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NEA Burn-up Credit Benchmark Phase VIII

Numerical benchmark for the analysis of small-sample reactivity experiments

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Foreword

Under the auspices of the NEA Nuclear Science Committee (NSC), the Working Party on Nuclear Criticality Safety (WPNCS) has been established to co-ordinate scientific activities relevant to criticality safety. Specific areas of interest include investigations of static and transient configurations during fuel fabrication, transport and storage.

The WPNCS Expert Group on Burn-up Credit (EGBUC) was established in 1991 to address scientific and technical issues connected to the use of burn-up credit in nuclear fuel cycle operations. Criticality safety methodologies that take into account a reduction in the reactivity of irradiated fuel due to the fuel burn-up are commonly referred to as taking burn-up credit. This reduction of reactivity with fuel burn-up is mostly due to the net reduction of fissile nuclides and the net production of actinide nuclide and fission-product neutron absorbers.

In the ICSBEP international database, several experiments are related to the reactivity worths of actinide nuclides. For instance, critical solutions and fuel lattices, including isotopes of U, Pu and sometimes Np and Am, are useful to evaluate realistic margins on the contribution of actinide nuclides to the reactivity loss of the burned fuel. Post-irradiation experiments are also of great interest to check how accurate calculation codes are to predict the material balance of fuel with the burn-up. However, very few experiments exist to assess the fission product build-up and related reactivity worths. Some experiments have been performed in critical mock-ups like DIMPLE (UKAEA) and MINERVE (CEA), based on the measurement of the reactivity worths of small samples containing either separated fission products or rod cuts of irradiated fuels. The evaluation of these data is on-going for the International Reactor Physics Benchmark Experiments database (IRPhE).

As a consequence, the Burn-up Credit Criticality Safety Benchmark Phase VIII was proposed to study specific problems related to the analysis of small sample reactivity experiments which imply the calculation of small reactivity, typically in the order of a few pcm to a few tens of pcm (1 pcm = 10^{-5} dk/k). One of the specificities of this benchmark is that all participants have been asked to use the same input nuclear data. The idea was to evaluate the calculation bias due to approximations in solving the Boltzmann equation, especially in the discretisation of the phase space (energy, space, and angle). For this purpose, four sub-phases containing single fuel cell, 2D and 3D lattice geometries have been considered. Participants have been asked to evaluate several quantities like the effective multiplication factor (k_{eff}), reaction rates and reactivity worths for 28 of the main nuclides contributing to the reactivity loss with burn-up.

Acknowledgments

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List of abbreviations and acronyms

BUC	Burn-up Credit
CEA	Commissariat à l’énergie atomique et aux énergies alternatives
EGBUC	Expert Group on Burn-up Credit Criticality
EMS	E. Mennerdahl Systems
ENDF	Evaluated Neutron Data Files
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit
ICSBEP	International Criticality Safety Benchmark Evaluation Project
IRPhE	International Reactor Physics Experiment Evaluation
JEFF	Joint Evaluated Fission and Fusion Nuclear Data Library
MOX	Mixed oxide
NSC	Nuclear Science Committee
ORNL	Oak Ridge National Laboratory
UOX	Uranium oxide
VUJE	Nuclear Power Plant Research Institute
WPNCS	Working Party on Nuclear Criticality Safety

Executive summary

Small-sample reactivity experiments are relevant to provide accurate information on the integral cross-sections of materials. One of the specificities of these experiments is that the measured reactivity worth generally ranges between 1 and 10 pcm, which complicates the use of Monte Carlo for the analysis. As a consequence, several papers have been devoted to deterministic calculation routes, implying spatial and/or energetic discretisation which could involve calculation bias. Within the Expert Group on Burn-Up Credit Criticality, a benchmark was proposed to compare different calculation codes and methods for the analysis of these experiments. In four sub-phases with geometries ranging from a single cell to a full 3D core model, participants were asked to evaluate the reactivity worths due to the addition of small quantities of separated fission products and actinides into a UO_2 fuel. Fourteen contributions using six different codes have participated in the benchmark.

Considering the calculation of the k-effective, flux and reaction rates, comparisons between different codes were relevant to identify calculation biases due to the different approximations used in the deterministic approaches. The treatment of the self-shielding effect due to the addition of BUC nuclide in a UO_2 fuel has been identified as the key-point of these comparisons. The use of more than two hundred energy groups, like in the SCALE6, CASMO5 and APOLLO2 calculations, are required to evaluate the reaction rate of the BUC nuclide within a few percents. To reach this agreement is more problematic for resonant absorbers like ^{240}Pu or ^{101}Ru which require more energy groups or an appropriate model to account for the flux depression inside large resonances.

For a reactivity worth of more than a few tens of pcm, the Monte-Carlo approach based on the eigen-value difference method appears clearly as the reference method. However, in the case of reactivity worth as low as 10 pcm, it is concluded that approaches based on exact perturbation formalism are more accurate than standard eigen-value difference methods, as the accuracy is not limited by a very small magnitude of the reactivity worth.

Comparisons between a full 3D core model and an infinite 7x7 lattice in 2D model were performed. It concludes that considering ratii of reactivity worths, only small errors (typically less than 1%) are introduced by the simplified geometry model. This is especially true for neutron absorbers like fission products. It should not be generalised to all nuclides especially for fissile actinides where the modification of the production rate integrated over the whole geometry is overestimated in the reduced geometry compared to the full core geometry. One solution should be to consider only the numerator term of the perturbation formulation to avoid the evaluation of the denominator modifications which is generally small (less than 0.1%) for reactivity-worth of less than 100 pcm in the full core geometry.

1. Introduction

This report describes the results of the Burn-Up Credit Criticality Safety Benchmark Phase VIII, conducted by the Expert Group on Burn-up Credit Criticality Safety, which is co-ordinated by the Working Party on Nuclear Criticality Safety of the Nuclear Energy Agency (NEA). The purpose of the Burn-Up Credit Criticality Safety Benchmark Phase VIII was to test the ability of calculation codes to predict small reactivity effects and to share a methodology for the analysis of small sample reactivity experiments.

Burn-up credit is a concept that considers a reduction in reactivity occurring with the fuel burn-up due to the change in the actinide nuclide inventory due to the build-up of fission-products. On the one side, several experiments relevant for the reactivity worths of actinide nuclides can be found in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) experiments (for instance LCT-COMP-THERM benchmarks with MOX fuel). On the other side, very few experiments are available on the reactivity worths of fission products. Such experiments have been performed in the DIMPLE and MINERVE zero power reactors, within the framework of the CERES international programme [1]. Evaluation of these experiments is on-going for the International Reactor Physics Experiment Evaluation (IRPhE) database. The Burn-Up Credit Criticality Safety Benchmark Phase VIII was proposed to prepare the analysis of these experiments [2].

The benchmark is divided into four sub-phases, each of them being devoted to a specific problem.

- Sub-phase I deals with a single PWR fuel cell geometry. Small amounts of BUC nuclides have been added to the fuel. Twenty-five isotopes are considered, covering the major fission products and actinide nuclides. They represent more than 90% of the reactivity loss of a 4-cycle irradiated fuel assembly. Concentrations correspond to the inventory of a 40 GWd/t spent fuel rod.
- Sub-phase II of the benchmark is a more complex survey with a natural UO_2 fuel cell of interest surrounded by PWR fuel cells in a reduced two-dimension 7x7 lattice of the core with reflective conditions on each boundary. This simplified model is supposed to emphasise specific problems in the analysis of small-sample reactivity worth measurements (Dancoff effect in space-dependent self-shielding, 2D heterogeneous calculation). In this sub-phase, concentrations of separated BUC nuclides are derived from mass amounts used in the CERES programme, to provide a reactivity effect of a few pcm in the experiment.
- Sub-phase III of the benchmark is similar to sub-phase II, with the exception that the axial dimension of the problem is treated. A finite height for the core lattice is imposed with leakage conditions on the lower and upper planes to provide a realistic axial distribution of the neutron flux along the height of the oscillation sample. In this way, questions associated with leakage reactivity effects and “finite-size effect” are taken into account. Reflective boundaries are maintained in the radial direction.

- Sub-phase IV of the benchmark is similar to sub-phase III, with the exception that the radial dimension of the problem is treated. A simplified model of the whole core of the reactor is defined as a 49x49 lattice of PWR fuel cells with finite axial dimensions and leakage conditions on axial and radial boundaries. In this way, the real problem can be treated so as to provide a k_{eff} close to unity. It is worth noting that as the main objective of this benchmark was to compare numerical methods and models from different codes to emphasise specific problems associated with the analysis of small reactivity effects, calculations have been required to be performed with the same nuclear data library.

Organisations participating in the benchmark, computer codes and key parameters are presented in Chapter 2. Calculations are compared between all the participants in Chapter 3. Concluding remarks on the four sub-phases of the benchmark are summarised in Chapter 4. Recommendation for a calculation model is proposed in Chapter 5. Appendix A contains the specifications of the Phase VIII benchmark. The summary information provided by the participants about the computational method is presented in Appendix B.

2. Computer codes and nuclear data

Fourteen contributions from seven organisations in seven countries were submitted for the Phase VIII benchmark. A wide variety of codes was used, including SCALE6 [3], DORTOREST [4], APOLLO-2.8 [5], CASMO-5M [6], DRAGON-305F [7], GMVP-II [8], MCNP5 [9] and TRIPOLI4 [10]. The source of the nuclear data was asked to be the United States Evaluated Nuclear Data File ENDF/B-VII.0 [11] for all the participants, as it is the standard library in the SCALE6 and CASMO5 code packages. Calculations were performed with either continuous energy or multi-group cross-section data.

The participants of benchmark Phase VIII and the calculation codes are listed in Table 1.

A more detailed description of the methods, data and assumptions are included in Appendix B.

Contributors were asked to submit data even if they did not complete all the calculations.

Table 2 summarises which of the parameters have been calculated, partially or fully.

In the list, the calculations with GMVP-II and DRAGON-305F are complementary.

Table 1. Participating organisations and calculation methods

Contribution Number	Institute	Country	Code	Nuclear data	Method of resolution	Anisotropy
1	Commissariat à l'Energie et aux Energies Alternatives (CEA)	France	APOLLO2.8-3	ENDF/B-VII.0 281 energy groups	Method of characteristics (MOC)	P0c[1]
2			TRIPOLI4.8	ENDF/B-VII.0 continuous energy	Monte Carlo	Exact Treatment
3			MCNP5	ENDF/B-VII.0 continuous energy	Monte Carlo	Exact Treatment
4	E Mennerdahl Systems (EMS)	Sweden	SCALE6.1/XSDRN	ENDF/B-VII.0 238 energy groups	Discrete ordinate method (Sn)	P5
5			SCALE6.1/NEWT	ENDF/B-VII.0 238 energy groups	Discrete ordinate method (Sn)	P5
6			SCALE6.1/KENO-Va	ENDF/B-VII.0 238 energy groups	Monte Carlo	P5
7	Gesellschaft für Anlagen- und Reaktorsicherheit mbH (GRS)	Germany	DORTOREST/XSDRNPM	ENDF/B-VII.0 238 energy groups	Discrete ordinate method (Sn)	P3
8			MCNP5	ENDF/B-VII.0 continuous energy	Monte Carlo	Exact Treatment
9	Japan Nuclear Energy Safety Organisation (JNES)	Japan	DRAGON-305F	ENDF/B-VII.0 69 energy groups	Collision Probability method (Pij)	P0
10			GMVP-II	ENDF/B-VII.0 69 energy groups	Monte Carlo	P0
11	Oak Ridge National Laboratory (ORNL)	US	SCALE6.1/KENO-Va	ENDF/B-VII.0 238 energy groups	Monte Carlo	P5
12			SCALE6.1/KENO-VI	ENDF/B-VII.0, 238 energy groups	Monte Carlo	P5
13	Paul Scherrer Institute (PSI)	Switzerland	CASMO-5M Version 1.07.01	ENDF/B-VII.0 + Studsvik modif. 586 energy groups	Method of characteristics (MOC)	P0
14	Nuclear Power Plant Research Institute Trnava Inc. (VUJE)	Slovakia	SCALE6.1.1/KENO-VI	ENDF/B-VII.0 238 energy groups	Monte Carlo	P5

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[1] P0c means corrected P0.

Table 2. Overview of provided results

		SUB_PHASE 1						SUB_PHASE 2						SUB_PHASE 3						SUB_PHASE 4					
Organisation	Code system	Keff	Flux	Reaction Rates	Reactivity worth (EV)	Reactivity worth (PT)	Reactivity worth / reaction	Keff	Flux	Reaction Rates	Reactivity worth (EV)	Reactivity worth (PT)	Reactivity worth / reaction	Keff	Flux	Reaction Rates	Reactivity worth (EV)	Reactivity worth (PT)	Reactivity worth / reaction	Keff	Flux	Reaction Rates	Reactivity worth (EV)	Reactivity worth (PT)	Reactivity worth / reaction
CEA	APOLLO2.8.3/MOC (281G)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	☐	■	■	■
	TRIPOLI4 (CONT. NRG)	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	■	☐	■	■	■	■	■	☐
	MCNP5 (CONT. NRG)	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐
EMS	SCALE6.1/XSDRNPM (238G)	■	■	■	■	■	■	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	SCALE6.1/NEWT (238G)	■	■	■	■	■	■	■	■	■	■	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	SCALE6.1/KENO5a (238G)	■	■	■	■	■	■	■	■	■	■	▨	▨	■	■	■	■	▨	▨	■	■	■	■	▨	▨
GRS	DORTOREST/XSDRN (238G)	■	■	■	■	☐	☐	■	■	■	■	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	MCNP (CONT. NRG)	■	■	■	■	▨	▨	■	■	■	■	■	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
∗JNES	GMVP-II (69G)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	DRAGON305F (69G)	■	■	■	■	■	■	■	■	■	■	■	■	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ORNL	SCALE6.1/KENO5a (238G)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	■	■	■	■	☐	▨	■	■	■	■	☐	▨
	SCALE6.1/KENO6 (238G)	■	■	■	■	☐	▨	■	■	■	■	☐	▨	■	■	■	■	☐	▨	■	■	■	■	☐	▨
PSI	CASMO5/MOC (586/19G)	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐
VUJE	SCALE6.1.1/KENO6 (238G)	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐	■	■	■	■	☐	☐

☐ **Missing data**

▨ **Incomplete data**

■ **Complete data**

∗Subsidiary calculations with 69 group cross-sections for comparative studies

3. Calculation results and their analysis

This section presents the results of the benchmark calculations for each of the four sub-phases. All the calculations have been compared to what we can consider as the most "reference" calculations. It was chosen to be the calculations based on TRIPOLI4.8 calculation code. "Reference" means that the calculations have few approximations in order to stay as close as possible to real physical laws, using for instance the Monte Carlo solver which allows any kind of geometry modelling, continuous-energy cross-sections which prevents from any bias due to self-shielding and exact treatment of scattering law as described in the nuclear data file. Results are presented as relative difference compared with the reference code package. Differences are given in tables and illustrated in bar graphs. Results are presented either in the form of absolute differences, like for instance on the k_{eff} which is defined $(k_{eff,C} - k_{eff,ref}) \times 10^5$, or in the form of relative differences, like for instance on the one-group neutron flux which is defined as $(\phi_C - \phi_{ref})/\phi_{ref}$.

Uncertainties are presented with a confidence level of 68% (k=1). The notation f.ffff(uu) means that the central value is f.ffff while the value in the brackets is the standard deviation. The uu refers to the last 2 digits of f.ffff. For instance, 1.328301(25) is equivalent to 1.328301 ± 0.000025 (or ±2.5 pcm). It should be noted that the common unit "pcm" will be used to describe variation of the order of 10^{-5} on the k_{eff}.

For each sub-phase, 28 cases were considered:

- one reference case without BUC nuclide;
- twenty-five cases with the addition of separated BUC nuclides consisting of 15 fission products and 10 actinides;
- one case with the addition of the sum of the 25 BUC nuclides;
- one case with the addition of a calibration nuclide (^{10}B).

For sub-phases 2, 3 and 4, two additional cases were added with the substitution of the central fuel cell by the same volume filled with air and light water.

3.1 Sub-phase 1 results

The calculation results for sub-phases 1 and their analysis are presented in Sections 3.1.1 to 3.1.4

3.1.1 Effective multiplication factor

Calculations of the k_{eff} are presented in Figures 1 and 2. Calculated values are given in Table 3.

Differences are between -1300 pcm and +100 pcm compared with TRIPOLI4 calculations. Trends are almost the same for cases 0 to 27, which means that the k_{eff} calculations do not depend on the kind BUC nuclide added to the fuel. The closest agreement with the reference calculation is obtained by Monte Carlo codes using continuous-energy cross-sections, i.e. MCNP5 calculations from CEA and GRS with differences lower than 100 pcm. The same accuracy is obtained by the deterministic codes APOLLO2 and CASMO5 for the prediction of the k_{eff}. SCALE6 calculations by EMS, VUJE and ORNL underestimate the k_{eff} by 600 to 800 pcm. The same underestimation is observed for DORTOREST calculations by GRS, using the 238 energy group library. Since S_n and Monte Carlo methods using the same multi-group libraries yield similar results, some of the differences appear to be related primarily to the nuclear data library used and especially to the way the self-shielding is accounted for, and not on the neutron transport method. Larger differences are obtained by calculations based on GMVP-II and DRAGON3 simulations. The low number of energy groups for the input cross-sections may be responsible for this as the two codes use the same energy mesh for the calculations. Here again, the impact of using either MOC or Monte Carlo is less than 100 pcm.

For case 28, which corresponds to the addition of all BUC nuclide in the fuel, differences with TRIPOLI4 are reduced by 500 pcm using DRAGON3 and GMVP-II and are also slightly improved for SCALE6 calculations by ORNL and VUJE. Due to a misunderstanding, there was no EMS contribution for case 27. Some early estimated results to account for this were not based on full and reliable calculations and should not be considered (to be deleted).

Figure 1. Absolute difference in the effective multiplication factor k_{eff} for cases 0 to 13 of sub-phase 1

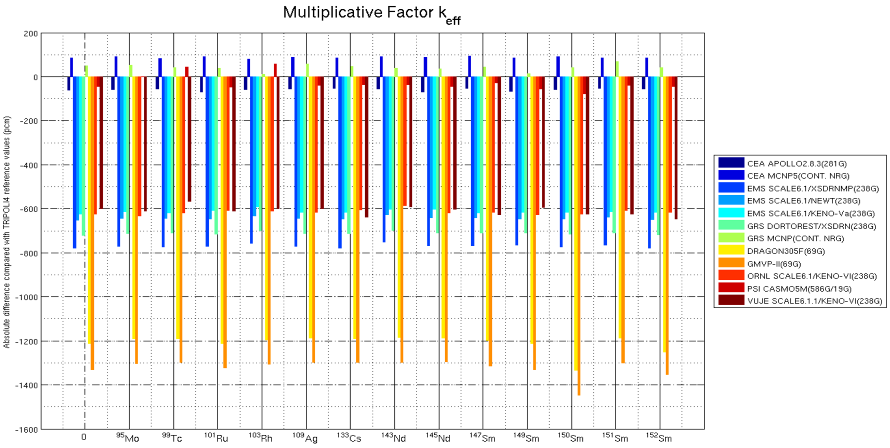


Figure 2. Absolute difference in the effective multiplication factor k_{eff} for cases 14 to 27 of sub-phase 1

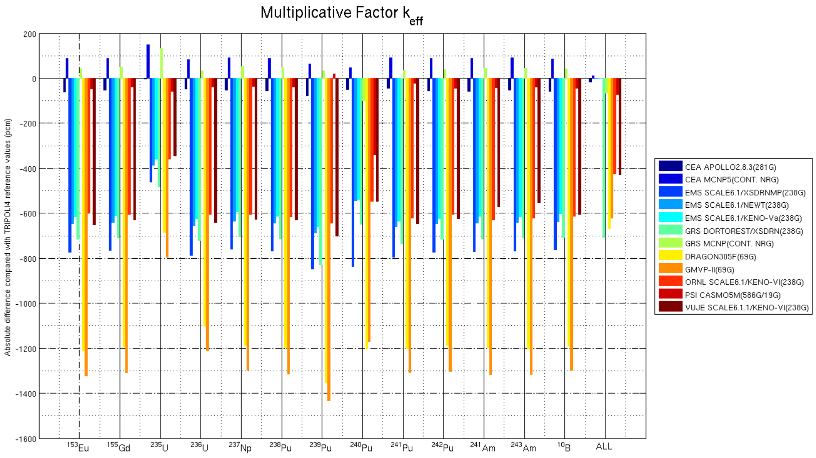


Table 3. k_{eff} calculations (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTO REST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	1.390897	1.391505	1.39235	1.383726	1.384984	1.385270(60)	1.38429	1.391990(100)	1.37937	1.378200(18)	1.385256(99)	1.39105	1.385510(300)
^{95}Mo	1.386709	1.387285(33)	1.388190(10)	1.379569	1.380834	1.381140(60)	1.38015	1.387790(100)	1.37537	1.374250(19)	1.380979(99)	1.38728	1.381180(290)
^{99}Tc	1.380951	1.381519(33)	1.382330(10)	1.373766	1.375085	1.375320(60)	1.37441	1.381920(100)	1.36962	1.368530(19)	1.375322(99)	1.38194	1.375850(290)
^{101}Ru	1.387431	1.388123(33)	1.389020(10)	1.380404	1.381669	1.382040(60)	1.38098	1.388500(100)	1.37601	1.374890(18)	1.382043(99)	1.38766	1.382010(280)
^{103}Rh	1.365419	1.365996(33)	1.366790(10)	1.358411	1.35967	1.360080(60)	1.359	1.366090(100)	1.35403	1.352930(19)	1.359891(100)	1.36658	1.359990(290)
^{109}Ag	1.387585	1.388134(33)	1.389020(10)	1.380418	1.381685	1.381960(60)	1.38101	1.388700(100)	1.37625	1.375140(19)	1.381962(99)	1.38774	1.382140(320)
^{133}Cs	1.378585	1.379127(33)	1.379970(10)	1.371345	1.37266	1.372950(60)	1.372	1.379590(100)	1.36721	1.366140(19)	1.373065(99)	1.37875	1.372750(290)
^{143}Nd	1.363609	1.364176(33)	1.365090(10)	1.356659	1.357894	1.358160(60)	1.35718	1.364560(100)	1.35233	1.351180(19)	1.358316(99)	1.36382	1.358270(340)
^{145}Nd	1.383984	1.384678(33)	1.385550(10)	1.376993	1.378252	1.378650(60)	1.37757	1.385040(100)	1.37281	1.371730(18)	1.378480(99)	1.38423	1.378650(280)
^{147}Sm	1.38845	1.388972(33)	1.389900(10)	1.381305	1.382565	1.382780(60)	1.38188	1.389400(100)	1.37698	1.375840(19)	1.382829(99)	1.38868	1.382700(370)
^{149}Sm	1.361497	1.362162(33)	1.363010(10)	1.354517	1.355699	1.356000(60)	1.35506	1.362310(100)	1.35003	1.348850(18)	1.355887(99)	1.3616	1.356210(300)
^{150}Sm	1.387218	1.387791(33)	1.388700(10)	1.380056	1.381321	1.381620(60)	1.38063	1.388190(100)	1.37446	1.373320(18)	1.381562(99)	1.38702	1.381540(300)
^{151}Sm	1.37343	1.373961(33)	1.374810(10)	1.366324	1.367572	1.367840(60)	1.36687	1.374650(100)	1.3621	1.360960(18)	1.367886(99)	1.37356	1.367730(310)
^{152}Sm	1.382211	1.382770(33)	1.383630(10)	1.374978	1.37628	1.376600(60)	1.3756	1.383170(100)	1.37025	1.369230(19)	1.376629(100)	1.38233	1.376310(320)
^{153}Eu	1.384513	1.385123(33)	1.385990(10)	1.377399	1.378658	1.378960(60)	1.37797	1.385520(100)	1.37304	1.371890(18)	1.379151(99)	1.38464	1.378590(280)
^{155}Gd	1.381812	1.382345(33)	1.383230(10)	1.374687	1.375936	1.376250(60)	1.37524	1.382840(100)	1.37041	1.369250(18)	1.376295(100)	1.38195	1.376050(310)
^{235}U	0.95555	0.955581(33)	0.957081(10)	0.950981	0.951727	0.952000(60)	0.95075	0.956890(80)	0.94874	0.947640(20)	0.952008(99)	0.95499	0.952130(210)
^{236}U	1.379284	1.379766(33)	1.380580(10)	1.371893	1.373212	1.373530(60)	1.37254	1.380100(100)	1.36874	1.367680(19)	1.373706(99)	1.37937	1.373350(290)
^{237}Np	1.379344	1.379879(33)	1.380780(10)	1.372273	1.373532	1.373920(60)	1.37284	1.380380(100)	1.36801	1.366890(19)	1.373838(99)	1.3795	1.373610(310)
^{238}Pu	1.384988	1.385544(33)	1.386430(10)	1.377856	1.379108	1.379410(60)	1.37842	1.386020(100)	1.37355	1.372390(18)	1.379385(99)	1.38515	1.379250(310)
^{239}Pu	1.442946	1.443729(33)	1.444360(10)	1.435251	1.436845	1.437130(60)	1.43545	1.444040(100)	1.43018	1.429390(18)	1.437299(99)	1.44391	1.436700(290)
^{240}Pu	1.273112	1.273606(33)	1.274070(10)	1.26524	1.268155	1.268210(60)	1.2671	1.272600(110)	1.26157	1.261880(29)	1.268127(100)	1.27019	1.268130(330)
^{241}Pu	1.428605	1.429065(33)	1.429960(10)	1.421114	1.42246	1.422720(60)	1.42172	1.429410(100)	1.41705	1.415970(18)	1.422844(99)	1.42884	1.422600(290)
^{242}Pu	1.382837	1.383405(33)	1.384270(10)	1.375657	1.376927	1.377170(60)	1.37626	1.383780(100)	1.37153	1.370380(18)	1.377340(99)	1.38296	1.377170(290)
^{241}Am	1.383578	1.384157(33)	1.385030(10)	1.376456	1.377715	1.378020(60)	1.37703	1.384580(100)	1.37216	1.370990(18)	1.377863(99)	1.38373	1.378440(310)
^{243}Am	1.387249	1.387789(33)	1.388700(10)	1.380114	1.381371	1.381630(60)	1.38068	1.388210(100)	1.37573	1.374610(19)	1.381567(100)	1.3874	1.382250(290)
^{10}B	1.366869	1.367445(33)	1.368300(10)	1.359819	1.361053	1.361430(60)	1.36036	1.367840(100)	1.35555	1.354450(18)	1.361314(99)	1.36701	1.361390(290)
ALL	1.037545	1.037720(33)	1.037840(10)	N.R.	N.R.	N.R.	1.03064	1.037060(110)	1.03103	1.031500(31)	1.033478(96)	1.03699	1.033440(280)

3.1.2 Neutron flux

As a first step to reaction rate calculations, participants were asked to evaluate the neutron flux, integrated over the phase space (energy, space, angle), after a normalisation to one source neutron.

Comparisons are illustrated in Figures 3 and 4, and calculation results are reported in Table 4.

All of them succeed in the calculation of this parameter within less than 1%, which is acceptable, whatever BUC nuclide is added to the fuel.

Figure 3. Relative difference in the integrated neutron flux for cases 0 to 13 of sub-phase 1

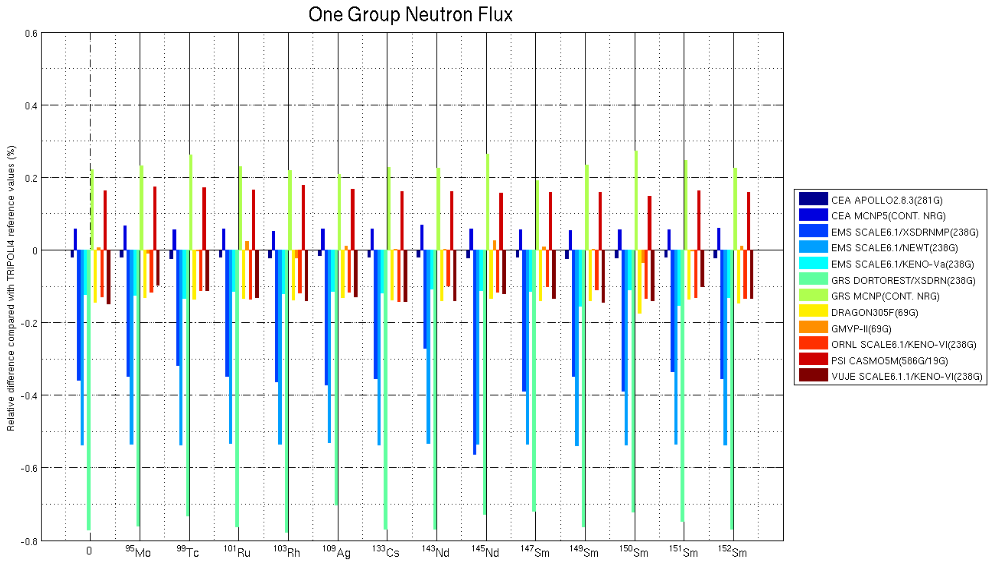


Figure 4. Relative difference in the integrated neutron flux for cases 14 to 27 of sub-phase 1

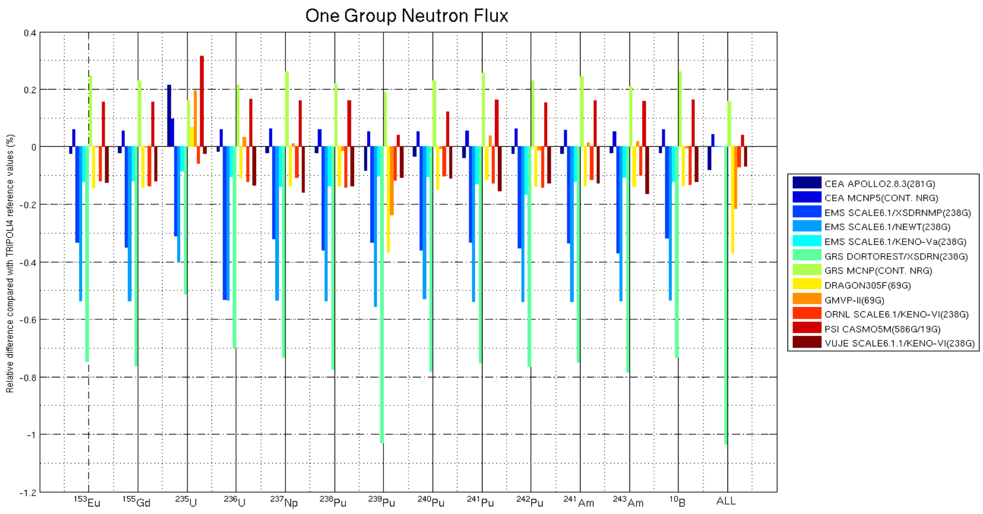


Table 4. Neutron flux in cm^{-2}.s^{-1}(sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1.1 KENO-VI 238G
0	1.209E+01	1.209E+01	1.210E+01	1.205E+01	1.203E+01	1.208E+01	1.200E+01	1.212E+01	1.208E+01	1.209E+01	1.208E+01	1.211E+01	1.222E+01
^{95}Mo	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.207E+01	1.208E+01	1.207E+01	1.210E+01	1.220E+01
^{99}Tc	1.207E+01	1.207E+01	1.207E+01	1.203E+01	1.200E+01	1.205E+01	1.198E+01	1.210E+01	1.205E+01	1.207E+01	1.205E+01	1.209E+01	1.219E+01
^{101}Ru	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.207E+01	1.209E+01	1.207E+01	1.210E+01	1.221E+01
^{103}Rh	1.204E+01	1.204E+01	1.205E+01	1.200E+01	1.198E+01	1.203E+01	1.195E+01	1.207E+01	1.203E+01	1.204E+01	1.203E+01	1.206E+01	1.216E+01
^{109}Ag	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.200E+01	1.211E+01	1.207E+01	1.209E+01	1.207E+01	1.211E+01	1.221E+01
^{133}Cs	1.206E+01	1.206E+01	1.207E+01	1.202E+01	1.200E+01	1.205E+01	1.197E+01	1.209E+01	1.205E+01	1.206E+01	1.205E+01	1.208E+01	1.218E+01
^{143}Nd	1.205E+01	1.205E+01	1.206E+01	1.202E+01	1.199E+01	1.204E+01	1.196E+01	1.208E+01	1.204E+01	1.205E+01	1.204E+01	1.207E+01	1.217E+01
^{145}Nd	1.208E+01	1.208E+01	1.208E+01	1.201E+01	1.201E+01	1.206E+01	1.199E+01	1.211E+01	1.206E+01	1.208E+01	1.206E+01	1.210E+01	1.219E+01
^{147}Sm	1.208E+01	1.209E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.200E+01	1.211E+01	1.207E+01	1.209E+01	1.207E+01	1.211E+01	1.221E+01
^{149}Sm	1.205E+01	1.205E+01	1.206E+01	1.201E+01	1.199E+01	1.203E+01	1.196E+01	1.208E+01	1.204E+01	1.205E+01	1.204E+01	1.207E+01	1.217E+01
^{150}Sm	1.208E+01	1.209E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.200E+01	1.212E+01	1.207E+01	1.208E+01	1.207E+01	1.211E+01	1.221E+01
^{151}Sm	1.207E+01	1.207E+01	1.208E+01	1.203E+01	1.201E+01	1.205E+01	1.198E+01	1.210E+01	1.205E+01	1.207E+01	1.205E+01	1.209E+01	1.218E+01
^{152}Sm	1.207E+01	1.207E+01	1.208E+01	1.203E+01	1.201E+01	1.206E+01	1.198E+01	1.210E+01	1.205E+01	1.207E+01	1.206E+01	1.209E+01	1.220E+01
^{153}Eu	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.206E+01	1.208E+01	1.207E+01	1.210E+01	1.220E+01
^{155}Gd	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.206E+01	1.208E+01	1.207E+01	1.210E+01	1.220E+01
^{235}U	1.488E+01	1.485E+01	1.486E+01	1.480E+01	1.479E+01	1.483E+01	1.477E+01	1.487E+01	1.486E+01	1.488E+01	1.484E+01	1.489E+01	1.499E+01
^{236}U	1.205E+01	1.205E+01	1.206E+01	1.199E+01	1.199E+01	1.204E+01	1.197E+01	1.208E+01	1.204E+01	1.206E+01	1.204E+01	1.207E+01	1.217E+01
^{237}Np	1.207E+01	1.207E+01	1.208E+01	1.203E+01	1.200E+01	1.205E+01	1.198E+01	1.210E+01	1.205E+01	1.207E+01	1.206E+01	1.209E+01	1.219E+01
^{238}Pu	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.207E+01	1.208E+01	1.207E+01	1.210E+01	1.221E+01
^{239}Pu	1.148E+01	1.149E+01	1.149E+01	1.145E+01	1.142E+01	1.148E+01	1.137E+01	1.151E+01	1.145E+01	1.146E+01	1.147E+01	1.149E+01	1.160E+01
^{240}Pu	1.185E+01	1.185E+01	1.186E+01	1.181E+01	1.179E+01	1.184E+01	1.176E+01	1.188E+01	1.184E+01	1.185E+01	1.184E+01	1.187E+01	1.196E+01
^{241}Pu	1.189E+01	1.189E+01	1.190E+01	1.185E+01	1.183E+01	1.187E+01	1.180E+01	1.192E+01	1.188E+01	1.189E+01	1.187E+01	1.191E+01	1.201E+01
^{242}Pu	1.207E+01	1.207E+01	1.208E+01	1.203E+01	1.201E+01	1.205E+01	1.198E+01	1.210E+01	1.206E+01	1.207E+01	1.206E+01	1.209E+01	1.219E+01
^{241}Am	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.206E+01	1.208E+01	1.207E+01	1.210E+01	1.220E+01
^{243}Am	1.208E+01	1.208E+01	1.209E+01	1.204E+01	1.202E+01	1.207E+01	1.199E+01	1.211E+01	1.207E+01	1.209E+01	1.207E+01	1.210E+01	1.220E+01
^{10}B	1.206E+01	1.206E+01	1.207E+01	1.202E+01	1.199E+01	1.204E+01	1.197E+01	1.209E+01	1.204E+01	1.206E+01	1.204E+01	1.208E+01	1.219E+01
ALL	1.172E+01	1.173E+01	1.174E+01	N.R.	N.R.	N.R.	1.161E+01	1.175E+01	1.169E+01	1.171E+01	1.172E+01	1.174E+01	1.184E+01

3.1.3 Reaction rates

Absorption, production and total scattering rates were requested for ^{235}U, ^{238}U and ^{16}O of the fuel, just like on for the BUC nuclides added to the central fuel.

