.70	-1.275E-04	-2.861E-05	-5.641E-05	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-5.939E-05	-1.255E-05	-2.326E-05	0.	0.	0.	0.	0.
	10.0	-2.744E-05	-5.511E-06	-9.913E-06	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM									-4.182E-03

TABLE 4.92. LOCAL FUEL DOPPLER CONSTANT AT EOC (cont.)

Relative standard deviation JAEA KAERI IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	-16%	-16%	-7%	0.	0.	0.	0.	0.
	8.23	-17%	-17%	-11%	0.	0.	0.	0.	0.
	8.23	-18%	-18%	-12%	0.	0.	0.	0.	0.
	8.23	-18%	-18%	-12%	0.	0.	0.	0.	0.
	8.23	-17%	-18%	-13%	0.	0.	0.	0.	0.
IBZ	5.10	-15%	-16%	-13%	0.	0.	0.	0.	0.
	8.23	-17%	-16%	-12%	0.	0.	0.	0.	0.
	8.23	-17%	-16%	-12%	0.	0.	0.	0.	0.
	8.23	-17%	-16%	-11%	0.	0.	0.	0.	0.
	8.23	-16%	-15%	-11%	0.	0.	0.	0.	0.
	8.23	-15%	-14%	-10%	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-13%	-12%	-8%	0.	0.	0.	0.	0.
	9.70	-13%	-12%	-9%	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-13%	-12%	-9%	0.	0.	0.	0.	0.
	10.0	-17%	-17%	-12%	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM		0.	0.	0.	0.	0.	0.	0.	-14%

4.4.4 Steel Doppler coefficient.

TABLE 4.93. STEEL DOPPLER COEFFICIENT (PCM)

Participant	Diffusion Theory		Transport Theory		Transport Effect	
	BOC	EOC	BOC	EOC	BOC	EOC
IPPE	-30	-31				
France/UK	-80	-77	-79	-77	1	0
FZK/IKET	-61	-63				
IGCAR	-	-				
JAEA	-63.0	-65.0				
KAERI	-64.7	-68.0				
Average	-59.8	-60.8				
Std Dev.	18.1	17.6				

Data presented in the Table 4.93 are quite different, but the differences may not be very important for reactor safety analyses (see Table 4.111 in Section 4.6. ULOF transient analysis).

TABLE 4.94. LOCAL STEEL DOPPLER CONSTANT AT BOC

Mean: JAEA KAERI IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	-7.180-09	-7.535-09	-6.294-09	-7.462-09	-7.582-09	-4.726-09	-3.980-09	-9.08-10
cones	4.50	-7.586-09	-7.638-09	-7.435-09	-7.598-09	-7.634-09	-7.015-09	-7.279-09	-5.919-09
	5.00	-7.164E-09	-7.508E-09	-7.028E-09	-6.890E-09	-7.397E-09	1.866E-08	9.753E-09	3.377E-09
Upper boron shield	5.00	-3.906E-09	-6.632E-09	-4.704E-09	-4.524E-09	-6.233E-09	4.624E-08	2.049E-08	1.341E-08
	5.00	1.915E-08	-4.967E-10	1.199E-08	3.233E-10	-8.520E-10	8.310E-08	3.420E-08	3.008E-08
cones	4.50	3.059E-07	7.525E-08	1.567E-07	-2.307E-09	3.050E-09	8.317E-08	4.534E-08	4.809E-08
	8.00	-3.171E-07	-8.983E-08	-3.180E-07	-3.069E-08	-1.024E-08	-7.420E-08	1.013E-07	1.667E-07
Sodium plenum	8.00	-6.399E-07	-1.596E-07	-5.633E-07	-6.576E-08	-2.553E-08	-3.907E-07	1.007E-07	3.078E-07
	7.00	-9.088E-07	-2.074E-07	-6.649E-07	-8.217E-08	-1.253E-08	-6.161E-07	9.223E-08	4.400E-07
Plugs	5.30	-2.956E-06	-2.677E-07	-1.443E-06	-6.996E-08	1.227E-08	-7.352E-07	7.413E-08	4.769E-07
	8.23	-7.266E-06	-2.008E-06	-8.002E-06	-1.810E-07	6.300E-09	-9.910E-07	2.103E-07	1.084E-06
	8.23	-5.380E-06	-1.369E-06	-5.185E-06	-3.857E-07	-1.280E-07	-1.309E-06	3.160E-07	1.584E-06
	8.23	-7.316E-06	-1.903E-06	-6.658E-06	-6.340E-07	-3.283E-07	-1.931E-06	3.773E-07	2.120E-06
	8.23	-9.801E-06	-2.570E-06	-8.474E-06	-8.850E-07	-5.295E-07	-2.593E-06	3.887E-07	2.595E-06
	8.23	-1.265E-05	-3.253E-06	-9.906E-06	-1.267E-06	-6.561E-07	-3.081E-06	4.067E-07	2.921E-06
IBZ	5.10	-1.118E-05	-2.395E-06	-6.533E-06	-1.015E-06	-3.255E-07	-2.020E-06	2.183E-07	1.881E-06
	8.23	-1.559E-05	-4.070E-06	-1.053E-05	-2.079E-06	-5.278E-07	-3.154E-06	3.527E-07	2.977E-06
	8.23	-1.472E-05	-3.863E-06	-9.662E-06	-2.029E-06	-4.821E-07	-2.713E-06	3.740E-07	2.699E-06
	8.23	-1.265E-05	-3.258E-06	-8.026E-06	-1.514E-06	-3.597E-07	-2.001E-06	4.057E-07	2.235E-06
	8.23	-9.864E-06	-2.474E-06	-6.049E-06	-7.526E-07	-1.871E-07	-1.218E-06	4.277E-07	1.670E-06
	8.23	-7.609E-06	-1.870E-06	-4.748E-06	-2.763E-08	-2.190E-08	-5.297E-07	3.700E-07	1.111E-06
Axial blanket 1	5.50	-3.340E-06	-8.077E-07	-1.498E-06	1.977E-07	3.398E-08	-1.960E-07	1.844E-07	4.740E-07
	9.70	-2.735E-06	-6.268E-07	-1.115E-06	3.369E-07	6.684E-08	-8.100E-08	2.238E-07	4.771E-07
Axial blanket 2	10.0	-1.013E-06	-2.177E-07	-3.718E-07	1.709E-07	3.248E-08	1.040E-08	1.153E-07	2.012E-07
	10.0	-3.480E-07	-7.379E-08	-1.213E-07	5.097E-08	2.603E-09	2.657E-08	4.319E-08	6.478E-08
Reflector	30.0	-1.505E-07	-2.238E-08	-1.849E-06	1.296E-08	-3.000E-11	-1.007E-09	7.590E-09	3.724E-08
SUM									-2.558E-04

TABLE 4.94. LOCAL STEEL DOPPLER CONSTANT AT BOC (cont.)

Relative standard deviation: JAEA KAERI IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflect.
Reflect.	30.00	175%	173%	170%	173%	174%	165%	155%	177%
cones	4.50	173%	173%	170%	174%	175%	188%	154%	174%
	5.00	178%	175%	188%	176%	182%	162%	121%	175%
Upper boron shield	5.00	248%	188%	248%	192%	214%	94%	73%	177%
	5.00	135%	1347%	122%	431%	346%	27%	35%	180%
cones	4.50	68%	57%	50%	153%	210%	31%	23%	186%
	8.00	68%	61%	54%	81%	81%	40%	19%	506%
Sodium plenum	8.00	60%	56%	50%	57%	64%	43%	21%	8120%
	7.00	57%	52%	47%	61%	55%	41%	24%	2143%
Plugs	5.30	49%	49%	50%	69%	48%	25%	22%	1966%
	8.23	40%	39%	41%	69%	32%	37%	20%	821%
	8.23	41%	39%	37%	66%	38%	34%	19%	705%
	8.23	41%	40%	38%	66%	44%	34%	20%	618%
	8.23	42%	40%	38%	66%	48%	34%	20%	607%
	8.23	42%	41%	39%	62%	68%	34%	21%	600%
IBZ	5.10	42%	41%	39%	58%	95%	34%	18%	640%
	8.23	42%	41%	38%	65%	109%	34%	17%	617%
	8.23	41%	40%	38%	66%	113%	34%	17%	645%
	8.23	41%	40%	37%	64%	113%	34%	17%	682%
	8.23	40%	39%	36%	61%	111%	33%	19%	746%
	8.23	39%	37%	35%	57%	105%	33%	18%	855%
Axial blanket 1	5.50	38%	36%	33%	55%	93%	30%	20%	1825%
	9.70	40%	38%	36%	54%	85%	35%	19%	1237%
Axial blanket 2	10.00	41%	40%	38%	59%	59%	38%	19%	1270%
	10.00	48%	50%	50%	81%	34%	74%	30%	164%
Reflect.	30.00	50%	51%	155%	81%	68%	54%	65%	141%
SUM									37%

TABLE 4.95. LOCAL STEEL DOPPLER CONSTANT AT EOC

Mean: JAEA KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflect.
Reflector	30.0	4.275E-10	1.028E-10	1.260E-09	5.926E-11	1.740E-10	2.698E-09	3.376E-09	6.348E-09
cones	4.50	1.410E-10	2.234E-11	1.074E-09	4.802E-11	1.270E-10	1.188E-08	8.751E-09	4.623E-09
	5.00	4.572E-10	1.156E-10	2.991E-10	3.456E-10	6.413E-10	2.479E-08	1.624E-08	1.038E-08
Upper boron shield	5.00	3.575E-09	9.234E-10	2.225E-09	1.928E-09	2.558E-09	5.079E-08	2.638E-08	1.987E-08
	5.00	2.584E-08	6.597E-09	1.661E-08	7.598E-09	7.036E-09	8.524E-08	3.905E-08	3.559E-08
cones	4.50	3.121E-07	7.939E-08	1.517E-07	1.067E-08	3.560E-09	8.498E-08	4.933E-08	5.267E-08
	8.00	-3.203E-07	-8.339E-08	-3.112E-07	-8.440E-09	-2.000E-08	-7.050E-08	1.005E-07	1.649E-07
Sodium plenum	8.00	-6.333E-07	-1.517E-07	-5.499E-07	-2.787E-08	-4.786E-08	-3.813E-07	9.643E-08	2.984E-07
	7.00	-9.128E-07	-1.980E-07	-6.504E-07	-1.320E-08	-6.741E-08	-5.953E-07	8.540E-08	4.237E-07
Plugs	5.30	-3.024E-06	-3.287E-07	-1.636E-06	1.914E-08	-6.742E-08	-6.207E-07	6.880E-08	4.584E-07
	8.23	-7.252E-06	-1.939E-06	-7.693E-06	-1.743E-08	-1.614E-07	-9.787E-07	1.927E-07	1.031E-06
	8.23	-5.499E-06	-1.328E-06	-4.994E-06	-2.194E-07	-3.085E-07	-1.293E-06	2.763E-07	1.504E-06
	8.23	-7.503E-06	-1.850E-06	-6.413E-06	-4.935E-07	-5.023E-07	-1.904E-06	3.257E-07	2.012E-06
	8.23	-1.012E-05	-2.504E-06	-8.163E-06	-7.704E-07	-7.062E-07	-2.554E-06	3.337E-07	2.467E-06
	8.23	-1.311E-05	-3.192E-06	-9.571E-06	-1.108E-06	-9.046E-07	-3.030E-06	3.263E-07	2.785E-06
IBZ	5.10	-1.162E-05	-2.363E-06	-6.344E-06	-6.847E-07	-6.951E-07	-1.987E-06	2.137E-07	1.801E-06
	8.23	-1.634E-05	-4.045E-06	-1.026E-05	-1.323E-06	-1.399E-06	-3.123E-06	2.397E-07	2.860E-06
	8.23	-1.557E-05	-3.874E-06	-9.486E-06	-1.316E-06	-1.337E-06	-2.707E-06	3.300E-07	2.606E-06
	8.23	-1.356E-05	-3.304E-06	-7.958E-06	-1.088E-06	-9.352E-07	-2.078E-06	3.540E-07	2.173E-06
	8.23	-1.067E-05	-2.539E-06	-6.071E-06	-7.379E-07	-3.430E-07	-1.303E-06	3.763E-07	1.639E-06
	8.23	-8.178E-06	-1.906E-06	-4.757E-06	-3.790E-07	2.176E-07	-6.350E-07	3.233E-07	1.105E-06
Axial blanket 1	5.50	-3.900E-06	-8.921E-07	-1.641E-06	-1.066E-07	2.920E-07	-2.590E-07	1.605E-07	4.815E-07
	9.70	-3.533E-06	-7.617E-07	-1.346E-06	-5.860E-08	4.197E-07	-1.907E-07	1.891E-07	4.917E-07
Axial blanket 2	10.0	-1.439E-06	-2.880E-07	-4.949E-07	-1.187E-08	2.128E-07	-4.530E-08	9.863E-08	2.166E-07
	10.0	-5.303E-07	-1.001E-07	-1.738E-07	-8.170E-09	7.243E-08	9.867E-09	3.834E-08	7.785E-08
Reflect.	30.0	-2.641E-07	-3.340E-08	-5.553E-08	-1.660E-08	3.802E-08	5.273E-09	1.472E-08	5.091E-08
SUM									-2.625E-04

TABLE 4.95. LOCAL STEEL DOPPLER CONSTANT AT EOC (cont.)