Comparisons are illustrated in Figure 5 for ^{235}U, ^{238}U and ^{16}O, for only the first case (case 0 without BUC nuclide) as the same conclusions can be observed for cases 1 to 27. The full content of calculation results are reported in Table 6 to Table 13.

Absorption and production rates on ^{235}U are predicted within less than 1% compared with TRIPOLI4 calculations, for all the participants.

Scattering rates are much more discrepant with an underestimation of 5 to 11% of the calculations using DRAGON3, GMVP-II and CASMO5. This difference was investigated to be a consequence of the lack of anisotropy data in the input cross-sections, all these calculations being based on P0 scattering law. VUJE, EMS and ORNL calculations use a P5 law to describe the scattering, which lead to a good agreement with the exact treatment provided by TRIPOLI4 and MCNP5. It seems also that a P3 description of the anisotropy is enough to accurately evaluate the total scattering rate, as the DORTOREST calculations are in as good agreement with TRIPOLI4 as SCALE6 calculations using P5 cross-sections. It should be noted that the CEA calculations based on APOLLO2 are in agreement within less than 0.5% with TRIPOLI4, using a “P0c” law (corrected P0) which includes a transport correction for the anisotropy.

Absorption rates on ^{238}U are more discrepant than on ^{235}U. Due to the large number of neutron resonances, calculations using too few energy groups involve significant errors on the calculation of the absorption rate. As a consequence, GMVP-II and DRAGON3 calculations based on 69-energy group cross-sections overestimate the absorption rate by more than 2%. APOLLO2 and CASMO5 calculations both have a good agreement with TRIPOLI4 and MCNP5 calculations based on continuous-energy cross-sections, which demonstrate the accuracy of self-shielding calculations. Moreover, it should be noted that the 586 energy groups provided by the CASMO5 calculation code does not improve the calculation accuracy of the ^{238}U absorption rate compared with 281 energy groups in APOLLO2, as the latter was optimised to treat the main resonances of heavy nuclides and fission products below 22 eV. Moreover, a collapsing from 586 groups to 19 energy groups is performed in CASMO5, before using the MOC solver, a step which is not performed in APOLLO2 where the flux is solved on the same energy mesh as for cross-section self-shielding calculations.

Production rates on ^{238}U are in the same agreement with TRIPOLI4 than in the case of ^{235}U. It should be noted that there is a slight underestimation by 3% with DORTOREST by GRS. To understand this difference, it should be mentioned that the fission of ^{235}U is mostly thermal while the fission of ^{238}U only occurs above 1 MeV. It is likely that the Sn method which was used to solve the Boltzmann equation has introduced some bias compared with Monte Carlo methods used in SCALE6/KENO-VI, as the input library is the same between the two kinds of calculations.

Scattering rates on ^{238}U show similar trends as for ^{235}U. DRAGON3, GMVP-II and CASMO5 calculations underestimate the scattering rate due to the lack of anisotropy data. Other results are in good agreement with TRIPOLI4.

Absorption rates on ^{16}O show good agreement for all the participants except for DORTOREST calculations by GRS, which underestimate this reaction by around 3%. One should remark that this trend is similar to the one of the production rate on ^{238}U. As the absorption on ^{16}O mainly occurs in the MeV region, it is clear that this underprediction is due to a calculation bias on the level of fast neutrons, using DORTOREST.

Scattering rates on ^{16}O are correctly predicted by all participants within 2%, except for PSI calculations due to the missing of anisotropy data. Surprisingly, DRAGON3 and GMVP-II calculations which use also P0 scattering cross-sections are much more in agreement with TRIPOLI4. This could result from compensation of errors.

Comparisons of absorption, production and scattering rates on BUC nuclides are illustrated in Figure 6 to Figure 10. The full content of calculation results are reported in Table 14 to Table 16.

Absorption rate calculations show a reasonably good agreement between all participants, most of them within a few percents. All the MCNP5 calculations, by CEA and GRS, are in good agreement with TRIPOLI4, with the exception of ^{240}Pu and ^{242}Pu where the difference is a bit higher (> 1%), possibly due to a higher statistical uncertainty as these isotopes are purely resonant neutron absorbers. Good results are also obtained by ORNL and EMS using SCALE6: differences compared with TRIPOLI4 are lower than 1% for all nuclides, apart from ^{243}Am. Small differences are observed between the 1D Sn used in XSDRNMP and the KENO-VI 3D Monte Carlo solution, which means that most of the differences are linked to the input cross-sections and especially to the way the self-shielding is taken into account. APOLLO2 calculations show also a good agreement with TRIPOLI4 for most of the cases with differences lower than 1%. Higher values, between 3 and 4%, are observed for resonant absorbers like ^{95}Mo, ^{101}Ru and ^{145}Nd, due to the lack of resonance self-shielding below 22 eV. The 281-group SHEM energy mesh used by APOLLO2 was optimised to avoid self-shielding for the main actinides and fission products, improving significantly the calculation time. The errors observed for these isotopes are considered acceptable as ^{95}Mo, ^{101}Ru and ^{145}Nd have a relatively small contribution in the total reactivity loss of a burned fuel. PSI calculations based on CASMO5 show better results compared with APOLLO2 for ^{101}Ru and ^{145}Nd. Nevertheless, a 2% overprediction of the ^{240}Pu absorption rate was observed. Additional calculations performed by PSI have shown that the error was coming from the cross-section collapsing from 586 to 19 groups (standard recommendation for UOx assemblies). Another possibility in CASMO5 is to use a 35 group energy mesh for the flux calculation (standard recommendation for MOx assemblies). The calculation using 35 groups has shown a great improvement on ^{240}Pu with a reduction of 2% of the absorption rate, fitting perfectly the TRIPOLI4 value. It should be noted that the underprediction of ^{99}Tc and ^{103}Rh absorption rates by CASMO5 is due to the use of different nuclear data. In the standard cross-section library provided in the CASMO5 code package, ^{99}Tc and ^{103}Rh evaluations are taken from JEFF-3.1.1 [12]. In this library, these two nuclides have lower thermal values and resonance integrals than in ENDF/B-VII.0, as shown in Table 5. The 8% underprediction of the ^{95}Mo absorption rate, however, cannot be explained by a difference in the input nuclear data library. Concerning the large overprediction of ^{150}Sm in calculations based on 69 energy groups, it may be due to the overlapping of ^{238}U and ^{150}Sm resonances at 21 eV which requires an accurate calculation of the mutual shielding effect between the two isotopes.

Table 5. Comparison of ENDF/B-VII and JEFF-3.1.1 evaluations of ^{99}Tc and ^{103}Rh capture cross-sections

Isotope	JEFF-3.1.1		ENDF/B-VII.0	
	Thermal value (barn)	Resonance integral (barn)	Thermal value (barn)	Resonance integral (barn)
^{99}Tc	21.004	312.5	22.81	361.9
^{103}Rh	146.6	1053	149.4	1124

For production rates on the BUC nuclides, most of the calculations agree within 2% with TRIPOLI4. SCALE6 calculations using 238 energy groups, just like CASMO5 and APOLLO2 have the best results with differences lower than 1%. MCNP5 calculations by CEA and GRS are also fully consistent with TRIPOLI4. GRS calculations using DORTOREST disagree for fertile nuclides with fission occurring in the fast energy range, i.e. ^{236}U, ^{237}Np, ^{240}Pu, ^{242}Pu, ^{241}Am and ^{243}Am, are underestimated by 1 to 2%, as it was observed for the fission of ^{238}U and absorption of ^{16}O, due to an underprediction of the fast neutron flux. The same trend on fertile nuclides is observed for APOLLO2 calculations, but with much lower value, ranging from 0.6% to 0.8%.

Scattering rates on the BUC nuclides show the same trends that for ^{235}U, ^{238}U and ^{16}O, with an agreement within 1%, compared with TRIPOLI4 for SCALE6, APOLLO2, DORTOREST and MCNP5 calculations. CASMO5, DRAGON3 and GMVP-II are underestimated by 5 to 25%, due to P0 scattering cross-sections.

Figure 5. Relative difference in the reaction rates of ^{235}U, ^{238}U and ^{16}O of sub-phase 1 (case 0)

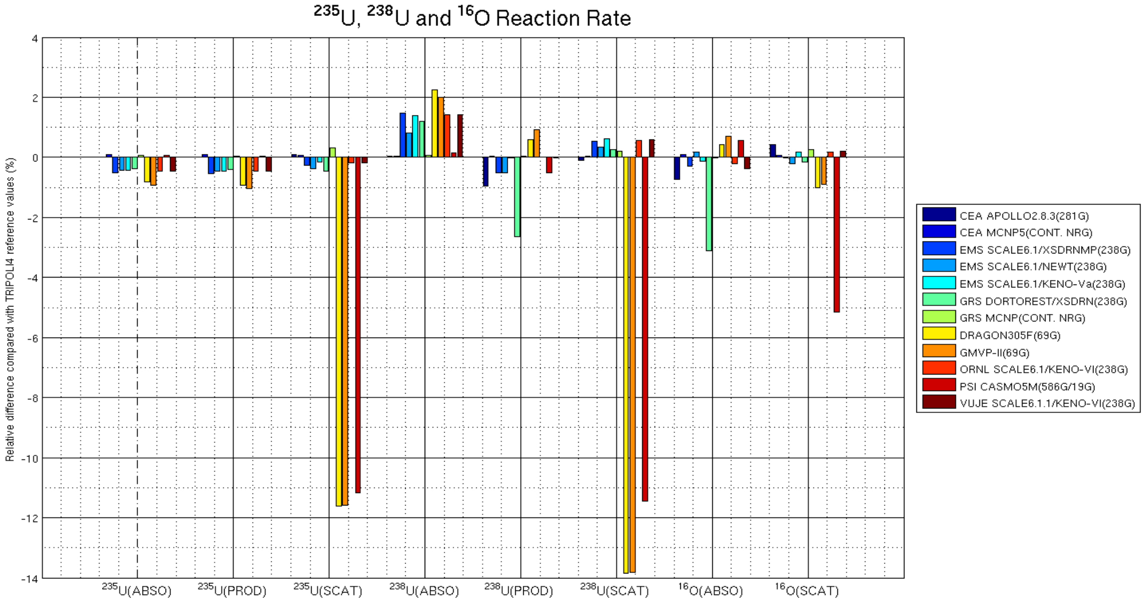


Table 6. Absorption rate (s^{-1}) on ^{235}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	6.516E-01	6.515E-01	6.518E-01	6.480E-01	6.486E-01	6.483E-01	6.490E-01	6.518E-01	6.461E-01	6.453E-01	6.486E-01	6.517E-01	6.488E-01
^{95}Mo	6.495E-01	6.494E-01	6.500E-01	6.460E-01	6.466E-01	6.466E-01	6.470E-01	6.499E-01	6.442E-01	6.434E-01	6.465E-01	6.498E-01	6.465E-01
^{99}Tc	6.468E-01	6.466E-01	6.471E-01	6.435E-01	6.438E-01	6.436E-01	6.443E-01	6.469E-01	6.414E-01	6.406E-01	6.438E-01	6.472E-01	6.442E-01
^{101}Ru	6.499E-01	6.498E-01	6.503E-01	6.464E-01	6.469E-01	6.470E-01	6.474E-01	6.500E-01	6.445E-01	6.437E-01	6.470E-01	6.500E-01	6.469E-01
^{103}Rh	6.393E-01	6.392E-01	6.396E-01	6.358E-01	6.364E-01	6.359E-01	6.368E-01	6.392E-01	6.339E-01	6.331E-01	6.363E-01	6.399E-01	6.359E-01
^{109}Ag	6.500E-01	6.498E-01	6.503E-01	6.463E-01	6.470E-01	6.469E-01	6.474E-01	6.501E-01	6.446E-01	6.438E-01	6.470E-01	6.501E-01	6.471E-01
^{133}Cs	6.456E-01	6.455E-01	6.459E-01	6.420E-01	6.426E-01	6.427E-01	6.431E-01	6.458E-01	6.402E-01	6.394E-01	6.427E-01	6.457E-01	6.423E-01
^{143}Nd	6.384E-01	6.384E-01	6.388E-01	6.355E-01	6.355E-01	6.357E-01	6.360E-01	6.386E-01	6.331E-01	6.323E-01	6.356E-01	6.386E-01	6.353E-01
^{145}Nd	6.482E-01	6.482E-01	6.486E-01	6.434E-01	6.453E-01	6.455E-01	6.458E-01	6.483E-01	6.429E-01	6.422E-01	6.453E-01	6.484E-01	6.456E-01
^{147}Sm	6.504E-01	6.502E-01	6.507E-01	6.466E-01	6.474E-01	6.471E-01	6.479E-01	6.505E-01	6.450E-01	6.442E-01	6.474E-01	6.505E-01	6.472E-01
^{149}Sm	6.375E-01	6.374E-01	6.378E-01	6.341E-01	6.345E-01	6.346E-01	6.350E-01	6.374E-01	6.321E-01	6.312E-01	6.345E-01	6.375E-01	6.346E-01
^{150}Sm	6.498E-01	6.497E-01	6.501E-01	6.460E-01	6.468E-01	6.470E-01	6.473E-01	6.499E-01	6.437E-01	6.430E-01	6.468E-01	6.497E-01	6.467E-01
^{151}Sm	6.432E-01	6.430E-01	6.434E-01	6.398E-01	6.402E-01	6.402E-01	6.407E-01	6.435E-01	6.378E-01	6.370E-01	6.402E-01	6.432E-01	6.404E-01
^{152}Sm	6.473E-01	6.473E-01	6.478E-01	6.438E-01	6.443E-01	6.445E-01	6.448E-01	6.476E-01	6.417E-01	6.409E-01	6.444E-01	6.474E-01	6.441E-01
^{153}Eu	6.485E-01	6.484E-01	6.489E-01	6.451E-01	6.455E-01	6.454E-01	6.460E-01	6.487E-01	6.431E-01	6.423E-01	6.456E-01	6.485E-01	6.451E-01
^{155}Gd	6.472E-01	6.471E-01	6.476E-01	6.437E-01	6.442E-01	6.442E-01	6.447E-01	6.472E-01	6.418E-01	6.410E-01	6.443E-01	6.473E-01	6.441E-01
^{235}U	4.292E-01	4.289E-01	4.296E-01	4.268E-01	4.272E-01	4.271E-01	4.275E-01	4.281E-01	4.255E-01	4.248E-01	4.272E-01	4.289E-01	4.274E-01
^{236}U	6.455E-01	6.453E-01	6.457E-01	6.407E-01	6.424E-01	6.424E-01	6.429E-01	6.456E-01	6.405E-01	6.398E-01	6.425E-01	6.456E-01	6.422E-01
^{237}Np	6.459E-01	6.457E-01	6.462E-01	6.426E-01	6.429E-01	6.426E-01	6.434E-01	6.460E-01	6.405E-01	6.397E-01	6.429E-01	6.459E-01	6.425E-01
^{238}Pu	6.484E-01	6.483E-01	6.488E-01	6.449E-01	6.454E-01	6.454E-01	6.459E-01	6.486E-01	6.430E-01	6.423E-01	6.455E-01	6.485E-01	6.455E-01
^{239}Pu	4.663E-01	4.669E-01	4.671E-01	4.640E-01	4.648E-01	4.650E-01	4.653E-01	4.660E-01	4.630E-01	4.630E-01	4.648E-01	4.663E-01	4.645E-01
^{240}Pu	5.943E-01	5.942E-01	5.945E-01	5.904E-01	5.918E-01	5.916E-01	5.921E-01	5.938E-01	5.889E-01	5.888E-01	5.916E-01	5.929E-01	5.917E-01
^{241}Pu	5.897E-01	5.898E-01	5.901E-01	5.867E-01	5.871E-01	5.870E-01	5.875E-01	5.896E-01	5.847E-01	5.840E-01	5.872E-01	5.898E-01	5.872E-01
^{242}Pu	6.476E-01	6.475E-01	6.480E-01	6.441E-01	6.446E-01	6.441E-01	6.451E-01	6.477E-01	6.422E-01	6.415E-01	6.447E-01	6.476E-01	6.446E-01
^{241}Am	6.480E-01	6.479E-01	6.483E-01	6.446E-01	6.450E-01	6.450E-01	6.455E-01	6.482E-01	6.426E-01	6.418E-01	6.449E-01	6.481E-01	6.450E-01
^{243}Am	6.498E-01	6.496E-01	6.501E-01	6.461E-01	6.468E-01	6.469E-01	6.473E-01	6.499E-01	6.443E-01	6.435E-01	6.468E-01	6.499E-01	6.469E-01
^{10}B	6.400E-01	6.399E-01	6.404E-01	6.367E-01	6.371E-01	6.369E-01	6.375E-01	6.402E-01	6.347E-01	6.339E-01	6.370E-01	6.401E-01	6.371E-01
ALL	1.496E-01	1.500E-01	1.500E-01	N.R.	N.R.	N.R.	1.495E-01	1.494E-01	1.489E-01	1.490E-01	1.493E-01	1.494E-01	1.494E-01

Table 7. Production rate on ^{235}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	1.318E+00	1.318E+00	1.318E+00	1.310E+00	1.312E+00	1.311E+00	1.312E+00	1.318E+00	1.305E+00	1.304E+00	1.312E+00	1.318E+00	1.312E+00
^{95}Mo	1.313E+00	1.313E+00	1.315E+00	1.306E+00	1.307E+00	1.307E+00	1.308E+00	1.314E+00	1.301E+00	1.300E+00	1.307E+00	1.314E+00	1.307E+00
^{99}Tc	1.308E+00	1.308E+00	1.309E+00	1.301E+00	1.302E+00	1.301E+00	1.303E+00	1.308E+00	1.295E+00	1.294E+00	1.302E+00	1.308E+00	1.303E+00
^{101}Ru	1.314E+00	1.314E+00	1.315E+00	1.307E+00	1.308E+00	1.308E+00	1.309E+00	1.315E+00	1.302E+00	1.300E+00	1.308E+00	1.314E+00	1.308E+00
^{103}Rh	1.292E+00	1.292E+00	1.293E+00	1.285E+00	1.286E+00	1.285E+00	1.287E+00	1.292E+00	1.280E+00	1.278E+00	1.286E+00	1.293E+00	1.285E+00
^{109}Ag	1.314E+00	1.314E+00	1.315E+00	1.307E+00	1.308E+00	1.308E+00	1.309E+00	1.315E+00	1.302E+00	1.301E+00	1.308E+00	1.314E+00	1.308E+00
^{133}Cs	1.305E+00	1.305E+00	1.306E+00	1.298E+00	1.299E+00	1.299E+00	1.300E+00	1.306E+00	1.293E+00	1.292E+00	1.299E+00	1.305E+00	1.299E+00
^{143}Nd	1.290E+00	1.290E+00	1.291E+00	1.284E+00	1.284E+00	1.285E+00	1.285E+00	1.291E+00	1.278E+00	1.277E+00	1.285E+00	1.290E+00	1.284E+00
^{145}Nd	1.311E+00	1.311E+00	1.312E+00	1.301E+00	1.305E+00	1.305E+00	1.306E+00	1.311E+00	1.299E+00	1.297E+00	1.305E+00	1.311E+00	1.305E+00
^{147}Sm	1.315E+00	1.315E+00	1.316E+00	1.307E+00	1.309E+00	1.309E+00	1.310E+00	1.315E+00	1.303E+00	1.301E+00	1.309E+00	1.315E+00	1.309E+00
^{149}Sm	1.288E+00	1.288E+00	1.289E+00	1.281E+00	1.282E+00	1.283E+00	1.283E+00	1.288E+00	1.276E+00	1.274E+00	1.282E+00	1.288E+00	1.282E+00
^{150}Sm	1.314E+00	1.314E+00	1.315E+00	1.306E+00	1.308E+00	1.308E+00	1.309E+00	1.314E+00	1.300E+00	1.299E+00	1.308E+00	1.314E+00	1.308E+00
^{151}Sm	1.300E+00	1.300E+00	1.301E+00	1.293E+00	1.294E+00	1.294E+00	1.295E+00	1.301E+00	1.288E+00	1.286E+00	1.294E+00	1.300E+00	1.295E+00
^{152}Sm	1.309E+00	1.309E+00	1.310E+00	1.302E+00	1.303E+00	1.303E+00	1.304E+00	1.309E+00	1.296E+00	1.295E+00	1.303E+00	1.309E+00	1.302E+00
^{153}Eu	1.311E+00	1.311E+00	1.312E+00	1.304E+00	1.305E+00	1.305E+00	1.306E+00	1.312E+00	1.299E+00	1.297E+00	1.305E+00	1.311E+00	1.304E+00
^{155}Gd	1.309E+00	1.309E+00	1.309E+00	1.301E+00	1.302E+00	1.302E+00	1.303E+00	1.309E+00	1.296E+00	1.295E+00	1.303E+00	1.308E+00	1.302E+00
^{235}U	8.820E-01	8.814E-01	8.828E-01	8.770E-01	8.779E-01	8.778E-01	8.784E-01	8.797E-01	8.740E-01	8.726E-01	8.779E-01	8.814E-01	8.783E-01
^{236}U	1.305E+00	1.305E+00	1.306E+00	1.295E+00	1.299E+00	1.299E+00	1.300E+00	1.305E+00	1.294E+00	1.292E+00	1.299E+00	1.305E+00	1.298E+00
^{237}Np	1.306E+00	1.306E+00	1.307E+00	1.299E+00	1.300E+00	1.299E+00	1.301E+00	1.306E+00	1.294E+00	1.292E+00	1.300E+00	1.306E+00	1.299E+00
^{238}Pu	1.311E+00	1.311E+00	1.312E+00	1.304E+00	1.305E+00	1.305E+00	1.306E+00	1.311E+00	1.299E+00	1.297E+00	1.305E+00	1.311E+00	1.305E+00
^{239}Pu	9.337E-01	9.348E-01	9.352E-01	9.286E-01	9.305E-01	9.308E-01	9.313E-01	9.329E-01	9.255E-01	9.256E-01	9.305E-01	9.334E-01	9.298E-01
^{240}Pu	1.199E+00	1.199E+00	1.199E+00	1.191E+00	1.194E+00	1.193E+00	1.194E+00	1.198E+00	1.186E+00	1.186E+00	1.193E+00	1.196E+00	1.193E+00
^{241}Pu	1.189E+00	1.190E+00	1.190E+00	1.183E+00	1.184E+00	1.184E+00	1.185E+00	1.189E+00	1.178E+00	1.177E+00	1.184E+00	1.189E+00	1.184E+00
^{242}Pu	1.309E+00	1.309E+00	1.310E+00	1.302E+00	1.303E+00	1.302E+00	1.304E+00	1.310E+00	1.297E+00	1.296E+00	1.303E+00	1.309E+00	1.303E+00
^{241}Am	1.310E+00	1.310E+00	1.311E+00	1.303E+00	1.304E+00	1.304E+00	1.305E+00	1.311E+00	1.298E+00	1.296E+00	1.304E+00	1.310E+00	1.304E+00
^{243}Am	1.314E+00	1.314E+00	1.315E+00	1.306E+00	1.308E+00	1.308E+00	1.309E+00	1.314E+00	1.301E+00	1.300E+00	1.308E+00	1.314E+00	1.308E+00
^{10}B	1.294E+00	1.294E+00	1.295E+00	1.287E+00	1.288E+00	1.287E+00	1.288E+00	1.294E+00	1.281E+00	1.280E+00	1.288E+00	1.294E+00	1.288E+00
ALL	3.012E-01	3.020E-01	3.020E-01	N.R.	N.R.	N.R.	3.008E-01	3.006E-01	2.993E-01	2.997E-01	3.004E-01	3.005E-01	3.006E-01

Table 8. Scattering rate on ^{235}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	8.242E-02	8.234E-02	8.240E-02	8.212E-02	8.203E-02	8.220E-02	8.196E-02	8.261E-02	7.279E-02	7.281E-02	8.216E-02	7.315E-02	8.216E-02
^{95}Mo	8.231E-02	8.224E-02	8.230E-02	8.202E-02	8.193E-02	8.211E-02	8.186E-02	8.250E-02	7.270E-02	7.271E-02	8.208E-02	7.306E-02	8.209E-02
^{99}Tc	8.219E-02	8.211E-02	8.216E-02	8.192E-02	8.180E-02	8.196E-02	8.172E-02	8.236E-02	7.256E-02	7.258E-02	8.195E-02	7.293E-02	8.195E-02
^{101}Ru	8.232E-02	8.225E-02	8.230E-02	8.203E-02	8.194E-02	8.211E-02	8.186E-02	8.250E-02	7.270E-02	7.273E-02	8.207E-02	7.305E-02	8.207E-02
^{103}Rh	8.193E-02	8.185E-02	8.190E-02	8.162E-02	8.155E-02	8.171E-02	8.147E-02	8.209E-02	7.230E-02	7.231E-02	8.168E-02	7.268E-02	8.167E-02
^{109}Ag	8.234E-02	8.226E-02	8.232E-02	8.203E-02	8.196E-02	8.213E-02	8.188E-02	8.252E-02	7.272E-02	7.274E-02	8.210E-02	7.307E-02	8.209E-02
^{133}Cs	8.213E-02	8.206E-02	8.212E-02	8.184E-02	8.175E-02	8.193E-02	8.167E-02	8.230E-02	7.251E-02	7.253E-02	8.189E-02	7.287E-02	8.188E-02
^{143}Nd	8.201E-02	8.194E-02	8.200E-02	8.178E-02	8.163E-02	8.181E-02	8.155E-02	8.219E-02	7.239E-02	7.241E-02	8.178E-02	7.274E-02	8.175E-02
^{145}Nd	8.227E-02	8.220E-02	8.225E-02	8.180E-02	8.189E-02	8.207E-02	8.181E-02	8.245E-02	7.265E-02	7.268E-02	8.204E-02	7.301E-02	8.204E-02
^{147}Sm	8.236E-02	8.228E-02	8.234E-02	8.203E-02	8.198E-02	8.215E-02	8.190E-02	8.253E-02	7.273E-02	7.276E-02	8.212E-02	7.309E-02	8.210E-02
^{149}Sm	8.199E-02	8.192E-02	8.197E-02	8.170E-02	8.161E-02	8.176E-02	8.153E-02	8.215E-02	7.236E-02	7.238E-02	8.175E-02	7.272E-02	8.173E-02
^{150}Sm	8.236E-02	8.228E-02	8.234E-02	8.203E-02	8.197E-02	8.216E-02	8.189E-02	8.253E-02	7.269E-02	7.271E-02	8.211E-02	7.308E-02	8.210E-02
^{151}Sm	8.219E-02	8.211E-02	8.216E-02	8.190E-02	8.180E-02	8.196E-02	8.172E-02	8.238E-02	7.256E-02	7.257E-02	8.194E-02	7.291E-02	8.196E-02
^{152}Sm	8.223E-02	8.215E-02	8.221E-02	8.193E-02	8.184E-02	8.200E-02	8.176E-02	8.240E-02	7.259E-02	7.261E-02	8.198E-02	7.296E-02	8.197E-02
^{153}Eu	8.229E-02	8.222E-02	8.227E-02	8.201E-02	8.191E-02	8.208E-02	8.183E-02	8.246E-02	7.266E-02	7.268E-02	8.204E-02	7.302E-02	8.204E-02
^{155}Gd	8.230E-02	8.223E-02	8.228E-02	8.201E-02	8.192E-02	8.209E-02	8.184E-02	8.247E-02	7.267E-02	7.269E-02	8.206E-02	7.303E-02	8.205E-02
^{235}U	2.889E-02	2.879E-02	2.882E-02	2.872E-02	2.872E-02	2.876E-02	2.871E-02	2.884E-02	2.631E-02	2.632E-02	2.876E-02	2.643E-02	2.877E-02
^{236}U	8.208E-02	8.200E-02	8.206E-02	8.163E-02	8.169E-02	8.188E-02	8.162E-02	8.225E-02	7.249E-02	7.251E-02	8.184E-02	7.282E-02	8.182E-02
^{237}Np	8.218E-02	8.210E-02	8.216E-02	8.191E-02	8.180E-02	8.196E-02	8.172E-02	8.236E-02	7.256E-02	7.258E-02	8.195E-02	7.291E-02	8.191E-02
^{238}Pu	8.232E-02	8.225E-02	8.230E-02	8.202E-02	8.194E-02	8.210E-02	8.186E-02	8.250E-02	7.269E-02	7.271E-02	8.207E-02	7.305E-02	8.207E-02
^{239}Pu	7.613E-02	7.612E-02	7.616E-02	7.594E-02	7.582E-02	7.601E-02	7.564E-02	7.629E-02	6.651E-02	6.652E-02	7.596E-02	6.681E-02	7.597E-02
^{240}Pu	8.004E-02	7.998E-02	8.003E-02	7.975E-02	7.969E-02	7.986E-02	7.960E-02	8.019E-02	7.043E-02	7.045E-02	7.983E-02	7.074E-02	7.982E-02
^{241}Pu	8.038E-02	8.032E-02	8.037E-02	8.013E-02	8.002E-02	8.019E-02	7.995E-02	8.056E-02	7.079E-02	7.081E-02	8.017E-02	7.113E-02	8.014E-02
^{242}Pu	8.222E-02	8.214E-02	8.220E-02	8.192E-02	8.183E-02	8.197E-02	8.176E-02	8.239E-02	7.260E-02	7.261E-02	8.197E-02	7.295E-02	8.198E-02
^{241}Am	8.229E-02	8.221E-02	8.227E-02	8.201E-02	8.190E-02	8.208E-02	8.183E-02	8.246E-02	7.266E-02	7.268E-02	8.204E-02	7.302E-02	8.204E-02
^{243}Am	8.234E-02	8.226E-02	8.231E-02	8.202E-02	8.195E-02	8.214E-02	8.187E-02	8.251E-02	7.271E-02	7.274E-02	8.210E-02	7.306E-02	8.206E-02
^{10}B	8.206E-02	8.199E-02	8.205E-02	8.180E-02	8.168E-02	8.186E-02	8.160E-02	8.224E-02	7.244E-02	7.245E-02	8.182E-02	7.279E-02	8.181E-02
ALL	2.049E-02	2.050E-02	2.051E-02	N.R.	N.R.	N.R.	2.037E-02	2.053E-02	1.799E-02	1.800E-02	2.046E-02	1.805E-02	2.047E-02

Table 9. Absorption rate on ^{238}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	2.748E-01	2.746E-01	2.748E-01	2.787E-01	2.769E-01	2.785E-01	2.780E-01	2.749E-01	2.808E-01	2.802E-01	2.785E-01	2.751E-01	2.785E-01
^{95}Mo	2.743E-01	2.742E-01	2.743E-01	2.782E-01	2.764E-01	2.780E-01	2.775E-01	2.744E-01	2.803E-01	2.797E-01	2.780E-01	2.746E-01	2.781E-01
^{99}Tc	2.737E-01	2.736E-01	2.737E-01	2.777E-01	2.758E-01	2.771E-01	2.769E-01	2.738E-01	2.796E-01	2.790E-01	2.774E-01	2.741E-01	2.775E-01
^{101}Ru	2.744E-01	2.742E-01	2.743E-01	2.782E-01	2.764E-01	2.780E-01	2.775E-01	2.744E-01	2.803E-01	2.798E-01	2.780E-01	2.746E-01	2.781E-01
^{103}Rh	2.731E-01	2.729E-01	2.730E-01	2.769E-01	2.752E-01	2.769E-01	2.763E-01	2.731E-01	2.791E-01	2.784E-01	2.768E-01	2.734E-01	2.768E-01
^{109}Ag	2.745E-01	2.744E-01	2.744E-01	2.783E-01	2.766E-01	2.783E-01	2.777E-01	2.745E-01	2.804E-01	2.798E-01	2.782E-01	2.748E-01	2.783E-01
^{133}Cs	2.734E-01	2.732E-01	2.733E-01	2.772E-01	2.754E-01	2.770E-01	2.766E-01	2.733E-01	2.793E-01	2.787E-01	2.771E-01	2.736E-01	2.769E-01
^{143}Nd	2.730E-01	2.728E-01	2.729E-01	2.771E-01	2.750E-01	2.767E-01	2.762E-01	2.730E-01	2.790E-01	2.784E-01	2.767E-01	2.732E-01	2.765E-01
^{145}Nd	2.742E-01	2.741E-01	2.741E-01	2.775E-01	2.763E-01	2.780E-01	2.774E-01	2.742E-01	2.802E-01	2.796E-01	2.779E-01	2.744E-01	2.778E-01
^{147}Sm	2.746E-01	2.744E-01	2.745E-01	2.783E-01	2.766E-01	2.783E-01	2.777E-01	2.746E-01	2.805E-01	2.799E-01	2.783E-01	2.748E-01	2.781E-01
^{149}Sm	2.729E-01	2.728E-01	2.729E-01	2.768E-01	2.750E-01	2.763E-01	2.761E-01	2.729E-01	2.789E-01	2.783E-01	2.767E-01	2.732E-01	2.768E-01
^{150}Sm	2.743E-01	2.742E-01	2.742E-01	2.781E-01	2.764E-01	2.779E-01	2.775E-01	2.743E-01	2.804E-01	2.797E-01	2.780E-01	2.747E-01	2.779E-01
^{151}Sm	2.737E-01	2.735E-01	2.736E-01	2.776E-01	2.758E-01	2.773E-01	2.769E-01	2.738E-01	2.797E-01	2.791E-01	2.774E-01	2.739E-01	2.775E-01
^{152}Sm	2.737E-01	2.736E-01	2.738E-01	2.776E-01	2.758E-01	2.775E-01	2.770E-01	2.738E-01	2.802E-01	2.795E-01	2.774E-01	2.740E-01	2.775E-01
^{153}Eu	2.743E-01	2.741E-01	2.742E-01	2.782E-01	2.763E-01	2.779E-01	2.775E-01	2.743E-01	2.802E-01	2.796E-01	2.779E-01	2.745E-01	2.781E-01
^{155}Gd	2.742E-01	2.741E-01	2.742E-01	2.781E-01	2.763E-01	2.778E-01	2.774E-01	2.743E-01	2.802E-01	2.796E-01	2.779E-01	2.745E-01	2.779E-01
^{235}U	4.100E-01	4.094E-01	4.098E-01	4.132E-01	4.115E-01	4.132E-01	4.128E-01	4.089E-01	4.150E-01	4.143E-01	4.133E-01	4.105E-01	4.133E-01
^{236}U	2.734E-01	2.733E-01	2.734E-01	2.768E-01	2.755E-01	2.772E-01	2.766E-01	2.735E-01	2.792E-01	2.786E-01	2.771E-01	2.737E-01	2.770E-01
^{237}Np	2.738E-01	2.737E-01	2.738E-01	2.778E-01	2.759E-01	2.776E-01	2.770E-01	2.739E-01	2.798E-01	2.792E-01	2.776E-01	2.741E-01	2.775E-01
^{238}Pu	2.744E-01	2.742E-01	2.743E-01	2.782E-01	2.764E-01	2.779E-01	2.776E-01	2.743E-01	2.803E-01	2.797E-01	2.781E-01	2.746E-01	2.781E-01
^{239}Pu	2.487E-01	2.487E-01	2.488E-01	2.527E-01	2.509E-01	2.525E-01	2.517E-01	2.486E-01	2.546E-01	2.541E-01	2.526E-01	2.488E-01	2.526E-01
^{240}Pu	2.665E-01	2.664E-01	2.665E-01	2.704E-01	2.687E-01	2.702E-01	2.698E-01	2.666E-01	2.726E-01	2.720E-01	2.703E-01	2.667E-01	2.702E-01
^{241}Pu	2.659E-01	2.658E-01	2.659E-01	2.698E-01	2.680E-01	2.697E-01	2.691E-01	2.660E-01	2.719E-01	2.713E-01	2.697E-01	2.661E-01	2.698E-01
^{242}Pu	2.742E-01	2.740E-01	2.740E-01	2.781E-01	2.763E-01	2.780E-01	2.774E-01	2.742E-01	2.802E-01	2.795E-01	2.779E-01	2.744E-01	2.780E-01
^{241}Am	2.743E-01	2.742E-01	2.742E-01	2.782E-01	2.764E-01	2.779E-01	2.775E-01	2.743E-01	2.803E-01	2.797E-01	2.780E-01	2.745E-01	2.779E-01
^{243}Am	2.745E-01	2.744E-01	2.744E-01	2.783E-01	2.766E-01	2.781E-01	2.777E-01	2.746E-01	2.805E-01	2.799E-01	2.783E-01	2.748E-01	2.782E-01
^{10}B	2.732E-01	2.731E-01	2.732E-01	2.772E-01	2.753E-01	2.770E-01	2.764E-01	2.732E-01	2.792E-01	2.786E-01	2.769E-01	2.735E-01	2.769E-01
ALL	2.637E-01	2.636E-01	2.636E-01	N.R.	N.R.	N.R.	2.665E-01	2.635E-01	2.696E-01	2.691E-01	2.675E-01	2.639E-01	2.675E-01

Table 10. Production rate on ^{238}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	7.303E-02	7.374E-02	7.376E-02	7.336E-02	7.337E-02	7.372E-02	7.178E-02	7.381E-02	7.417E-02	7.442E-02	7.369E-02	7.335E-02	7.366E-02
^{95}Mo	7.300E-02	7.371E-02	7.374E-02	7.334E-02	7.334E-02	7.370E-02	7.176E-02	7.374E-02	7.414E-02	7.439E-02	7.372E-02	7.333E-02	7.371E-02
^{99}Tc	7.300E-02	7.371E-02	7.372E-02	7.336E-02	7.334E-02	7.374E-02	7.175E-02	7.374E-02	7.414E-02	7.440E-02	7.370E-02	7.333E-02	7.369E-02
^{101}Ru	7.300E-02	7.371E-02	7.371E-02	7.334E-02	7.334E-02	7.378E-02	7.176E-02	7.373E-02	7.414E-02	7.442E-02	7.368E-02	7.333E-02	7.373E-02
^{103}Rh	7.301E-02	7.372E-02	7.373E-02	7.334E-02	7.335E-02	7.371E-02	7.177E-02	7.370E-02	7.415E-02	7.440E-02	7.373E-02	7.334E-02	7.364E-02
^{109}Ag	7.303E-02	7.373E-02	7.373E-02	7.334E-02	7.337E-02	7.366E-02	7.178E-02	7.375E-02	7.416E-02	7.443E-02	7.369E-02	7.335E-02	7.374E-02
^{133}Cs	7.300E-02	7.371E-02	7.371E-02	7.333E-02	7.334E-02	7.370E-02	7.175E-02	7.371E-02	7.414E-02	7.442E-02	7.367E-02	7.333E-02	7.371E-02
^{143}Nd	7.301E-02	7.371E-02	7.376E-02	7.340E-02	7.335E-02	7.375E-02	7.176E-02	7.375E-02	7.415E-02	7.442E-02	7.371E-02	7.333E-02	7.369E-02
^{145}Nd	7.301E-02	7.372E-02	7.373E-02	7.319E-02	7.335E-02	7.379E-02	7.176E-02	7.375E-02	7.415E-02	7.444E-02	7.373E-02	7.333E-02	7.367E-02
^{147}Sm	7.303E-02	7.373E-02	7.374E-02	7.333E-02	7.336E-02	7.372E-02	7.178E-02	7.375E-02	7.416E-02	7.444E-02	7.374E-02	7.335E-02	7.372E-02
^{149}Sm	7.303E-02	7.374E-02	7.374E-02	7.337E-02	7.337E-02	7.366E-02	7.178E-02	7.374E-02	7.416E-02	7.443E-02	7.370E-02	7.335E-02	7.369E-02
^{150}Sm	7.302E-02	7.373E-02	7.374E-02	7.333E-02	7.336E-02	7.375E-02	7.177E-02	7.378E-02	7.416E-02	7.441E-02	7.367E-02	7.334E-02	7.371E-02
^{151}Sm	7.303E-02	7.373E-02	7.374E-02	7.337E-02	7.337E-02	7.368E-02	7.178E-02	7.379E-02	7.416E-02	7.443E-02	7.376E-02	7.335E-02	7.364E-02
^{152}Sm	7.302E-02	7.374E-02	7.374E-02	7.336E-02	7.336E-02	7.377E-02	7.178E-02	7.373E-02	7.416E-02	7.444E-02	7.369E-02	7.335E-02	7.376E-02
^{153}Eu	7.303E-02	7.374E-02	7.375E-02	7.337E-02	7.336E-02	7.366E-02	7.178E-02	7.373E-02	7.416E-02	7.442E-02	7.372E-02	7.335E-02	7.373E-02
^{155}Gd	7.303E-02	7.374E-02	7.374E-02	7.337E-02	7.337E-02	7.374E-02	7.178E-02	7.376E-02	7.417E-02	7.443E-02	7.372E-02	7.335E-02	7.377E-02
^{235}U	7.341E-02	7.413E-02	7.414E-02	7.372E-02	7.376E-02	7.406E-02	7.221E-02	7.407E-02	7.462E-02	7.491E-02	7.412E-02	7.349E-02	7.419E-02
^{236}U	7.295E-02	7.366E-02	7.367E-02	7.315E-02	7.329E-02	7.372E-02	7.170E-02	7.366E-02	7.408E-02	7.434E-02	7.366E-02	7.327E-02	7.367E-02
^{237}Np	7.302E-02	7.372E-02	7.373E-02	7.337E-02	7.335E-02	7.366E-02	7.177E-02	7.374E-02	7.415E-02	7.443E-02	7.373E-02	7.334E-02	7.361E-02
^{238}Pu	7.302E-02	7.373E-02	7.375E-02	7.335E-02	7.336E-02	7.374E-02	7.178E-02	7.375E-02	7.416E-02	7.440E-02	7.368E-02	7.335E-02	7.366E-02
^{239}Pu	7.420E-02	7.492E-02	7.493E-02	7.451E-02	7.450E-02	7.490E-02	7.166E-02	7.492E-02	7.404E-02	7.430E-02	7.487E-02	7.410E-02	7.492E-02
^{240}Pu	7.297E-02	7.368E-02	7.368E-02	7.332E-02	7.332E-02	7.367E-02	7.174E-02	7.370E-02	7.412E-02	7.437E-02	7.369E-02	7.331E-02	7.368E-02
^{241}Pu	7.305E-02	7.376E-02	7.376E-02	7.340E-02	7.339E-02	7.378E-02	7.175E-02	7.379E-02	7.413E-02	7.440E-02	7.372E-02	7.337E-02	7.370E-02
^{242}Pu	7.302E-02	7.373E-02	7.374E-02	7.335E-02	7.336E-02	7.370E-02	7.177E-02	7.379E-02	7.415E-02	7.439E-02	7.367E-02	7.334E-02	7.364E-02
^{241}Am	7.303E-02	7.374E-02	7.375E-02	7.338E-02	7.337E-02	7.370E-02	7.178E-02	7.373E-02	7.416E-02	7.445E-02	7.373E-02	7.335E-02	7.369E-02
^{243}Am	7.303E-02	7.374E-02	7.373E-02	7.335E-02	7.336E-02	7.375E-02	7.178E-02	7.377E-02	7.416E-02	7.445E-02	7.372E-02	7.335E-02	7.372E-02
^{10}B	7.303E-02	7.373E-02	7.374E-02	7.339E-02	7.337E-02	7.372E-02	7.178E-02	7.376E-02	7.416E-02	7.443E-02	7.373E-02	7.335E-02	7.376E-02
ALL	7.505E-02	7.581E-02	7.581E-02	N.R.	N.R.	N.R.	7.172E-02	7.583E-02	7.410E-02	7.437E-02	7.592E-02	7.490E-02	7.589E-02

Table 11. Scattering rate on ^{238}U in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	2.633E+00	2.636E+00	2.637E+00	2.649E+00	2.645E+00	2.652E+00	2.643E+00	2.642E+00	2.271E+00	2.272E+00	2.650E+00	2.334E+00	2.650E+00
^{95}Mo	2.631E+00	2.634E+00	2.635E+00	2.647E+00	2.642E+00	2.650E+00	2.640E+00	2.639E+00	2.269E+00	2.270E+00	2.649E+00	2.332E+00	2.649E+00
^{99}Tc	2.628E+00	2.631E+00	2.632E+00	2.646E+00	2.640E+00	2.647E+00	2.638E+00	2.636E+00	2.266E+00	2.267E+00	2.646E+00	2.329E+00	2.646E+00
^{101}Ru	2.631E+00	2.634E+00	2.635E+00	2.647E+00	2.642E+00	2.650E+00	2.640E+00	2.639E+00	2.269E+00	2.271E+00	2.648E+00	2.332E+00	2.648E+00
^{103}Rh	2.623E+00	2.626E+00	2.627E+00	2.639E+00	2.635E+00	2.642E+00	2.632E+00	2.631E+00	2.261E+00	2.262E+00	2.641E+00	2.325E+00	2.641E+00
^{109}Ag	2.632E+00	2.634E+00	2.635E+00	2.647E+00	2.643E+00	2.651E+00	2.641E+00	2.639E+00	2.270E+00	2.271E+00	2.649E+00	2.333E+00	2.649E+00
^{133}Cs	2.627E+00	2.630E+00	2.631E+00	2.643E+00	2.639E+00	2.646E+00	2.636E+00	2.634E+00	2.265E+00	2.266E+00	2.644E+00	2.328E+00	2.644E+00
^{143}Nd	2.625E+00	2.628E+00	2.629E+00	2.643E+00	2.636E+00	2.644E+00	2.634E+00	2.633E+00	2.263E+00	2.264E+00	2.643E+00	2.326E+00	2.642E+00
^{145}Nd	2.630E+00	2.633E+00	2.634E+00	2.641E+00	2.642E+00	2.649E+00	2.639E+00	2.638E+00	2.268E+00	2.270E+00	2.648E+00	2.331E+00	2.647E+00
^{147}Sm	2.632E+00	2.635E+00	2.636E+00	2.647E+00	2.643E+00	2.651E+00	2.641E+00	2.640E+00	2.270E+00	2.271E+00	2.650E+00	2.333E+00	2.649E+00
^{149}Sm	2.625E+00	2.628E+00	2.628E+00	2.641E+00	2.636E+00	2.643E+00	2.634E+00	2.632E+00	2.263E+00	2.264E+00	2.642E+00	2.326E+00	2.642E+00
^{150}Sm	2.632E+00	2.635E+00	2.636E+00	2.647E+00	2.643E+00	2.651E+00	2.641E+00	2.640E+00	2.269E+00	2.270E+00	2.649E+00	2.333E+00	2.649E+00
^{151}Sm	2.629E+00	2.631E+00	2.632E+00	2.645E+00	2.640E+00	2.647E+00	2.638E+00	2.637E+00	2.267E+00	2.268E+00	2.646E+00	2.329E+00	2.647E+00
^{152}Sm	2.629E+00	2.632E+00	2.633E+00	2.645E+00	2.640E+00	2.647E+00	2.638E+00	2.637E+00	2.267E+00	2.268E+00	2.646E+00	2.330E+00	2.646E+00
^{153}Eu	2.630E+00	2.633E+00	2.634E+00	2.647E+00	2.642E+00	2.649E+00	2.640E+00	2.638E+00	2.268E+00	2.270E+00	2.648E+00	2.331E+00	2.648E+00
^{155}Gd	2.631E+00	2.634E+00	2.635E+00	2.647E+00	2.642E+00	2.650E+00	2.640E+00	2.639E+00	2.269E+00	2.270E+00	2.648E+00	2.332E+00	2.648E+00
^{235}U	3.207E+00	3.203E+00	3.205E+00	3.216E+00	3.213E+00	3.220E+00	3.212E+00	3.207E+00	2.840E+00	2.842E+00	3.219E+00	2.906E+00	3.220E+00
^{236}U	2.625E+00	2.628E+00	2.629E+00	2.637E+00	2.637E+00	2.645E+00	2.635E+00	2.633E+00	2.264E+00	2.265E+00	2.643E+00	2.326E+00	2.643E+00
^{237}Np	2.628E+00	2.631E+00	2.632E+00	2.645E+00	2.640E+00	2.647E+00	2.637E+00	2.636E+00	2.266E+00	2.268E+00	2.646E+00	2.329E+00	2.645E+00
^{238}Pu	2.631E+00	2.634E+00	2.635E+00	2.647E+00	2.643E+00	2.649E+00	2.640E+00	2.639E+00	2.269E+00	2.270E+00	2.648E+00	2.332E+00	2.649E+00
^{239}Pu	2.505E+00	2.509E+00	2.510E+00	2.524E+00	2.518E+00	2.526E+00	2.512E+00	2.513E+00	2.142E+00	2.143E+00	2.524E+00	2.204E+00	2.524E+00
^{240}Pu	2.583E+00	2.587E+00	2.587E+00	2.600E+00	2.596E+00	2.603E+00	2.593E+00	2.591E+00	2.222E+00	2.223E+00	2.602E+00	2.284E+00	2.602E+00
^{241}Pu	2.591E+00	2.594E+00	2.595E+00	2.609E+00	2.603E+00	2.610E+00	2.601E+00	2.599E+00	2.230E+00	2.232E+00	2.609E+00	2.292E+00	2.608E+00
^{242}Pu	2.629E+00	2.632E+00	2.633E+00	2.645E+00	2.640E+00	2.647E+00	2.638E+00	2.637E+00	2.267E+00	2.268E+00	2.646E+00	2.330E+00	2.646E+00
^{241}Am	2.631E+00	2.633E+00	2.634E+00	2.647E+00	2.642E+00	2.649E+00	2.640E+00	2.638E+00	2.269E+00	2.270E+00	2.648E+00	2.332E+00	2.648E+00
^{243}Am	2.631E+00	2.634E+00	2.635E+00	2.647E+00	2.643E+00	2.651E+00	2.641E+00	2.640E+00	2.269E+00	2.271E+00	2.649E+00	2.332E+00	2.648E+00
^{10}B	2.626E+00	2.629E+00	2.630E+00	2.643E+00	2.638E+00	2.645E+00	2.635E+00	2.634E+00	2.264E+00	2.265E+00	2.643E+00	2.327E+00	2.643E+00
ALL	2.557E+00	2.561E+00	2.561E+00	N.R.	N.R.	N.R.	2.563E+00	2.563E+00	2.194E+00	2.195E+00	2.576E+00	2.255E+00	2.577E+00

Table 12. Absorption rate on ^{16}O in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	1.416E-03	1.427E-03	1.427E-03	1.422E-03	1.430E-03	1.418E-03	1.382E-03	1.431E-03	1.433E-03	1.437E-03	1.421E-03	1.435E-03	1.416E-03
^{95}Mo	1.416E-03	1.426E-03	1.427E-03	1.422E-03	1.429E-03	1.424E-03	1.382E-03	1.426E-03	1.432E-03	1.436E-03	1.423E-03	1.434E-03	1.421E-03
^{99}Tc	1.416E-03	1.426E-03	1.426E-03	1.423E-03	1.430E-03	1.424E-03	1.382E-03	1.426E-03	1.432E-03	1.437E-03	1.421E-03	1.434E-03	1.422E-03
^{101}Ru	1.416E-03	1.426E-03	1.426E-03	1.423E-03	1.429E-03	1.423E-03	1.382E-03	1.426E-03	1.432E-03	1.437E-03	1.420E-03	1.434E-03	1.421E-03
^{103}Rh	1.416E-03	1.426E-03	1.426E-03	1.422E-03	1.429E-03	1.423E-03	1.382E-03	1.426E-03	1.432E-03	1.437E-03	1.421E-03	1.434E-03	1.421E-03
^{109}Ag	1.416E-03	1.426E-03	1.427E-03	1.422E-03	1.429E-03	1.420E-03	1.382E-03	1.427E-03	1.433E-03	1.437E-03	1.421E-03	1.435E-03	1.424E-03
^{133}Cs	1.416E-03	1.426E-03	1.426E-03	1.422E-03	1.429E-03	1.423E-03	1.382E-03	1.425E-03	1.432E-03	1.437E-03	1.421E-03	1.434E-03	1.421E-03
^{143}Nd	1.415E-03	1.426E-03	1.428E-03	1.423E-03	1.429E-03	1.422E-03	1.382E-03	1.428E-03	1.432E-03	1.438E-03	1.421E-03	1.434E-03	1.424E-03
^{145}Nd	1.416E-03	1.426E-03	1.427E-03	1.420E-03	1.430E-03	1.424E-03	1.382E-03	1.428E-03	1.432E-03	1.438E-03	1.422E-03	1.435E-03	1.421E-03
^{147}Sm	1.416E-03	1.427E-03	1.427E-03	1.422E-03	1.431E-03	1.418E-03	1.382E-03	1.427E-03	1.433E-03	1.438E-03	1.423E-03	1.435E-03	1.422E-03
^{149}Sm	1.416E-03	1.426E-03	1.427E-03	1.422E-03	1.430E-03	1.421E-03	1.382E-03	1.426E-03	1.432E-03	1.437E-03	1.422E-03	1.435E-03	1.420E-03
^{150}Sm	1.416E-03	1.427E-03	1.427E-03	1.422E-03	1.429E-03	1.423E-03	1.382E-03	1.428E-03	1.432E-03	1.437E-03	1.420E-03	1.435E-03	1.421E-03
^{151}Sm	1.416E-03	1.426E-03	1.427E-03	1.423E-03	1.429E-03	1.421E-03	1.382E-03	1.430E-03	1.433E-03	1.437E-03	1.423E-03	1.435E-03	1.420E-03
^{152}Sm	1.416E-03	1.426E-03	1.427E-03	1.422E-03	1.430E-03	1.423E-03	1.382E-03	1.426E-03	1.433E-03	1.437E-03	1.422E-03	1.435E-03	1.424E-03
^{153}Eu	1.416E-03	1.427E-03	1.428E-03	1.423E-03	1.430E-03	1.420E-03	1.382E-03	1.427E-03	1.433E-03	1.436E-03	1.421E-03	1.435E-03	1.418E-03
^{155}Gd	1.416E-03	1.427E-03	1.427E-03	1.422E-03	1.429E-03	1.421E-03	1.382E-03	1.427E-03	1.433E-03	1.437E-03	1.423E-03	1.435E-03	1.424E-03
^{235}U	1.441E-03	1.452E-03	1.453E-03	1.446E-03	1.455E-03	1.447E-03	1.409E-03	1.450E-03	1.460E-03	1.466E-03	1.448E-03	1.461E-03	1.449E-03
^{236}U	1.415E-03	1.425E-03	1.425E-03	1.418E-03	1.428E-03	1.424E-03	1.381E-03	1.424E-03	1.431E-03	1.435E-03	1.420E-03	1.433E-03	1.423E-03
^{237}Np	1.416E-03	1.426E-03	1.427E-03	1.423E-03	1.430E-03	1.418E-03	1.382E-03	1.427E-03	1.432E-03	1.438E-03	1.422E-03	1.435E-03	1.420E-03
^{238}Pu	1.416E-03	1.427E-03	1.426E-03	1.422E-03	1.429E-03	1.426E-03	1.382E-03	1.426E-03	1.433E-03	1.437E-03	1.422E-03	1.435E-03	1.419E-03
^{239}Pu	1.473E-03	1.484E-03	1.484E-03	1.477E-03	1.484E-03	1.477E-03	1.377E-03	1.484E-03	1.427E-03	1.431E-03	1.476E-03	1.468E-03	1.478E-03
^{240}Pu	1.414E-03	1.425E-03	1.425E-03	1.421E-03	1.428E-03	1.418E-03	1.380E-03	1.424E-03	1.431E-03	1.434E-03	1.420E-03	1.432E-03	1.420E-03
^{241}Pu	1.432E-03	1.443E-03	1.443E-03	1.439E-03	1.446E-03	1.436E-03	1.381E-03	1.445E-03	1.431E-03	1.435E-03	1.437E-03	1.445E-03	1.437E-03
^{242}Pu	1.416E-03	1.427E-03	1.426E-03	1.422E-03	1.429E-03	1.421E-03	1.382E-03	1.427E-03	1.432E-03	1.437E-03	1.420E-03	1.435E-03	1.418E-03
^{241}Am	1.416E-03	1.427E-03	1.427E-03	1.423E-03	1.430E-03	1.420E-03	1.382E-03	1.424E-03	1.433E-03	1.437E-03	1.422E-03	1.435E-03	1.419E-03
^{243}Am	1.416E-03	1.427E-03	1.427E-03	1.422E-03	1.429E-03	1.424E-03	1.382E-03	1.427E-03	1.433E-03	1.438E-03	1.422E-03	1.435E-03	1.423E-03
^{10}B	1.416E-03	1.427E-03	1.427E-03	1.423E-03	1.430E-03	1.427E-03	1.382E-03	1.427E-03	1.432E-03	1.437E-03	1.422E-03	1.435E-03	1.425E-03
ALL	1.535E-03	1.547E-03	1.546E-03	N.R.	N.R.	N.R.	1.379E-03	1.547E-03	1.430E-03	1.434E-03	1.545E-03	1.526E-03	1.544E-03

Table 13. Scattering rate on ^{16}O in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
0	1.921E+00	1.913E+00	1.914E+00	1.912E+00	1.909E+00	1.916E+00	1.909E+00	1.918E+00	1.894E+00	1.896E+00	1.916E+00	1.814E+00	1.916E+00
^{95}Mo	1.919E+00	1.91E+00	1.912E+00	1.911E+00	1.907E+00	1.914E+00	1.908E+00	1.916E+00	1.892E+00	1.894E+00	1.915E+00	1.812E+00	1.915E+00
^{99}Tc	1.917E+00	1.91E+00	1.910E+00	1.909E+00	1.904E+00	1.911E+00	1.905E+00	1.913E+00	1.889E+00	1.891E+00	1.912E+00	1.810E+00	1.912E+00
^{101}Ru	1.919E+00	1.91E+00	1.912E+00	1.911E+00	1.907E+00	1.914E+00	1.908E+00	1.916E+00	1.892E+00	1.894E+00	1.914E+00	1.812E+00	1.914E+00
^{103}Rh	1.912E+00	1.90E+00	1.905E+00	1.903E+00	1.900E+00	1.908E+00	1.901E+00	1.909E+00	1.885E+00	1.887E+00	1.907E+00	1.806E+00	1.907E+00
^{109}Ag	1.920E+00	1.91E+00	1.913E+00	1.911E+00	1.907E+00	1.915E+00	1.908E+00	1.916E+00	1.892E+00	1.894E+00	1.915E+00	1.813E+00	1.914E+00
^{133}Cs	1.916E+00	1.91E+00	1.909E+00	1.907E+00	1.903E+00	1.911E+00	1.904E+00	1.912E+00	1.888E+00	1.891E+00	1.911E+00	1.809E+00	1.910E+00
^{143}Nd	1.914E+00	1.91E+00	1.907E+00	1.907E+00	1.902E+00	1.909E+00	1.902E+00	1.910E+00	1.887E+00	1.889E+00	1.909E+00	1.807E+00	1.909E+00
^{145}Nd	1.918E+00	1.91E+00	1.911E+00	1.906E+00	1.906E+00	1.913E+00	1.907E+00	1.915E+00	1.891E+00	1.893E+00	1.914E+00	1.811E+00	1.914E+00
^{147}Sm	1.920E+00	1.91E+00	1.913E+00	1.911E+00	1.908E+00	1.915E+00	1.908E+00	1.916E+00	1.893E+00	1.895E+00	1.915E+00	1.813E+00	1.915E+00
^{149}Sm	1.914E+00	1.91E+00	1.907E+00	1.905E+00	1.901E+00	1.908E+00	1.902E+00	1.910E+00	1.886E+00	1.888E+00	1.909E+00	1.807E+00	1.908E+00
^{150}Sm	1.920E+00	1.91E+00	1.913E+00	1.911E+00	1.907E+00	1.915E+00	1.908E+00	1.917E+00	1.892E+00	1.894E+00	1.915E+00	1.813E+00	1.915E+00
^{151}Sm	1.917E+00	1.91E+00	1.910E+00	1.909E+00	1.905E+00	1.912E+00	1.905E+00	1.914E+00	1.890E+00	1.891E+00	1.912E+00	1.810E+00	1.913E+00
^{152}Sm	1.917E+00	1.91E+00	1.910E+00	1.909E+00	1.905E+00	1.912E+00	1.906E+00	1.914E+00	1.890E+00	1.892E+00	1.912E+00	1.810E+00	1.912E+00
^{153}Eu	1.919E+00	1.91E+00	1.912E+00	1.910E+00	1.906E+00	1.914E+00	1.907E+00	1.915E+00	1.891E+00	1.893E+00	1.914E+00	1.812E+00	1.914E+00
^{155}Gd	1.919E+00	1.91E+00	1.912E+00	1.910E+00	1.907E+00	1.914E+00	1.907E+00	1.916E+00	1.892E+00	1.894E+00	1.914E+00	1.812E+00	1.914E+00
^{235}U	2.420E+00	2.41E+00	2.408E+00	2.405E+00	2.403E+00	2.410E+00	2.404E+00	2.410E+00	2.391E+00	2.393E+00	2.410E+00	2.295E+00	2.411E+00
^{236}U	1.914E+00	1.91E+00	1.907E+00	1.902E+00	1.902E+00	1.910E+00	1.903E+00	1.911E+00	1.888E+00	1.890E+00	1.910E+00	1.808E+00	1.909E+00
^{237}Np	1.917E+00	1.91E+00	1.910E+00	1.909E+00	1.904E+00	1.912E+00	1.905E+00	1.913E+00	1.889E+00	1.892E+00	1.912E+00	1.810E+00	1.911E+00
^{238}Pu	1.919E+00	1.91E+00	1.912E+00	1.910E+00	1.907E+00	1.914E+00	1.908E+00	1.916E+00	1.892E+00	1.894E+00	1.914E+00	1.812E+00	1.914E+00
^{239}Pu	1.809E+00	1.80E+00	1.803E+00	1.802E+00	1.798E+00	1.806E+00	1.797E+00	1.806E+00	1.782E+00	1.784E+00	1.805E+00	1.706E+00	1.806E+00
^{240}Pu	1.878E+00	1.87E+00	1.871E+00	1.870E+00	1.866E+00	1.874E+00	1.867E+00	1.875E+00	1.851E+00	1.853E+00	1.874E+00	1.772E+00	1.874E+00
^{241}Pu	1.885E+00	1.88E+00	1.878E+00	1.877E+00	1.873E+00	1.880E+00	1.874E+00	1.881E+00	1.858E+00	1.860E+00	1.880E+00	1.779E+00	1.879E+00
^{242}Pu	1.917E+00	1.91E+00	1.910E+00	1.909E+00	1.905E+00	1.912E+00	1.906E+00	1.914E+00	1.890E+00	1.892E+00	1.912E+00	1.810E+00	1.913E+00
^{241}Am	1.919E+00	1.91E+00	1.912E+00	1.910E+00	1.906E+00	1.914E+00	1.907E+00	1.915E+00	1.891E+00	1.894E+00	1.914E+00	1.812E+00	1.914E+00
^{243}Am	1.919E+00	1.91E+00	1.912E+00	1.911E+00	1.907E+00	1.915E+00	1.908E+00	1.916E+00	1.892E+00	1.895E+00	1.915E+00	1.812E+00	1.914E+00
^{10}B	1.915E+00	1.91E+00	1.908E+00	1.907E+00	1.902E+00	1.910E+00	1.903E+00	1.911E+00	1.887E+00	1.889E+00	1.910E+00	1.808E+00	1.910E+00
ALL	1.851E+00	1.84E+00	1.845E+00	N.R.	N.R.	N.R.	1.840E+00	1.846E+00	1.825E+00	1.828E+00	1.848E+00	1.746E+00	1.848E+00

Figure 6. Relative difference in the absorption rate of the BUC nuclide for cases 1 to 14 of sub-phase 1

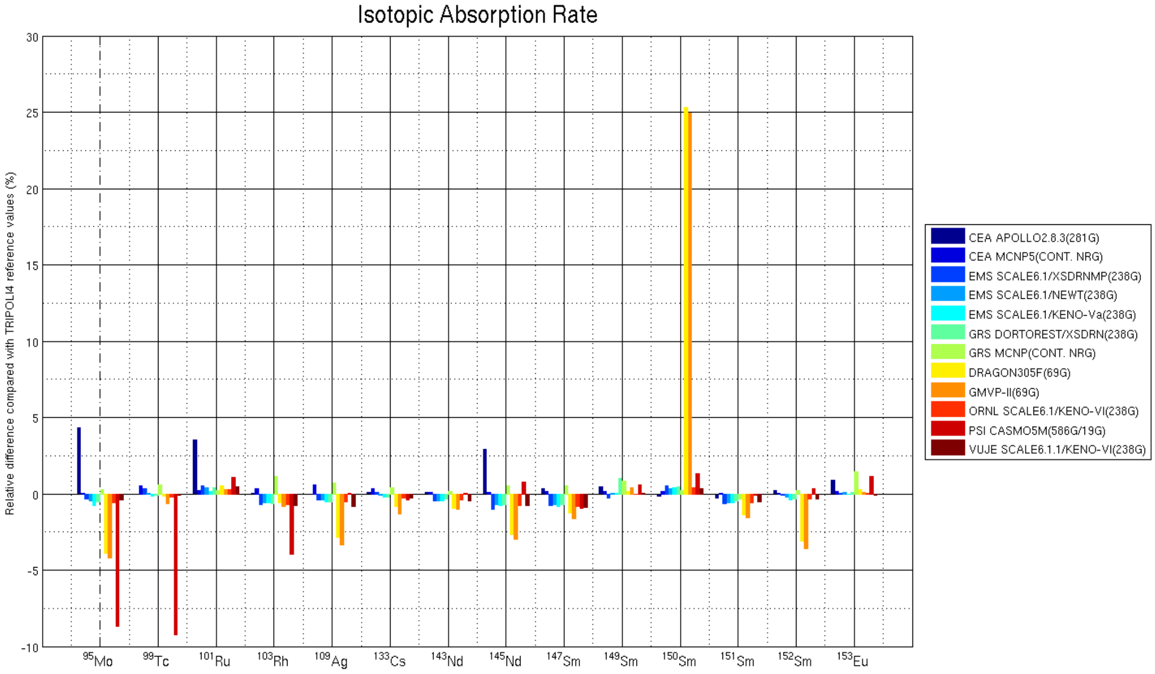


Figure 7. Relative difference in the absorption rate of the BUC nuclide for cases 15 to 27 of sub-phase 1