Relative standard deviation: JAEA KAERI IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	215%	113554%	262%	246%	179%	428%	345%	287%
cones	4.50	1672%	114%	469%	100%	173%	290%	319%	519%
	5.00	98%	98%	91%	103%	137%	11045%	92%	383%
Upper boron shield	5.00	103%	103%	102%	108%	111%	153%	35%	381%
	5.00	114%	116%	122%	103%	95%	20%	16%	442%
cones	4.50	69%	63%	50%	104%	484%	25%	12%	478%
	8.00	66%	61%	52%	46%	40%	37%	17%	502%
Sodium plenum	8.00	60%	56%	49%	50%	44%	40%	19%	533%
	7.00	55%	52%	46%	51%	41%	40%	21%	554%
Plugs	5.30	49%	47%	49%	47%	34%	40%	20%	582%
	8.23	43%	39%	41%	47%	27%	36%	20%	674%
	8.23	41%	39%	37%	51%	37%	34%	18%	654%
	8.23	41%	40%	38%	53%	43%	33%	19%	630%
	8.23	42%	40%	38%	54%	46%	34%	19%	622%
	8.23	42%	41%	38%	55%	67%	34%	19%	615%
IBZ	5.10	43%	40%	38%	58%	96%	34%	20%	622%
	8.23	42%	41%	38%	65%	109%	34%	14%	576%
	8.23	42%	40%	38%	66%	113%	34%	17%	628%
	8.23	41%	40%	37%	65%	113%	33%	17%	644%
	8.23	41%	39%	36%	62%	112%	33%	19%	677%
	8.23	40%	38%	35%	58%	108%	33%	18%	710%
Axial blanket 1	5.50	39%	37%	34%	54%	103%	31%	19%	718%
	9.70	41%	39%	37%	53%	98%	33%	18%	670%
Axial blanket 2	10.00	43%	42%	40%	54%	91%	38%	17%	777%
	10.00	51%	49%	49%	63%	59%	70%	15%	1946%
Reflector	30.00	54%	51%	50%	63%	90%	42%	28%	190%
SUM									-38%

One may see a large spread in values of above Tables (Tables 4.93–4.95), but the uncertainties in these data no so important for the initial transient phases (before fuel/clad melting and relocation occurs under hypothetical accident conditions).

4.4.5 Fuel density coefficient

Values of fuel density coefficients are shown in Tables 4.96–4.98. Differences increased from BOC to EOC.

TABLE 4.96. FUEL DENSITY COEFFICIENT

Participant	Diffusion Theory		Transport Theory		Transport Effect	
	BOC	EOC	BOC	EOC	BOC	EOC
IPPE	0.3733	0.3735				
France/UK	0.4456	0.3840	0.4402	0.3752	-0.0054	-0.0088
FZK/IKET	0.3781	0.3609				
IGCAR	0.3706	-				
JAEA	0.3775	0.3769				
KAERI	0.3731	0.3708				
Average	0.3864	0.3732				
Std Dev.	0.0292	0.0085				

TABLE 4.97. LOCAL FUEL DENSITY COEFFICIENT BOC

Mean: JAEA, KAERI, IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	7.523E-03	2.449E-03	7.460E-03	0.	0.	0.	0.	0.
	8.23	1.045E-02	3.463E-03	1.104E-02	0.	0.	0.	0.	0.
	8.23	1.364E-02	4.593E-03	1.497E-02	0.	0.	0.	0.	0.
	8.23	1.649E-02	5.647E-03	1.854E-02	0.	0.	0.	0.	0.
	8.23	1.836E-02	6.443E-03	2.116E-02	0.	0.	0.	0.	0.
IBZ	5.10	-1.868E-03	4.215E-03	1.385E-02	0.	0.	0.	0.	0.
	8.23	2.021E-02	6.893E-03	2.233E-02	0.	0.	0.	0.	0.
	8.23	1.988E-02	6.577E-03	2.081E-02	0.	0.	0.	0.	0.
	8.23	1.799E-02	5.787E-03	1.784E-02	0.	0.	0.	0.	0.
	8.23	1.493E-02	4.682E-03	1.390E-02	0.	0.	0.	0.	0.
	8.23	1.157E-02	3.519E-03	9.891E-03	0.	0.	0.	0.	0.
Axial blanket 1	5.50	-3.569E-04	-1.160E-05	2.765E-04	0.	0.	0.	0.	0.
	9.70	-5.075E-04	-4.917E-05	7.309E-05	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-1.564E-04	-9.410E-06	4.872E-06	0.	0.	0.	0.	0.
	10.0	-1.028E-05	6.782E-06	8.089E-06	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM									3.745E-01

TABLE 4.97. LOCAL FUEL DENSITY COEFFICIENT BOC (cont.)

Relative standard deviation: JAEA, KAERI, IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0								
cones	4.50								
	5.00								
Upper boron shield	5.00								
	5.00								
cones	4.50								
	8.00								
Sodium plenum	8.00								
	7.00								
Plugs	5.30								
	8.23	5%	4%	3%					
	8.23	4%	4%	2%					
	8.23	4%	4%	2%					
	8.23	4%	4%	2%					
	8.23	4%	4%	2%					
IBZ	5.10	4%	4%	1%					
	8.23	3%	4%	1%					
	8.23	3%	4%	1%					
	8.23	3%	4%	1%					
	8.23	3%	3%	2%					
	8.23	2%	3%	2%					
Axial blanket 1	5.50	21%	206%	19%					
	9.70	23%	77%	108%					
Axial blanket 2	10.0	45%	216%	833%					
	10.0	466%	175%	247%					
Reflector	30.0								
SUM									1.3%

TABLE 4.98. LOCAL FUEL DENSITY COEFFICIENT AT EOC

Mean: JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
Upper boron shield	5.00	0.	0.	0.	0.	0.	0.	0.	0.
	5.00	0.	0.	0.	0.	0.	0.	0.	0.
cones	4.50	0.	0.	0.	0.	0.	0.	0.	0.
	8.00	0.	0.	0.	0.	0.	0.	0.	0.
Sodium plenum	8.00	0.	0.	0.	0.	0.	0.	0.	0.
	7.00	0.	0.	0.	0.	0.	0.	0.	0.
Plugs	5.30	0.	0.	0.	0.	0.	0.	0.	0.
	8.23	7.553E-03	2.333E-03	6.743E-03	0.	0.	0.	0.	0.
	8.23	1.046E-02	3.291E-03	9.951E-03	0.	0.	0.	0.	0.
	8.23	1.366E-02	4.349E-03	1.344E-02	0.	0.	0.	0.	0.
	8.23	1.652E-02	5.344E-03	1.664E-02	0.	0.	0.	0.	0.
	8.23	1.849E-02	6.107E-03	1.903E-02	0.	0.	0.	0.	0.
IBZ	5.10	-3.181E-4	4.002E-03	1.247E-02	0.	0.	0.	0.	0.
	8.23	2.037E-02	6.565E-03	2.020E-02	0.	0.	0.	0.	0.
	8.23	2.011E-02	6.298E-03	1.896E-02	0.	0.	0.	0.	0.
	8.23	1.830E-02	5.589E-03	1.639E-02	0.	0.	0.	0.	0.
	8.23	1.534E-02	4.573E-03	1.292E-02	0.	0.	0.	0.	0.
	8.23	1.198E-02	3.476E-03	9.310E-03	0.	0.	0.	0.	0.
Axial blanket 1	5.50	3.496E-05	8.000E-05	4.149E-04	0.	0.	0.	0.	0.
	9.70	-3.155E-04	-4.500E-07	1.427E-04	0.	0.	0.	0.	0.
Axial blanket 2	10.0	-7.893E-05	1.083E-05	3.261E-05	0.	0.	0.	0.	0.
	10.0	3.937E-05	1.834E-05	2.241E-05	0.	0.	0.	0.	0.
Reflector	30.0	0.	0.	0.	0.	0.	0.	0.	0.
SUM									3.608E-01

TABLE 4.98. LOCAL FUEL DENSITY COEFFICIENT AT EOC (cont.)

Relative standard deviation: JAEA, KAERI, IPPE									
		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0								
cones	4.50								
	5.00								
Upper boron shield	5.00								
	5.00								
cones	4.50								
	8.00								
Sodium plenum	8.00								
	7.00								
Plugs	5.30								
	8.23	3%	3%	3%					
	8.23	3%	4%	3%					
	8.23	4%	4%	3%					
	8.23	5%	4%	3%					
	8.23	6%	5%	4%					
IBZ	5.10	62%	5%	4%					
	8.23	6%	5%	4%					
	8.23	6%	6%	5%					
	8.23	7%	6%	5%					
	8.23	6%	6%	5%					
	8.23	6%	6%	5%					
Axial blanket 1	5.50	180%	20%	9%					
	9.70	62%	12212%	78%					
Axial blanket 2	10.0	107%	212%	147%					
	10.0	118%	63%	94%					
Reflector	30.0								
SUM									5%

4.4.6 Sodium density

TABLE 4.99. SODIUM DENSITY

Sodium density coefficient		
Diffusion theory		
Participant	BOC	EOC
IPPE	-0.0114	-0.0137
France/UK	-0.0168	-0.0175
FZK/IKET	-0.0112	-0.0110
IGCAR	-0.0139	-
JAEA	-0.0162	-0.0162
KAERI	-0.0113	-0.0106
Average	-0.0135	-0.0138
Std Dev.	0.0025	0.0031
Transport theory		
Participant	BOC	EOC
IPPE		
France/UK	-0.0188	-0.0187
FZK/IKET		
IGCAR		
JAEA		
KAERI		
Transport effect		
Participant	BOC	EOC
IPPE		
France/UK	-0.0020	-0.0012
FZKIKET	-	-
IGCAR	-	-
JAEA	-	-
KAERI	-	-

TABLE 4.100. LOCAL SODIUM DENSITY AT BOC

Mean JAEA, KAERI IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	3.074E-07	2.507E-07	4.807E-07	2.602E-07	2.545E-07	6.983E-07	9.062E-07	2.636E-07
cones	4.50	2.549E-07	2.392E-07	3.145E-07	2.744E-07	2.713E-07	4.365E-07	3.964E-07	2.562E-07
	5.00	3.278E-07	2.598E-07	3.070E-07	5.004E-07	4.519E-07	7.635E-07	5.756E-07	2.893E-07
Upper boron shield	5.00	1.621E-06	6.239E-07	1.323E-06	1.535E-06	1.276E-06	1.548E-06	8.752E-07	3.460E-07
	5.00	1.692E-05	4.851E-06	1.350E-05	4.739E-06	4.383E-06	3.122E-06	1.353E-06	4.451E-07
cones	4.50	9.717E-05	2.828E-05	8.774E-05	5.480E-06	1.165E-05	4.325E-06	1.827E-06	5.570E-07
	8.00	2.833E-04	8.508E-05	2.835E-04	2.493E-06	1.195E-05	7.148E-06	4.521E-06	1.288E-06
Sodium plenum	8.00	3.994E-04	1.274E-04	4.195E-04	-1.325E-08	1.443E-05	7.562E-06	6.809E-06	2.250E-06
	7.00	5.198E-04	1.800E-04	5.937E-04	6.584E-06	3.322E-05	8.857E-06	9.385E-06	3.269E-06
Plugs	5.30	1.700E-04	6.287E-05	1.995E-04	1.937E-05	6.290E-05	1.167E-05	1.100E-05	3.696E-06
	8.23	9.508E-05	4.759E-05	2.563E-04	2.156E-05	1.138E-04	4.207E-05	2.765E-05	8.349E-06
	8.23	-4.162E-04	-1.157E-04	-3.308E-05	-4.257E-05	5.962E-05	6.719E-05	4.298E-05	1.244E-05
	8.23	-9.638E-04	-2.912E-04	-3.306E-04	-1.239E-04	-2.046E-05	8.771E-05	5.760E-05	1.683E-05
	8.23	-1.453E-03	-4.494E-04	-5.940E-04	-1.990E-04	-9.704E-05	1.042E-04	6.968E-05	2.072E-05
	8.23	-1.789E-03	-5.637E-04	-7.789E-04	-2.355E-04	-1.472E-04	1.157E-04	7.791E-05	2.344E-05
IBZ	5.10	-1.180E-03	-3.806E-04	-5.277E-04	-2.150E-04	-1.282E-04	7.496E-05	5.051E-05	1.525E-05
	8.23	-1.957E-03	-6.137E-04	-8.338E-04	-4.039E-04	-2.351E-04	1.209E-04	8.094E-05	2.410E-05
	8.23	-1.863E-03	-5.473E-04	-6.968E-04	-3.356E-04	-1.987E-04	1.154E-04	7.581E-05	2.198E-05
	8.23	-1.453E-03	-4.039E-04	-4.420E-04	-1.181E-04	-7.158E-05	1.031E-04	6.569E-05	1.831E-05
	8.23	-8.235E-04	-2.084E-04	-1.122E-04	1.958E-04	1.144E-04	8.477E-05	5.161E-05	1.372E-05
	8.23	-1.238E-04	-3.683E-06	2.239E-04	4.875E-04	2.871E-04	6.118E-05	3.534E-05	9.104E-06
Axial blanket 1	5.50	9.162E-05	4.300E-05	1.662E-04	3.595E-04	2.134E-04	2.330E-05	1.484E-05	3.961E-06
	9.70	6.905E-05	3.451E-05	1.100E-04	4.131E-04	2.540E-04	1.868E-05	1.366E-05	3.789E-06
Axial blanket 2	10.00	2.433E-05	1.167E-05	2.750E-05	1.794E-04	1.155E-04	6.961E-06	5.510E-06	1.660E-06
	10.00	1.666E-05	5.660E-06	9.162E-06	6.163E-05	4.013E-05	5.157E-06	2.187E-06	7.042E-07
Reflector	30.00	1.149E-04	2.740E-05	4.871E-05	1.736E-05	1.274E-05	9.124E-06	8.481E-06	5.592E-07
SUM									-1.238E-02

TABLE 4.100. LOCAL SODIUM DENSITY AT BOC (cont.)