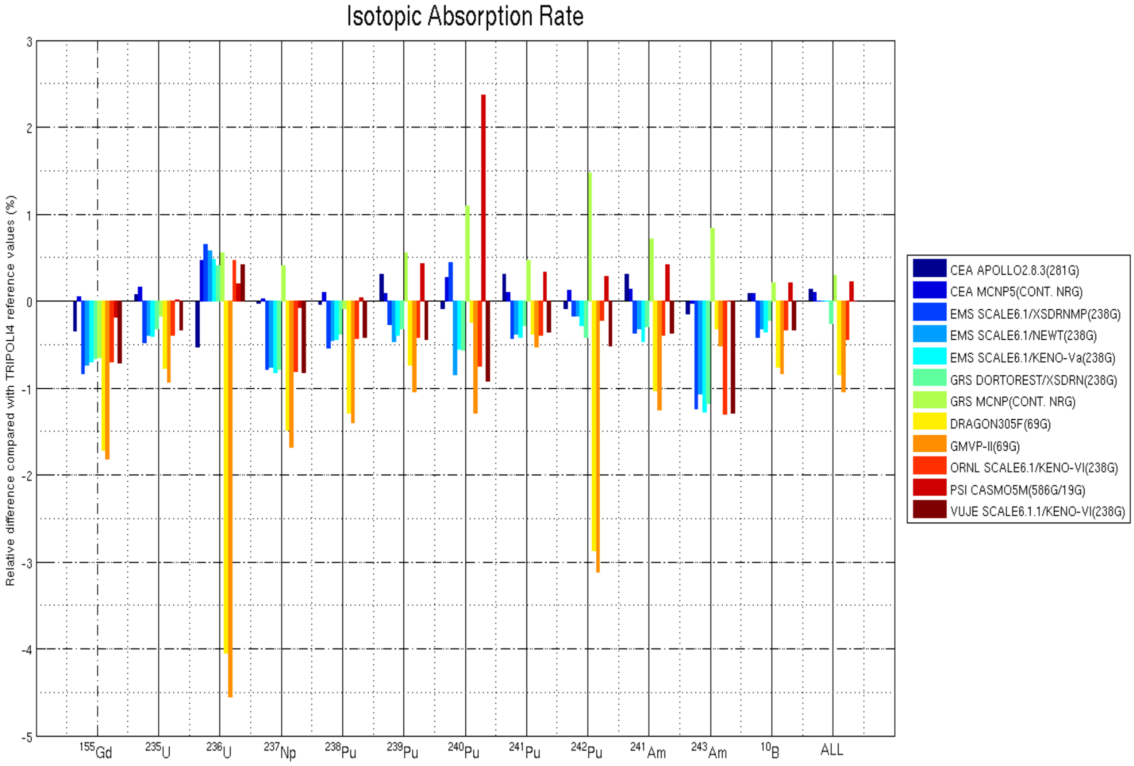


Figure 8. Relative difference in the production rate of the BUC nuclide for cases 16 to 27 of sub-phase 1

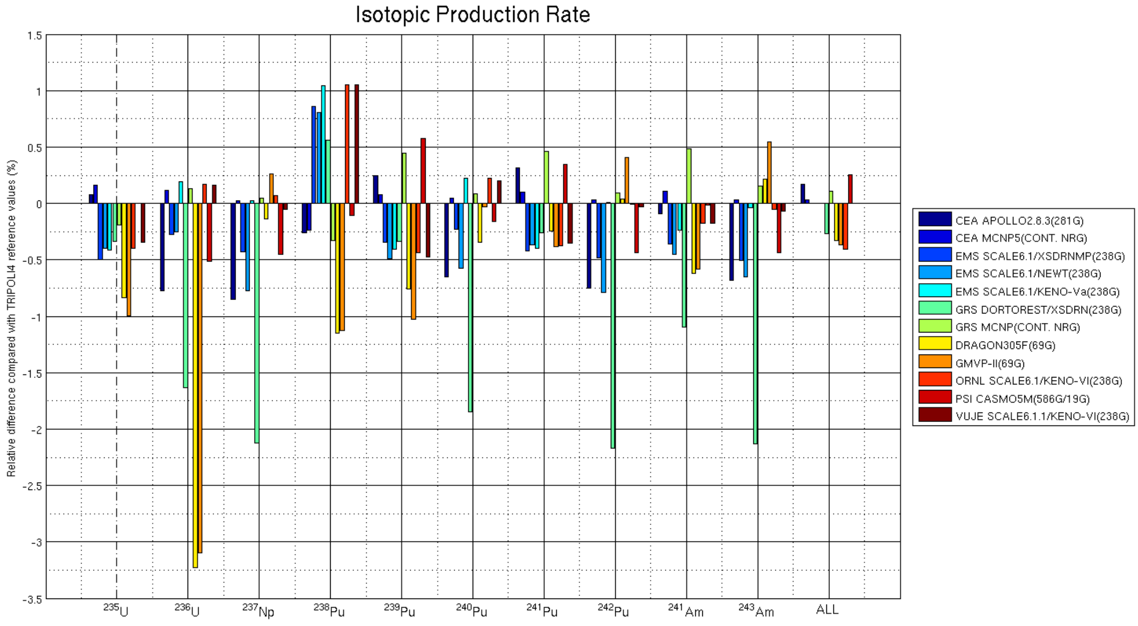


Figure 9. Relative difference in the scattering rate of the BUC nuclide for cases 1 to 14 of sub-phase 1

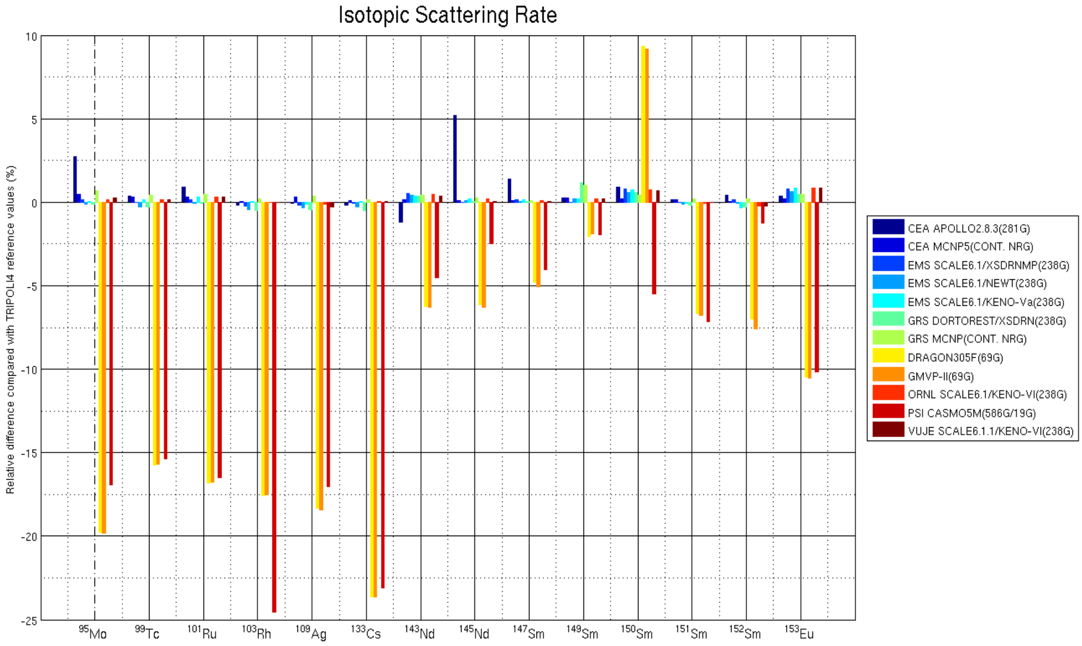


Figure 10. Relative difference in the scattering rate of the BUC nuclide for cases 15 to 27 of sub-phase 1

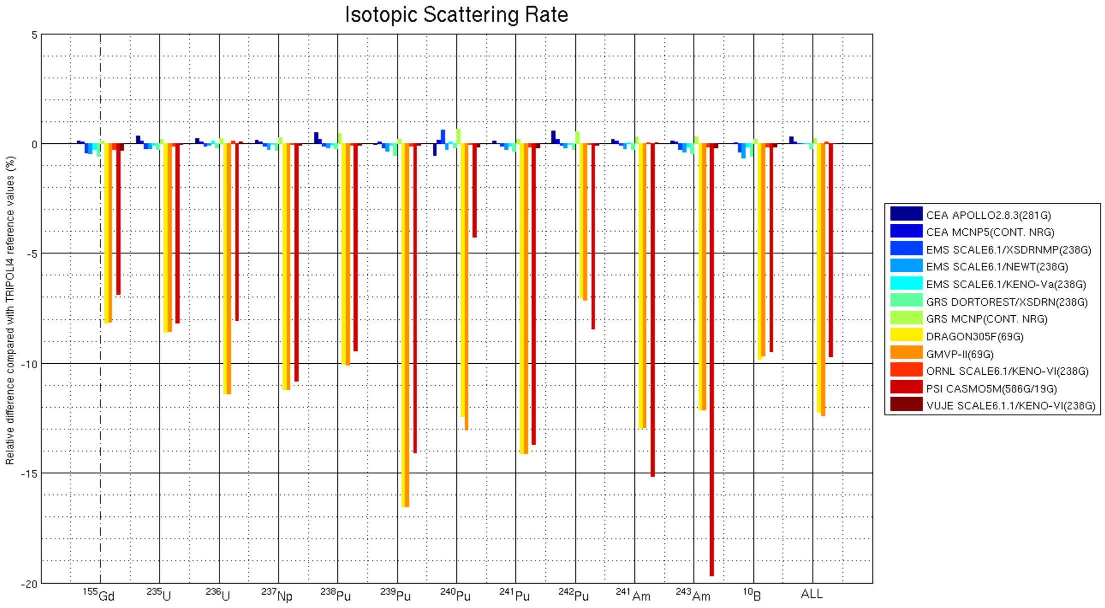


Table 14. Absorption rate on the BUC nuclide in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
^{95}Mo	2.819E-03	2.702E-03	2.704E-03	2.693E-03	2.690E-03	2.681E-03	2.689E-03	2.710E-03	2.597E-03	2.588E-03	2.687E-03	2.467E-03	2.692E-03
^{99}Tc	6.428E-03	6.431E-03	6.466E-03	6.454E-03	6.433E-03	6.421E-03	6.427E-03	6.468E-03	6.420E-03	6.389E-03	6.416E-03	5.838E-03	6.425E-03
^{101}Ru	2.324E-03	2.245E-03	2.250E-03	2.257E-03	2.253E-03	2.248E-03	2.254E-03	2.250E-03	2.256E-03	2.250E-03	2.251E-03	2.268E-03	2.255E-03
^{103}Rh	1.524E-02	1.524E-02	1.529E-02	1.513E-02	1.515E-02	1.515E-02	1.514E-02	1.541E-02	1.515E-02	1.511E-02	1.513E-02	1.464E-02	1.512E-02
^{109}Ag	2.105E-03	2.105E-03	2.118E-03	2.097E-03	2.096E-03	2.094E-03	2.094E-03	2.120E-03	2.046E-03	2.035E-03	2.094E-03	2.107E-03	2.089E-03
^{133}Cs	8.060E-03	8.053E-03	8.080E-03	8.061E-03	8.045E-03	8.033E-03	8.035E-03	8.085E-03	7.984E-03	7.946E-03	8.030E-03	8.020E-03	8.029E-03
^{143}Nd	1.611E-02	1.610E-02	1.611E-02	1.602E-02	1.603E-02	1.603E-02	1.604E-02	1.612E-02	1.595E-02	1.593E-02	1.603E-02	1.610E-02	1.602E-02
^{145}Nd	4.334E-03	4.211E-03	4.214E-03	4.168E-03	4.180E-03	4.180E-03	4.181E-03	4.232E-03	4.098E-03	4.086E-03	4.179E-03	4.243E-03	4.178E-03
^{147}Sm	1.569E-03	1.563E-03	1.565E-03	1.552E-03	1.552E-03	1.550E-03	1.552E-03	1.572E-03	1.544E-03	1.538E-03	1.551E-03	1.548E-03	1.549E-03
^{149}Sm	1.730E-02	1.722E-02	1.725E-02	1.717E-02	1.722E-02	1.723E-02	1.739E-02	1.736E-02	1.725E-02	1.729E-02	1.722E-02	1.732E-02	1.722E-02
^{150}Sm	2.427E-03	2.431E-03	2.434E-03	2.444E-03	2.439E-03	2.440E-03	2.442E-03	2.436E-03	3.045E-03	3.037E-03	2.440E-03	2.463E-03	2.439E-03
^{151}Sm	1.025E-02	1.028E-02	1.028E-02	1.021E-02	1.022E-02	1.022E-02	1.023E-02	1.024E-02	1.013E-02	1.011E-02	1.022E-02	1.027E-02	1.022E-02
^{152}Sm	5.744E-03	5.733E-03	5.734E-03	5.727E-03	5.720E-03	5.710E-03	5.712E-03	5.744E-03	5.555E-03	5.526E-03	5.712E-03	5.753E-03	5.712E-03
^{153}Eu	3.939E-03	3.904E-03	3.911E-03	3.907E-03	3.909E-03	3.904E-03	3.908E-03	3.960E-03	3.916E-03	3.909E-03	3.907E-03	3.949E-03	3.902E-03
^{155}Gd	5.306E-03	5.324E-03	5.327E-03	5.280E-03	5.285E-03	5.287E-03	5.289E-03	5.290E-03	5.233E-03	5.228E-03	5.287E-03	5.315E-03	5.287E-03
^{235}U	4.292E-01	4.289E-01	4.296E-01	4.268E-01	4.272E-01	4.271E-01	4.275E-01	4.281E-01	4.255E-01	4.248E-01	4.272E-01	4.289E-01	4.274E-01
^{236}U	8.094E-03	8.137E-03	8.174E-03	8.189E-03	8.183E-03	8.175E-03	8.169E-03	8.181E-03	7.807E-03	7.766E-03	8.175E-03	8.153E-03	8.171E-03
^{237}Np	7.251E-03	7.253E-03	7.255E-03	7.196E-03	7.198E-03	7.194E-03	7.196E-03	7.283E-03	7.145E-03	7.132E-03	7.194E-03	7.248E-03	7.194E-03
^{238}Pu	3.851E-03	3.852E-03	3.856E-03	3.832E-03	3.835E-03	3.835E-03	3.838E-03	3.849E-03	3.803E-03	3.799E-03	3.836E-03	3.854E-03	3.836E-03
^{239}Pu	2.288E-01	2.281E-01	2.283E-01	2.275E-01	2.271E-01	2.272E-01	2.274E-01	2.294E-01	2.265E-01	2.257E-01	2.272E-01	2.291E-01	2.271E-01
^{240}Pu	7.130E-02	7.136E-02	7.156E-02	7.168E-02	7.076E-02	7.097E-02	7.096E-02	7.214E-02	7.119E-02	7.044E-02	7.083E-02	7.306E-02	7.071E-02
^{241}Pu	7.658E-02	7.634E-02	7.641E-02	7.602E-02	7.605E-02	7.603E-02	7.613E-02	7.670E-02	7.605E-02	7.594E-02	7.605E-02	7.660E-02	7.607E-02
^{242}Pu	5.066E-03	5.070E-03	5.077E-03	5.061E-03	5.062E-03	5.056E-03	5.049E-03	5.145E-03	4.925E-03	4.912E-03	5.059E-03	5.084E-03	5.044E-03
^{241}Am	4.450E-03	4.436E-03	4.442E-03	4.420E-03	4.422E-03	4.416E-03	4.423E-03	4.468E-03	4.390E-03	4.381E-03	4.419E-03	4.455E-03	4.420E-03
^{243}Am	2.285E-03	2.288E-03	2.287E-03	2.259E-03	2.263E-03	2.259E-03	2.261E-03	2.307E-03	2.280E-03	2.276E-03	2.258E-03	2.288E-03	2.259E-03
^{10}B	1.418E-02	1.417E-02	1.418E-02	1.411E-02	1.413E-02	1.412E-02	1.414E-02	1.420E-02	1.406E-02	1.405E-02	1.412E-02	1.420E-02	1.412E-02
ALL	5.223E-01	5.217E-01	5.221E-01	N.R.	N.R.	N.R.	5.203E-01	5.232E-01	5.173E-01	5.162E-01	5.194E-01	5.228E-01	N.R.

Table 15. Production rate on the BUC nuclide in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
^{235}U	8.820E-01	8.814E-01	8.828E-01	8.770E-01	8.779E-01	8.778E-01	8.784E-01	8.797E-01	8.740E-01	8.726E-01	8.779E-01	8.814E-01	8.783E-01
^{236}U	8.759E-04	8.827E-04	8.837E-04	8.803E-04	8.805E-04	8.844E-04	8.683E-04	8.839E-04	8.542E-04	8.554E-04	8.842E-04	8.782E-04	8.841E-04
^{237}Np	2.741E-04	2.765E-04	2.765E-04	2.753E-04	2.743E-04	2.765E-04	2.706E-04	2.766E-04	2.761E-04	2.772E-04	2.767E-04	2.752E-04	2.763E-04
^{238}Pu	5.940E-04	5.956E-04	5.942E-04	6.007E-04	6.004E-04	6.018E-04	5.989E-04	5.936E-04	5.887E-04	5.889E-04	6.018E-04	5.950E-04	6.018E-04
^{239}Pu	4.349E-01	4.339E-01	4.342E-01	4.324E-01	4.318E-01	4.321E-01	4.324E-01	4.358E-01	4.306E-01	4.294E-01	4.320E-01	4.364E-01	4.318E-01
^{240}Pu	1.134E-03	1.141E-03	1.142E-03	1.138E-03	1.135E-03	1.144E-03	1.120E-03	1.142E-03	1.137E-03	1.141E-03	1.144E-03	1.139E-03	1.143E-03
^{241}Pu	1.662E-01	1.656E-01	1.658E-01	1.649E-01	1.650E-01	1.650E-01	1.652E-01	1.664E-01	1.652E-01	1.650E-01	1.650E-01	1.662E-01	1.651E-01
^{242}Pu	2.193E-04	2.210E-04	2.211E-04	2.199E-04	2.193E-04	2.210E-04	2.162E-04	2.212E-04	2.211E-04	2.219E-04	2.210E-04	2.200E-04	2.209E-04
^{241}Am	1.326E-04	1.328E-04	1.329E-04	1.323E-04	1.322E-04	1.324E-04	1.313E-04	1.334E-04	1.319E-04	1.320E-04	1.325E-04	1.327E-04	1.325E-04
^{243}Am	6.289E-05	6.332E-05	6.334E-05	6.300E-05	6.291E-05	6.330E-05	6.197E-05	6.342E-05	6.346E-05	6.366E-05	6.329E-05	6.304E-05	6.328E-05
ALL	6.609E-01	6.598E-01	6.600E-01	N.R.	N.R.	N.R.	6.580E-01	6.605E-01	6.576E-01	6.573E-01	6.571E-01	6.614E-01	N.R.

Table 16. Scattering rate on the BUC nuclide in s^{-1} (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
^{95}Mo	6.388E-03	6.218E-03	6.247E-03	6.226E-03	6.211E-03	6.220E-03	6.209E-03	6.260E-03	4.988E-03	4.985E-03	6.227E-03	5.167E-03	6.232E-03
^{99}Tc	4.480E-03	4.465E-03	4.478E-03	4.465E-03	4.453E-03	4.471E-03	4.452E-03	4.484E-03	3.762E-03	3.764E-03	4.472E-03	3.780E-03	4.472E-03
^{101}Ru	4.154E-03	4.118E-03	4.131E-03	4.124E-03	4.115E-03	4.131E-03	4.114E-03	4.136E-03	3.424E-03	3.428E-03	4.130E-03	3.438E-03	4.130E-03
^{103}Rh	2.292E-03	2.296E-03	2.297E-03	2.291E-03	2.286E-03	2.296E-03	2.285E-03	2.301E-03	1.892E-03	1.893E-03	2.296E-03	1.733E-03	2.296E-03
^{109}Ag	4.283E-04	4.287E-04	4.300E-04	4.280E-04	4.272E-04	4.282E-04	4.267E-04	4.302E-04	3.502E-04	3.496E-04	4.282E-04	3.556E-04	4.276E-04
^{133}Cs	4.509E-03	4.517E-03	4.520E-03	4.514E-03	4.504E-03	4.520E-03	4.495E-03	4.524E-03	3.450E-03	3.450E-03	4.519E-03	3.475E-03	4.518E-03
^{143}Nd	1.472E-02	1.490E-02	1.491E-02	1.497E-02	1.496E-02	1.495E-02	1.495E-02	1.496E-02	1.396E-02	1.396E-02	1.496E-02	1.422E-02	1.495E-02
^{145}Nd	8.526E-03	8.106E-03	8.113E-03	8.107E-03	8.115E-03	8.120E-03	8.108E-03	8.128E-03	7.608E-03	7.594E-03	8.121E-03	7.905E-03	8.110E-03
^{147}Sm	1.521E-03	1.500E-03	1.501E-03	1.502E-03	1.501E-03	1.502E-03	1.500E-03	1.501E-03	1.428E-03	1.424E-03	1.501E-03	1.439E-03	1.500E-03
^{149}Sm	1.641E-04	1.637E-04	1.640E-04	1.636E-04	1.640E-04	1.640E-04	1.656E-04	1.653E-04	1.603E-04	1.606E-04	1.639E-04	1.605E-04	1.640E-04
^{150}Sm	3.145E-03	3.117E-03	3.124E-03	3.142E-03	3.136E-03	3.140E-03	3.135E-03	3.130E-03	3.409E-03	3.403E-03	3.140E-03	2.946E-03	3.139E-03
^{151}Sm	1.516E-04	1.514E-04	1.516E-04	1.514E-04	1.512E-04	1.513E-04	1.511E-04	1.517E-04	1.412E-04	1.411E-04	1.513E-04	1.406E-04	1.513E-04
^{152}Sm	9.189E-03	9.149E-03	9.152E-03	9.163E-03	9.142E-03	9.121E-03	9.123E-03	9.168E-03	8.511E-03	8.454E-03	9.127E-03	9.035E-03	9.128E-03
^{153}Eu	5.630E-04	5.610E-04	5.620E-04	5.656E-04	5.645E-04	5.659E-04	5.637E-04	5.638E-04	5.022E-04	5.020E-04	5.658E-04	5.041E-04	5.659E-04
^{155}Gd	1.658E-05	1.656E-05	1.657E-05	1.649E-05	1.649E-05	1.652E-05	1.647E-05	1.658E-05	1.521E-05	1.521E-05	1.652E-05	1.543E-05	1.652E-05
^{235}U	2.889E-02	2.879E-02	2.882E-02	2.872E-02	2.872E-02	2.876E-02	2.871E-02	2.884E-02	2.631E-02	2.632E-02	2.876E-02	2.643E-02	2.877E-02
^{236}U	1.468E-02	1.465E-02	1.466E-02	1.463E-02	1.463E-02	1.466E-02	1.462E-02	1.468E-02	1.298E-02	1.298E-02	1.467E-02	1.347E-02	1.466E-02
^{237}Np	1.888E-03	1.885E-03	1.886E-03	1.883E-03	1.880E-03	1.884E-03	1.879E-03	1.890E-03	1.674E-03	1.674E-03	1.884E-03	1.681E-03	1.884E-03
^{238}Pu	8.965E-04	8.921E-04	8.938E-04	8.909E-04	8.903E-04	8.914E-04	8.900E-04	8.960E-04	8.025E-04	8.022E-04	8.914E-04	8.080E-04	8.915E-04
^{239}Pu	1.464E-02	1.465E-02	1.466E-02	1.462E-02	1.460E-02	1.464E-02	1.457E-02	1.468E-02	1.223E-02	1.223E-02	1.463E-02	1.259E-02	1.464E-02
^{240}Pu	1.048E-02	1.053E-02	1.055E-02	1.060E-02	1.050E-02	1.054E-02	1.051E-02	1.060E-02	9.224E-03	9.159E-03	1.053E-02	1.008E-02	1.052E-02
^{241}Pu	3.980E-03	3.975E-03	3.976E-03	3.970E-03	3.964E-03	3.971E-03	3.961E-03	3.983E-03	3.415E-03	3.415E-03	3.969E-03	3.431E-03	3.968E-03
^{242}Pu	2.429E-03	2.415E-03	2.420E-03	2.414E-03	2.410E-03	2.414E-03	2.409E-03	2.428E-03	2.245E-03	2.243E-03	2.414E-03	2.211E-03	2.413E-03
^{241}Am	3.209E-04	3.203E-04	3.206E-04	3.200E-04	3.195E-04	3.204E-04	3.194E-04	3.212E-04	2.788E-04	2.789E-04	3.204E-04	2.717E-04	3.204E-04
^{243}Am	4.295E-04	4.290E-04	4.293E-04	4.278E-04	4.273E-04	4.284E-04	4.271E-04	4.303E-04	3.770E-04	3.770E-04	4.284E-04	3.447E-04	4.281E-04
^{10}B	7.643E-05	7.642E-05	7.645E-05	7.613E-05	7.592E-05	7.630E-05	7.597E-05	7.657E-05	6.892E-05	6.902E-05	7.629E-05	6.917E-05	7.629E-05
ALL	1.076E-01	1.073E-01	1.074E-01	N.R.	N.R.	N.R.	1.070E-01	1.075E-01	9.413E-02	9.399E-02	1.073E-01	9.686E-02	N.R.

3.1.4 Reactivity worth

3.1.4.1 Eigen-value difference method

Reactivity worths due to the addition of BUC nuclides in the fuel were calculated for cases 1 to 27, with the standard eigen-value difference method, defined as follows:

$$\delta\rho = \frac{k_2 - k_1}{k_2 k_1}$$

k_1 and k_2 are the effective multiplication factors for respectively case 0 and case i (with i ranging from 1 to 27).

Comparisons are illustrated in Figures 11 and 12, while the calculated values are reported in Table 17.

Calculations show very similar trends compared with the analysis of BUC nuclide absorption rates. Indeed, the reactivity worth due to the addition of a purely neutron absorber can be written as:

$$\delta\rho = \frac{\Sigma_{a1}\phi_1}{\nu\Sigma_{f1}\phi_1} - \frac{\Sigma_{a2}\phi_2}{\nu\Sigma_{f2}\phi_2}$$

with Σ_a the absorption cross-section, $\nu\Sigma_f$ the production cross-section.

Assuming that the change in the neutron flux between case 1 and 2 is small, the equation can be simplified in:

$$\delta\rho = \frac{1}{k_1}\frac{\frac{\delta(\nu\Sigma_f)}{\nu\Sigma_{f1}} - \frac{\delta(\Sigma_a)}{\Sigma_{a1}}}{1 + \frac{\delta(\nu\Sigma_f)}{\nu\Sigma_{f1}}}$$

where $\delta\Sigma_a$ and $\delta\nu\Sigma_f$ stand for the modification of the absorption and production cross-section due to the addition of the BUC nuclide.

As a consequence, most of the errors already observed on the calculation of reaction rates are repeated on the calculation of the reactivity worth. Like previously, the main reason of the difference comes from the treatment of self-shielding effects, or from the substitution of one evaluation from ENDF/B-VII by JEFF-3.1.1 (^{99}Tc for instance in CASMO5 calculations). This can be seen on EMS calculations, where the differences do not depend on the kind of solver which is used for flux calculation XSDRNMP, NEWT or KENO-Va. Some SCALE6 calculations show significant inconsistencies, especially between ORNL and VUJE, in spite of the same number of energy groups and the same kind of solver. Most of these differences can be explained by the limitations in the statistical convergence of KENO-VI calculations, which was not represented here to avoid too much information on the figures. The results presented in the tables show that the uncertainty of VUJE calculations, mostly around 22 pcm, is higher than most of the differences comparing reactivity worth obtained by ORNL calculations, where the statistical convergence is around 7 pcm.

Figure 11. Relative difference in the reactivity worth calculated by the eigen-value difference method for cases 1 to 14 of sub-phase 1

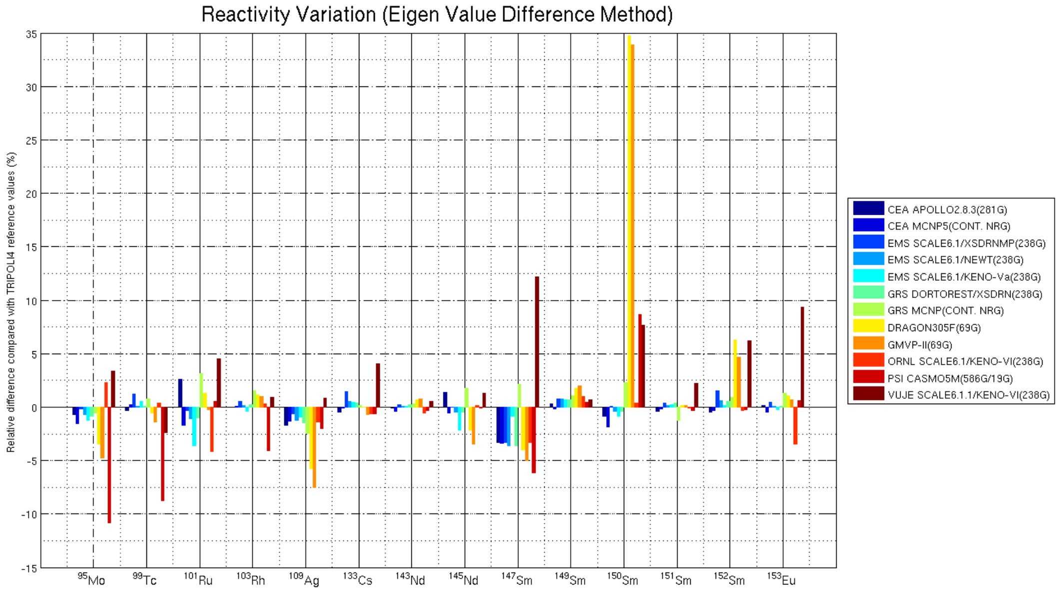


Figure 12. Relative difference in the reactivity worth calculated by the eigen-value difference method for cases 15 to 27 of sub-phase 1