Rel. stand. Dev. JAEA KAERI IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	141%	182%	92%	174%	178%	67%	59%	179%
cones	4.50	179%	193%	146%	167%	166%	103%	121%	185%
	5.00	129%	174%	139%	90%	91%	59%	88%	169%
Upper boron shield	5.00	40%	58%	35%	33%	27%	36%	67%	147%
	5.00	57%	50%	48%	17%	26%	25%	54%	124%
cones	4.50	39%	40%	40%	86%	45%	31%	51%	108%
	8.00	6%	3%	4%	402%	51%	45%	53%	78%
Sodium plenum	8.00	8%	4%	2%	117427%	71%	58%	57%	70%
	7.00	11%	14%	12%	466%	70%	61%	54%	66%
Plugs	5.30	20%	13%	9%	213%	67%	37%	48%	62%
	8.23	20%	11%	9%	385%	73%	24%	40%	57%
	8.23	6%	6%	110%	216%	143%	23%	37%	54%
	8.23	5%	3%	17%	74%	378%	24%	36%	52%
	8.23	4%	3%	13%	45%	71%	25%	37%	51%
	8.23	4%	2%	11%	33%	36%	25%	37%	51%
IBZ	5.10	4%	2%	11%	39%	61%	25%	37%	51%
	8.23	5%	2%	11%	41%	71%	25%	36%	50%
	8.23	5%	3%	13%	41%	70%	24%	35%	50%
	8.23	5%	3%	16%	42%	81%	23%	34%	50%
	8.23	8%	7%	50%	41%	44%	22%	34%	51%
	8.23	40%	396%	17%	41%	50%	21%	34%	53%
Axial blanket 1	5.50	31%	19%	11%	40%	51%	23%	37%	59%
	9.70	35%	20%	11%	38%	56%	30%	42%	64%
Axial blanket 2	10.0	62%	34%	28%	35%	62%	45%	51%	78%
	10.0	61%	42%	43%	32%	71%	118%	58%	102%
Reflector	30.0	34%	28%	31%	55%	99%	37%	24%	98%
SUM									10.9%

TABLE 4.101. LOCAL SODIUM DENSITY AT EOC

Mean JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	2.721E-07	2.095E-07	4.858E-07	2.151E-07	2.174E-07	5.843E-07	7.488E-07	2.268E-07
cones	4.50	1.859E-07	1.881E-07	2.662E-07	2.300E-07	2.282E-07	3.465E-07	3.265E-07	2.115E-07
	5.00	3.103E-07	2.223E-07	2.879E-07	4.515E-07	3.737E-07	5.628E-07	4.714E-07	2.440E-07
Upper boron shield	5.00	1.814E-06	6.332E-07	1.413E-06	1.457E-06	9.470E-07	1.083E-06	7.198E-07	4.913E-07
	5.00	2.081E-05	5.743E-06	1.581E-05	4.778E-06	2.764E-06	2.150E-06	1.124E-06	4.340E-06
cones	4.50	7.940E-05	2.225E-05	6.882E-05	6.447E-06	5.858E-06	3.093E-06	1.540E-06	2.758E-05
	8.00	2.908E-04	8.377E-05	2.739E-04	4.642E-06	6.355E-06	5.767E-06	4.051E-06	1.014E-04
Sodium plenum	8.00	4.246E-04	1.288E-04	4.153E-04	3.035E-06	6.804E-06	6.923E-06	6.482E-06	1.461E-04
	7.00	5.076E-04	1.665E-04	5.477E-04	1.224E-05	1.536E-05	8.430E-06	9.027E-06	1.767E-04
Plugs	5.30	1.922E-04	6.606E-05	2.022E-04	2.560E-05	3.158E-05	1.018E-05	1.030E-05	6.685E-05
	8.23	1.159E-04	4.964E-05	2.549E-04	3.444E-05	5.324E-05	3.362E-05	2.497E-05	5.189E-05
	8.23	-4.042E-04	-1.093E-04	-1.426E-05	-2.775E-05	1.598E-05	5.288E-05	3.818E-05	-1.175E-04
	8.23	-9.612E-04	-2.801E-04	-2.886E-04	-1.094E-04	-3.428E-05	6.955E-05	5.126E-05	-3.013E-04
	8.23	-1.462E-03	-4.344E-04	-5.312E-04	-1.863E-04	-8.223E-05	8.330E-05	6.234E-05	-4.667E-04
	8.23	-1.816E-03	-5.476E-04	-7.031E-04	-2.251E-04	-1.104E-04	9.293E-05	6.999E-05	-5.829E-04
IBZ	5.10	-1.197E-03	-3.716E-04	-4.785E-04	-2.016E-04	-1.087E-04	6.034E-05	4.541E-05	-3.875E-04
	8.23	-2.006E-03	-6.005E-04	-7.573E-04	-3.746E-04	-2.102E-04	9.717E-05	7.259E-05	-6.427E-04
	8.23	-1.916E-03	-5.373E-04	-6.333E-04	-3.169E-04	-1.773E-04	9.203E-05	6.759E-05	-6.121E-04
	8.23	-1.506E-03	-3.998E-04	-4.004E-04	-1.217E-04	-6.642E-05	8.127E-05	5.803E-05	-4.756E-04
	8.23	-8.677E-04	-2.098E-04	-9.546E-05	1.661E-04	9.362E-05	6.595E-05	4.522E-05	-2.620E-04
	8.23	-1.498E-04	-8.484E-06	2.206E-04	4.417E-04	2.414E-04	4.699E-05	3.085E-05	-2.375E-05
Axial blanket 1	5.50	9.745E-05	4.440E-05	1.694E-04	3.343E-04	1.813E-04	1.829E-05	1.316E-05	4.130E-05
	9.70	8.305E-05	3.815E-05	1.169E-04	4.014E-04	2.201E-04	1.543E-05	1.261E-05	2.886E-05
Axial blanket 2	10.0	3.743E-05	1.498E-05	3.349E-05	1.879E-04	1.037E-04	5.681E-06	5.248E-06	1.041E-05
	10.0	2.722E-05	7.999E-06	1.277E-05	6.963E-05	3.872E-05	2.102E-06	2.005E-06	7.317E-06
Reflector	30.0	1.604E-04	3.606E-05	6.354E-05	2.364E-05	1.282E-05	6.346E-06	6.276E-06	4.534E-05
SUM									-1.585E-02

TABLE 4.101. LOCAL SODIUM DENSITY AT EOC (cont.)

Relative standard deviation: JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	102%	149%	46%	145%	140%	82%	83%	138%
cones	4.50	180%	175%	119%	138%	134%	103%	112%	148%
	5.00	78%	137%	86%	70%	86%	85%	92%	123%
Upper boron shield	5.00	30%	15%	23%	28%	78%	80%	81%	125%
	5.00	35%	30%	31%	18%	85%	80%	75%	163%
cones	4.50	9%	6%	4%	81%	108%	80%	72%	171%
	8.00	6%	3%	2%	238%	120%	76%	69%	171%
Sodium plenum	8.00	3%	0%	1%	577%	162%	69%	67%	171%
	7.00	3%	1%	0%	286%	168%	64%	65%	170%
Plugs	5.30	5%	3%	1%	188%	165%	65%	65%	164%
	8.23	18%	10%	9%	281%	182%	71%	65%	144%
	8.23	10%	9%	281%	384%	547%	71%	66%	192%
	8.23	6%	5%	20%	98%	258%	71%	65%	183%
	8.23	4%	4%	14%	57%	133%	70%	65%	181%
	8.23	4%	4%	12%	40%	111%	70%	65%	180%
IBZ	5.10	3%	4%	11%	47%	118%	70%	65%	180%
	8.23	4%	4%	11%	51%	122%	70%	65%	180%
	8.23	4%	4%	12%	51%	120%	71%	65%	180%
	8.23	4%	5%	16%	54%	130%	72%	66%	180%
	8.23	6%	8%	55%	47%	97%	72%	66%	183%
	8.23	34%	190%	18%	49%	104%	73%	66%	244%
Axial blanket 1	5.50	18%	10%	6%	50%	104%	73%	67%	156%
	9.70	17%	12%	7%	48%	106%	71%	67%	149%
Axial blanket 2	10.0	37%	24%	22%	47%	107%	69%	68%	146%
	10.0	32%	25%	28%	46%	108%	70%	70%	159%
Reflector	30.0	16%	15%	18%	58%	118%	82%	82%	171%
SUM									27%

One may observe a good agreement in the central part of the core (non-leakage component) (Table 4.100 and Table 4.101). A higher discrepancy in the EOC values (as compared to the BOC ones) can be observed, see Table 4.99.

4.4.7 Steel density

Values of steel density coefficients are reported in Tables 4.102–4.104.

TABLE 4.102. STEEL DENSITY COEFFICIENT

Steel density coefficient		
Diffusion theory		
Participant	BOC	EOC
IPPE	-0.0329	-0.0340
France/UK	-0.0391	-0.0398
FZK/IKET	-0.0350	-0.0348
IGCAR	-0.0337	-
JAEA	-0.0375	-0.0383
KAERI	-0.0291	-0.0291
Average	-0.0345	-0.0352
Std Dev.	0.0036	0.0042
Transport theory		
Participant	BOC	EOC
IPPE		
France/UK	-0.0439	-0.0434
FZK/IKET		
IGCAR		
JAEA		
KAERI		
Transport effect		
Participant	BOC	EOC
IPPE		
France/UK	-0.0048	-0.0036
FZK/IKET	-	-
IGCAR	-	-
JAEA	-	-
KAERI	-	-

The results are in reasonable agreement.

TABLE 4.103. STEEL DENSITY COEFFICIENT AT BOC

Mean: JAEA, KAERI IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	3.282E-07	2.588E-07	5.225E-07	2.656E-07	2.467E-07	1.011E-06	1.339E-06	6.867E-07
cones	4.50	3.121E-07	2.559E-07	4.280E-07	2.915E-07	2.564E-07	1.308E-06	1.224E-06	5.114E-07
	5.00	4.853E-07	3.058E-07	4.826E-07	7.837E-07	4.627E-07	4.375E-06	3.072E-06	1.049E-06
Upper boron shield	5.00	3.793E-06	1.250E-06	3.187E-06	2.761E-06	1.496E-06	1.058E-05	5.562E-06	1.820E-06
	5.00	4.541E-05	1.295E-05	3.815E-05	7.952E-06	6.901E-06	2.355E-05	9.550E-06	3.125E-06
cones	4.50	2.329E-04	6.789E-05	2.116E-04	8.898E-06	6.848E-06	3.276E-05	1.341E-05	4.569E-06
	8.00	1.339E-04	4.015E-05	1.230E-04	8.979E-06	7.564E-06	5.546E-05	3.604E-05	1.404E-05
Sodium plenum	8.00	1.822E-04	5.711E-05	1.681E-04	6.805E-06	9.323E-06	5.791E-05	5.556E-05	2.606E-05
	7.00	2.250E-04	7.624E-05	2.230E-04	1.026E-05	1.944E-05	6.488E-05	7.505E-05	3.820E-05
Plugs	5.30	1.031E-03	3.854E-04	1.106E-03	1.640E-05	3.273E-05	7.919E-05	8.459E-05	4.274E-05
	8.23	1.161E-04	7.673E-05	4.316E-04	2.308E-06	5.972E-05	2.854E-04	2.051E-04	9.807E-05
	8.23	-1.117E-03	-3.208E-04	-3.174E-04	-1.033E-04	3.815E-05	4.636E-04	3.112E-04	1.453E-04
	8.23	-2.431E-03	-7.485E-04	-1.108E-03	-2.231E-04	2.663E-06	6.109E-04	4.147E-04	1.957E-04
	8.23	-3.596E-03	-1.136E-03	-1.811E-03	-3.296E-04	-3.169E-05	7.287E-04	5.011E-04	2.405E-04
	8.23	-4.401E-03	-1.426E-03	-2.312E-03	-3.724E-04	-5.182E-05	8.104E-04	5.602E-04	2.715E-04
IBZ	5.10	-2.896E-03	-9.788E-04	-1.558E-03	-9.684E-05	-2.926E-05	5.254E-04	3.622E-04	1.754E-04
	8.23	-4.959E-03	-1.600E-03	-2.474E-03	-2.154E-04	-4.979E-05	8.481E-04	5.797E-04	2.785E-04
	8.23	-4.803E-03	-1.445E-03	-2.113E-03	-1.887E-04	-4.329E-05	8.067E-04	5.411E-04	2.537E-04
	8.23	-3.811E-03	-1.088E-03	-1.435E-03	-7.864E-05	-1.698E-05	7.183E-04	4.670E-04	2.110E-04
	8.23	-2.241E-03	-5.920E-04	-5.509E-04	8.156E-05	2.291E-05	5.902E-04	3.670E-04	1.579E-04
	8.23	-4.646E-04	-6.345E-05	3.732E-04	2.305E-04	6.057E-05	4.294E-04	2.538E-04	1.049E-04
Axial blanket 1	5.50	2.188E-04	1.018E-04	3.848E-04	1.741E-04	4.582E-05	1.660E-04	1.088E-04	4.477E-05
	9.70	2.519E-04	1.059E-04	3.136E-04	2.047E-04	5.472E-05	1.403E-04	1.043E-04	4.355E-05
Axial blanket 2	10.0	1.100E-04	4.163E-05	9.690E-05	9.017E-05	2.474E-05	5.370E-05	4.307E-05	1.810E-05
	10.0	5.000E-05	1.630E-05	2.917E-05	3.057E-05	1.141E-05	1.541E-05	1.587E-05	6.309E-06
Reflector	30.0	9.387E-05	2.300E-05	4.208E-05	1.768E-05	6.577E-06	8.128E-06	7.591E-06	4.258E-06
SUM									-3.203E-02

TABLE 4.103. STEEL DENSITY COEFFICIENT AT BOC (cont.)

Relative standard deviation: JAEA KAERI IPPE IGCAR		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	130%	175%	81%	169%	186%	47%	45%	78%
cones	4.50	141%	179%	108%	158%	180%	66%	68%	111%
	5.00	77%	142%	80%	48%	89%	13%	18%	63%
Upper boron shield	5.00	37%	27%	31%	13%	20%	10%	13%	50%
	5.00	47%	43%	42%	15%	21%	6%	10%	44%
cones	4.50	34%	36%	37%	23%	26%	9%	12%	42%
	8.00	6%	8%	10%	88%	7%	15%	14%	40%
Sodium plenum	8.00	2%	5%	4%	145%	9%	16%	15%	40%
	7.00	17%	19%	16%	101%	8%	19%	16%	39%
Plugs	5.30	15%	12%	9%	47%	7%	13%	16%	37%
	8.23	43%	18%	5%	646%	7%	9%	15%	36%
	8.23	9%	8%	20%	21%	10%	7%	15%	35%
	8.23	6%	4%	10%	16%	122%	8%	15%	34%
	8.23	5%	3%	9%	14%	8%	8%	16%	34%
	8.23	4%	3%	8%	13%	16%	9%	16%	34%
IBZ	5.10	3%	3%	8%	7%	3%	9%	16%	34%
	8.23	4%	2%	8%	2%	1%	8%	15%	33%
	8.23	3%	2%	8%	2%	2%	8%	14%	33%
	8.23	3%	3%	9%	4%	4%	6%	13%	33%
	8.23	4%	4%	15%	9%	7%	5%	12%	32%
	8.23	10%	23%	8%	7%	6%	2%	10%	33%
Axial blanket 1	5.50	11%	7%	3%	7%	7%	5%	9%	34%
	9.70	17%	12%	9%	7%	6%	3%	10%	36%
Axial blanket 2	10.00	25%	18%	15%	9%	5%	16%	10%	39%
	10.0	37%	27%	24%	11%	51%	18%	15%	45%
Reflector	30.0	20%	17%	20%	32%	20%	34%	23%	22%
SUM									6.5%

TABLE 4.104. STEEL DENSITY COEFFICIENT AT EOC

Mean JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.00	2.861E-07	2.155E-07	5.000E-07	2.129E-07	2.115E-07	1.026E-06	1.360E-06	7.292E-07
cones	4.50	2.207E-07	1.981E-07	4.058E-07	2.552E-07	2.570E-07	1.811E-06	1.565E-06	6.060E-07
	5.00	4.873E-07	2.715E-07	4.758E-07	6.142E-07	5.572E-07	4.320E-06	3.055E-06	1.120E-06
Upper boron shield	5.00	4.173E-06	1.277E-06	3.296E-06	2.290E-06	1.855E-06	1.028E-05	5.538E-06	1.980E-06
	5.00	5.393E-05	1.475E-05	4.268E-05	8.096E-06	7.009E-06	2.224E-05	9.453E-06	3.434E-06
cones	4.50	1.978E-04	5.504E-05	1.685E-04	7.684E-06	7.802E-06	3.212E-05	1.339E-05	5.035E-06
	8.00	1.330E-04	3.784E-05	1.134E-04	8.491E-06	1.128E-05	5.663E-05	3.631E-05	1.555E-05
Sodium plenum	8.00	1.869E-04	5.520E-05	1.593E-04	7.828E-06	1.262E-05	5.958E-05	5.572E-05	2.869E-05
	7.00	2.138E-04	6.781E-05	1.972E-04	1.445E-05	2.077E-05	6.700E-05	7.435E-05	4.177E-05
Plugs	5.30	1.144E-03	3.903E-04	1.078E-03	1.946E-05	2.871E-05	7.402E-05	8.248E-05	4.636E-05
	8.23	1.437E-04	7.508E-05	4.100E-04	1.591E-05	4.679E-05	2.704E-04	1.986E-04	1.058E-04
	8.23	-1.108E-03	-3.065E-04	-2.732E-04	-6.463E-05	4.523E-06	4.446E-04	3.006E-04	1.558E-04
	8.23	-2.449E-03	-7.177E-04	-9.936E-04	-1.606E-04	-5.175E-05	5.896E-04	4.004E-04	2.092E-04
	8.23	-3.659E-03	-1.092E-03	-1.636E-03	-2.480E-04	-1.053E-04	7.069E-04	4.846E-04	2.570E-04
	8.23	-4.539E-03	-1.382E-03	-2.100E-03	-2.843E-04	-1.296E-04	7.892E-04	5.426E-04	2.905E-04
IBZ	5.10	-3.018E-03	-9.549E-04	-1.421E-03	-7.676E-05	-5.107E-05	5.132E-04	3.518E-04	1.883E-04
	8.23	-5.179E-03	-1.563E-03	-2.263E-03	-1.614E-04	-1.057E-04	8.297E-04	5.643E-04	2.992E-04
	8.23	-5.025E-03	-1.422E-03	-1.949E-03	-1.442E-04	-9.370E-05	7.910E-04	5.287E-04	2.741E-04
	8.23	-4.037E-03	-1.085E-03	-1.341E-03	-6.544E-05	-4.162E-05	7.054E-04	4.584E-04	2.295E-04
	8.23	-2.449E-03	-6.095E-04	-5.340E-04	5.293E-05	3.530E-05	5.799E-04	3.626E-04	1.739E-04
	8.23	-6.284E-04	-9.602E-05	3.210E-04	1.679E-04	1.077E-04	4.215E-04	2.529E-04	1.173E-04
Axial blanket 1	5.50	1.739E-04	9.035E-05	3.608E-04	1.310E-04	8.347E-05	1.608E-04	1.094E-04	5.097E-05
	9.70	2.287E-04	1.007E-04	3.005E-04	1.605E-04	1.041E-04	1.400E-04	1.072E-04	5.090E-05
Axial blanket 2	10.0	1.208E-04	4.485E-05	1.015E-04	7.618E-05	5.010E-05	5.739E-05	4.595E-05	2.208E-05
	10.0	7.018E-05	2.088E-05	3.541E-05	2.801E-05	2.300E-05	1.664E-05	1.799E-05	8.116E-06
Reflector	30.0	1.400E-04	3.169E-05	5.695E-05	1.994E-05	1.454E-05	1.037E-05	9.497E-06	5.994E-06
SUM									-3.223E-02

TABLE 4.104. STEEL DENSITY COEFFICIENT AT EOC (cont.)

Relative standard deviation : JAEA, KAERI, IPPE		LEZ	MEZ	HEZ	SHR	SCR	SSA1	SSA2	Radial Reflector
Reflector	30.0	94%	144%	45%	147%	146%	40%	45%	36%
cones	4.50	145%	165%	70%	123%	112%	11%	14%	52%
	5.00	28%	102%	33%	57%	44%	12%	4%	33%
Upper boron shield	5.00	36%	13%	32%	33%	33%	12%	1%	25%
	5.00	33%	30%	30%	9%	14%	9%	3%	22%
cones	4.50	8%	6%	7%	25%	40%	10%	7%	22%
	8.00	2%	3%	1%	41%	54%	10%	7%	23%
Sodium plenum	8.00	3%	5%	2%	50%	41%	6%	11%	25%
	7.00	5%	6%	3%	48%	9%	7%	15%	25%
Plugs	5.30	8%	8%	7%	69%	30%	15%	16%	25%
	8.23	38%	19%	6%	240%	56%	10%	16%	25%
	8.23	9%	9%	26%	135%	1396%	6%	16%	25%
	8.23	6%	5%	12%	87%	192%	7%	17%	26%
	8.23	5%	4%	9%	75%	125%	7%	17%	26%
	8.23	4%	4%	8%	69%	110%	7%	18%	26%
IBZ	5.10	2%	4%	8%	52%	73%	7%	18%	26%
	8.23	3%	4%	8%	59%	90%	7%	17%	26%
	8.23	3%	4%	8%	60%	89%	6%	16%	25%
	8.23	3%	4%	10%	62%	91%	5%	15%	25%
	8.23	4%	6%	17%	56%	74%	3%	13%	24%
	8.23	11%	25%	14%	59%	77%	0%	11%	23%
Axial blanket 1	5.50	6%	2%	2%	59%	76%	5%	10%	23%
	9.70	22%	16%	11%	58%	77%	3%	11%	25%
Axial blanket 2	10.0	32%	23%	21%	58%	78%	17%	9%	26%
	10.0	34%	27%	27%	58%	56%	21%	4%	26%
Reflector	30.0	16%	14%	17%	56%	66%	30%	20%	18%
SUM									9%

4.4.8 Axial expansion

TABLE 4.105. AXIAL EXPANSION ΔK/KK'/ΔH/H.

Participant	Diffusion Theory		Transport Theory		Transport Effect	
	BOC	EOC	BOC	EOC	BOC	EOC
IPPE						
France/UK	-0.1404	-0.1394	-0.1362	-0.1361	0.0042	0.0033
FZK/IKET	-0.1469	-0.1469				
IGCAR	-	-				
JAEA	-0.1489	-0.1473				
KAERI	-0.1403	-0.1403				
Average	-0.1441	-0.1435				
Std Dev.	0.0038	0.0036				

Radial expansion coefficients are presented in Table 4.105. The values are in good agreement.

4.4.9 Radial expansion

Radial expansion coefficients are presented in the Table 4.106. The values are in good agreement.

TABLE 4.106. RADIAL EXPANSION COEFFICIENT, ΔK/KK'/ΔR/R

	Diffusion Theory		Transport Theory		Transport Effect	
Participant	BOC	EOC	BOC	EOC	BOC	EOC
IPPE	-	-				
France/UK	-0.5198	-0.5187	-0.5016	-0.5024	0.0182	0.0163
FZK/IKET	-0.5317	-0.5298				
IGCAR	-	-				
JAEA	-0.5287	-0.5274				
KAERI	-0.5251	-0.5299				
Average	-0.5263	-0.5264				
Std Dev.	0.0044	0.0046				

4.4.10 Analyses on energy and nuclide contributions

CEA performed a series of analyses to investigate energy and nuclide contributions to the observed variations (from Phase 4 to Phase 6) in computed parameters. The direct and adjoint flux spectra for the MOX fuel options considered in the two benchmarks are provided in Figs 4.5 and 4.6.

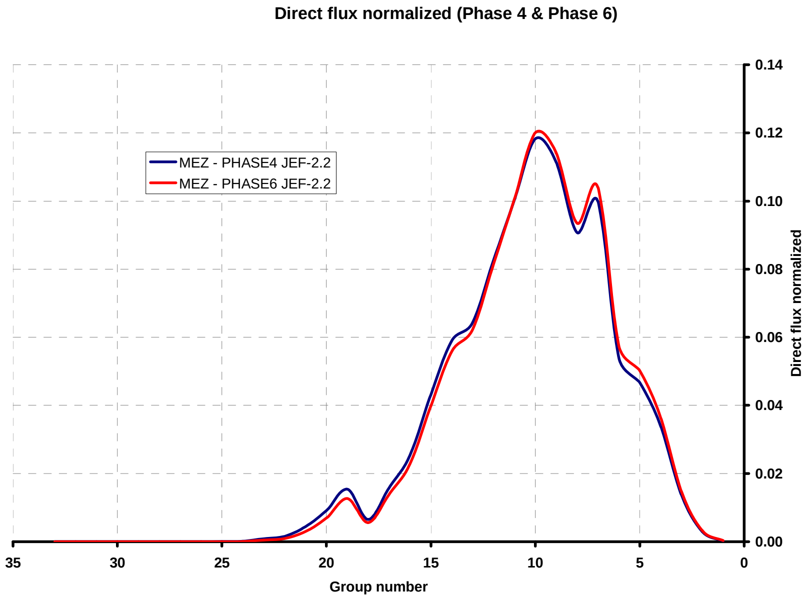


FIG. 4.5. The neutron flux spectra in the MEZ region for the two MOX fuel options.