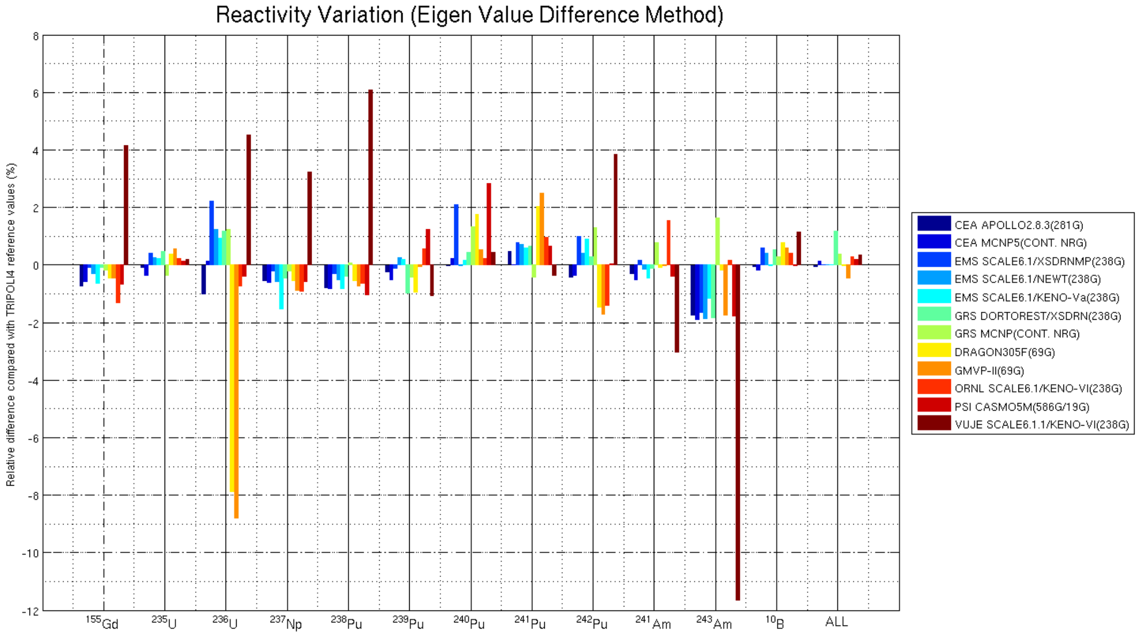


Table 17. Reactivity worth by the eigen-value difference method in pcm (sub-phase 1)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTO REST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO6-VI 238G
^{95}Mo	-217.1	-218.6(1.7)	-215.2(0.5)	-218.2	-217	-215.9(4.4)	-216.7	-217.4(7.3)	-211.1	-208.3(1.4)	-223.6(7.3)	-195	-226.0(21.8)
^{99}Tc	-517.8	-519.5(1.7)	-520.6(0.5)	-525.7	-519.8	-522.3(4.5)	-519.7	-523.5(7.4)	-516.5	-512.3(1.4)	-521.4(7.3)	-474	-507.0(21.9)
^{101}Ru	-179.6	-175.1(1.7)	-172.2(0.5)	-174.6	-173.2	-168.7(4.4)	-173.3	-180.6(7.3)	-177.4	-174.7(1.3)	-167.8(7.3)	-176	-183.0(21.4)
^{103}Rh	-1341.6	-1342.0(1.7)	-1343.1(0.5)	-1348.7	-1344.3	-1337.0(4.5)	-1345	-1362.0(7.4)	-1357.1	-1354.9(1.4)	-1346.5(7.5)	-1287	-1354.0(22.1)
^{109}Ag	-171.6	-174.5(1.7)	-172.2(0.5)	-173.5	-172.4	-172.9(4.4)	-172	-170.2(7.3)	-164.4	-161.4(1.4)	-172.1(7.3)	-171	-176.0(22.9)
^{133}Cs	-642.1	-645.0(1.7)	-644.3(0.5)	-654.3	-648.2	-647.8(4.5)	-647.5	-645.7(7.4)	-645	-640.4(1.4)	-640.9(7.4)	-641	-671.0(21.9)
^{143}Nd	-1438.8	-1439.7(1.7)	-1434.2(0.5)	-1443.2	-1440.5	-1440.9(4.5)	-1443	-1444.0(7.4)	-1449.9	-1450.7(1.4)	-1431.8(7.4)	-1435	-1447.0(24.1)
^{145}Nd	-359.1	-354.3(1.7)	-352.5(0.5)	-354.2	-352.7	-346.6(4.4)	-352.6	-360.5(7.3)	-346.8	-342.0(1.3)	-354.8(7.3)	-354	-359.0(21.5)
^{147}Sm	-126.7	-131.1(1.7)	-126.6(0.5)	-126.8	-126.3	-130.0(4.4)	-126.3	-133.9(7.3)	-125.8	-124.5(1.4)	-126.7(7.3)	-123	-147.0(24.9)
^{149}Sm	-1552.6	-1548.1(1.7)	-1546.0(0.5)	-1560.4	-1559.7	-1558.2(4.5)	-1559	-1565.0(7.5)	-1575.7	-1578.8(1.4)	-1563.6(7.5)	-1555	-1559.0(22.6)
^{150}Sm	-190.7	-192.3(1.7)	-188.8(0.5)	-192.4	-191.5	-190.7(4.4)	-191.5	-196.7(7.3)	-259.1	-257.5(1.3)	-193.0(7.3)	-209	-207.0(22.2)
^{151}Sm	-914.4	-917.6(1.7)	-916.3(0.5)	-920.9	-919.3	-919.9(4.5)	-921	-906.2(7.4)	-919.3	-918.8(1.4)	-916.7(7.4)	-915	-938.0(22.8)
^{152}Sm	-451.8	-454.0(1.7)	-452.6(0.5)	-461	-456.7	-454.6(4.4)	-456.5	-458.1(7.3)	-482.6	-475.3(1.4)	-452.4(7.4)	-453	-482.0(23.0)
^{153}Eu	-331.5	-331.1(1.7)	-329.6(0.5)	-332.5	-331.3	-330.3(4.4)	-331.4	-335.5(7.3)	-334.6	-333.4(1.3)	-319.6(7.3)	-333	-362.0(21.5)
^{155}Gd	-472.7	-476.2(1.7)	-473.5(0.5)	-475.8	-474.8	-473.1(4.5)	-475.8	-475.3(7.3)	-474	-474.1(1.3)	-470.0(7.4)	-473	-496.0(22.6)
^{235}U	-32755.8	-32783.7(2.5)	-32663.3(0.8)	-32913.8	-32869.1	-32853.9(6.4)	-32940	-32670.0(9.6)	-32906	-32967.0(2.1)	-32852.3(10.6)	-32825	-32852.0(27.8)
^{236}U	-605.4	-611.4(1.7)	-612.3(0.5)	-625	-619	-617.0(4.5)	-618.6	-618.9(7.4)	-563.3	-557.7(1.4)	-607.0(7.4)	-609	-639.0(21.9)
^{237}Np	-602.2	-605.5(1.7)	-601.8(0.5)	-604.3	-602	-596.3(4.5)	-602.8	-604.2(7.4)	-602.2	-600.2(1.4)	-600.0(7.4)	-602	-625.0(22.7)
^{238}Pu	-306.7	-309.2(1.7)	-306.7(0.5)	-308.3	-307.6	-306.7(4.4)	-308	-309.4(7.3)	-307.5	-306.9(1.3)	-307.3(7.3)	-306	-328.0(22.6)
^{239}Pu	2593.4	2599.6(1.6)	2586.2(0.5)	2596.3	2606.1	2605.0(4.3)	2574	2589.0(7.0)	2575.3	2598.6(1.3)	2613.9(7.0)	2632	2572.0(21.0)
^{240}Pu	-6651.7	-6652.6(1.9)	-6667.6(0.6)	-6791.1	-6651.7	-6663.2(4.8)	-6681	-6740.0(8.4)	-6769.8	-6688.0(2.0)	-6667.6(8.0)	-6840	-6681.0(25.4)
^{241}Pu	1897.7	1888.8(1.7)	1889.0(0.5)	1903.2	1902.2	1900.2(4.3)	1901	1881.0(7.1)	1927.5	1935.8(1.3)	1907.0(7.1)	1901	1882.0(21.2)
^{242}Pu	-419.1	-420.8(1.7)	-419.2(0.5)	-425	-422.5	-424.6(4.4)	-422	-426.2(7.3)	-414.6	-413.6(1.3)	-414.9(7.3)	-421	-437.0(21.9)
^{241}Am	-380.3	-381.5(1.7)	-379.6(0.5)	-382.2	-381	-379.8(4.4)	-381.1	-384.5(7.3)	-381.2	-381.5(1.3)	-387.3(7.3)	-380	-370.0(22.6)
^{243}Am	-189.1	-192.4(1.7)	-188.8(0.5)	-189.3	-188.8	-190.2(4.4)	-188.9	-195.6(7.3)	-192.1	-189.1(1.4)	-192.8(7.4)	-189	-170.0(21.8)
^{10}B	-1263.9	-1264.4(1.7)	-1262.4(0.5)	-1271.7	-1269.5	-1264.1(4.5)	-1271	-1268.0(7.4)	-1274.1	-1272.1(1.4)	-1269.6(7.4)	-1264	-1279.0(22.1)
ALL	-24485.3	-24500.5(2.3)	-24532.9(0.7)	N.R.	N.R.	N.R.	-24790	-24590.0(10.3)	-24494	-24387.0(2.5)	-24571.8(9.6)	-24545	-24589.0(28.7)

3.1.4.2 Perturbation method

Following the calculations based on the eigen value difference method, participants were asked to use perturbation capabilities of their code to evaluate the reactivity worth due to the addition of BUC nuclides in the fuel. Different methods have been employed:

- SCALE6 use a formulation of the reactivity worth based on the first order perturbation theory;
- APOLLO2, GMVP-II and DRAGON3 use a formulation of the reactivity worth based on the exact perturbation theory;
- MCNP5 use the same capability but with a different method called "Differential operator method" which is based on a second order Taylor expansion.

Comparisons are illustrated in Figures 13 and 14, while the calculated values are reported in Table 18. It should be noted that TRIPOLI4 eigen value difference method remains the reference for the comparison of perturbation method.

Calculations based on the first order perturbation theory by EMS are less consistent with TRIPOLI4 calculations, compared with the eigen value difference method. The difference is larger than 3% for a number of isotopes like ^{95}Mo, ^{99}Tc, ^{147}Sm, ^{152}Sm. This is especially true for fissile isotopes like ^{239}Pu and ^{240}Pu where the neutron flux cannot be assumed unchanged with the addition of the BUC nuclide in the fuel. In such cases the difference can reach 30% which exclude the possibility of using this method for accurate calculations of reactivity worth. For GRS calculations based on MCNP5, fairly good results are observed for fission products which are pure neutron absorbers, with an agreement better than 2%. For fissiles and fertile nuclides, large errors are observed especially for ^{236}U, ^{239}Pu and ^{240}Pu where it is larger than 10%. Results for ^{235}U were not provided as the flux variation is so huge that the perturbation method is clearly out of the validation range. GMVP-II and DRAGON3 calculations are globally in the same agreement with TRIPOLI4 than the eigen value difference method, which clearly indicates that the exact perturbation method is required when calculating the reactivity worth of individual BUC nuclides. Most of the remaining errors, especially on ^{109}Ag, ^{147}Sm, ^{150}Sm, ^{236}U, were already observed before and can be explained by the low number of energy groups which were used in the calculations. Concerning APOLLO2 calculations, they also agree within 1% with TRIPOLI4, with the exception of ^{101}Ru and ^{145}Nd where a slight overprediction is still observed, due to the lack of self-shielding below 22 eV.

Figure 13. Relative difference in the reactivity worth calculated by the perturbation method for cases 1 to 14 of sub-phase 1

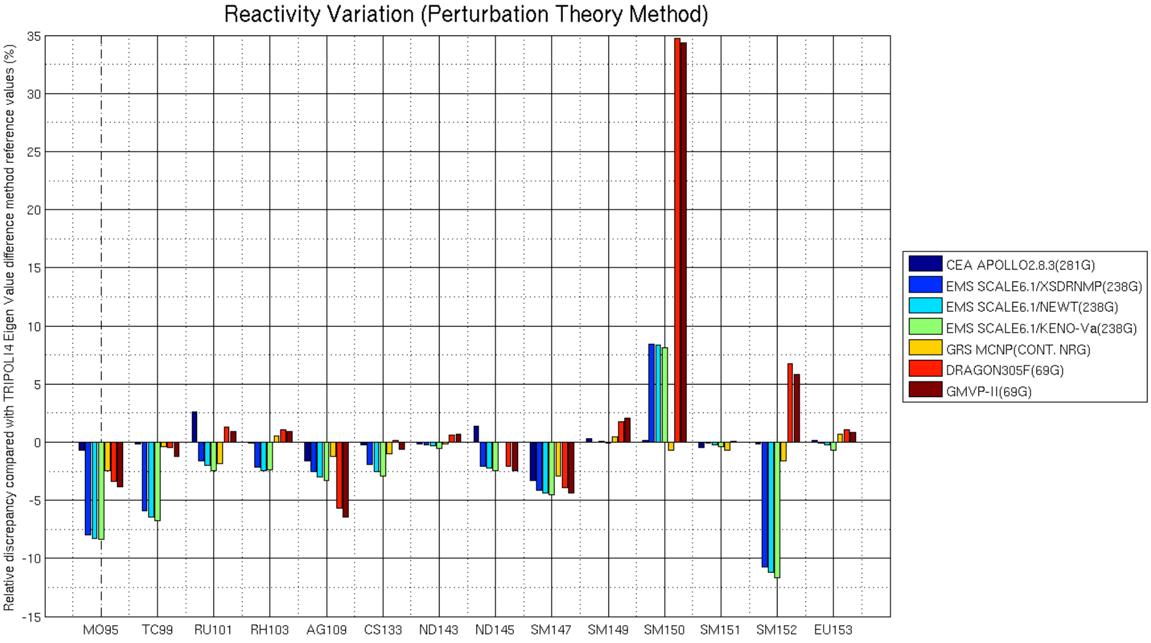


Figure 14. Relative difference in the reactivity worth calculated by the perturbation method for cases 15 to 27 of sub-phase 1

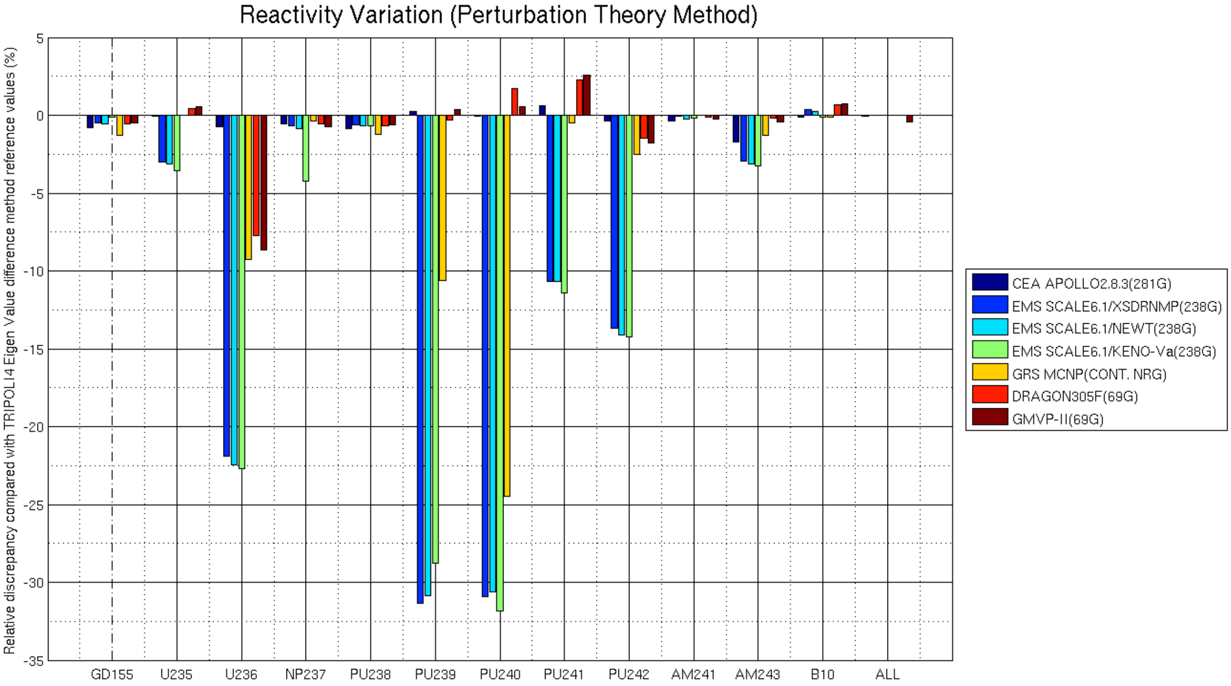


Table 18. Reactivity worth by the perturbation method in pcm (sub-phase 1)

Case	CEA APOLLO2 281G	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	DRAGON305 F 69G	GMVP-II 69G
^{95}Mo	-217.1	-201.2	-200.4	-200.3	-213.3	-211.2	-210.3
^{99}Tc	-518.6	-488.8	-485.9	-484.4	-517.3	-517.1	-513.1
^{101}Ru	-179.6	-172.2	-171.6	-170.8	-171.8	-177.4	-176.8
^{103}Rh	-1341.3	-1312.9	-1309.4	-1310.5	-1349	-1356.7	-1354
^{109}Ag	-171.7	-170.1	-169.3	-168.7	-172.3	-164.7	-163.3
^{133}Cs	-643.2	-632.7	-628.7	-626.1	-638.4	-645.7	-641
^{143}Nd	-1437.8	-1436.6	-1435.2	-1431.5	-1437	-1448.7	-1449.6
^{145}Nd	-359.1	-347.1	-346.4	-345.5	-354.3	-347	-345.7
^{147}Sm	-126.7	-125.6	-125.3	-125.2	-127.2	-125.9	-125.3
^{149}Sm	-1552.6	-1548.1	-1549	-1547.1	-1555	-1574.9	-1580.5
^{150}Sm	-192.6	-208.6	-208.3	-207.9	-191	-259.2	-258.4
^{151}Sm	-913.6	-916.9	-915.7	-913.9	-911.4	-918.3	-917.9
^{152}Sm	-453.4	-405.2	-403.1	-401.1	-446.7	-484.6	-480.3
^{153}Eu	-331.5	-330.8	-330.3	-328.8	-333.4	-334.5	-333.9
^{155}Gd	-472.3	-473.9	-473.5	-475.6	-470.2	-473.5	-473.9
^{235}U	-32762.4	-31807	-31758	-31626	N.R.	-32919	-32971
^{236}U	-606.7	-477.4	-474	-472.7	-554.9	-564.3	-558.6
^{237}Np	-602.1	-601.4	-600.3	-579.7	-603.2	-602	-600.9
^{238}Pu	-306.5	-307.3	-307	-307.1	-305.3	-307.2	-307.2
^{239}Pu	2606.6	1784.9	1798.1	1851.7	2324	2591.4	2609.8
^{240}Pu	-6649.8	-4597.4	-4616.9	-4534.1	-5024	-6766.9	-6690.2
^{241}Pu	1900.8	1687.1	1687.7	1673.3	1879	1931.7	1937.4
^{242}Pu	-419.1	-363.3	-361.3	-360.9	-410.1	-414.6	-413.3
^{241}Am	-380.2	-381.3	-380.5	-380.8	-381.4	-381.1	-380.5
^{243}Am	-189.1	-186.7	-186.4	-186.1	-189.9	-192.1	-191.6
^{10}B	-1263.1	-1268.8	-1267.7	-1262.9	-1263	-1273.2	-1273.9
ALL	-24490.8	N.R.	N.R.	N.R.	N.R.	-24504	-24394

3.1.4.3 Individual components

Participants who provided reactivity worth results based on perturbation calculations were also asked to give the individual components on the reactivity worth. Specifications of the benchmark were adapted to the calculation code capabilities but additional contributions provided a different definition for the components.

In the official file which was distributed in December 2012, after a first review by the EGBUC participants, the absorption (capture+fission), production (nu x fission), scattering and leakage effect contributions were asked to the participants. Calculations performed by EMS, using perturbation capabilities in SCALE6, could only provide components due to capture (absorption term), fission (including a production term and an absorption term) and scattering cross-sections.

In order to be able to compare results, CEA performed the two kinds of calculations. The first one reports capture and fission components to be compared with DRAGON3 and GMVP.

The second one reports absorption and production components to be compared with SCALE6 calculations by EMS and MCNP5 calculation by GRS.

Comparisons are illustrated in Figures 15 and 16 for the cases of ^{235}U, ^{239}Pu and ^{241}Pu where significant absorption and production effects occur. The complete list of provided results is given in Tables 19 and 20.

Comparisons between APOLLO2, GMVP-II and DRAGON3 calculations, which all use an exact perturbation formulation, show an excellent agreement with less than 1% difference on individual contributions due to absorption and production. This means that despite the low number of groups used in both GMVP-II and DRAGON3 calculations, the adjoint flux calculation is accurate to evaluate the individual components of the reactivity effect, both in GMVP-II and DRAGON3 calculations.

Comparisons between CEA, EMS and GRS calculations, projected on capture and fission components show an excellent agreement between APOLLO2 and SCALE6. Individual components do not depend significantly on the kind of solver used in SCALE6, XSDRNMP, NEWT and KENO-Va being in an around 2% agreement with APOLLO2. The difference with GRS calculations based on MCNP5 is much higher, with individual contributions lower by 4 to 10%. Moreover, one should notice that the sum of capture, fission and scattering components does not equal the total reactivity worth, unlike CEA and EMS calculations where the sum is exactly 1. This remark confirms the inability of MCNP5 calculations to provide accurate prediction of both the total reactivity worth just like individual components.

Figure 15. Comparison of reactivity worth components due to absorption and production for cases 16, 20, 22 of sub-phase 1

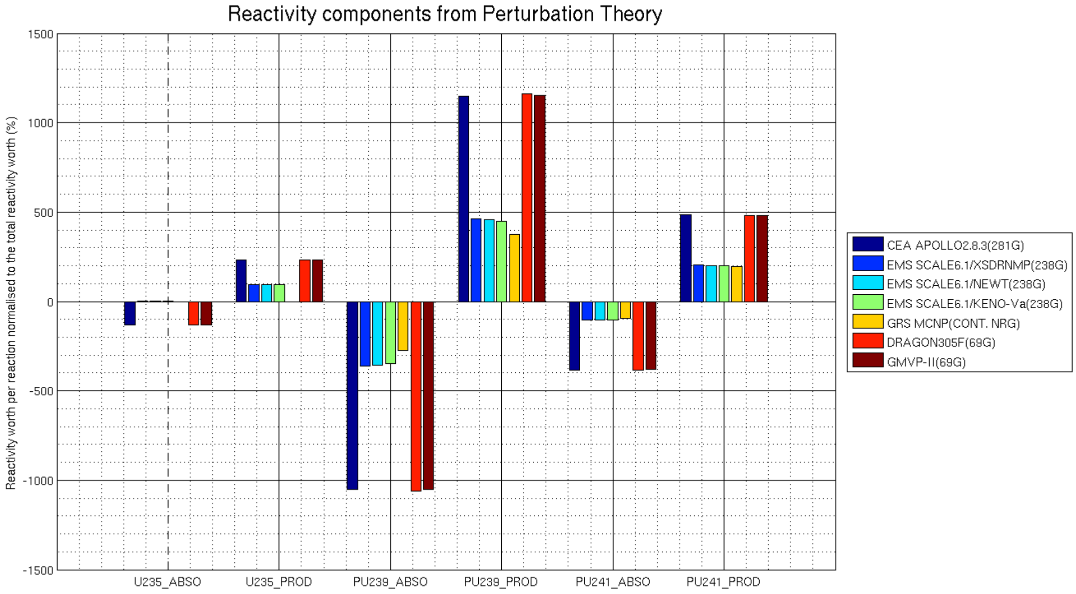


Figure 16. Comparison of reactivity worth components due to capture, fission and scattering for cases 15, 19, 21 of sub-phase 1

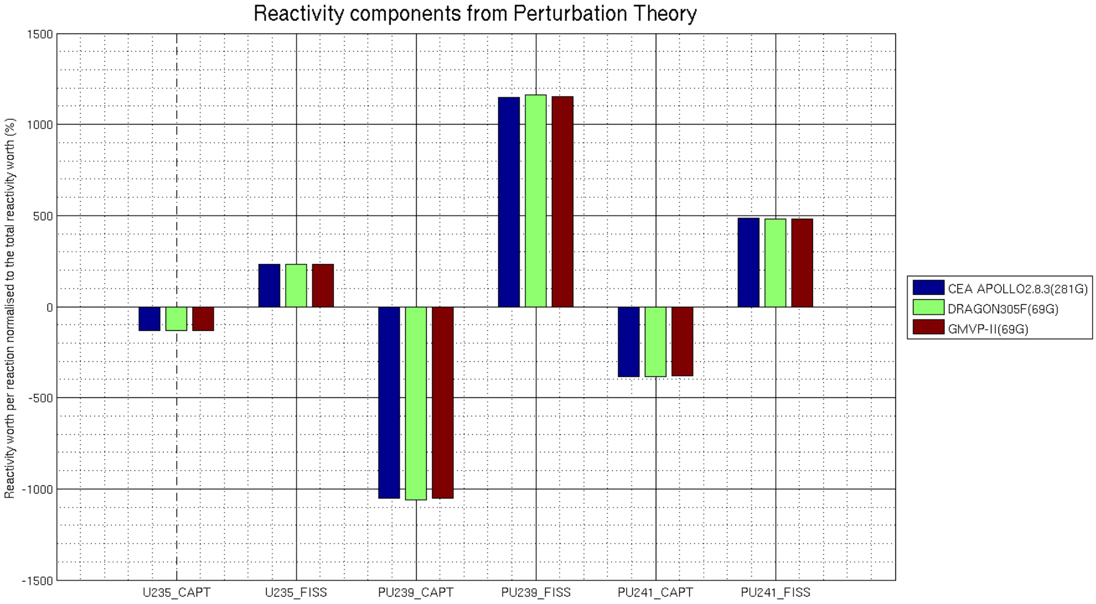


Table 19. Components of the reactivity worth due to absorption, production and scattering in percent of the total reactivity worth (sub-phase 1)

	Absorption / Total			Production / Total			Scattering / Total		
Case	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G
^{95}Mo	99.318	99.867	99.862	-0.02	-0.196	-0.196	0.8	0.329	0.335
^{99}Tc	99.934	100.048	100.045	-0.003	-0.18	-0.18	0.094	0.132	0.135
^{101}Ru	99.341	99.763	99.757	-0.006	-0.122	-0.122	0.393	0.358	0.364
^{103}Rh	100.015	99.978	99.97	-0.001	-0.002	-0.002	0.031	0.027	0.028
^{109}Ag	100.104	100.164	100.159	-0.003	-0.192	-0.193	0.016	0.031	0.032
^{133}Cs	99.84	100.057	100.056	-0.005	-0.167	-0.167	0.085	0.11	0.112
^{143}Nd	99.985	99.972	99.972	-0.004	-0.011	-0.011	0.048	0.036	0.036
^{145}Nd	99.83	100.055	100.049	-0.012	-0.196	-0.196	0.232	0.144	0.147
^{147}Sm	99.599	100.103	100.104	-0.03	-0.16	-0.16	0.012	0.058	0.059
^{149}Sm	100.052	100	100	0	-0.001	-0.001	0	0	0
^{150}Sm	101.93	100.05	100.046	-0.006	-0.148	-0.147	-1.797	0.101	0.103
^{151}Sm	100.01	100.003	100.003	0	-0.005	-0.005	-0.001	0.001	0.001
^{152}Sm	98.397	100.454	100.454	-0.001	-0.485	-0.487	1.197	0.03	0.031
^{153}Eu	100.025	100.018	100.018	-0.005	-0.038	-0.038	0.013	0.019	0.02
^{155}Gd	100.004	100	100	0	0	0	0.001	0	0
^{235}U	-131.057	-131.392	-131.27	231.115	231.401	231.279	-0.008	-0.008	-0.008
^{236}U	107.049	108.051	108.154	-7.584	-8.297	-8.404	0.244	0.245	0.25
^{237}Np	102.409	102.46	102.478	-2.391	-2.481	-2.5	0.023	0.021	0.021
^{238}Pu	110.091	110.161	110.178	-10.093	-10.17	-10.187	0.011	0.009	0.009
^{239}Pu	-1049.964	-1062.322	-1051.23	1150.109	1162.383	1151.276	-0.066	-0.053	-0.054
^{240}Pu	101.101	101.054	101.069	-1.053	-1.061	-1.076	0.004	0.007	0.007
^{241}Pu	-385.015	-382.228	-380.835	485.08	482.249	480.861	-0.024	-0.022	-0.022
^{242}Pu	102.747	102.805	102.829	-2.739	-2.841	-2.865	0.049	0.036	0.036
^{241}Am	101.858	101.842	101.85	-1.83	-1.848	-1.854	0.006	0.005	0.005
^{243}Am	101.764	101.755	101.769	-1.735	-1.771	-1.784	0.016	0.015	0.015
^{10}B	100.026	100.008	100.008	0	-0.005	-0.005	0.001	0	0
ALL	38.897	39.275	38.635	61.097	60.713	61.355	0.023	0.01	0.01

Table 20. Components of the reactivity worth due to capture, fission and scattering in percents of the total reactivity worth (sub-phase 1)

	Capture / Total					Fission / Total					Scattering / Total				
Case	CEA APOLLO2 281G	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	CEA APOLLO2 281G	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	CEA APOLLO2 281G	EMS SCALE6.1 XSDRNPM 238G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy
^{95}Mo	99.306	102.629	102.395	102.396	100.469	-0.008	0	0	0	0	0.8	-2.405	-2.395	-2.396	-3.155
^{99}Tc	99.932	99.959	99.946	99.963	99.884	-0.001	0	0	0	0	0.094	0.042	0.054	0.039	0
^{101}Ru	99.338	99.385	99.365	99.356	99.36	-0.002	0	0	0	0	0.393	0.619	0.636	0.643	0.301
^{103}Rh	100.015	99.962	99.962	99.962	99.926	0	0	0	0	0	0.031	0.039	-0.039	-0.039	0
^{109}Ag	100.102	100.024	100.024	100.018	100	-0.001	0	0	0	0	0.016	-0.022	0.021	-0.023	0
^{133}Cs	99.838	99.776	99.769	99.773	99.922	-0.002	0	0	0	0	0.085	0.224	0.23	0.227	-0.082
^{143}Nd	99.982	100.153	100.167	100.182	99.791	-0.002	0	0	0	0	0.048	-0.154	-0.166	-0.181	0.073
^{145}Nd	99.823	100.458	100.45	100.501	99.407	-0.005	0	0	0	0	0.232	-0.459	-0.45	-0.5	-0.293
^{147}Sm	99.583	99.984	99.976	99.968	99.607	-0.014	0	0	0	0	0.012	0.016	0.026	0.033	0
^{149}Sm	100.052	99.994	100	100.013	100	0	0	0	0	0	0	0.001	0.001	0	0
^{150}Sm	101.926	97.588	97.47	97.571	101.885	-0.002	0	0	0	0	-1.797	2.416	2.53	2.426	-1.897
^{151}Sm	100.01	99.999	99.998	99.998	100	0	0	0	0	0	-0.001	0.002	0.002	0.002	0
^{152}Sm	98.396	104.655	104.503	104.456	99.306	-0.001	0	0	0	0	1.197	-4.655	-4.502	-4.454	-1.279
^{153}Eu	100.023	99.979	99.979	99.976	99.85	-0.002	0	0	0	0	0.013	0.02	0.023	0.022	0
^{155}Gd	100.004	100	99.998	99.998	100	0	0	0	0	0	0.001	-0.001	0.001	0.001	0
^{235}U	-20.325	3.65	3.626	3.586	-	120.383	96.34	96.363	96.402	-	-0.008	0.011	0.012	0.013	-
^{236}U	102.889	107.015	107.011	107.051	104.307	-3.424	-4.8	-4.819	-4.85	-4.033	0.244	-2.216	-2.193	-2.202	-1.407
^{237}Np	101.287	101.235	101.229	104.39	101.293	-1.27	-1.296	-1.292	-1.348	-1.294	0.023	0.06	0.061	0.064	0
^{238}Pu	104.817	104.858	104.846	104.858	104.913	-4.819	-4.932	-4.922	-4.929	-4.753	0.011	0.073	0.074	0.073	-0.17
^{239}Pu	-354.24	-362.631	-358.006	-346.611	-319.535	454.386	462.771	458.145	446.746	436.747	-0.066	-0.136	-0.138	-0.136	-0.043
^{240}Pu	100.666	101.353	101.163	101.217	101.234	-0.618	-0.922	-0.909	-0.934	-0.764	0.004	-0.43	-0.254	-0.284	-0.359
^{241}Pu	-101.83	-102.632	-101.345	-102.373	-95.796	201.895	201.6	201.381	202.408	197.765	-0.024	-0.036	-0.037	-0.037	0
^{242}Pu	101.543	102.45	102.452	102.463	101.78	-1.534	-1.803	-1.803	-1.82	-1.519	0.049	-0.647	-0.647	-0.644	-0.506
^{241}Am	100.979	100.947	100.946	100.945	100.944	-0.951	-0.959	-0.959	-0.959	-0.952	0.006	0.014	0.014	0.013	0
^{243}Am	101.074	101.044	101.035	101.048	101.369	-1.045	-1.077	-1.074	-1.081	-1.09	0.016	0.034	0.036	0.036	-0.273
^{10}B	100.026	100	100	100	100	0	0	0	0	0	0.001	0.002	0.002	0.002	0
ALL	87.31	-	-	-	-	12.684	-	-	-	-	0.023	-	-	-	-

3.2 Sub-phase 2 results

The calculation results for sub-phase 2 and their analysis are presented in Sections 3.2.1 to 3.2.4

3.2.1 Effective multiplication factor

Calculations of the k_{eff} are presented in Figures 17 and 18. Corresponding values are given in Table 21.

The same trends than in sub-phase 1 are observed in sub-phase 2. Differences mainly depend on the code system and not on the case number. CASMO5 and APOLLO2 calculations are in the best agreement with TRIPOLI4, just like MCNP5 from GRS and CEA. SCALE6 calculations by EMS, ORNL and VUJE agree in the underestimation of the k_{eff} by 600 to 800 pcm. Cases 28 and 29, which were not in sub-phase 1, show similar results as cases 0 to 27.

The only difference concerns the calculation of case 28 where EMS calculations are underestimated by 900 pcm, corresponding to an increase of 300 pcm compared to other cases. The same is observed for calculations using CASMO5, SCALE6, DRAGON3 and GMVP-II with an increase of the underestimation by 300 to 1000 pcm.

Figure 17. Absolute difference in the effective multiplication factor k_{eff} for cases 0 to 14 of sub-phase 2

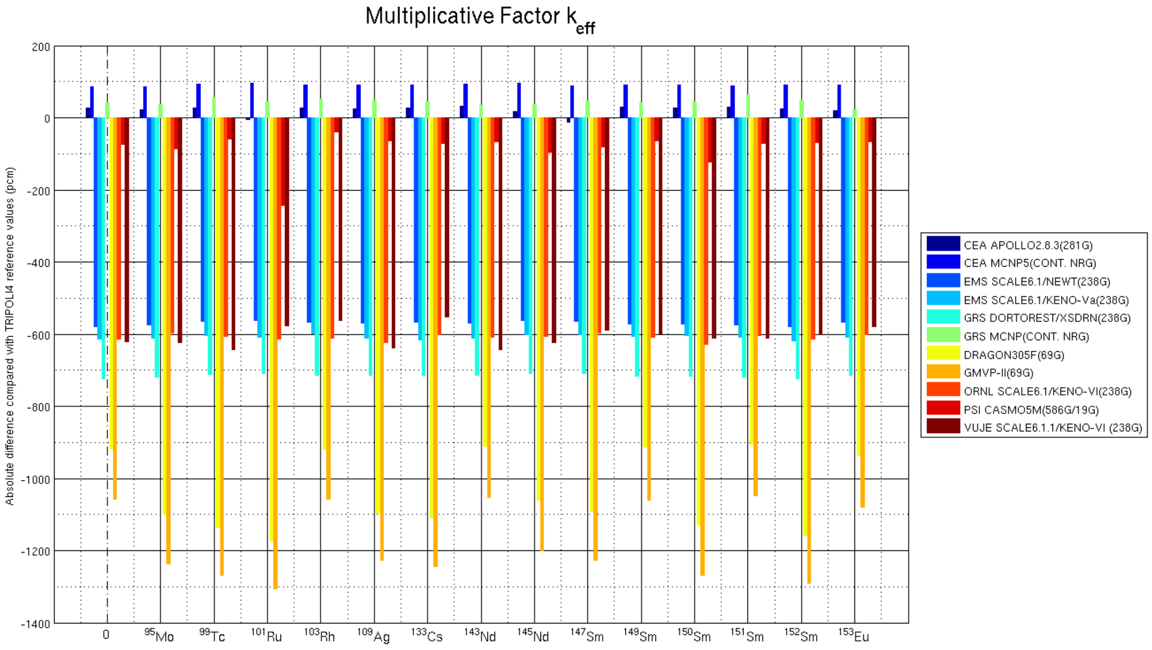
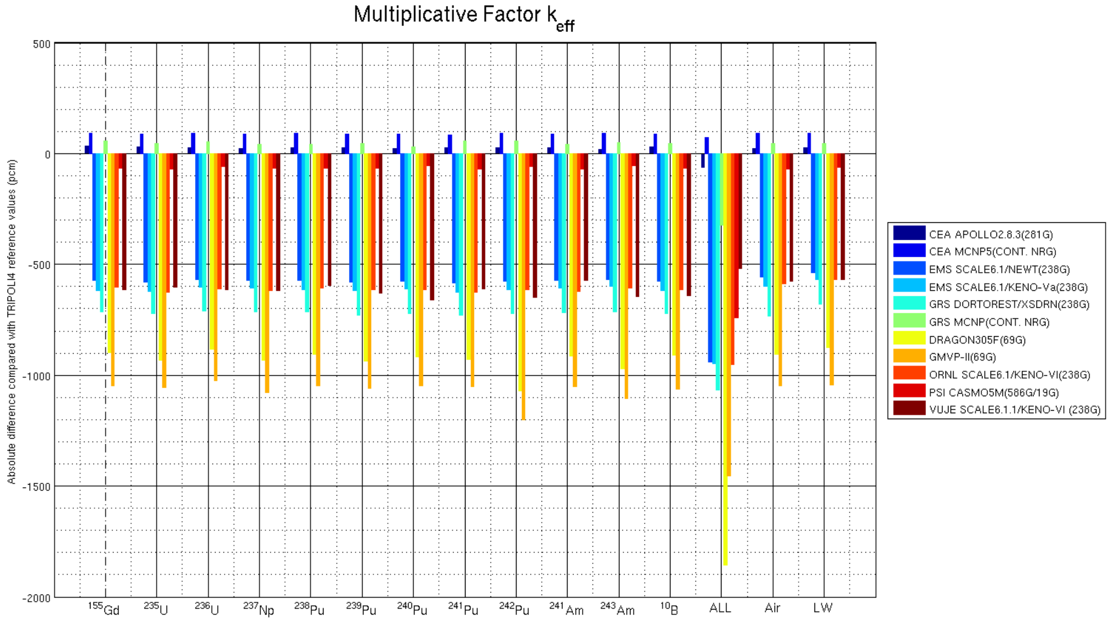


Figure 18. Absolute difference in the effective multiplication factor k_{eff} for cases 15 to 29 of sub-phase 2



3.2.2 Neutron flux

Comparisons of the integrated neutron flux over the central fuel cell are illustrated in Figures 19 and 20, and calculation results are reported in Table 22.