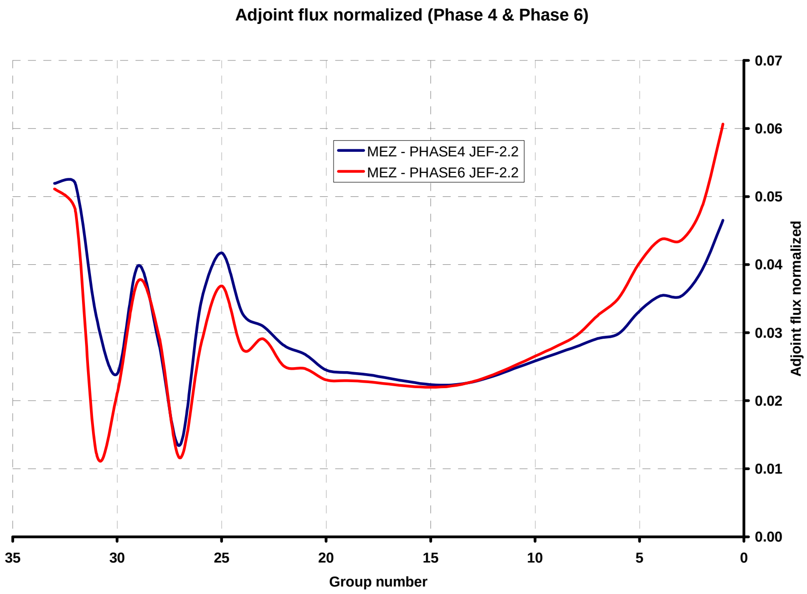


FIG. 4.6. The adjoint flux spectra in the MEZ region for the two MOX fuel options.

The energy scale in Figs 4.5 and 4.6 is given by group numbers of the 33-group structure, groups 20, 10 and 5 being bounded by the following energies (keV): ca. 0.749 and 1.23, 111 and 183, 1350 and 2230, respectively. One may conclude that the neutron flux spectra are slightly “harder”, while the adjoint ones are appreciably “harder” for Phase 6. The latter effect is a consequence of higher threshold fission due to the higher content of Pu-240 and the presence the of MAs in the fuel. Relatively lower importance of neutrons at lower energies for the MA-bearing fuel leads to a higher (lower by magnitude) fuel Doppler constant and to a lower (increased by magnitude) sodium density coefficient.

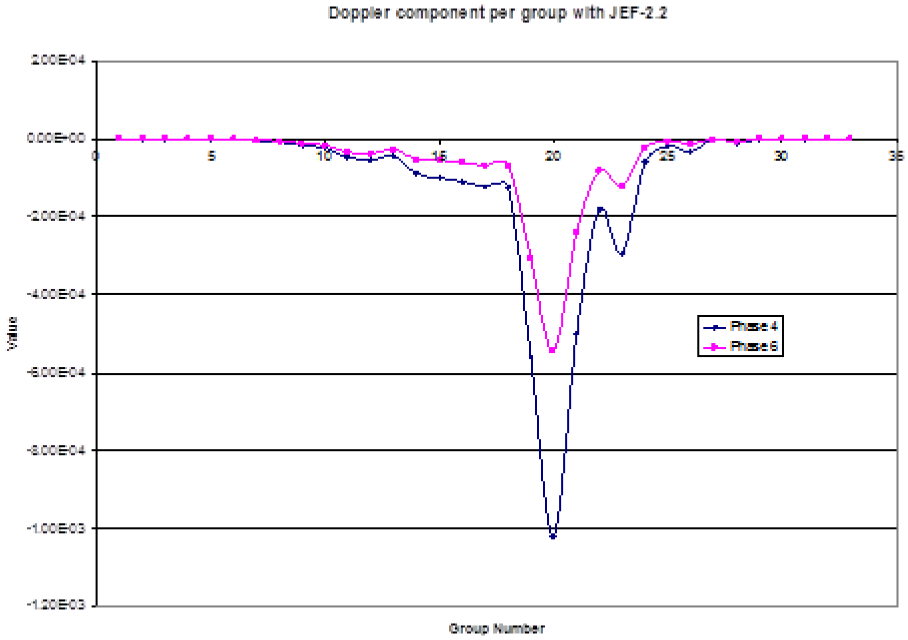


FIG. 4.7. Energy contributions to the fuel Doppler constant.

Figure 4.7 helps to understand why the fuel Doppler constant is reduced in Phase 6: the main energy contributions to this parameter come from energies near 1 keV (near group 20). The sharp variations of the curve — shown in Fig. 4.7 — result from the two compensating effects: an increase of neutron absorption by fertile isotopes (contributing to the Doppler effect) at low energies and a decrease of the neutron flux. The first factor determines the curve behavior above 1 keV, the second one dominates at lower energies. The steep variations of the curve near 1 keV may also be the reason for underestimating the Doppler constant if the basic library with a relatively low number (e.g. 30) of energy groups is employed, as the spectra used for computing the cross-sections employed in core calculations may not be accurate enough to take the observed effects into account. More analyses are needed to confirm this suspicion.

The nuclide contributions to the core reactivity for the two considered MOX fuel options can be analysed by considering so-called reactivity equivalence coefficients (see Table 4.107), assuming this coefficient for U-238 being zero and for Pu-239 being one. Such isotope reactivity worth values or equivalence coefficients are usually used in fuel cycle analyses including fuel burnup and reloading. A negative value indicates that the nuclide is a stronger — than U-238 — net absorber, while a higher — than one — value indicates that the nuclide is a stronger — than Pu-239 — net neutron generator. An intermediate value (e.g. 0.5) indicates that with respect to the contribution to the neutron balance, the nuclide properties are intermediate as compared to those for U-238 and Pu-239.

TABLE 4.107. EQUIVALENCE COEFFICIENTS COMPUTED WITH JEF-2.2 DATA AT BOC

Nuclide	Phase 4	Phase 6
Np-237	-0.244	-0.196
Pu-238	0.599	0.625
Pu-240	0.126	0.155
Pu-241	1.462	1.411
Pu-242	0.089	0.109
Am-241	-0.308	-0.258
Am-243	-0.297	-0.251
Am-242m	2.150	2.071

These equivalence coefficients show that the relative importance of high energy neutrons increases after Pu-240 and MAs are added to the fuel. For example the observed augmentation of the coefficient for Pu-240 may be associated with an increased contribution of the Pu-240 threshold fission rate to the total fission one.

Increase of the sodium density coefficient between Phase 4 and Phase 6 was found to be mainly due to an increased content of Pu-240, Np-237 and Am-241 in the fuel that was only partially compensated by a reduced content of U-238, see Table 4.108 obtained with JEFF-3.1 data at BOC. This Table includes also a contribution of the fission products (FPs) of Pu-239.

TABLE 4.108. NUCLIDE CONTRIBUTIONS TO VARIATIONS OF THE SODIUM DENSITY EFFECT FROM THE PHASE 4 TO PHASE 6 VALUES

Nuclide	Contribution
U-238	-1.87E-03
Pu-238	2.28E-04
Pu-239	1.39E-03
Pu-240	5.49E-03
Pu-241	-6.26E-04
Np-237	3.53E-03
Am-241	6.77E-03
Am-242m	-2.04E-04
Am-243	8.42E-04
Solid FPs of Pu239	-1.94E-04
TOTAL	1.56E-02
MAs	1.14E-02
Pu	6.32E-03
U	-1.92E-03

The total effect — of the influence of the fuel composition on the variation of the sodium density coefficient — as predicted by FOPT is not exactly the same (as one may obtain by employing the results of the above Table), but the accuracy is sufficient to evaluate the effect and contributions of particular nuclides.

4.5 ULOF TRANSIENT ANALYSIS

A simplified simulation approach was employed, in which no phase transition (i.e. sodium boiling or structure melting) was modelled. A limited time interval at the beginning of the transient was considered. Similar to Phase 4, a sodium flow rate of 30% (compared to nominal conditions) was assumed to be reached after about 12 s and then remained constant.

A limited set of transient simulation results was provided by IPPE, mainly as plots (see Figs 4.8–4.13). The employed in transient simulations power profile was computed at IPPE. Feedbacks related to the radial expansion were neglected in the applied computation model (unlike Phase 4 where the radial expansion effect was an essential contribution to the net reactivity variation). Other parameters (integral axial expansion coefficient, spatial distributions of the Doppler and density coefficients) were taken as provided by JAEA (preliminary results, slightly different from those given in this report), KAERI and IPPE. Additional calculations were performed with the mean (JAEA-preliminary, KAERI, IPPE) reactivity coefficients, the results being denoted as “average” in the following.

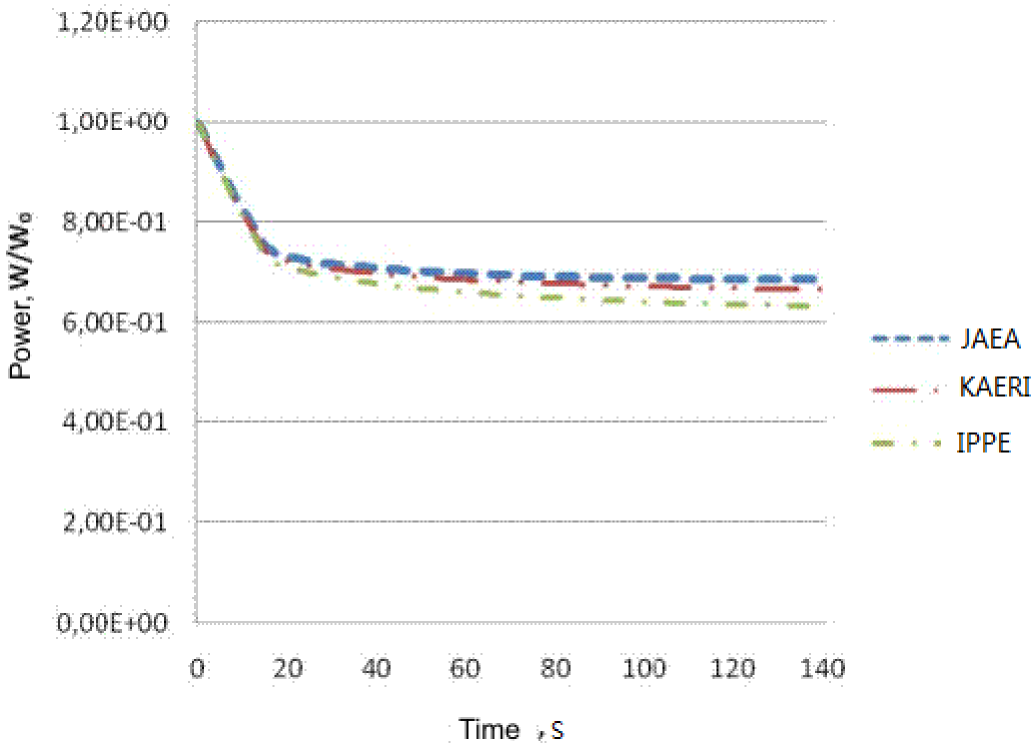


FIG. 4.8. Power in ULOF with BOC data.

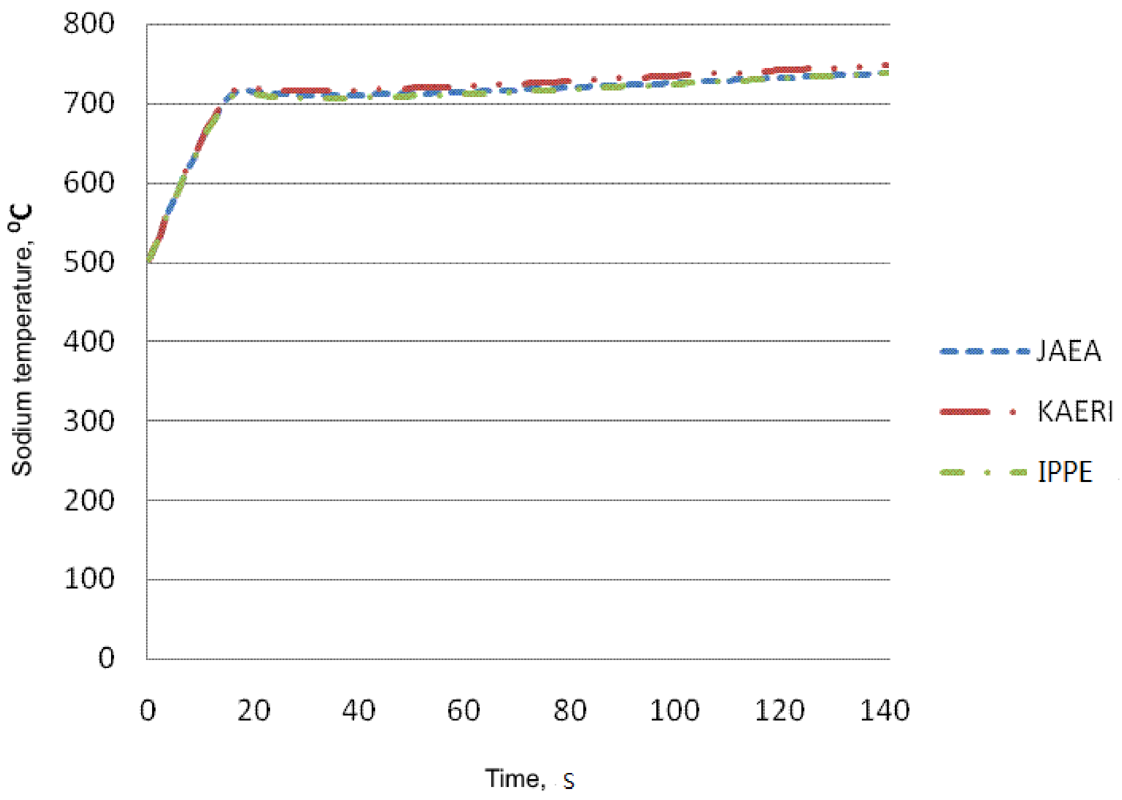


FIG. 4.9. Sodium temperature in ULOF with BOC data.

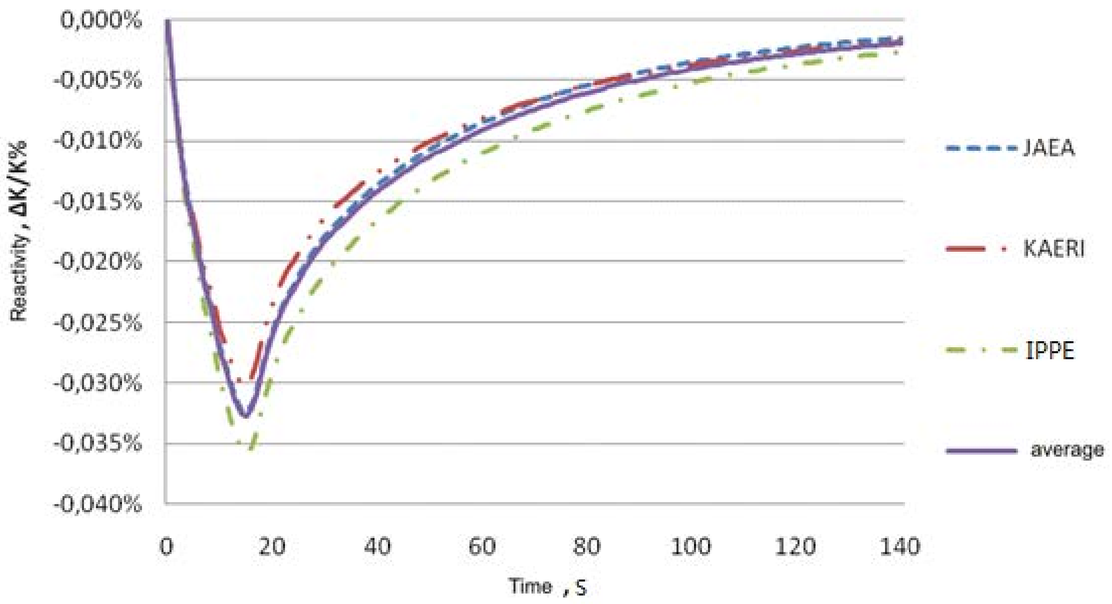


FIG. 4.10. Reactivity in ULOF with BOC data.

TABLE 4.109. DIFFERENCES OF SODIUM CORE OUTLET TEMPERATURE ON THE 100th SECOND OF THE TRANSIENT, BOC

	Temperature, C°
Difference between the average value and the IPPE value	7

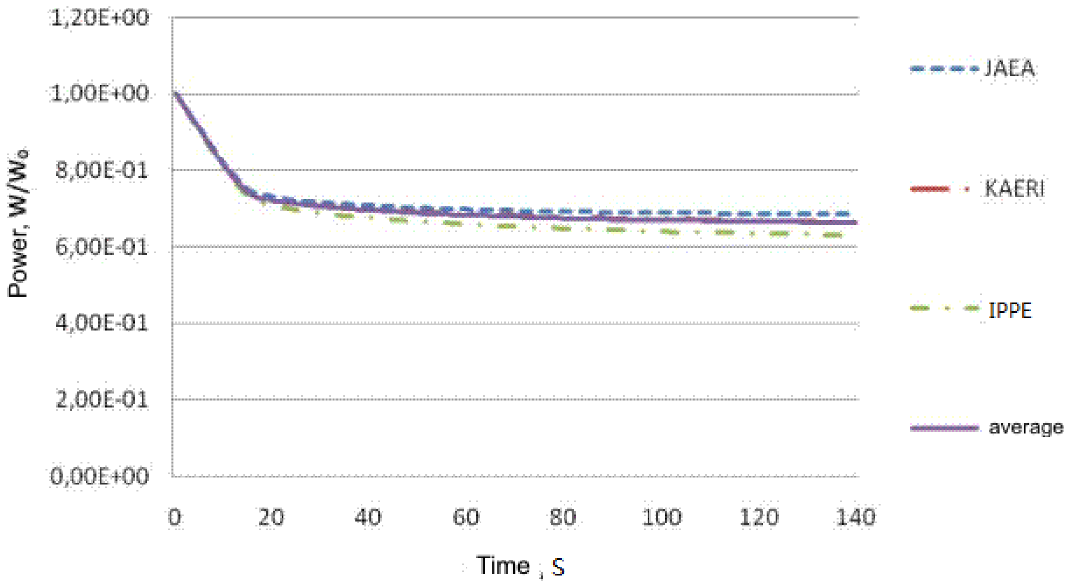


FIG. 4.11. Power in in ULOF with EOC data.

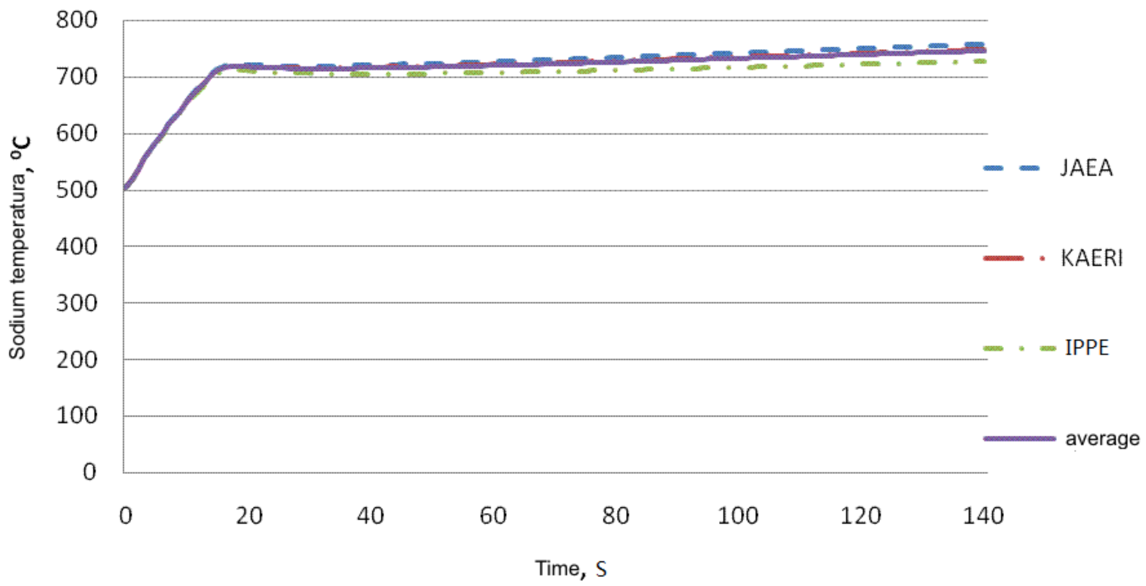


FIG. 4.12. Sodium outlet temperatures in ULOF with EOC data.

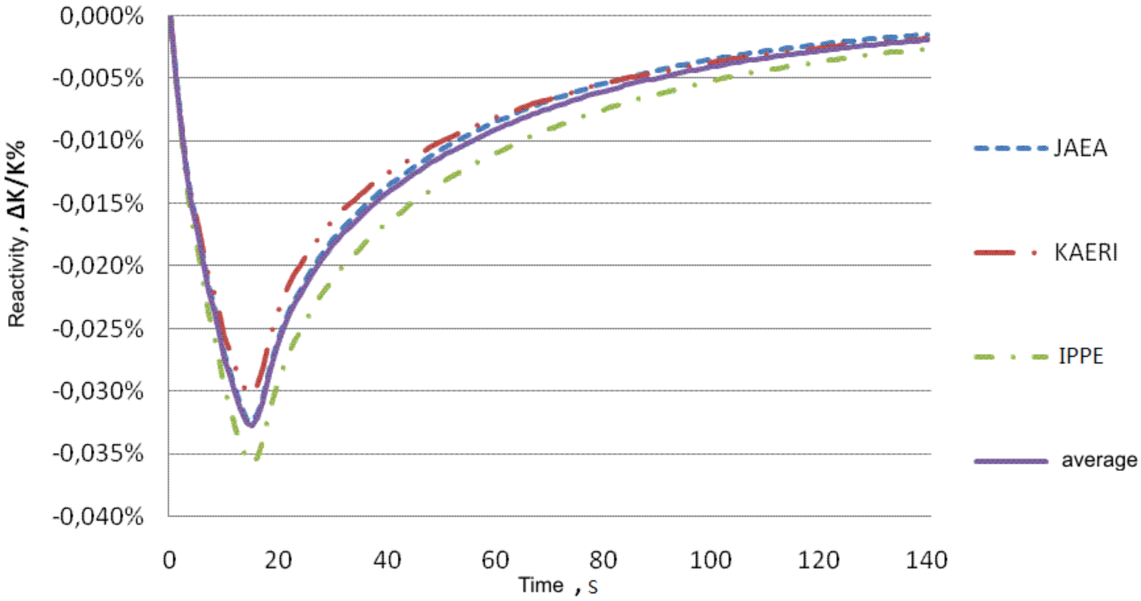


FIG. 4.13. Reactivity in ULOF with EOC data.

TABLE 4.110. DIFFERENCES OF SODIUM CORE OUTLET TEMPERATURE ON THE 100th SECOND OF THE TRANSIENT, EOC

	Temperature, C°
Difference between the average value and the IPPE value	14

Deviations in power on the 100th second (Fig. 4.11) are ~ 2%. Deviations in reactivity at minimum are ~ 0.003%ΔK/K (see Fig. 4.13). The presented in the tables (Table 4.109 and Table 4.110) results show, that the deviations in the sodium outlet temperatures are increasing from BOC to EOC. For revealing the most significant reasons, calculations with sets of averaged reactivity coefficients, in which a part of parameters was replaced by IPPE ones, were made. The results for BOC are shown in Table 4.111 and Figs 4.14–4.16. The results are practically identical, excluding the reactivity shown in the Fig. 4.16. The fuel Doppler coefficient (Table 4.111) appears to be the most important reason for the mentioned deviations.

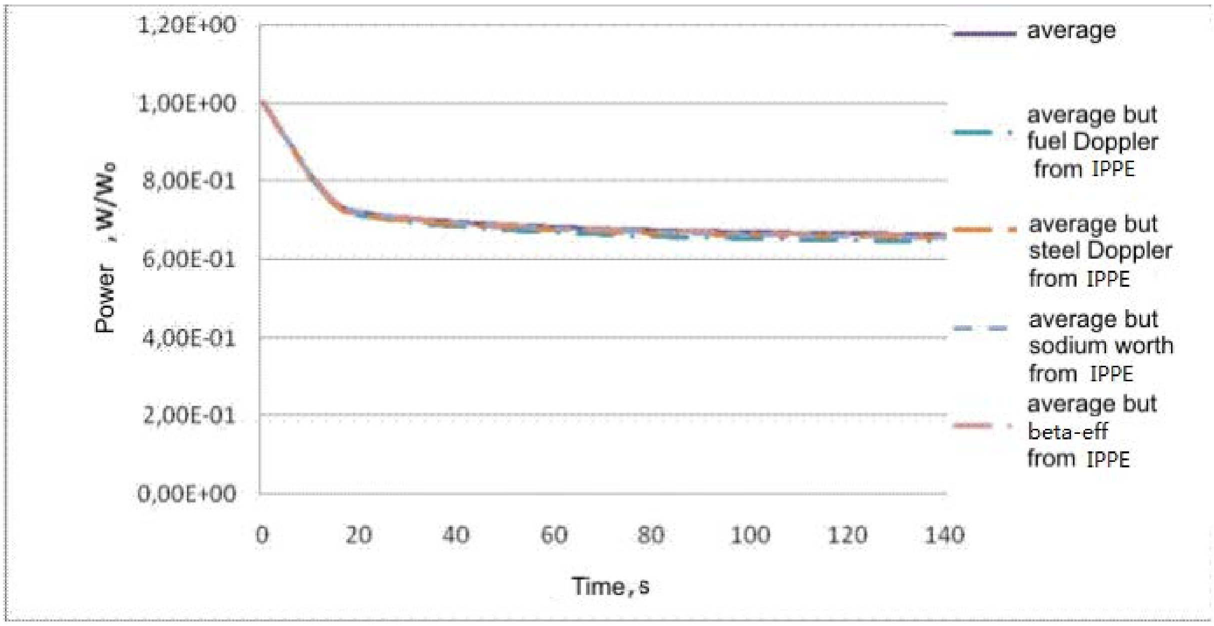


FIG. 4.14. Influence of differences in neutronic parameters on power variation.