All of them succeed in the calculation of this parameter within less than 1%, except for case 27, 28 and 29.

In case 27, where all BUC nuclides have been added to the central fuel cell, calculations using SCALE6 and GMVP-II are a bit more discrepant compared with TRIPOLI4, although they stay below 3%, though. Much more discrepant results are observed for case 28 and 29 where GRS calculations differ by more than 50% compared with TRIPOLI4. A large disagreement is also observed for GMVP-II and DRAGON3 calculations but only for the case corresponding to the substitution of UO_2 by air (case 28). Other calculation codes all agree within 2% compared with TRIPOLI4.

Table 21. k_{eff} calculations (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOR EST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	1.38705	1.386780(27)	1.387630(6)	1.38099	1.380650(60)	1.37954	1.387190(70)	1.37761	1.376200(19)	1.380650(99)	1.38604	1.380570(330)
^{95}Mo	1.38271	1.382480(27)	1.383350(6)	1.37673	1.376360(60)	1.37528	1.382850(70)	1.37149	1.370110(19)	1.376510(99)	1.38162	1.376240(290)
^{99}Tc	1.38186	1.381580(27)	1.382510(6)	1.37593	1.375550(60)	1.37447	1.382140(70)	1.37022	1.368900(19)	1.375530(99)	1.381	1.375160(270)
^{101}Ru	1.38167	1.381730(27)	1.382680(6)	1.3761	1.375650(60)	1.37465	1.382170(70)	1.37	1.368680(19)	1.375590(99)	1.37931	1.375970(290)
^{103}Rh	1.38048	1.380200(27)	1.381100(6)	1.37452	1.374220(60)	1.37305	1.380720(70)	1.37099	1.369630(19)	1.374090(99)	1.3798	1.374590(320)
^{109}Ag	1.38259	1.382340(27)	1.383240(6)	1.37664	1.376220(60)	1.37519	1.382840(70)	1.37136	1.370080(19)	1.376100(99)	1.38171	1.375960(290)
^{133}Cs	1.38225	1.381970(27)	1.382890(6)	1.3763	1.375800(60)	1.37484	1.382420(70)	1.37089	1.369540(19)	1.375950(99)	1.38125	1.376440(280)
^{143}Nd	1.37994	1.379630(27)	1.380560(6)	1.37394	1.373510(60)	1.37249	1.379980(70)	1.37053	1.369100(19)	1.373540(99)	1.37897	1.373200(310)
^{145}Nd	1.38047	1.380310(27)	1.381260(6)	1.37468	1.374310(60)	1.37322	1.380680(70)	1.3697	1.368300(19)	1.374250(99)	1.37935	1.374070(320)
^{147}Sm	1.38144	1.381570(27)	1.382460(6)	1.37592	1.375550(60)	1.37447	1.382040(70)	1.37065	1.369310(19)	1.375610(99)	1.38077	1.375670(310)
^{149}Sm	1.38028	1.379980(27)	1.380900(6)	1.37426	1.373910(60)	1.37281	1.380400(70)	1.37086	1.369380(19)	1.373900(99)	1.37934	1.374000(290)
^{150}Sm	1.38001	1.379750(27)	1.380650(6)	1.37404	1.373710(60)	1.37259	1.380190(70)	1.36847	1.367070(19)	1.373480(99)	1.37852	1.373630(340)
^{151}Sm	1.37973	1.379430(27)	1.380320(6)	1.37369	1.373350(60)	1.37225	1.380060(70)	1.37038	1.368960(19)	1.373390(99)	1.37872	1.373320(290)
^{152}Sm	1.38311	1.382860(27)	1.383760(6)	1.37707	1.376670(60)	1.37562	1.383350(70)	1.37128	1.369940(19)	1.376720(99)	1.38218	1.376860(280)
^{153}Eu	1.37981	1.379620(27)	1.380540(6)	1.37394	1.373530(60)	1.37248	1.379850(70)	1.37025	1.368830(19)	1.373620(99)	1.37896	1.373820(300)
^{155}Gd	1.38001	1.379670(27)	1.380600(6)	1.37397	1.373490(60)	1.37253	1.380250(70)	1.37068	1.369190(19)	1.373650(99)	1.379	1.373520(310)
^{235}U	1.39134	1.391050(27)	1.391930(6)	1.38526	1.384830(60)	1.38383	1.391500(70)	1.38173	1.380490(18)	1.384810(99)	1.39035	1.385030(280)
^{236}U	1.38478	1.384520(27)	1.385440(6)	1.37886	1.378490(60)	1.37741	1.385050(70)	1.37571	1.374280(19)	1.378430(99)	1.38396	1.378370(290)
^{237}Np	1.38028	1.380060(27)	1.380930(6)	1.37436	1.373986(60)	1.37291	1.380470(70)	1.37075	1.369290(19)	1.373870(99)	1.37942	1.373880(300)
^{238}Pu	1.37965	1.379370(27)	1.380270(6)	1.37366	1.373251(60)	1.37222	1.379790(70)	1.3703	1.368890(19)	1.373290(99)	1.3787	1.373430(280)
^{239}Pu	1.39296	1.392680(27)	1.393540(6)	1.38687	1.386507(60)	1.38538	1.393140(70)	1.38332	1.382080(18)	1.386560(99)	1.39203	1.386390(300)
^{240}Pu	1.3834	1.383170(27)	1.384040(6)	1.37743	1.377064(60)	1.37597	1.383470(70)	1.37401	1.372710(19)	1.377050(99)	1.38263	1.376570(320)
^{241}Pu	1.39385	1.393570(27)	1.394410(6)	1.38774	1.387307(60)	1.3863	1.394160(70)	1.38428	1.383070(18)	1.387320(99)	1.39287	1.387480(310)
^{242}Pu	1.38471	1.384460(27)	1.385360(6)	1.37871	1.378337(60)	1.37726	1.385050(70)	1.37377	1.372470(18)	1.378310(99)	1.3839	1.377960(300)
^{241}Am	1.38061	1.380350(27)	1.381230(6)	1.37462	1.374294(60)	1.37317	1.380760(70)	1.37122	1.369830(19)	1.374150(99)	1.37967	1.374640(270)
^{243}Am	1.3819	1.381710(27)	1.382610(6)	1.37603	1.375740(60)	1.37457	1.382200(70)	1.37199	1.370670(19)	1.375650(99)	1.38117	1.375250(300)
^{10}B	1.38164	1.381350(27)	1.382240(6)	1.3756	1.375180(60)	1.37415	1.381800(70)	1.37227	1.370740(19)	1.375210(99)	1.38071	1.374940(300)
ALL	1.33871	1.339320(27)	1.340062(6)	1.32993	1.329830(60)	1.32865	1.336100(70)	1.32077	1.324790(26)	1.329800(99)	1.33191	1.334130(320)
Air	1.39319	1.392957(27)	1.393861(6)	1.38739	1.386973(60)	1.38563	1.393410(70)	1.38391	1.382470(18)	1.387070(100)	1.39225	1.387220(290)
LW	1.39401	1.393740(27)	1.394670(6)	1.38836	1.388078(60)	1.38694	1.394180(70)	1.38498	1.383300(18)	1.388060(99)	1.39312	1.388050(280)

Figure 19. Relative difference in the neutron flux for cases 0 to 14 of sub-phase 2

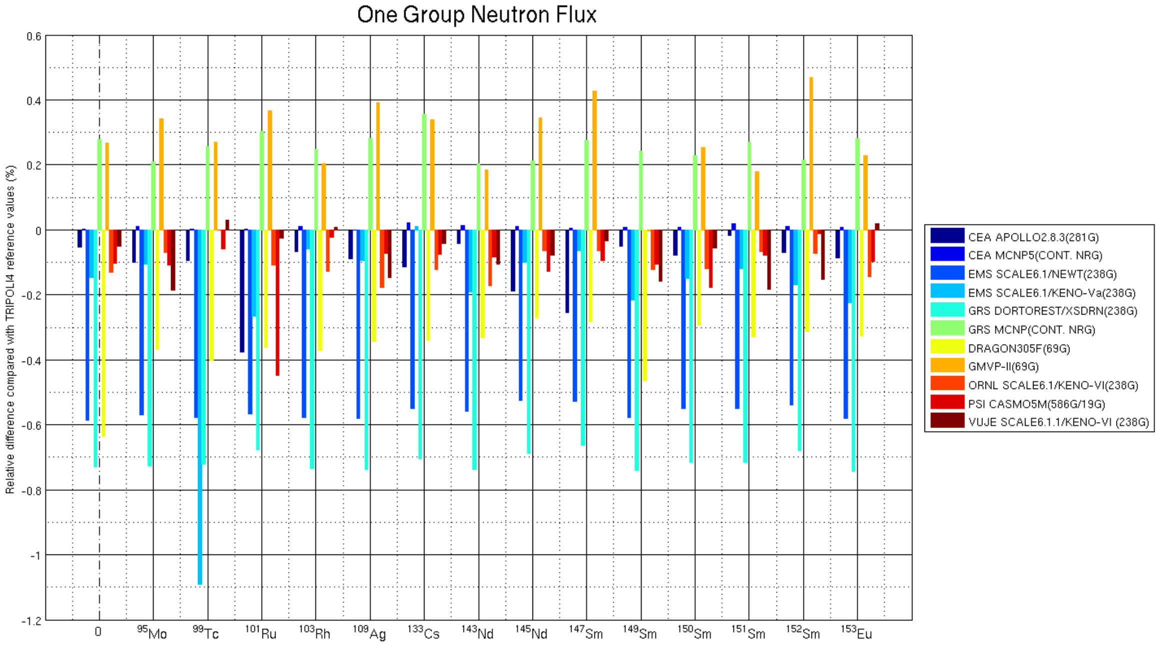


Figure 20. Relative difference in the neutron flux for cases 15 to 29 of sub-phase 2

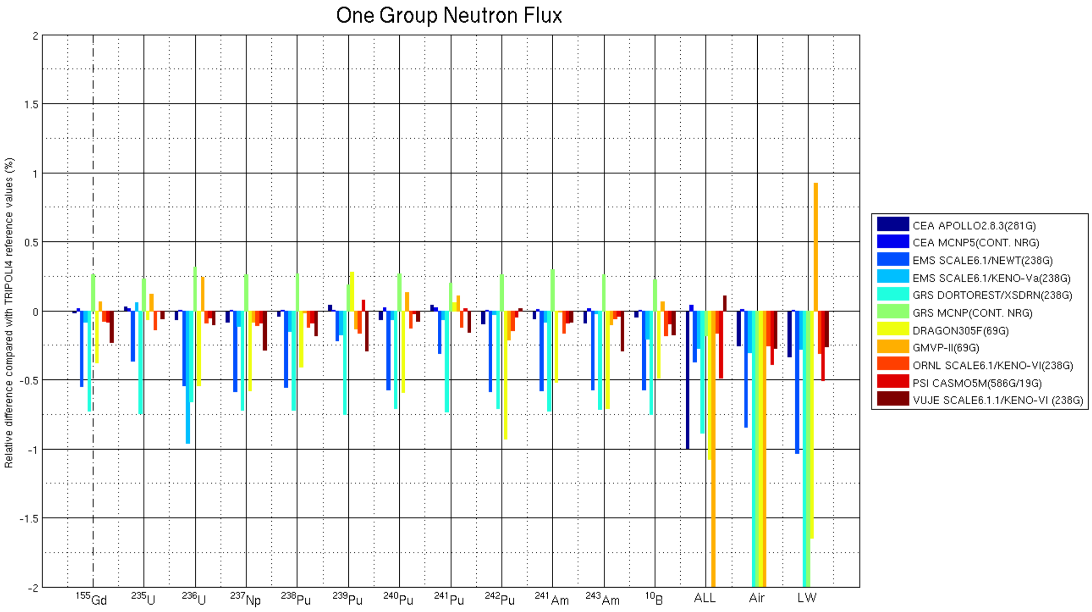


Table 22. Neutron flux in cm^{-2}.s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	2.479E-01	2.480E-01	2.480E-01	2.466E-01	2.476E-01	2.462E-01	2.487E-01	2.464E-01	2.487E-01	2.477E-01	2.477E-01	2.479E-01
^{95}Mo	2.452E-01	2.455E-01	2.455E-01	2.441E-01	2.452E-01	2.437E-01	2.460E-01	2.446E-01	2.463E-01	2.453E-01	2.452E-01	2.450E-01
^{99}Tc	2.449E-01	2.452E-01	2.452E-01	2.438E-01	2.425E-01	2.434E-01	2.458E-01	2.442E-01	2.458E-01	2.452E-01	2.450E-01	2.452E-01
^{101}Ru	2.443E-01	2.453E-01	2.453E-01	2.439E-01	2.446E-01	2.436E-01	2.460E-01	2.444E-01	2.462E-01	2.450E-01	2.442E-01	2.452E-01
^{103}Rh	2.443E-01	2.445E-01	2.445E-01	2.431E-01	2.444E-01	2.427E-01	2.451E-01	2.436E-01	2.450E-01	2.442E-01	2.444E-01	2.445E-01
^{109}Ag	2.454E-01	2.456E-01	2.456E-01	2.442E-01	2.454E-01	2.438E-01	2.463E-01	2.448E-01	2.466E-01	2.452E-01	2.454E-01	2.452E-01
^{133}Cs	2.450E-01	2.453E-01	2.454E-01	2.440E-01	2.454E-01	2.436E-01	2.462E-01	2.445E-01	2.462E-01	2.450E-01	2.451E-01	2.452E-01
^{143}Nd	2.437E-01	2.438E-01	2.438E-01	2.424E-01	2.433E-01	2.420E-01	2.443E-01	2.430E-01	2.442E-01	2.434E-01	2.436E-01	2.435E-01
^{145}Nd	2.438E-01	2.443E-01	2.443E-01	2.430E-01	2.440E-01	2.426E-01	2.448E-01	2.436E-01	2.451E-01	2.441E-01	2.440E-01	2.441E-01
^{147}Sm	2.445E-01	2.451E-01	2.451E-01	2.438E-01	2.450E-01	2.435E-01	2.458E-01	2.444E-01	2.462E-01	2.450E-01	2.449E-01	2.450E-01
^{149}Sm	2.440E-01	2.441E-01	2.441E-01	2.427E-01	2.436E-01	2.423E-01	2.447E-01	2.430E-01	2.441E-01	2.438E-01	2.439E-01	2.437E-01
^{150}Sm	2.437E-01	2.438E-01	2.439E-01	2.425E-01	2.435E-01	2.421E-01	2.444E-01	2.431E-01	2.445E-01	2.436E-01	2.434E-01	2.437E-01
^{151}Sm	2.435E-01	2.435E-01	2.436E-01	2.422E-01	2.432E-01	2.418E-01	2.442E-01	2.427E-01	2.440E-01	2.434E-01	2.434E-01	2.431E-01
^{152}Sm	2.455E-01	2.457E-01	2.457E-01	2.443E-01	2.453E-01	2.440E-01	2.462E-01	2.449E-01	2.468E-01	2.455E-01	2.456E-01	2.453E-01
^{153}Eu	2.439E-01	2.441E-01	2.441E-01	2.427E-01	2.436E-01	2.423E-01	2.448E-01	2.433E-01	2.447E-01	2.438E-01	2.439E-01	2.442E-01
^{155}Gd	2.436E-01	2.437E-01	2.437E-01	2.423E-01	2.435E-01	2.419E-01	2.443E-01	2.427E-01	2.438E-01	2.435E-01	2.435E-01	2.431E-01
^{235}U	2.466E-01	2.465E-01	2.466E-01	2.456E-01	2.467E-01	2.447E-01	2.471E-01	2.464E-01	2.468E-01	2.462E-01	2.465E-01	2.464E-01
^{236}U	2.466E-01	2.467E-01	2.467E-01	2.454E-01	2.444E-01	2.451E-01	2.475E-01	2.454E-01	2.473E-01	2.465E-01	2.466E-01	2.465E-01
^{237}Np	2.442E-01	2.444E-01	2.444E-01	2.429E-01	2.441E-01	2.426E-01	2.450E-01	2.429E-01	2.442E-01	2.441E-01	2.442E-01	2.437E-01
^{238}Pu	2.434E-01	2.435E-01	2.435E-01	2.421E-01	2.431E-01	2.417E-01	2.441E-01	2.425E-01	2.434E-01	2.432E-01	2.432E-01	2.430E-01
^{239}Pu	2.450E-01	2.449E-01	2.450E-01	2.444E-01	2.445E-01	2.431E-01	2.454E-01	2.456E-01	2.446E-01	2.445E-01	2.451E-01	2.442E-01
^{240}Pu	2.459E-01	2.460E-01	2.461E-01	2.446E-01	2.459E-01	2.443E-01	2.467E-01	2.446E-01	2.464E-01	2.457E-01	2.460E-01	2.459E-01
^{241}Pu	2.471E-01	2.470E-01	2.471E-01	2.463E-01	2.469E-01	2.452E-01	2.475E-01	2.472E-01	2.473E-01	2.467E-01	2.470E-01	2.466E-01
^{242}Pu	2.465E-01	2.468E-01	2.468E-01	2.453E-01	2.467E-01	2.450E-01	2.474E-01	2.445E-01	2.462E-01	2.464E-01	2.466E-01	2.468E-01
^{241}Am	2.443E-01	2.445E-01	2.445E-01	2.431E-01	2.443E-01	2.427E-01	2.452E-01	2.432E-01	2.445E-01	2.441E-01	2.443E-01	2.443E-01
^{243}Am	2.451E-01	2.454E-01	2.454E-01	2.439E-01	2.453E-01	2.436E-01	2.460E-01	2.436E-01	2.451E-01	2.452E-01	2.453E-01	2.446E-01
^{10}B	2.447E-01	2.448E-01	2.449E-01	2.434E-01	2.443E-01	2.430E-01	2.454E-01	2.437E-01	2.450E-01	2.444E-01	2.446E-01	2.444E-01
ALL	2.109E-01	2.130E-01	2.131E-01	2.122E-01	2.124E-01	2.111E-01	2.126E-01	2.107E-01	2.061E-01	2.126E-01	2.119E-01	2.132E-01
Air	2.536E-01	2.542E-01	2.542E-01	2.521E-01	2.535E-01	N.R.	N.R.	1.820E-01	1.850E-01	2.536E-01	2.532E-01	2.535E-01
LW	2.546E-01	2.554E-01	2.555E-01	2.528E-01	2.547E-01	N.R.	N.R.	2.512E-01	2.578E-01	2.547E-01	2.542E-01	2.548E-01

3.2.3 Reaction rates

Comparisons of reaction rate calculations performed on ^{235}U, ^{238}U and ^{16}O are illustrated in Figure 21, for the first case (case 0 without BUC nuclide) as the same conclusions can be observed for cases 0 to 27. The full content of calculation results are reported in Table 23 to Table 30.

The same conclusions than in sub-phase 1 can be formulated, in spite of the difference in the central fuel ^{235}U enrichment which is changed from 3% to 0.7% in sub-phase 2. Results are in the same agreement with TRIPOLI4, except for the absorption and production rate on ^{235}U which is slightly less accurate with calculations based on GMVP-II where the calculation bias moves from -1% to more than 2%.

Comparisons of reaction rate calculations on the BUC nuclide are illustrated in Figure 22 to Figure 26, with the full list of results in Table 31 to Table 33.

Results are quite different to the ones of sub-phase 1, as the higher concentration of the added BUC nuclide in the central fuel cell leads to limitations in the calculation of the self-shielding effect. This is especially true for DRAGON3 and GMVP-II calculations based on 69 energy groups where the absorption rates are underestimated by more than 10% for most of the fission products. A better agreement is observed for actinides, with the exception of ^{242}Pu where a disagreement of more than 50% is observed. The CASMO5 calculation overestimates the absorption rate of ^{101}Ru in sub-phase 2 by 35% whereas it was predicted within 1% in sub-phase 1. The reason is that the tabulation of self-shielded resonance cross-sections as a function of background cross-section in the library used does not cover the concentration of this nuclide in sub-phase 2. Less pronounced differences in the deviations of CASMO5 results from the reference solution between sub-phases 1 and 2, which are probably due to the same cause, can also be observed for ^{95}Mo, ^{99}Tc, ^{145}Nd and ^{147}Sm. The better agreement of the CASMO5 absorption rates for ^{95}Mo and ^{99}Tc with the reference values than in sub-phase 1 thus appears to be due to coincidentally compensating effects. Additional calculations performed with 35 groups, the default group structure for MOX calculations in CASMO5, have been reported by PSI. They show that the ^{240}Pu and ^{242}Pu absorption rates are increased by around 6% which cancels most of the underestimation previously observed. An increase of the difference is also observed for APOLLO2 calculations, especially for resonant nuclides like ^{101}Ru and ^{147}Sm where the overprediction reaches more than 6%. For other nuclides thought, differences stay within 2% which is acceptable. One also should observe that most of the participants overestimate the absorption and production rates of case 27 (sum of all BUC nuclides) by more than 4%, making this case the case with the worst agreement in terms of self-shielding effects.

For scattering rates, the same trends than in sub-phase 1 can be observed, with an underprediction of calculations based on P0 scattering cross-sections. Most surprising are the results from PSI for ^{145}Nd and ^{147}Sm which are both overestimated by more than 30%, just like ^{150}Sm by 10%, a trend which was not observed in sub-phase 1.

Calculation of reaction rates on isotopes of air and light water (cases 28 and 29) are not presented as some misunderstandings in the specifications lead to inconsistent data in the results provided by the participants.

Figure 21. Relative difference in reaction rates of ^{235}U, ^{238}U and ^{16}O for case 0 of sub-phase 2

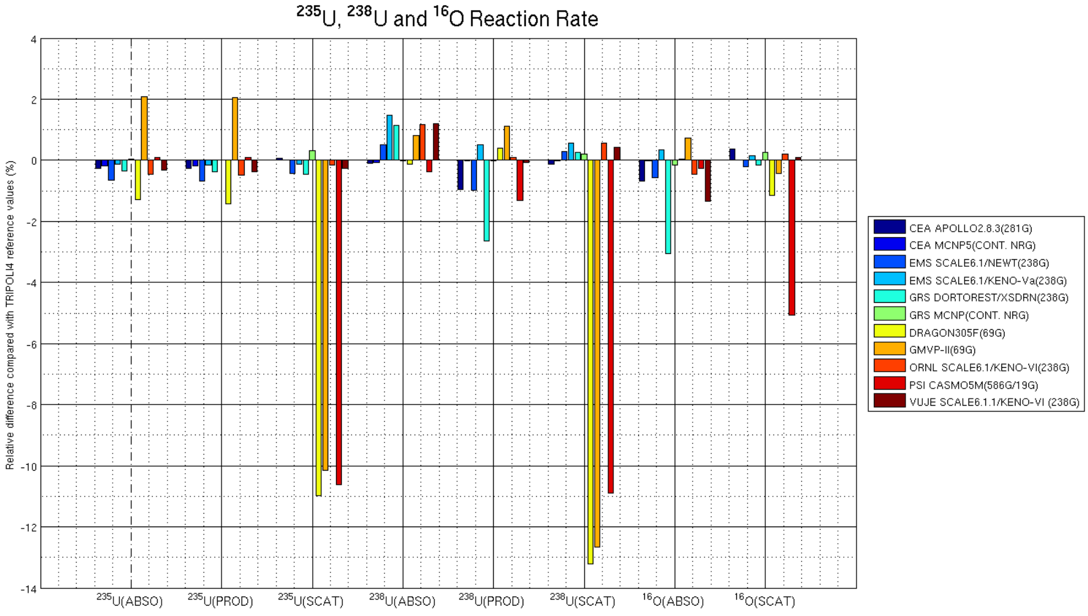


Table 23. Absorption rate on ^{235}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON 305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	4.177E-03	4.191E-03	4.183E-03	4.159E-03	4.174E-03	4.176E-03	4.196E-03	4.058E-03	4.226E-03	4.174E-03	4.202E-03	4.181E-03
^{95}Mo	4.003E-03	4.014E-03	4.007E-03	3.987E-03	4.009E-03	4.000E-03	4.015E-03	3.962E-03	4.098E-03	3.995E-03	4.018E-03	4.001E-03
^{99}Tc	4.020E-03	4.031E-03	4.024E-03	4.005E-03	3.862E-03	4.018E-03	4.038E-03	3.961E-03	4.098E-03	4.017E-03	4.047E-03	4.011E-03
^{101}Ru	4.059E-03	4.074E-03	4.067E-03	4.047E-03	4.050E-03	4.061E-03	4.080E-03	3.992E-03	4.138E-03	4.060E-03	4.061E-03	4.061E-03
^{103}Rh	3.960E-03	3.971E-03	3.964E-03	3.945E-03	3.966E-03	3.958E-03	3.978E-03	3.897E-03	4.010E-03	3.954E-03	3.980E-03	3.954E-03
^{109}Ag	4.043E-03	4.054E-03	4.048E-03	4.027E-03	4.036E-03	4.041E-03	4.060E-03	3.985E-03	4.127E-03	4.038E-03	4.063E-03	4.029E-03
^{133}Cs	4.025E-03	4.036E-03	4.031E-03	4.011E-03	4.022E-03	4.024E-03	4.043E-03	3.971E-03	4.110E-03	4.021E-03	4.043E-03	4.016E-03
^{143}Nd	3.805E-03	3.809E-03	3.804E-03	3.789E-03	3.784E-03	3.797E-03	3.813E-03	3.762E-03	3.841E-03	3.798E-03	3.812E-03	3.778E-03
^{145}Nd	3.917E-03	3.925E-03	3.920E-03	3.903E-03	3.918E-03	3.914E-03	3.927E-03	3.892E-03	4.006E-03	3.911E-03	3.928E-03	3.911E-03
^{147}Sm	4.027E-03	4.041E-03	4.033E-03	4.014E-03	4.018E-03	4.028E-03	4.044E-03	3.976E-03	4.118E-03	4.017E-03	4.047E-03	4.014E-03
^{149}Sm	3.866E-03	3.875E-03	3.868E-03	3.850E-03	3.849E-03	3.861E-03	3.872E-03	3.793E-03	3.879E-03	3.864E-03	3.878E-03	3.858E-03
^{150}Sm	3.830E-03	3.835E-03	3.830E-03	3.814E-03	3.820E-03	3.823E-03	3.837E-03	3.835E-03	3.937E-03	3.820E-03	3.834E-03	3.817E-03
^{151}Sm	3.729E-03	3.731E-03	3.725E-03	3.713E-03	3.723E-03	3.719E-03	3.733E-03	3.691E-03	3.762E-03	3.718E-03	3.732E-03	3.720E-03
^{152}Sm	4.036E-03	4.048E-03	4.040E-03	4.022E-03	4.025E-03	4.036E-03	4.050E-03	3.988E-03	4.134E-03	4.031E-03	4.057E-03	4.031E-03
^{153}Eu	3.920E-03	3.929E-03	3.923E-03	3.904E-03	3.920E-03	3.916E-03	3.934E-03	3.875E-03	3.985E-03	3.912E-03	3.933E-03	3.912E-03
^{155}Gd	3.738E-03	3.739E-03	3.733E-03	3.721E-03	3.726E-03	3.728E-03	3.742E-03	3.685E-03	3.751E-03	3.726E-03	3.740E-03	3.718E-03
^{235}U	1.327E-02	1.326E-02	1.324E-02	1.321E-02	1.320E-02	1.321E-02	1.327E-02	1.317E-02	1.317E-02	1.320E-02	1.324E-02	1.323E-02
^{236}U	4.127E-03	4.141E-03	4.133E-03	4.111E-03	3.944E-03	4.127E-03	4.148E-03	4.014E-03	4.168E-03	4.115E-03	4.151E-03	4.110E-03
^{237}Np	3.944E-03	3.955E-03	3.948E-03	3.930E-03	3.943E-03	3.942E-03	3.955E-03	3.856E-03	3.960E-03	3.939E-03	3.960E-03	3.944E-03
^{238}Pu	3.726E-03	3.729E-03	3.723E-03	3.710E-03	3.714E-03	3.717E-03	3.730E-03	3.670E-03	3.731E-03	3.720E-03	3.730E-03	3.736E-03
^{239}Pu	2.966E-03	2.964E-03	2.960E-03	2.960E-03	2.952E-03	2.955E-03	2.957E-03	2.985E-03	2.903E-03	2.954E-03	2.956E-03	2.954E-03
^{240}Pu	4.077E-03	4.090E-03	4.083E-03	4.062E-03	4.078E-03	4.077E-03	4.093E-03	3.973E-03	4.111E-03	4.071E-03	4.100E-03	4.070E-03
^{241}Pu	3.306E-03	3.304E-03	3.300E-03	3.294E-03	3.298E-03	3.294E-03	3.301E-03	3.295E-03	3.270E-03	3.292E-03	3.301E-03	3.287E-03
^{242}Pu	4.126E-03	4.140E-03	4.132E-03	4.110E-03	4.127E-03	4.126E-03	4.143E-03	4.001E-03	4.147E-03	4.122E-03	4.151E-03	4.122E-03
^{241}Am	3.923E-03	3.932E-03	3.926E-03	3.908E-03	3.921E-03	3.919E-03	3.944E-03	3.840E-03	3.936E-03	3.917E-03	3.939E-03	3.914E-03
^{243}Am	4.061E-03	4.076E-03	4.068E-03	4.047E-03	4.067E-03	4.062E-03	4.082E-03	3.953E-03	4.085E-03	4.057E-03	4.085E-03	4.065E-03
^{10}B	3.896E-03	3.902E-03	3.896E-03	3.879E-03	3.879E-03	3.890E-03	3.904E-03	3.819E-03	3.917E-03	3.889E-03	3.876E-03	3.895E-03
ALL	1.493E-03	5.472E-03	1.793E-03	N.R.	N.R.	1.496E-03	1.490E-03	5.450E-03	4.877E-03	1.496E-03	1.464E-03	5.469E-03

Table 24. Production rate on ^{235}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTORES T 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	8.480E-03	8.509E-03	8.491E-03	8.441E-03	8.473E-03	8.476E-03	8.519E-03	8.220E-03	8.571E-03	8.472E-03	8.528E-03	8.486E-03
^{95}Mo	8.121E-03	8.143E-03	8.128E-03	8.086E-03	8.131E-03	8.112E-03	8.144E-03	8.026E-03	8.310E-03	8.103E-03	8.150E-03	8.113E-03
^{99}Tc	8.157E-03	8.181E-03	8.166E-03	8.124E-03	7.828E-03	8.151E-03	8.194E-03	8.027E-03	8.314E-03	8.148E-03	8.211E-03	8.137E-03
^{101}Ru	8.242E-03	8.274E-03	8.259E-03	8.215E-03	8.221E-03	8.244E-03	8.284E-03	8.091E-03	8.399E-03	8.243E-03	8.251E-03	8.243E-03
^{103}Rh	8.031E-03	8.054E-03	8.040E-03	7.999E-03	8.041E-03	8.024E-03	8.069E-03	7.889E-03	8.123E-03	8.018E-03	8.070E-03	8.017E-03
^{109}Ag	8.205E-03	8.230E-03	8.216E-03	8.171E-03	8.189E-03	8.200E-03	8.241E-03	8.075E-03	8.372E-03	8.193E-03	8.243E-03	8.175E-03
^{133}Cs	8.169E-03	8.192E-03	8.180E-03	8.137E-03	8.159E-03	8.164E-03	8.205E-03	8.046E-03	8.339E-03	8.157E-03	8.202E-03	8.149E-03
^{143}Nd	7.708E-03	7.717E-03	7.706E-03	7.674E-03	7.663E-03	7.690E-03	7.724E-03	7.606E-03	7.771E-03	7.692E-03	7.719E-03	7.652E-03
^{145}Nd	7.944E-03	7.961E-03	7.950E-03	7.914E-03	7.944E-03	7.935E-03	7.963E-03	7.881E-03	8.121E-03	7.929E-03	7.963E-03	7.930E-03
^{147}Sm	8.175E-03	8.204E-03	8.187E-03	8.146E-03	8.156E-03	8.174E-03	8.211E-03	8.058E-03	8.354E-03	8.153E-03	8.214E-03	8.146E-03
^{149}Sm	7.833E-03	7.850E-03	7.836E-03	7.797E-03	7.796E-03	7.820E-03	7.844E-03	7.670E-03	7.848E-03	7.825E-03	7.854E-03	7.814E-03
^{150}Sm	7.761E-03	7.771E-03	7.760E-03	7.726E-03	7.741E-03	7.744E-03	7.776E-03	7.765E-03	7.977E-03	7.738E-03	7.766E-03	7.732E-03
^{151}Sm	7.552E-03	7.555E-03	7.543E-03	7.516E-03	7.536E-03	7.528E-03	7.558E-03	7.459E-03	7.609E-03	7.525E-03	7.555E-03	7.531E-03
^{152}Sm	8.191E-03	8.217E-03	8.199E-03	8.159E-03	8.165E-03	8.188E-03	8.220E-03	8.081E-03	8.387E-03	8.178E-03	8.229E-03	8.177E-03
^{153}Eu	7.953E-03	7.973E-03	7.959E-03	7.920E-03	7.951E-03	7.943E-03	7.981E-03	7.845E-03	8.075E-03	7.935E-03	7.976E-03	7.935E-03
^{155}Gd	7.568E-03	7.571E-03	7.558E-03	7.532E-03	7.541E-03	7.545E-03	7.576E-03	7.445E-03	7.583E-03	7.541E-03	7.568E-03	7.527E-03
^{235}U	2.684E-02	2.681E-02	2.678E-02	2.671E-02	2.669E-02	2.671E-02	2.684E-02	2.661E-02	2.660E-02	2.669E-02	2.677E-02	2.675E-02
^{236}U	8.377E-03	8.406E-03	8.389E-03	8.343E-03	7.996E-03	8.375E-03	8.422E-03	8.133E-03	8.454E-03	8.351E-03	8.423E-03	8.341E-03
^{237}Np	7.999E-03	8.022E-03	8.007E-03	7.968E-03	7.994E-03	7.992E-03	8.022E-03	7.805E-03	8.024E-03	7.986E-03	8.030E-03	7.998E-03
^{238}Pu	7.545E-03	7.550E-03	7.538E-03	7.510E-03	7.518E-03	7.523E-03	7.551E-03	7.417E-03	7.543E-03	7.529E-03	7.548E-03	7.562E-03
^{239}Pu	5.973E-03	5.970E-03	5.961E-03	5.960E-03	5.944E-03	5.948E-03	5.955E-03	6.003E-03	5.833E-03	5.948E-03	5.950E-03	5.948E-03
^{240}Pu	8.274E-03	8.301E-03	8.286E-03	8.241E-03	8.275E-03	8.271E-03	8.305E-03	8.044E-03	8.332E-03	8.260E-03	8.317E-03	8.257E-03
^{241}Pu	6.678E-03	6.673E-03	6.665E-03	6.651E-03	6.658E-03	6.649E-03	6.666E-03	6.643E-03	6.593E-03	6.647E-03	6.663E-03	6.636E-03
^{242}Pu	8.375E-03	8.405E-03	8.388E-03	8.340E-03	8.375E-03	8.373E-03	8.410E-03	8.104E-03	8.409E-03	8.365E-03	8.424E-03	8.364E-03
^{241}Am	7.955E-03	7.974E-03	7.960E-03	7.921E-03	7.949E-03	7.945E-03	7.997E-03	7.770E-03	7.973E-03	7.940E-03	7.985E-03	7.936E-03
^{243}Am	8.243E-03	8.273E-03	8.257E-03	8.212E-03	8.252E-03	8.242E-03	8.285E-03	8.008E-03	8.284E-03	8.232E-03	8.289E-03	8.250E-03
^{10}B	7.898E-03	7.910E-03	7.897E-03	7.860E-03	7.861E-03	7.881E-03	7.913E-03	7.724E-03	7.929E-03	7.881E-03	7.853E-03	7.894E-03
ALL	2.956E-03	1.083E-02	4.632E-04	N.R.	N.R.	2.960E-03	2.949E-03	1.088E-02	9.708E-03	2.960E-03	2.901E-03	1.081E-02