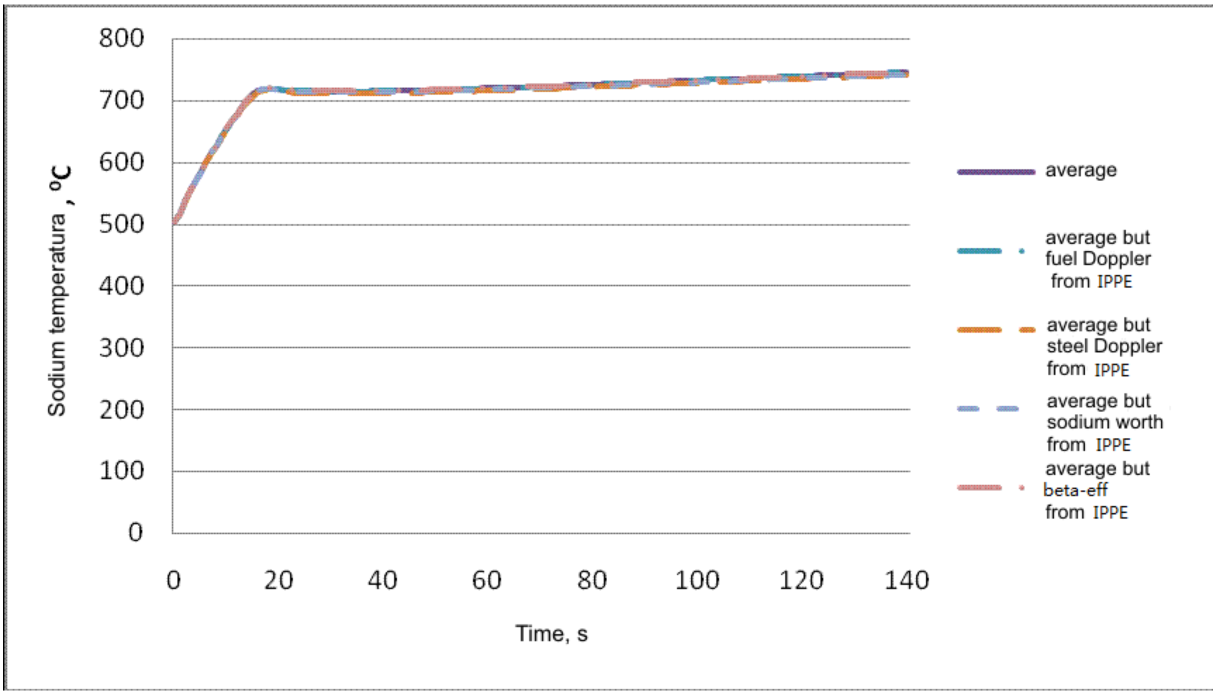


FIG. 4.15. Influence of different components on the sodium outlet temperature.

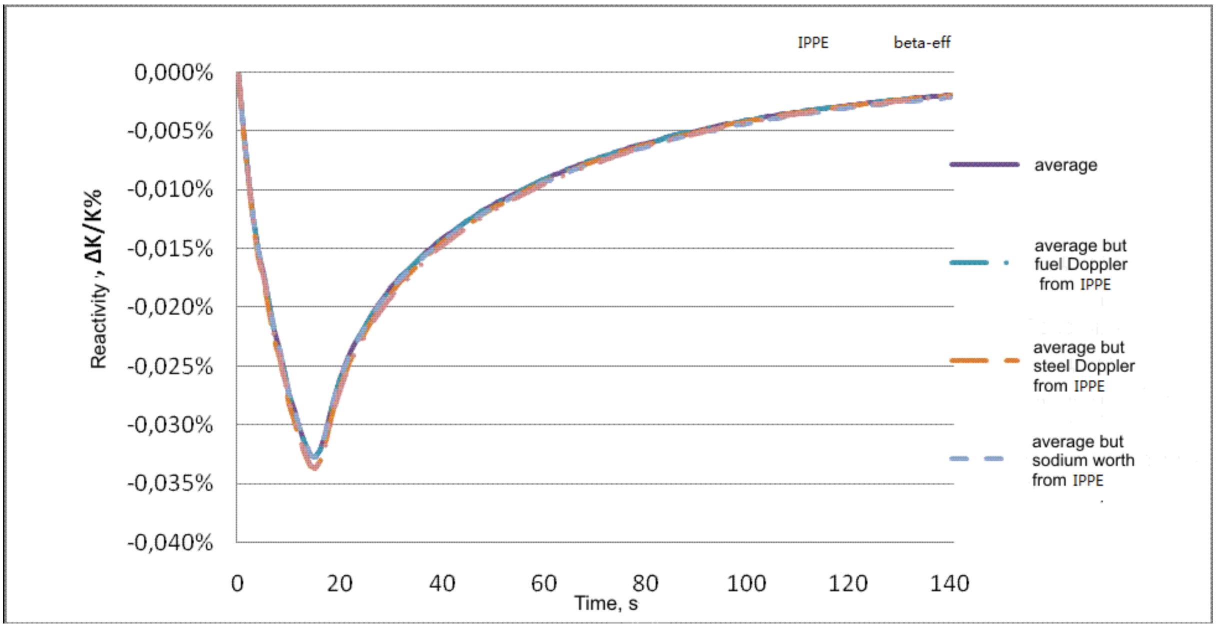


FIG. 4.16. Influence of different components on the reactivity.

TABLE 4.111. DIFFERENCES OF SODIUM CORE OUTLET TEMPERATURE ON THE 100th SECOND OF THE TRANSIENT

Variant	Sodium core outlet temperature (C˚)on the 100th second of the transient
Basic case: with averaged reactivity coefficients and kinetics parameters	732
Same as Basic case, but β_{eff} from IPPE	732
Same as Basic case, but fuel worth from IPPE	732
Same as Basic case, but steel worth from IPPE	732
Same as Basic case, but sodium density coefficient from IPPE	729
Same as Basic case, but steel Doppler constant from IPPE	728
Same as Basic case, but fuel Doppler constant from IPPE	723 (maximum deviation from Basic case)
Mean with IPPE fuel Doppler coefficient	9

The results obtained for Phase 6 are summarized in Table 4.112 and compared with those of Phase 4 (given in Table 4.113).

TABLE 4.112. ULOF TRANSIENT RESULTS FOR BN-600, MOX FUEL WITH MAs OF PHASE 6, BOC

Time (s)	0	20	40	100
Power (relative to t=0)	1	0.75(±0.01)	0.68 (±0.02)	0.66 (±0.03)
Net reactivity, pcm	0	-325(±30)	-150(±20)	-40(±5)
Sodium outlet Temperature, °C	500	710 (±2)	720 (±5)	730 (±12)

For Phase 6, using of the IPPE parameters led to lower sodium outlet temperatures compared to those of KAERI and JAEA, so a certain spread in computed parameters was observed. Therefore the results of Table 4.112 show approximate mean values and the range in which the parameters vary.

TABLE 4.113. ULOF TRANSIENT RESULTS FOR BN-600, MOX FUEL OF PHASE 4, BOC

Time (s)	0	20	40	100
Net reactivity, pcm	0	-500(±100)	-210(±50)	-60(±10)
Sodium outlet temperature, °C	500	780 (±20)	770 (±20)	760 (±20)
Power (relative to t=0), IPPE	1	0.65	0.63	0.62
Maximal fuel temperature, IPPE, °C	2300	1800	1750	1700

The reactivity variations in Phase 4 were mainly affected by positive fuel Doppler and negative radial expansion contributions. The positive sodium density effects and negative axial expansion effects were much smaller and partially compensated each other.

Phase 6 results show a certain similarity, but they are different due to assuming a negligible radial expansion feedback, a lower (by magnitude) fuel Doppler constant and higher (by magnitude) sodium density coefficients. As earlier, one may observe that deviations in the reactivity coefficients may not lead to substantial variations in transient results at the beginning of the initial phase of the ULOF transient. More studies are needed to investigate the effect of uncertainties in reactor physics parameters on transient results for extended in time transient ULOF simulations and other than ULOF cases.

With the limited amount of results available, no definite conclusion on the reactor safety can be made. On the other hand, the available results do not give any particular reason that would prevent utilization of weapons-grade plutonium or TRUs from LWR spent fuel in a BN-600 type reactor.

4.6 SENSITIVITY STUDIES ON THE EFFECTS INDUCED BY APPLICATION OF THE JENDL-3.2 AND JEFF-3.1 DATA

JAEA studied the effects of employing JEFF-3.1 data instead of JENDL-3.2 ones. The 18-group average cross-sections were computed on the basis of the corresponding libraries at KAERI and JAEA, respectively. Since KAERI provided only the total scattering data, JAEA subdivided them into the elastic and inelastic parts by using the ratio of the JENDL-3.2 library (this approach is certainly an approximation, in particular taking into account that a new ratio for sodium was adopted for JEFF-3.1). The average cosine values for JEFF-3.1 were neither available to JAEA and, therefore, assumed to be the same as those for JENDL-3.2.

Some results of the sensitivity analyses, showing contributions from particular nuclides and nuclear reactions, are given in Figs 4.17–4.19 as concerns the criticality, sodium density coefficient, reactivity loss after 140 EFPDs, respectively.

The differences between the results obtained with the libraries are affected by a large cancellation of contributions from many nuclides and reactions, especially, U-238 inelastic (JAEA did not get the exact one of JEFF-3.1 from KAERI as mentioned above), Pu-239 FP capture (there are many different ways to generate the lumped FP cross-sections), Pu-239 fission (due to its large sensitivity), Am-241 capture (needs to be investigated), Pu-238 fission, Pu-240 nu-bar value, oxygen capture, nickel capture, etc.

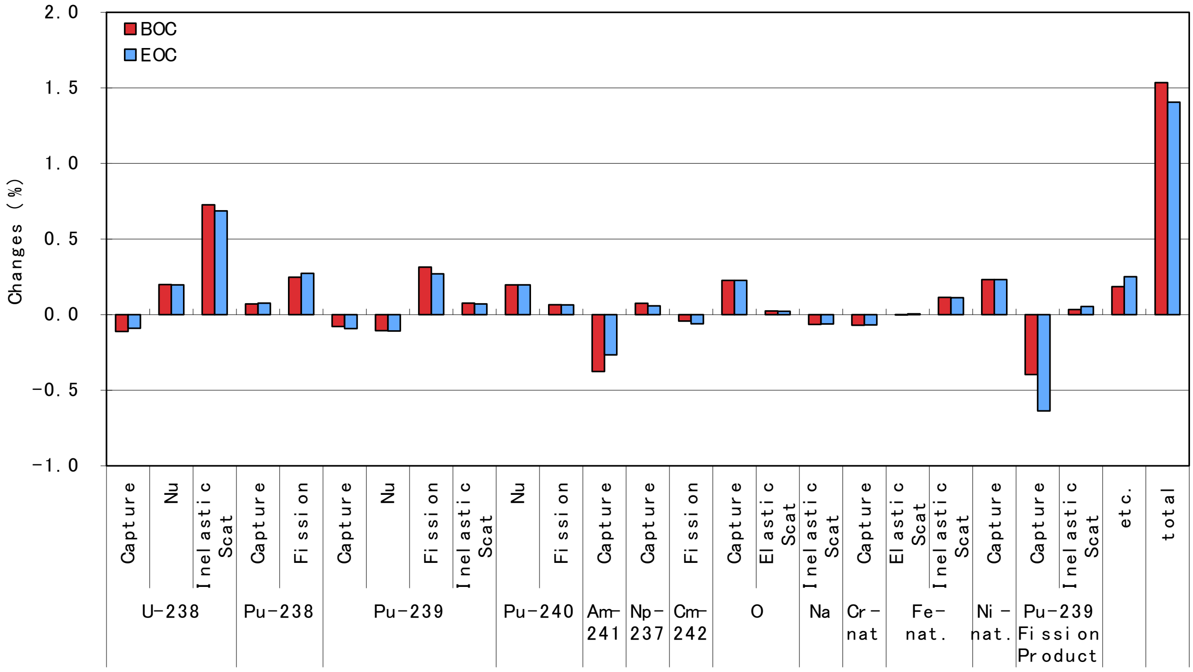


FIG. 4.17. Contributions to variations in criticality (JEFF-3.1 instead of JENDL-3.2).

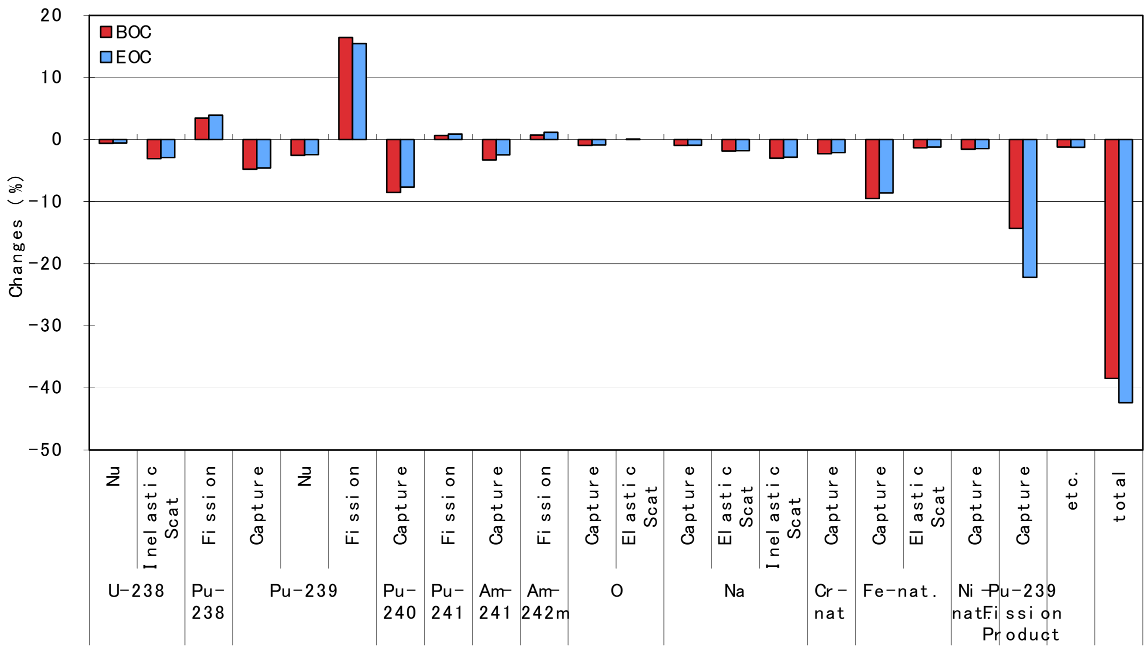


FIG. 4.18. Contributions to variations in sodium density coefficient (JEFF-3.1 instead of JENDL-3.2).

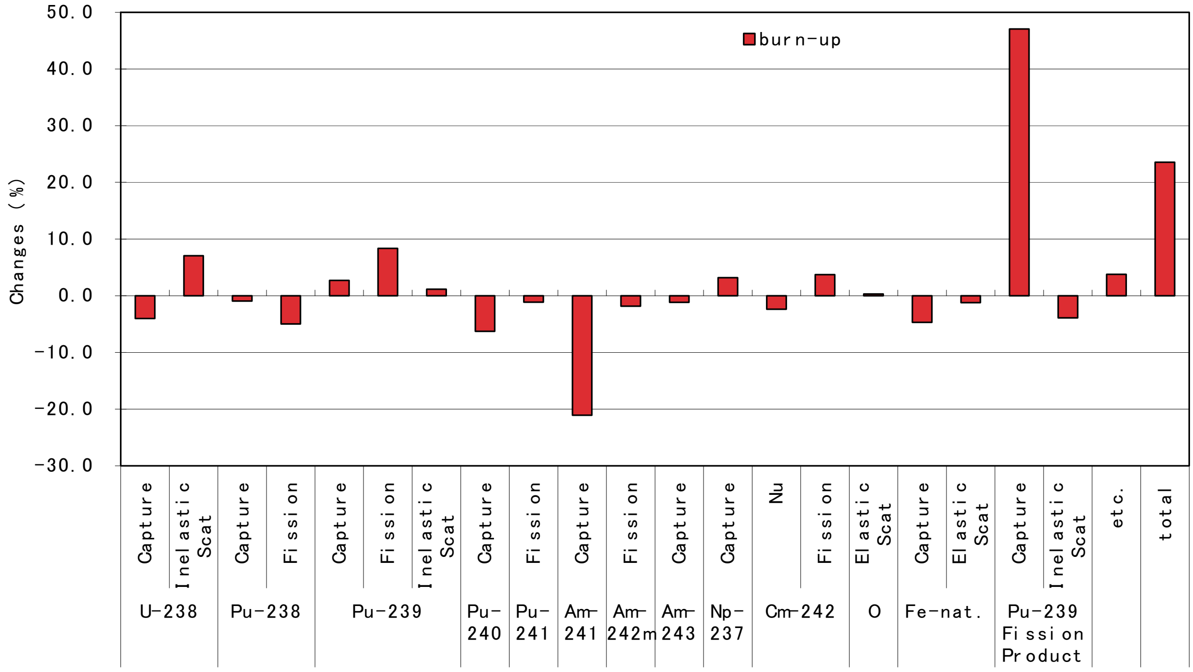


FIG. 4.19. Contributions to variations in reactivity loss after 140 EFPDs (JEFF-3.1 instead of JENDL-3.2).

The comparisons between the library effects (JEFF-3.1 - JENDL-3.2)/JENDL-3.2 * 100 %) obtained by direct calculations and by employing the FOPT approach in sensitivity studies are provided in Table 4.114.

TABLE 4.114. SENSITIVITY AND DIRECT CALCULATION RESULTS ON PARAMETER VARIATIONS (%) DUE TO USING OF JEFF-3.1 INSTEAD OF JENDL-3.2

	Sensitivity	Direct
Criticality, BOC	1.53	1.48
Criticality, EOC	1.41	1.68
Sodium density coefficient, BOC	-38.5	-27.9
Sodium density coefficient, EOC	-42.4	-34.1
Burnup reactivity loss	23.5	-37.5
Atomic Number Density of LEZ region at EOC		
Pu-239	-0.2	0.3
Pu-241	-4.0	-7.2
Am-241	-1.2	-0.3
Np-237	0.0	0.7
Cm-242	6.2	-1.4
Cm-245	1.9	2.2

One may conclude that the sensitivity approach is reasonably accurate and may help to identify main contributions from particular nuclides and nuclear reactions as concerns the criticality and the reactivity coefficients. For the burnup results, this approach is less accurate due to non-linear effects and possible differences in the burnup models due to potentially different burnup chains, branching ratios and decay constants. For example the burnup reactivity loss variation due to using alternative to JENDL-3.2 data is negative (the reactivity loss is lower by 37.5%) according to the direct calculations, but positive according to sensitivity ones (this parameter is higher by 23.5%).

4.7 CONCLUSIONS ON ANALYSES FOR PHASE 6

A BN-600 core model with MOX fuel containing a substantial amount of minor actinides (MAs), more than 5% in the fresh fuel, was investigated in Phase 6 studies of the IAEA coordinated research project on Updated Codes and Methods to Reduce the Calculational Uncertainties of the LMFR Reactivity Effects. To establish an envelope case (with a TRU content deviating at most from weapons-grade plutonium while assuming no separation of plutonium and minor actinides during reprocessing) it was suggested to consider a 60 GWd/t reprocessed LWR uranium fuel and allowing for a fuel storage period of 50 years before reuse. Thus the problem of utilizing TRUs coming from spent LWR nuclear fuel in BN-600 type reactors was addressed.

The computation model for a beginning of an equilibrium fuel cycle was established at IPPE by employing the TRU isotopic composition evaluated at CEA. Reactor physics parameters relevant for safety analyses were computed by institutions representing several IAEA member states while employing their up to date computation tools and data libraries.

The obtained values for criticality, reactivity coefficients, burnup reactivity loss and variations in the fuel composition due to burnup are in qualitative agreement. The parameters computed by different benchmark participants show the same trends with respect to those computed for a previous benchmark phase for a similar reactor model, but with MOX fuel containing weapons-grade plutonium. In particular, the absolute value of the fuel Doppler constant is lower by about 50% or more, the sodium density coefficient increased appreciably (by magnitude), the effective delayed neutron fraction and neutron lifetime become smaller. This is in line with the trend observed worldwide in transmutation studies: the safety parameters deteriorate if MAs are added to supplemented to the fuel.

Higher MA content leads to higher deviations in criticality due to using of JEFF-3.1 instead of JEF-2.2 data as compared to Phase 4. A quite large relative spread in the obtained values for the fuel Doppler constant was observed initially, but later reduced after recalculations. These observations indicate a potentially higher uncertainty of computed reactor parameters in case of using fuel with MAs instead of MOX with weapons-grade plutonium.

Sensitivity studies performed by CEA and JAEA help to understand the origin of deviations between the results of Phase 4 and Phase 6, nuclide and energy contributions to the reactivity effects, influence of different data evaluations on the computed parameters. The benchmark has shown that using of a relatively small (about 30) number of energy groups may lead to an underestimation of the absolute value of the fuel Doppler coefficient by a value of the order of 10%.

A limited set of transient results was provided by IPPE for the beginning of the ULOF initiation phase, while employing a few different sets of reactor physics parameters. The results confirm an earlier observation on a substantial effect of compensations of deviations between the parameters with respect to their influence on transient progression at the considered transient phase (it was shown previously that this compensation no longer takes place at later transient phases).

Investigations show that the observed deviations in calculated reactivity coefficients do not lead to substantial variations in the results of transient analyses at BOC. Differences in sodium core outlet temperatures caused by deviations in applied reactivity coefficients are about 7 C˚ while the temperature variation itself is more than 200 C˚.

Larger deviations are observed by simulating the transient with different safety parameters computed at EOC, the sodium outlet temperatures deviation after 100 s up to ca. 14 C˚ .

For ULOF, the fuel Doppler constant uncertainties is one of the major sources of uncertainties in the results of the transient simulation.

The available results of the study do not indicate any reason that would prevent utilization of weapons-grade Pu or TRUs from LWR spent fuel in a BN-600 type reactor.

5. CONCLUSIONS

Two BN-600 core designs, (i) with mixed oxide (MOX) fuel containing weapons-grade Pu and (ii) with MOX fuel containing Pu and Minor Actinides (MAs) from spent LWR fuel, both designs incorporating a sodium plenum above the core, are described in the report. These analyses extend studies for the BN-600 hybrid core — with uranium oxide (UOX) and MOX fuels — carried out in 1999–2001. The considered MOX and hybrid UOX/MOX designs were proposed to investigate options for utilization of Pu and MAs in this reactor.

The participants applied up to date libraries and computer codes, which partly evolved during the CRP studies. Experimental analyses for Phase 5 confirmed that criticality and sodium void effects are computed reasonably accurately for cores with UOX fuel and weapons-grade Pu. The studies performed outside of this CRP (the applied tools were also used for other projects, including analyses of reactor experiments and code-to-code benchmarking, the results being published elsewhere) support the opinion that the computation tools are also applicable for the BN-600-MOX (with reactor grade PU) and BN-600-MA core models.

Larger deviations (as compared to the case of the BN-600-Hybrid core) between results provided by different participants for BN-600-MOX and BN-600-MA core are observed, mainly due to different nuclear data employed. The uncertainties are more pronounced in case of the core with MA-bearing fuel.

The spatial distributions of reactivity coefficients were computed by employing the first order perturbation theory. The transient results appear relatively insensitive to the way of computation of these distributions (transport vs. diffusion, homogeneous vs. heterogeneous) for the initial phase of ULOF (before sodium boiling onset), partially because of compensation effects. On the other hand, 3-D (HEX-Z) calculations are mandatory to provide realistic spatial distributions of power and reactivity coefficients.

The analyses reveal a high potential of fast reactor designs for utilization of weapons-grade Pu and TRUs from spent LWR fuel, though additional safety studies should be performed to prove the viability and safety of the considered reactor designs.

The conducted CRP studies contributed to the progress in development and application of new codes and data libraries for fast reactor analyses; promoted deeper understanding of the influence of reactivity coefficients and their uncertainties on the results of experience and transient analyses in the initial phase of transients, such as ULOF; facilitated exchange of opinions between specialists from leading countries in fast reactor technology; helped in keeping high level standards in the area of fast reactor safety in the organizations participating in the study.

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LIST OF ABBREVIATIONS

AB	axial blanket
AR	axial reflector
BFS	big physical stand, Russian Federation
EBR-2	experimental breeder reactor -2, USA
FFTF	fast flux test facility, USA
FSA	fuel subassembly
HEZ	high enrichment zone
IBZ	internal blanket zone
LEZ	low enrichment zone
LMFR	liquid metal fast reactor
LWR	light water reactor
MEZ	medium enrichment zone
MOX	mixed oxide (U, Pu)O_2 fuelled zone
RC	reactivity coefficient
REF	radial reflector
SHR	shim rod absorber
SCR	scram rod absorber
SP	sodium plenum
SSA	steel shielding subassembly
FSA	fuel subassembly
UBS	upper boron shield

ORGANIZATIONS

ANL	Argonne National Laboratory, USA
CEA	Commisariat à l'Énergie Atomique, France
CIAE	China Institute of Atomic Energy, China
FZK/IKET	Forschungszentrum Karlsruhe/ Institut für Kern- und Energietechnik, Germany
IGCAR	Indira Gandhi Centre for Atomic Research, India
IPPE	Institute of Physics and Power Engineering, Russian Federation
JNC	Japan Nuclear Cycle Development Institute, Japan
KAERI	Korea Atomic Energy Research Institute, Republic of Korea
SA	SERCO Assurance, United Kingdom
IAEA	International Atomic Energy Agency

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