Table 25. Scattering rate on ^{235}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	4.431E-04	4.429E-04	4.429E-04	4.409E-04	4.422E-04	4.409E-04	4.445E-04	3.932E-04	3.979E-04	4.420E-04	3.963E-04	4.423E-04
^{95}Mo	4.373E-04	4.370E-04	4.370E-04	4.352E-04	4.365E-04	4.351E-04	4.384E-04	3.891E-04	3.927E-04	4.363E-04	3.906E-04	4.359E-04
^{99}Tc	4.366E-04	4.365E-04	4.364E-04	4.346E-04	4.304E-04	4.345E-04	4.380E-04	3.883E-04	3.918E-04	4.361E-04	3.903E-04	4.361E-04
^{101}Ru	4.368E-04	4.369E-04	4.369E-04	4.351E-04	4.358E-04	4.351E-04	4.386E-04	3.889E-04	3.926E-04	4.362E-04	3.888E-04	4.365E-04
^{103}Rh	4.345E-04	4.344E-04	4.344E-04	4.325E-04	4.341E-04	4.324E-04	4.359E-04	3.865E-04	3.893E-04	4.335E-04	3.884E-04	4.341E-04
^{109}Ag	4.375E-04	4.374E-04	4.374E-04	4.355E-04	4.369E-04	4.354E-04	4.390E-04	3.896E-04	3.933E-04	4.364E-04	3.910E-04	4.364E-04
^{133}Cs	4.370E-04	4.368E-04	4.369E-04	4.351E-04	4.366E-04	4.350E-04	4.386E-04	3.889E-04	3.925E-04	4.360E-04	3.905E-04	4.363E-04
^{143}Nd	4.329E-04	4.326E-04	4.326E-04	4.308E-04	4.315E-04	4.306E-04	4.338E-04	3.849E-04	3.873E-04	4.315E-04	3.862E-04	4.316E-04
^{145}Nd	4.343E-04	4.340E-04	4.341E-04	4.324E-04	4.335E-04	4.323E-04	4.353E-04	3.868E-04	3.899E-04	4.335E-04	3.875E-04	4.335E-04
^{147}Sm	4.365E-04	4.363E-04	4.363E-04	4.347E-04	4.358E-04	4.346E-04	4.378E-04	3.888E-04	3.924E-04	4.356E-04	3.899E-04	4.358E-04
^{149}Sm	4.334E-04	4.332E-04	4.332E-04	4.313E-04	4.320E-04	4.312E-04	4.346E-04	3.848E-04	3.868E-04	4.324E-04	3.867E-04	4.320E-04
^{150}Sm	4.331E-04	4.328E-04	4.328E-04	4.311E-04	4.319E-04	4.309E-04	4.341E-04	3.856E-04	3.883E-04	4.319E-04	3.860E-04	4.324E-04
^{151}Sm	4.323E-04	4.319E-04	4.319E-04	4.302E-04	4.312E-04	4.300E-04	4.335E-04	3.843E-04	3.866E-04	4.313E-04	3.856E-04	4.306E-04
^{152}Sm	4.378E-04	4.377E-04	4.377E-04	4.360E-04	4.367E-04	4.359E-04	4.390E-04	3.898E-04	3.938E-04	4.370E-04	3.916E-04	4.367E-04
^{153}Eu	4.338E-04	4.337E-04	4.337E-04	4.318E-04	4.328E-04	4.318E-04	4.352E-04	3.861E-04	3.888E-04	4.328E-04	3.873E-04	4.335E-04
^{155}Gd	4.326E-04	4.322E-04	4.322E-04	4.304E-04	4.316E-04	4.302E-04	4.336E-04	3.843E-04	3.864E-04	4.314E-04	3.859E-04	4.308E-04
^{235}U	1.681E-03	1.678E-03	1.679E-03	1.674E-03	1.678E-03	1.671E-03	1.683E-03	1.485E-03	1.487E-03	1.675E-03	1.490E-03	1.677E-03
^{236}U	4.404E-04	4.401E-04	4.401E-04	4.384E-04	4.343E-04	4.384E-04	4.419E-04	3.909E-04	3.950E-04	4.393E-04	3.939E-04	4.390E-04
^{237}Np	4.343E-04	4.342E-04	4.341E-04	4.323E-04	4.335E-04	4.322E-04	4.356E-04	3.850E-04	3.875E-04	4.333E-04	3.878E-04	4.329E-04
^{238}Pu	4.317E-04	4.314E-04	4.314E-04	4.296E-04	4.306E-04	4.294E-04	4.329E-04	3.833E-04	3.851E-04	4.305E-04	3.850E-04	4.307E-04
^{239}Pu	4.183E-04	4.178E-04	4.178E-04	4.172E-04	4.168E-04	4.159E-04	4.188E-04	3.677E-04	3.651E-04	4.169E-04	3.679E-04	4.161E-04
^{240}Pu	4.384E-04	4.382E-04	4.383E-04	4.363E-04	4.377E-04	4.363E-04	4.398E-04	3.889E-04	3.925E-04	4.373E-04	3.922E-04	4.375E-04
^{241}Pu	4.283E-04	4.276E-04	4.277E-04	4.267E-04	4.272E-04	4.256E-04	4.288E-04	3.776E-04	3.771E-04	4.268E-04	3.787E-04	4.265E-04
^{242}Pu	4.401E-04	4.400E-04	4.400E-04	4.381E-04	4.395E-04	4.380E-04	4.415E-04	3.888E-04	3.925E-04	4.391E-04	3.938E-04	4.396E-04
^{241}Am	4.344E-04	4.342E-04	4.342E-04	4.323E-04	4.335E-04	4.322E-04	4.360E-04	3.854E-04	3.879E-04	4.332E-04	3.878E-04	4.334E-04
^{243}Am	4.367E-04	4.367E-04	4.367E-04	4.348E-04	4.364E-04	4.348E-04	4.383E-04	3.867E-04	3.899E-04	4.360E-04	3.905E-04	4.353E-04
^{10}B	4.354E-04	4.351E-04	4.351E-04	4.332E-04	4.339E-04	4.331E-04	4.364E-04	3.865E-04	3.893E-04	4.340E-04	3.893E-04	4.340E-04
ALL	3.443E-04	1.343E-03	8.402E-04	N.R.	N.R.	3.440E-04	3.452E-04	1.126E-03	1.092E-03	3.451E-04	2.951E-04	1.344E-03

Table 26. Absorption rate on ^{238}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	6.342E-03	6.353E-03	6.349E-03	6.380E-03	6.457E-03	6.422E-03	6.364E-03	6.366E-03	6.452E-03	6.431E-03	6.342E-03	6.453E-03
^{95}Mo	6.240E-03	6.246E-03	6.242E-03	6.277E-03	6.339E-03	6.317E-03	6.245E-03	6.239E-03	6.297E-03	6.319E-03	6.223E-03	6.320E-03
^{99}Tc	6.155E-03	6.167E-03	6.162E-03	6.195E-03	6.149E-03	6.236E-03	6.177E-03	6.153E-03	6.207E-03	6.238E-03	6.218E-03	6.229E-03
^{101}Ru	6.247E-03	6.235E-03	6.230E-03	6.269E-03	6.314E-03	6.310E-03	6.247E-03	6.261E-03	6.324E-03	6.316E-03	6.223E-03	6.327E-03
^{103}Rh	6.214E-03	6.224E-03	6.222E-03	6.255E-03	6.339E-03	6.294E-03	6.229E-03	6.269E-03	6.321E-03	6.306E-03	6.213E-03	6.310E-03
^{109}Ag	6.228E-03	6.243E-03	6.237E-03	6.270E-03	6.301E-03	6.311E-03	6.249E-03	6.199E-03	6.259E-03	6.317E-03	6.261E-03	6.341E-03
^{133}Cs	6.170E-03	6.177E-03	6.173E-03	6.212E-03	6.245E-03	6.253E-03	6.183E-03	6.185E-03	6.241E-03	6.258E-03	6.181E-03	6.263E-03
^{143}Nd	6.143E-03	6.144E-03	6.139E-03	6.175E-03	6.200E-03	6.212E-03	6.149E-03	6.196E-03	6.231E-03	6.220E-03	6.124E-03	6.201E-03
^{145}Nd	6.188E-03	6.179E-03	6.174E-03	6.211E-03	6.270E-03	6.250E-03	6.189E-03	6.166E-03	6.211E-03	6.260E-03	6.174E-03	6.249E-03
^{147}Sm	6.245E-03	6.240E-03	6.234E-03	6.271E-03	6.305E-03	6.312E-03	6.244E-03	6.237E-03	6.297E-03	6.312E-03	6.212E-03	6.303E-03
^{149}Sm	6.165E-03	6.177E-03	6.172E-03	6.205E-03	6.245E-03	6.244E-03	6.184E-03	6.214E-03	6.252E-03	6.251E-03	6.158E-03	6.253E-03
^{150}Sm	6.054E-03	6.048E-03	6.043E-03	6.076E-03	6.114E-03	6.112E-03	6.047E-03	6.150E-03	6.188E-03	6.116E-03	6.124E-03	6.128E-03
^{151}Sm	6.094E-03	6.100E-03	6.096E-03	6.133E-03	6.187E-03	6.170E-03	6.109E-03	6.161E-03	6.195E-03	6.182E-03	6.082E-03	6.189E-03
^{152}Sm	6.195E-03	6.205E-03	6.203E-03	6.249E-03	6.289E-03	6.290E-03	6.211E-03	6.207E-03	6.271E-03	6.292E-03	6.191E-03	6.290E-03
^{153}Eu	6.161E-03	6.174E-03	6.170E-03	6.203E-03	6.218E-03	6.243E-03	6.187E-03	6.210E-03	6.257E-03	6.244E-03	6.164E-03	6.235E-03
^{155}Gd	6.102E-03	6.108E-03	6.106E-03	6.142E-03	6.202E-03	6.178E-03	6.115E-03	6.162E-03	6.193E-03	6.185E-03	6.090E-03	6.176E-03
^{235}U	5.948E-03	5.954E-03	5.948E-03	5.990E-03	6.029E-03	6.021E-03	5.964E-03	6.041E-03	6.031E-03	6.039E-03	5.940E-03	6.022E-03
^{236}U	6.289E-03	6.299E-03	6.294E-03	6.334E-03	6.315E-03	6.376E-03	6.315E-03	6.324E-03	6.397E-03	6.394E-03	6.304E-03	6.390E-03
^{237}Np	6.180E-03	6.192E-03	6.186E-03	6.220E-03	6.269E-03	6.260E-03	6.200E-03	6.230E-03	6.272E-03	6.277E-03	6.183E-03	6.243E-03
^{238}Pu	6.095E-03	6.101E-03	6.099E-03	6.136E-03	6.195E-03	6.172E-03	6.112E-03	6.151E-03	6.176E-03	6.178E-03	6.081E-03	6.202E-03
^{239}Pu	5.755E-03	5.762E-03	5.760E-03	5.807E-03	5.848E-03	5.831E-03	5.753E-03	5.866E-03	5.803E-03	5.847E-03	5.752E-03	5.827E-03
^{240}Pu	6.279E-03	6.292E-03	6.288E-03	6.320E-03	6.344E-03	6.360E-03	6.305E-03	6.314E-03	6.382E-03	6.360E-03	6.283E-03	6.369E-03
^{241}Pu	5.906E-03	5.909E-03	5.907E-03	5.947E-03	5.986E-03	5.978E-03	5.913E-03	6.008E-03	5.983E-03	5.976E-03	5.899E-03	5.947E-03
^{242}Pu	6.308E-03	6.320E-03	6.314E-03	6.346E-03	6.400E-03	6.387E-03	6.329E-03	6.322E-03	6.393E-03	6.386E-03	6.307E-03	6.395E-03
^{241}Am	6.193E-03	6.205E-03	6.201E-03	6.234E-03	6.283E-03	6.272E-03	6.211E-03	6.237E-03	6.282E-03	6.283E-03	6.191E-03	6.273E-03
^{243}Am	6.240E-03	6.254E-03	6.249E-03	6.281E-03	6.337E-03	6.322E-03	6.264E-03	6.282E-03	6.340E-03	6.330E-03	6.243E-03	6.340E-03
^{10}B	6.183E-03	6.192E-03	6.188E-03	6.222E-03	6.258E-03	6.261E-03	6.192E-03	6.227E-03	6.271E-03	6.258E-03	6.147E-03	6.272E-03
ALL	4.426E-03	4.296E-03	4.296E-03	N.R.	N.R.	4.446E-03	4.341E-03	3.825E-03	3.647E-03	4.457E-03	4.538E-03	4.415E-03

Table 27. Production rate on ^{238}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	1.479E-03	1.493E-03	1.493E-03	1.479E-03	1.495E-03	1.454E-03	1.494E-03	1.496E-03	1.507E-03	1.493E-03	1.477E-03	1.498E-03
^{95}Mo	1.470E-03	1.484E-03	1.484E-03	1.469E-03	1.492E-03	1.445E-03	1.484E-03	1.490E-03	1.501E-03	1.485E-03	1.465E-03	1.483E-03
^{99}Tc	1.473E-03	1.487E-03	1.487E-03	1.473E-03	1.472E-03	1.448E-03	1.487E-03	1.492E-03	1.502E-03	1.489E-03	1.470E-03	1.488E-03
^{101}Ru	1.469E-03	1.483E-03	1.482E-03	1.468E-03	1.479E-03	1.444E-03	1.484E-03	1.490E-03	1.501E-03	1.482E-03	1.463E-03	1.489E-03
^{103}Rh	1.474E-03	1.489E-03	1.488E-03	1.474E-03	1.487E-03	1.449E-03	1.490E-03	1.491E-03	1.502E-03	1.489E-03	1.472E-03	1.490E-03
^{109}Ag	1.476E-03	1.490E-03	1.490E-03	1.476E-03	1.489E-03	1.451E-03	1.491E-03	1.494E-03	1.504E-03	1.489E-03	1.473E-03	1.486E-03
^{133}Cs	1.474E-03	1.488E-03	1.488E-03	1.474E-03	1.494E-03	1.449E-03	1.490E-03	1.493E-03	1.504E-03	1.488E-03	1.471E-03	1.482E-03
^{143}Nd	1.471E-03	1.486E-03	1.485E-03	1.471E-03	1.480E-03	1.446E-03	1.485E-03	1.489E-03	1.499E-03	1.484E-03	1.468E-03	1.484E-03
^{145}Nd	1.471E-03	1.486E-03	1.485E-03	1.471E-03	1.483E-03	1.446E-03	1.486E-03	1.490E-03	1.501E-03	1.485E-03	1.467E-03	1.481E-03
^{147}Sm	1.475E-03	1.489E-03	1.489E-03	1.475E-03	1.487E-03	1.450E-03	1.490E-03	1.493E-03	1.504E-03	1.492E-03	1.472E-03	1.493E-03
^{149}Sm	1.473E-03	1.487E-03	1.487E-03	1.473E-03	1.484E-03	1.447E-03	1.488E-03	1.490E-03	1.501E-03	1.486E-03	1.471E-03	1.487E-03
^{150}Sm	1.470E-03	1.484E-03	1.484E-03	1.470E-03	1.485E-03	1.445E-03	1.485E-03	1.489E-03	1.498E-03	1.484E-03	1.467E-03	1.482E-03
^{151}Sm	1.471E-03	1.484E-03	1.484E-03	1.470E-03	1.487E-03	1.445E-03	1.486E-03	1.488E-03	1.498E-03	1.485E-03	1.468E-03	1.483E-03
^{152}Sm	1.476E-03	1.490E-03	1.490E-03	1.476E-03	1.488E-03	1.451E-03	1.490E-03	1.494E-03	1.504E-03	1.491E-03	1.474E-03	1.486E-03
^{153}Eu	1.474E-03	1.488E-03	1.488E-03	1.474E-03	1.483E-03	1.448E-03	1.489E-03	1.491E-03	1.501E-03	1.487E-03	1.471E-03	1.486E-03
^{155}Gd	1.471E-03	1.484E-03	1.485E-03	1.470E-03	1.482E-03	1.445E-03	1.486E-03	1.488E-03	1.496E-03	1.488E-03	1.468E-03	1.475E-03
^{235}U	1.605E-03	1.620E-03	1.619E-03	1.615E-03	1.623E-03	1.578E-03	1.619E-03	1.629E-03	1.636E-03	1.619E-03	1.601E-03	1.618E-03
^{236}U	1.475E-03	1.490E-03	1.489E-03	1.475E-03	1.480E-03	1.450E-03	1.491E-03	1.492E-03	1.502E-03	1.490E-03	1.472E-03	1.497E-03
^{237}Np	1.475E-03	1.489E-03	1.489E-03	1.475E-03	1.490E-03	1.449E-03	1.488E-03	1.491E-03	1.500E-03	1.489E-03	1.472E-03	1.487E-03
^{238}Pu	1.475E-03	1.489E-03	1.489E-03	1.475E-03	1.484E-03	1.449E-03	1.491E-03	1.492E-03	1.500E-03	1.490E-03	1.473E-03	1.486E-03
^{239}Pu	1.711E-03	1.726E-03	1.725E-03	1.730E-03	1.727E-03	1.669E-03	1.726E-03	1.730E-03	1.726E-03	1.725E-03	1.717E-03	1.724E-03
^{240}Pu	1.477E-03	1.492E-03	1.491E-03	1.477E-03	1.496E-03	1.452E-03	1.491E-03	1.494E-03	1.505E-03	1.492E-03	1.475E-03	1.493E-03
^{241}Pu	1.642E-03	1.657E-03	1.657E-03	1.655E-03	1.661E-03	1.615E-03	1.656E-03	1.671E-03	1.675E-03	1.654E-03	1.643E-03	1.648E-03
^{242}Pu	1.478E-03	1.493E-03	1.492E-03	1.478E-03	1.493E-03	1.453E-03	1.492E-03	1.494E-03	1.505E-03	1.495E-03	1.476E-03	1.496E-03
^{241}Am	1.475E-03	1.489E-03	1.489E-03	1.475E-03	1.492E-03	1.449E-03	1.492E-03	1.491E-03	1.501E-03	1.487E-03	1.473E-03	1.491E-03
^{243}Am	1.477E-03	1.491E-03	1.491E-03	1.477E-03	1.494E-03	1.452E-03	1.492E-03	1.493E-03	1.502E-03	1.492E-03	1.475E-03	1.489E-03
^{10}B	1.474E-03	1.488E-03	1.488E-03	1.474E-03	1.491E-03	1.448E-03	1.487E-03	1.491E-03	1.499E-03	1.486E-03	1.468E-03	1.486E-03
ALL	1.616E-03	1.669E-03	1.669E-03	N.R.	N.R.	1.581E-03	1.630E-03	1.678E-03	1.650E-03	1.632E-03	1.610E-03	1.667E-03

Table 28. Scattering rate on ^{238}U in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	5.843E-02	5.853E-02	5.853E-02	5.868E-02	5.889E-02	5.866E-02	5.868E-02	5.078E-02	5.120E-02	5.883E-02	5.223E-02	5.886E-02
^{95}Mo	5.788E-02	5.796E-02	5.795E-02	5.813E-02	5.828E-02	5.811E-02	5.808E-02	5.031E-02	5.062E-02	5.829E-02	5.165E-02	5.821E-02
^{99}Tc	5.784E-02	5.795E-02	5.794E-02	5.811E-02	5.777E-02	5.809E-02	5.809E-02	5.028E-02	5.058E-02	5.833E-02	5.164E-02	5.835E-02
^{101}Ru	5.777E-02	5.786E-02	5.785E-02	5.804E-02	5.814E-02	5.803E-02	5.802E-02	5.028E-02	5.059E-02	5.819E-02	5.137E-02	5.825E-02
^{103}Rh	5.766E-02	5.778E-02	5.777E-02	5.793E-02	5.813E-02	5.791E-02	5.789E-02	5.017E-02	5.041E-02	5.808E-02	5.152E-02	5.817E-02
^{109}Ag	5.791E-02	5.804E-02	5.802E-02	5.818E-02	5.838E-02	5.816E-02	5.817E-02	5.042E-02	5.074E-02	5.830E-02	5.174E-02	5.835E-02
^{133}Cs	5.786E-02	5.795E-02	5.796E-02	5.813E-02	5.836E-02	5.811E-02	5.813E-02	5.034E-02	5.064E-02	5.826E-02	5.166E-02	5.834E-02
^{143}Nd	5.756E-02	5.763E-02	5.763E-02	5.781E-02	5.793E-02	5.777E-02	5.773E-02	5.005E-02	5.026E-02	5.791E-02	5.134E-02	5.795E-02
^{145}Nd	5.764E-02	5.767E-02	5.766E-02	5.786E-02	5.803E-02	5.783E-02	5.777E-02	5.013E-02	5.039E-02	5.802E-02	5.136E-02	5.804E-02
^{147}Sm	5.783E-02	5.790E-02	5.789E-02	5.809E-02	5.829E-02	5.807E-02	5.803E-02	5.029E-02	5.060E-02	5.825E-02	5.153E-02	5.826E-02
^{149}Sm	5.758E-02	5.769E-02	5.768E-02	5.784E-02	5.799E-02	5.781E-02	5.781E-02	5.005E-02	5.022E-02	5.800E-02	5.140E-02	5.798E-02
^{150}Sm	5.755E-02	5.762E-02	5.762E-02	5.780E-02	5.794E-02	5.777E-02	5.773E-02	5.005E-02	5.028E-02	5.793E-02	5.129E-02	5.801E-02
^{151}Sm	5.748E-02	5.757E-02	5.757E-02	5.774E-02	5.788E-02	5.770E-02	5.771E-02	5.000E-02	5.021E-02	5.790E-02	5.130E-02	5.780E-02
^{152}Sm	5.789E-02	5.800E-02	5.799E-02	5.818E-02	5.831E-02	5.815E-02	5.811E-02	5.045E-02	5.081E-02	5.834E-02	5.175E-02	5.833E-02
^{153}Eu	5.755E-02	5.767E-02	5.767E-02	5.782E-02	5.796E-02	5.780E-02	5.782E-02	5.009E-02	5.032E-02	5.796E-02	5.137E-02	5.807E-02
^{155}Gd	5.751E-02	5.759E-02	5.759E-02	5.776E-02	5.795E-02	5.773E-02	5.772E-02	5.001E-02	5.018E-02	5.792E-02	5.132E-02	5.788E-02
^{235}U	5.783E-02	5.791E-02	5.790E-02	5.816E-02	6.436E-02	5.804E-02	5.801E-02	5.003E-02	5.009E-02	5.822E-02	5.133E-02	5.825E-02
^{236}U	5.818E-02	5.828E-02	5.827E-02	5.846E-02	5.819E-02	5.844E-02	5.843E-02	5.053E-02	5.088E-02	5.863E-02	5.197E-02	5.859E-02
^{237}Np	5.760E-02	5.772E-02	5.771E-02	5.787E-02	5.805E-02	5.785E-02	5.785E-02	5.001E-02	5.021E-02	5.804E-02	5.143E-02	5.793E-02
^{238}Pu	5.744E-02	5.754E-02	5.753E-02	5.770E-02	5.788E-02	5.766E-02	5.769E-02	4.991E-02	5.006E-02	5.783E-02	5.124E-02	5.782E-02
^{239}Pu	5.725E-02	5.732E-02	5.732E-02	5.765E-02	5.761E-02	5.747E-02	5.741E-02	4.935E-02	4.912E-02	5.763E-02	5.055E-02	5.750E-02
^{240}Pu	5.798E-02	5.810E-02	5.810E-02	5.825E-02	5.845E-02	5.823E-02	5.824E-02	5.038E-02	5.070E-02	5.840E-02	5.185E-02	5.842E-02
^{241}Pu	5.791E-02	5.794E-02	5.795E-02	5.823E-02	5.830E-02	5.808E-02	5.805E-02	5.000E-02	4.999E-02	5.826E-02	5.131E-02	5.820E-02
^{242}Pu	5.815E-02	5.826E-02	5.825E-02	5.841E-02	5.862E-02	5.839E-02	5.838E-02	5.036E-02	5.068E-02	5.855E-02	5.199E-02	5.862E-02
^{241}Am	5.765E-02	5.776E-02	5.775E-02	5.791E-02	5.814E-02	5.789E-02	5.791E-02	5.008E-02	5.030E-02	5.804E-02	5.147E-02	5.809E-02
^{243}Am	5.782E-02	5.795E-02	5.794E-02	5.810E-02	5.831E-02	5.808E-02	5.809E-02	5.016E-02	5.042E-02	5.829E-02	5.167E-02	5.816E-02
^{10}B	5.774E-02	5.785E-02	5.784E-02	5.800E-02	5.810E-02	5.797E-02	5.796E-02	5.019E-02	5.043E-02	5.811E-02	5.165E-02	5.815E-02
ALL	5.017E-02	5.012E-02	5.013E-02	N.R.	N.R.	5.042E-02	5.014E-02	4.125E-02	4.031E-02	5.059E-02	4.304E-02	5.064E-02

Table 29. Absorption rate on ^{16}O in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	2.811E-05	2.831E-05	2.830E-05	2.816E-05	2.822E-05	2.745E-05	2.836E-05	2.824E-05	2.846E-05	2.823E-05	2.830E-05	2.841E-05
^{95}Mo	2.792E-05	2.810E-05	2.810E-05	2.795E-05	2.820E-05	2.725E-05	2.806E-05	2.812E-05	2.831E-05	2.797E-05	2.803E-05	2.772E-05
^{99}Tc	2.798E-05	2.817E-05	2.817E-05	2.803E-05	2.778E-05	2.732E-05	2.821E-05	2.815E-05	2.833E-05	2.809E-05	2.812E-05	2.805E-05
^{101}Ru	2.789E-05	2.807E-05	2.807E-05	2.792E-05	2.784E-05	2.723E-05	2.809E-05	2.811E-05	2.834E-05	2.798E-05	2.796E-05	2.832E-05
^{103}Rh	2.801E-05	2.820E-05	2.820E-05	2.805E-05	2.803E-05	2.734E-05	2.819E-05	2.814E-05	2.838E-05	2.808E-05	2.817E-05	2.788E-05
^{109}Ag	2.804E-05	2.824E-05	2.824E-05	2.808E-05	2.818E-05	2.738E-05	2.825E-05	2.820E-05	2.841E-05	2.810E-05	2.821E-05	2.796E-05
^{133}Cs	2.800E-05	2.819E-05	2.819E-05	2.803E-05	2.826E-05	2.733E-05	2.827E-05	2.816E-05	2.840E-05	2.808E-05	2.813E-05	2.785E-05
^{143}Nd	2.794E-05	2.813E-05	2.812E-05	2.798E-05	2.774E-05	2.727E-05	2.807E-05	2.808E-05	2.828E-05	2.800E-05	2.808E-05	2.811E-05
^{145}Nd	2.794E-05	2.812E-05	2.812E-05	2.799E-05	2.799E-05	2.727E-05	2.810E-05	2.811E-05	2.831E-05	2.803E-05	2.806E-05	2.806E-05
^{147}Sm	2.803E-05	2.822E-05	2.821E-05	2.809E-05	2.796E-05	2.736E-05	2.826E-05	2.818E-05	2.839E-05	2.819E-05	2.819E-05	2.827E-05
^{149}Sm	2.798E-05	2.816E-05	2.816E-05	2.803E-05	2.785E-05	2.730E-05	2.825E-05	2.810E-05	2.835E-05	2.800E-05	2.814E-05	2.792E-05
^{150}Sm	2.792E-05	2.810E-05	2.810E-05	2.796E-05	2.780E-05	2.725E-05	2.817E-05	2.810E-05	2.826E-05	2.804E-05	2.806E-05	2.802E-05
^{151}Sm	2.793E-05	2.810E-05	2.811E-05	2.795E-05	2.818E-05	2.725E-05	2.816E-05	2.806E-05	2.829E-05	2.804E-05	2.808E-05	2.793E-05
^{152}Sm	2.805E-05	2.824E-05	2.824E-05	2.810E-05	2.811E-05	2.738E-05	2.825E-05	2.820E-05	2.840E-05	2.814E-05	2.822E-05	2.797E-05
^{153}Eu	2.800E-05	2.819E-05	2.818E-05	2.806E-05	2.814E-05	2.733E-05	2.820E-05	2.814E-05	2.833E-05	2.810E-05	2.816E-05	2.787E-05
^{155}Gd	2.793E-05	2.810E-05	2.811E-05	2.797E-05	2.765E-05	2.725E-05	2.818E-05	2.806E-05	2.823E-05	2.807E-05	2.808E-05	2.762E-05
^{235}U	3.037E-05	3.059E-05	3.058E-05	3.063E-05	3.062E-05	2.966E-05	3.056E-05	3.071E-05	3.083E-05	3.044E-05	3.056E-05	3.041E-05
^{236}U	2.804E-05	2.825E-05	2.825E-05	2.807E-05	2.821E-05	2.738E-05	2.830E-05	2.817E-05	2.841E-05	2.810E-05	2.822E-05	2.829E-05
^{237}Np	2.801E-05	2.820E-05	2.820E-05	2.806E-05	2.801E-05	2.734E-05	2.817E-05	2.814E-05	2.833E-05	2.811E-05	2.818E-05	2.793E-05
^{238}Pu	2.801E-05	2.819E-05	2.820E-05	2.806E-05	2.791E-05	2.733E-05	2.824E-05	2.814E-05	2.834E-05	2.807E-05	2.817E-05	2.790E-05
^{239}Pu	3.278E-05	3.302E-05	3.299E-05	3.326E-05	3.302E-05	3.130E-05	3.298E-05	3.260E-05	3.245E-05	3.296E-05	3.367E-05	3.279E-05
^{240}Pu	2.807E-05	2.826E-05	2.826E-05	2.813E-05	2.824E-05	2.740E-05	2.819E-05	2.819E-05	2.842E-05	2.820E-05	2.825E-05	2.814E-05
^{241}Pu	3.144E-05	3.166E-05	3.166E-05	3.182E-05	3.161E-05	3.034E-05	3.157E-05	3.150E-05	3.158E-05	3.149E-05	3.237E-05	3.117E-05
^{242}Pu	2.809E-05	2.828E-05	2.828E-05	2.814E-05	2.816E-05	2.742E-05	2.830E-05	2.820E-05	2.844E-05	2.826E-05	2.827E-05	2.786E-05
^{241}Am	2.802E-05	2.821E-05	2.821E-05	2.807E-05	2.819E-05	2.734E-05	2.829E-05	2.814E-05	2.838E-05	2.802E-05	2.818E-05	2.817E-05
^{243}Am	2.807E-05	2.827E-05	2.826E-05	2.813E-05	2.814E-05	2.740E-05	2.831E-05	2.818E-05	2.841E-05	2.812E-05	2.825E-05	2.805E-05
^{10}B	2.799E-05	2.817E-05	2.818E-05	2.802E-05	2.794E-05	2.732E-05	2.818E-05	2.812E-05	2.828E-05	2.800E-05	2.810E-05	2.783E-05
ALL	N.R.	3.170E-05	3.171E-05	N.R.	N.R.	2.949E-05	3.105E-05	3.141E-05	3.083E-05	3.099E-05	3.151E-05	3.168E-05

Table 30. Scattering rate on ^{16}O in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
0	4.190E-02	4.175E-02	4.175E-02	4.165E-02	4.181E-02	4.167E-02	4.188E-02	4.117E-02	4.155E-02	4.182E-02	3.963E-02	4.186E-02
^{95}Mo	4.146E-02	4.131E-02	4.131E-02	4.122E-02	4.137E-02	4.124E-02	4.141E-02	4.084E-02	4.113E-02	4.139E-02	3.921E-02	4.135E-02
^{99}Tc	4.137E-02	4.124E-02	4.124E-02	4.115E-02	4.091E-02	4.117E-02	4.136E-02	4.076E-02	4.104E-02	4.136E-02	3.916E-02	4.138E-02
^{101}Ru	4.139E-02	4.128E-02	4.128E-02	4.119E-02	4.130E-02	4.121E-02	4.141E-02	4.080E-02	4.111E-02	4.136E-02	3.904E-02	4.138E-02
^{103}Rh	4.125E-02	4.110E-02	4.111E-02	4.101E-02	4.121E-02	4.103E-02	4.122E-02	4.065E-02	4.088E-02	4.117E-02	3.904E-02	4.124E-02
^{109}Ag	4.145E-02	4.131E-02	4.131E-02	4.122E-02	4.139E-02	4.123E-02	4.143E-02	4.086E-02	4.117E-02	4.136E-02	3.922E-02	4.138E-02
^{133}Cs	4.141E-02	4.126E-02	4.127E-02	4.118E-02	4.137E-02	4.120E-02	4.140E-02	4.081E-02	4.110E-02	4.134E-02	3.918E-02	4.141E-02
^{143}Nd	4.113E-02	4.097E-02	4.098E-02	4.089E-02	4.102E-02	4.090E-02	4.107E-02	4.054E-02	4.074E-02	4.103E-02	3.889E-02	4.106E-02
^{145}Nd	4.122E-02	4.107E-02	4.108E-02	4.101E-02	4.117E-02	4.102E-02	4.117E-02	4.066E-02	4.090E-02	4.117E-02	3.897E-02	4.117E-02
^{147}Sm	4.133E-02	4.122E-02	4.123E-02	4.115E-02	-1.692E-02	4.117E-02	4.134E-02	4.080E-02	4.110E-02	4.132E-02	3.913E-02	4.132E-02
^{149}Sm	4.118E-02	4.103E-02	4.104E-02	4.094E-02	4.108E-02	4.095E-02	4.114E-02	4.054E-02	4.071E-02	4.111E-02	3.894E-02	4.107E-02
^{150}Sm	4.115E-02	4.099E-02	4.099E-02	4.091E-02	4.104E-02	4.092E-02	4.109E-02	4.057E-02	4.079E-02	4.107E-02	3.887E-02	4.110E-02
^{151}Sm	4.108E-02	4.092E-02	4.093E-02	4.084E-02	4.100E-02	4.085E-02	4.104E-02	4.049E-02	4.069E-02	4.101E-02	3.884E-02	4.098E-02
^{152}Sm	4.146E-02	4.132E-02	4.132E-02	4.125E-02	4.137E-02	4.126E-02	4.142E-02	4.088E-02	4.121E-02	4.141E-02	3.925E-02	4.139E-02
^{153}Eu	4.117E-02	4.103E-02	4.104E-02	4.094E-02	4.109E-02	4.096E-02	4.114E-02	4.060E-02	4.082E-02	4.110E-02	3.894E-02	4.117E-02
^{155}Gd	4.111E-02	4.095E-02	4.095E-02	4.087E-02	4.104E-02	4.087E-02	4.106E-02	4.049E-02	4.066E-02	4.102E-02	3.886E-02	4.101E-02
^{235}U	4.130E-02	4.111E-02	4.112E-02	4.108E-02	4.125E-02	4.104E-02	4.121E-02	4.073E-02	4.079E-02	4.117E-02	3.894E-02	4.121E-02
^{236}U	4.167E-02	4.153E-02	4.153E-02	4.145E-02	4.123E-02	4.147E-02	4.166E-02	4.098E-02	4.132E-02	4.162E-02	3.944E-02	4.158E-02
^{237}Np	4.121E-02	4.108E-02	4.108E-02	4.098E-02	4.115E-02	4.100E-02	4.119E-02	4.053E-02	4.073E-02	4.116E-02	3.899E-02	4.108E-02
^{238}Pu	4.105E-02	4.090E-02	4.090E-02	4.082E-02	4.096E-02	4.082E-02	4.101E-02	4.042E-02	4.058E-02	4.096E-02	3.881E-02	4.095E-02
^{239}Pu	4.073E-02	4.052E-02	4.052E-02	4.054E-02	4.056E-02	4.048E-02	4.060E-02	4.028E-02	4.010E-02	4.058E-02	3.832E-02	4.052E-02
^{240}Pu	4.153E-02	4.139E-02	4.140E-02	4.130E-02	4.147E-02	4.132E-02	4.151E-02	4.083E-02	4.113E-02	4.146E-02	3.932E-02	4.148E-02
^{241}Pu	4.131E-02	4.111E-02	4.112E-02	4.110E-02	4.118E-02	4.102E-02	4.121E-02	4.075E-02	4.076E-02	4.119E-02	3.892E-02	4.117E-02
^{242}Pu	4.166E-02	4.152E-02	4.152E-02	4.143E-02	4.163E-02	4.144E-02	4.163E-02	4.081E-02	4.110E-02	4.158E-02	3.943E-02	4.164E-02
^{241}Am	4.124E-02	4.110E-02	4.110E-02	4.100E-02	4.119E-02	4.102E-02	4.122E-02	4.057E-02	4.078E-02	4.115E-02	3.900E-02	4.119E-02
^{243}Am	4.140E-02	4.126E-02	4.127E-02	4.117E-02	4.136E-02	4.119E-02	4.138E-02	4.065E-02	4.091E-02	4.136E-02	3.918E-02	4.126E-02
^{10}B	4.132E-02	4.117E-02	4.117E-02	4.108E-02	4.119E-02	4.109E-02	4.126E-02	4.065E-02	4.088E-02	4.122E-02	3.906E-02	4.123E-02
ALL	N.R.	3.477E-02	3.478E-02	N.R.	N.R.	3.479E-02	3.480E-02	3.394E-02	3.317E-02	3.492E-02	3.276E-02	3.495E-02

Figure 22. Relative difference in the BUC absorption rate for cases 1 to 14 of sub-phase 2

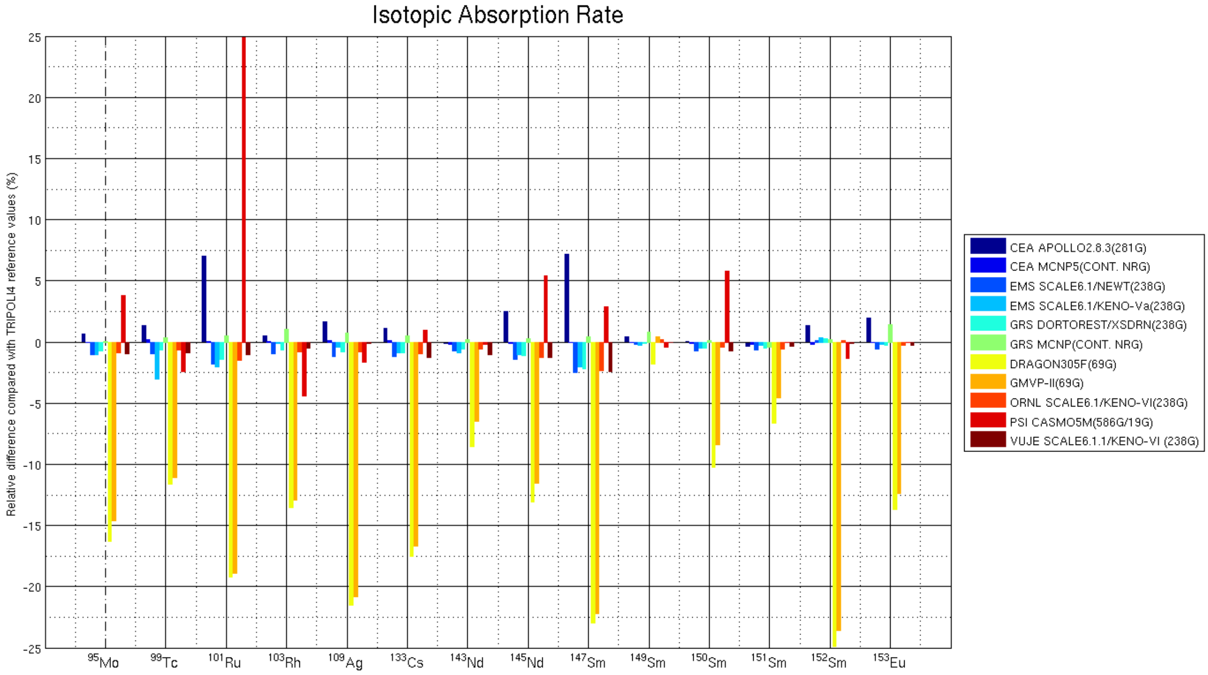


Figure 23. Relative difference in the BUC absorption rate for cases 15 to 27 of sub-phase 2

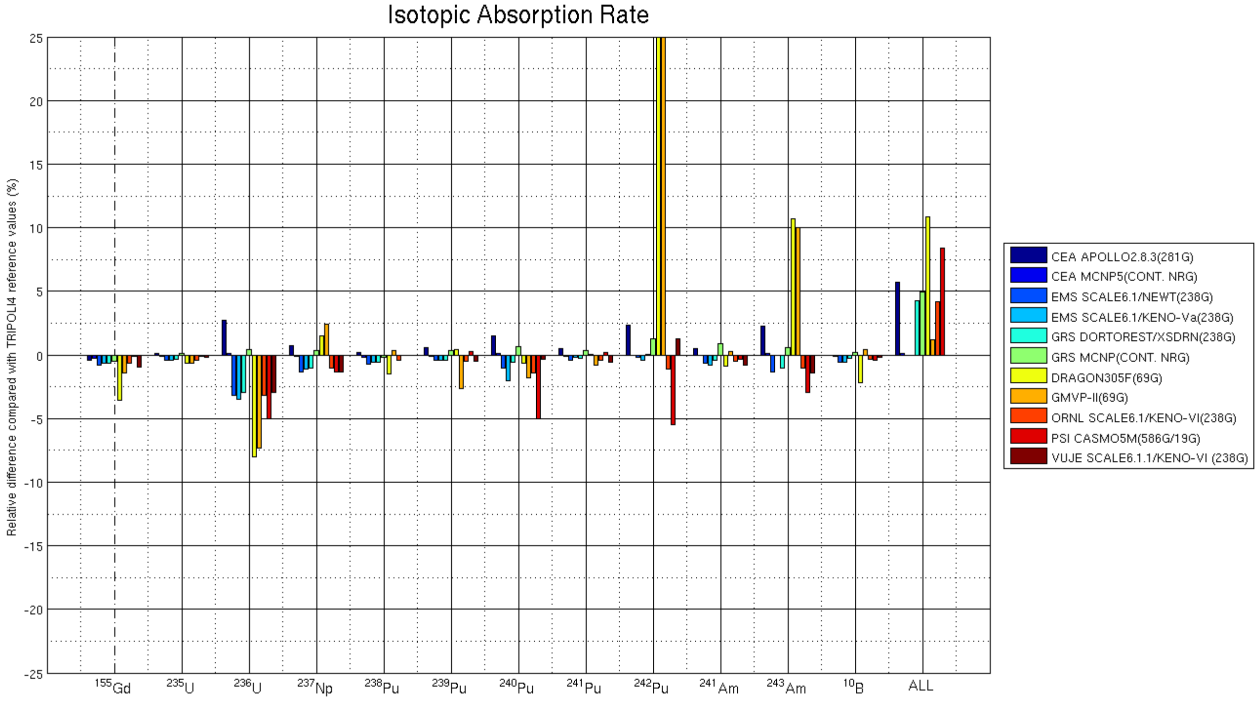


Figure 24. Relative difference in the BUC production rate for cases 16 to 27 of sub-phase 2

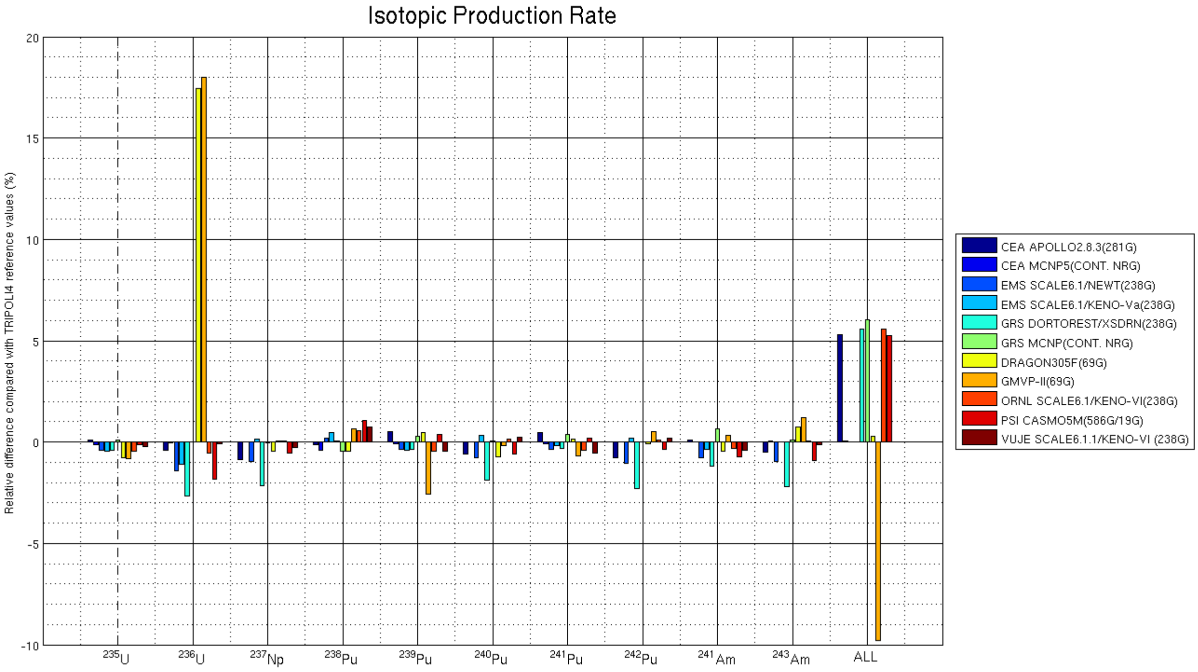


Figure 25. Relative difference in the BUC scattering rate for cases 1 to 14 of sub-phase 2

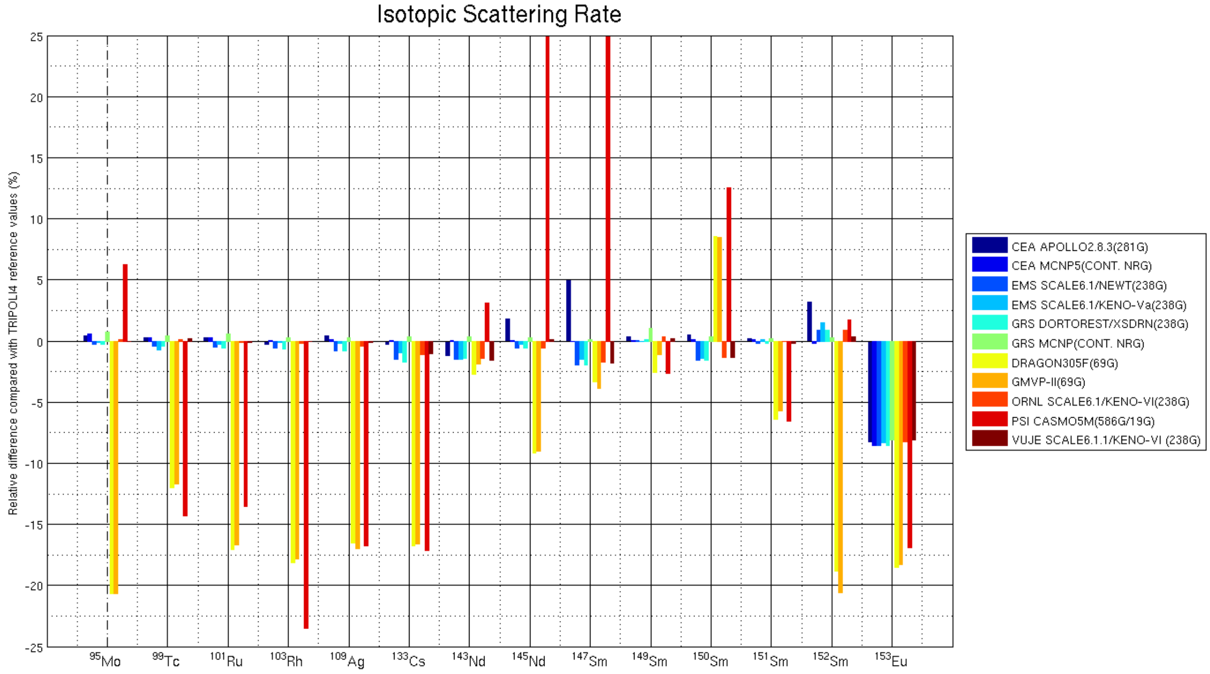


Figure 26. Relative difference in the BUC scattering rate for cases 15 to 27 of sub-phase 2

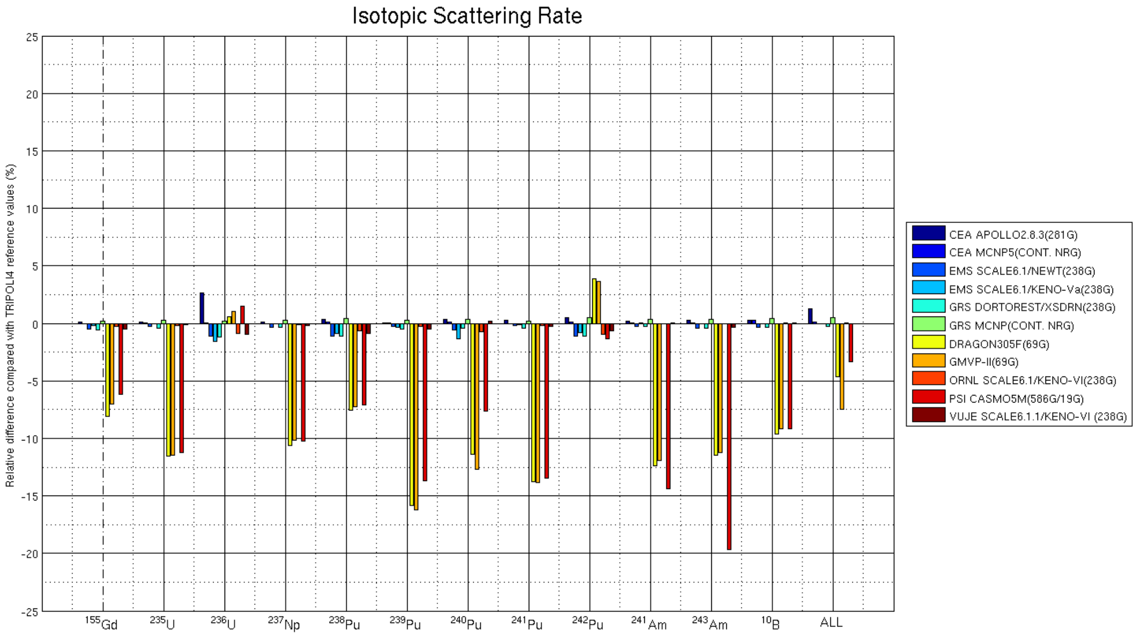


Table 31. Absorption rate on the BUC nuclide in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
^{95}Mo	2.778E-03	2.760E-03	2.759E-03	2.732E-03	2.732E-03	2.740E-03	2.761E-03	2.310E-03	2.357E-03	2.737E-03	2.864E-03	2.733E-03
^{99}Tc	3.413E-03	3.367E-03	3.373E-03	3.334E-03	3.266E-03	3.346E-03	3.378E-03	2.977E-03	2.995E-03	3.345E-03	3.285E-03	3.337E-03
^{101}Ru	3.591E-03	3.356E-03	3.356E-03	3.296E-03	3.288E-03	3.307E-03	3.373E-03	2.710E-03	2.721E-03	3.306E-03	4.547E-03	3.322E-03
^{103}Rh	4.060E-03	4.039E-03	4.042E-03	4.000E-03	4.036E-03	4.014E-03	4.082E-03	3.491E-03	3.516E-03	4.006E-03	3.862E-03	4.019E-03
^{109}Ag	2.851E-03	2.805E-03	2.807E-03	2.771E-03	2.794E-03	2.782E-03	2.825E-03	2.202E-03	2.221E-03	2.782E-03	2.757E-03	2.802E-03
^{133}Cs	3.159E-03	3.126E-03	3.128E-03	3.088E-03	3.099E-03	3.099E-03	3.140E-03	2.578E-03	2.603E-03	3.095E-03	3.156E-03	3.087E-03
^{143}Nd	4.430E-03	4.434E-03	4.427E-03	4.400E-03	4.394E-03	4.410E-03	4.441E-03	4.056E-03	4.146E-03	4.410E-03	4.425E-03	4.387E-03
^{145}Nd	4.167E-03	4.067E-03	4.061E-03	4.009E-03	4.023E-03	4.020E-03	4.078E-03	3.534E-03	3.598E-03	4.014E-03	4.287E-03	4.016E-03
^{147}Sm	3.622E-03	3.379E-03	3.377E-03	3.295E-03	3.310E-03	3.305E-03	3.393E-03	2.604E-03	2.628E-03	3.300E-03	3.477E-03	3.299E-03
^{149}Sm	4.191E-03	4.174E-03	4.171E-03	4.165E-03	4.163E-03	4.169E-03	4.207E-03	4.100E-03	4.193E-03	4.182E-03	4.157E-03	4.174E-03
^{150}Sm	4.519E-03	4.516E-03	4.510E-03	4.484E-03	4.494E-03	4.495E-03	4.521E-03	4.055E-03	4.136E-03	4.496E-03	4.778E-03	4.484E-03
^{151}Sm	4.581E-03	4.597E-03	4.587E-03	4.566E-03	4.584E-03	4.574E-03	4.578E-03	4.292E-03	4.387E-03	4.572E-03	4.595E-03	4.580E-03
^{152}Sm	2.589E-03	2.555E-03	2.549E-03	2.557E-03	2.563E-03	2.561E-03	2.560E-03	1.920E-03	1.953E-03	2.558E-03	2.519E-03	2.551E-03
^{153}Eu	4.614E-03	4.525E-03	4.525E-03	4.500E-03	4.517E-03	4.512E-03	4.589E-03	3.906E-03	3.963E-03	4.515E-03	4.522E-03	4.513E-03
^{155}Gd	4.397E-03	4.417E-03	4.406E-03	4.380E-03	4.389E-03	4.388E-03	4.394E-03	4.258E-03	4.356E-03	4.388E-03	4.413E-03	4.374E-03
^{235}U	1.327E-02	1.326E-02	1.324E-02	1.321E-02	1.320E-02	1.321E-02	1.327E-02	1.317E-02	1.317E-02	1.320E-02	1.324E-02	1.323E-02
^{236}U	1.720E-03	1.674E-03	1.675E-03	1.620E-03	1.615E-03	1.624E-03	1.680E-03	1.539E-03	1.551E-03	1.620E-03	1.590E-03	1.624E-03
^{237}Np	4.389E-03	4.357E-03	4.353E-03	4.300E-03	4.308E-03	4.311E-03	4.373E-03	4.423E-03	4.464E-03	4.311E-03	4.299E-03	4.300E-03
^{238}Pu	5.101E-03	5.092E-03	5.084E-03	5.056E-03	5.063E-03	5.065E-03	5.083E-03	5.017E-03	5.108E-03	5.070E-03	5.090E-03	5.092E-03
^{239}Pu	1.790E-02	1.780E-02	1.778E-02	1.773E-02	1.773E-02	1.773E-02	1.786E-02	1.787E-02	1.733E-02	1.772E-02	1.784E-02	1.771E-02
^{240}Pu	2.270E-03	2.237E-03	2.240E-03	2.214E-03	2.191E-03	2.224E-03	2.251E-03	2.222E-03	2.197E-03	2.205E-03	2.125E-03	2.229E-03
^{241}Pu	1.180E-02	1.174E-02	1.173E-02	1.169E-02	1.172E-02	1.171E-02	1.178E-02	1.175E-02	1.164E-02	1.169E-02	1.176E-02	1.168E-02
^{242}Pu	1.586E-03	1.550E-03	1.550E-03	1.547E-03	1.544E-03	1.551E-03	1.570E-03	2.494E-03	2.432E-03	1.533E-03	1.465E-03	1.570E-03
^{241}Am	4.075E-03	4.054E-03	4.053E-03	4.027E-03	4.023E-03	4.038E-03	4.089E-03	4.020E-03	4.066E-03	4.035E-03	4.039E-03	4.023E-03
^{243}Am	3.337E-03	3.262E-03	3.265E-03	3.219E-03	N.R.	3.228E-03	3.281E-03	3.612E-03	3.588E-03	3.229E-03	3.165E-03	3.215E-03
^{10}B	3.375E-03	3.377E-03	3.372E-03	3.358E-03	3.357E-03	3.367E-03	3.383E-03	3.303E-03	3.391E-03	3.366E-03	3.362E-03	3.371E-03
ALL	5.344E-02	5.055E-02	5.060E-02	N.R.	N.R.	5.270E-02	5.304E-02	5.603E-02	5.113E-02	5.265E-02	5.479E-02	N.R.

Table 32. Production rate on the BUC nuclide in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
^{235}U	2.684E-02	2.681E-02	2.678E-02	2.671E-02	2.669E-02	2.671E-02	2.684E-02	2.661E-02	2.660E-02	2.669E-02	2.677E-02	2.675E-02
^{236}U	3.331E-04	3.345E-04	3.344E-04	3.298E-04	3.308E-04	3.256E-04	3.346E-04	3.929E-04	3.947E-04	3.327E-04	3.283E-04	3.342E-04
^{237}Np	1.521E-04	1.534E-04	1.534E-04	1.519E-04	1.537E-04	1.501E-04	1.534E-04	1.527E-04	1.535E-04	1.535E-04	1.526E-04	1.530E-04
^{238}Pu	7.339E-04	7.348E-04	7.317E-04	7.361E-04	7.381E-04	7.351E-04	7.313E-04	7.314E-04	7.397E-04	7.391E-04	7.426E-04	7.403E-04
^{239}Pu	3.461E-02	3.443E-02	3.439E-02	3.430E-02	3.429E-02	3.430E-02	3.452E-02	3.459E-02	3.354E-02	3.427E-02	3.456E-02	3.427E-02
^{240}Pu	2.922E-05	2.940E-05	2.941E-05	2.917E-05	2.950E-05	2.885E-05	2.942E-05	2.918E-05	2.935E-05	2.945E-05	2.922E-05	2.947E-05
^{241}Pu	2.565E-02	2.553E-02	2.551E-02	2.543E-02	2.549E-02	2.545E-02	2.562E-02	2.557E-02	2.536E-02	2.543E-02	2.558E-02	2.539E-02
^{242}Pu	1.861E-04	1.876E-04	1.875E-04	1.856E-04	1.879E-04	1.833E-04	1.876E-04	1.874E-04	1.885E-04	1.877E-04	1.869E-04	1.880E-04
^{241}Am	1.145E-04	1.144E-04	1.144E-04	1.135E-04	1.139E-04	1.130E-04	1.151E-04	1.138E-04	1.147E-04	1.140E-04	1.135E-04	1.139E-04
^{243}Am	1.203E-04	1.209E-04	1.209E-04	1.197E-04	N.R.	1.182E-04	1.210E-04	1.218E-04	1.223E-04	1.209E-04	1.197E-04	1.207E-04
ALL	3.133E-02	2.975E-02	2.976E-02	N.R.	N.R.	3.141E-02	3.155E-02	2.984E-02	2.684E-02	3.142E-02	3.132E-02	N.R.

Table 33. Scattering rate on the BUC nuclide in s^{-1} (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
^{95}Mo	7.942E-03	7.909E-03	7.955E-03	7.887E-03	7.902E-03	7.888E-03	7.964E-03	6.274E-03	6.276E-03	7.921E-03	8.405E-03	7.906E-03
^{99}Tc	3.581E-03	3.572E-03	3.580E-03	3.557E-03	3.545E-03	3.556E-03	3.588E-03	3.144E-03	3.155E-03	3.577E-03	3.061E-03	3.578E-03
^{101}Ru	9.514E-03	9.490E-03	9.515E-03	9.441E-03	9.465E-03	9.439E-03	9.544E-03	7.872E-03	7.911E-03	9.477E-03	8.203E-03	9.481E-03
^{103}Rh	6.578E-04	6.594E-04	6.595E-04	6.555E-04	6.589E-04	6.551E-04	6.610E-04	5.399E-04	5.418E-04	6.582E-04	5.044E-04	6.591E-04
^{109}Ag	7.472E-04	7.437E-04	7.444E-04	7.376E-04	7.423E-04	7.375E-04	7.456E-04	6.207E-04	6.173E-04	7.407E-04	6.190E-04	7.430E-04
^{133}Cs	2.341E-03	2.347E-03	2.347E-03	2.311E-03	2.324E-03	2.307E-03	2.355E-03	1.953E-03	1.958E-03	2.321E-03	1.944E-03	2.322E-03
^{143}Nd	3.442E-03	3.484E-03	3.485E-03	3.432E-03	3.430E-03	3.434E-03	3.497E-03	3.390E-03	3.417E-03	3.433E-03	3.593E-03	3.429E-03
^{145}Nd	7.191E-03	7.064E-03	7.066E-03	7.026E-03	7.044E-03	7.023E-03	7.081E-03	6.419E-03	6.429E-03	7.024E-03	9.269E-03	7.070E-03
^{147}Sm	3.465E-03	3.302E-03	3.301E-03	3.237E-03	3.254E-03	3.238E-03	3.306E-03	3.193E-03	3.174E-03	3.245E-03	4.323E-03	3.242E-03
^{149}Sm	3.808E-05	3.796E-05	3.798E-05	3.797E-05	3.793E-05	3.799E-05	3.835E-05	3.697E-05	3.754E-05	3.808E-05	3.694E-05	3.804E-05
^{150}Sm	5.018E-03	4.992E-03	5.000E-03	4.915E-03	4.921E-03	4.915E-03	5.011E-03	5.418E-03	5.415E-03	4.926E-03	5.617E-03	4.927E-03
^{151}Sm	6.173E-05	6.161E-05	6.166E-05	6.147E-05	6.167E-05	6.148E-05	6.174E-05	5.766E-05	5.809E-05	6.159E-05	5.759E-05	6.150E-05
^{152}Sm	2.750E-03	2.664E-03	2.660E-03	2.688E-03	2.705E-03	2.688E-03	2.671E-03	2.163E-03	2.116E-03	2.688E-03	2.710E-03	2.674E-03
^{153}Eu	6.367E-04	6.938E-04	6.344E-04	6.347E-04	6.362E-04	6.343E-04	6.379E-04	5.651E-04	5.667E-04	6.365E-04	5.763E-04	6.376E-04
^{155}Gd	1.264E-05	1.263E-05	1.262E-05	1.256E-05	1.260E-05	1.256E-05	1.265E-05	1.160E-05	1.174E-05	1.260E-05	1.185E-05	1.256E-05
^{235}U	1.681E-03	1.678E-03	1.679E-03	1.674E-03	1.678E-03	1.671E-03	1.683E-03	1.485E-03	1.487E-03	1.675E-03	1.490E-03	1.677E-03
^{236}U	6.547E-03	6.378E-03	6.379E-03	6.305E-03	6.277E-03	6.304E-03	6.391E-03	6.417E-03	6.446E-03	6.322E-03	6.473E-03	6.315E-03
^{237}Np	1.139E-03	1.138E-03	1.138E-03	1.134E-03	1.137E-03	1.134E-03	1.141E-03	1.017E-03	1.022E-03	1.137E-03	1.022E-03	1.136E-03
^{238}Pu	1.064E-03	1.061E-03	1.062E-03	1.049E-03	1.051E-03	1.049E-03	1.065E-03	9.801E-04	9.838E-04	1.053E-03	9.855E-04	1.051E-03
^{239}Pu	1.080E-03	1.079E-03	1.080E-03	1.076E-03	1.075E-03	1.074E-03	1.082E-03	9.085E-04	9.042E-04	1.076E-03	9.320E-04	1.074E-03
^{240}Pu	2.944E-04	2.935E-04	2.939E-04	2.918E-04	2.895E-04	2.923E-04	2.946E-04	2.601E-04	2.562E-04	2.913E-04	2.711E-04	2.941E-04
^{241}Pu	5.961E-04	5.947E-04	5.945E-04	5.936E-04	5.940E-04	5.922E-04	5.959E-04	5.129E-04	5.124E-04	5.935E-04	5.144E-04	5.931E-04
^{242}Pu	1.751E-03	1.742E-03	1.744E-03	1.722E-03	1.728E-03	1.723E-03	1.751E-03	1.809E-03	1.805E-03	1.726E-03	1.719E-03	1.731E-03
^{241}Am	2.814E-04	2.809E-04	2.811E-04	2.800E-04	2.810E-04	2.801E-04	2.819E-04	2.462E-04	2.473E-04	2.808E-04	2.405E-04	2.810E-04
^{243}Am	8.619E-04	8.594E-04	8.599E-04	8.558E-04	N.R.	8.559E-04	8.621E-04	7.607E-04	7.628E-04	8.591E-04	6.903E-04	8.565E-04
^{10}B	1.554E-05	1.550E-05	1.554E-05	1.545E-05	1.550E-05	1.545E-05	1.557E-05	1.401E-05	1.408E-05	1.551E-05	1.408E-05	1.551E-05
ALL	5.160E-02	5.096E-02	5.103E-02	N.R.	N.R.	5.083E-02	5.121E-02	4.861E-02	4.715E-02	5.097E-02	4.925E-02	N.R.

3.2.4 Reactivity worth

3.2.4.1 Eigen value difference method

Reactivity worth calculated by the eigen value difference method are presented in Figures 27 and 28, with the calculated values reported in Table 34.

As observed in sub-phase 1, most of the trends on reactivity worth are similar to the ones of absorption and production rate of the BUC nuclide.

The best agreement with TRIPOLI4 is obtained by SCALE6 calculations from ORNL and EMS, and also DORTOREST calculations from GRS with differences within 2% for most cases. More complications are observed for the calculation of cases 27 to 29.

For the case 27, which considers the addition of all BUC nuclides into the central fuel cell, most of calculations overestimate the reactivity worth by more than 5%, while they all succeed in sub-phase 1. Even the MCNP5 calculations by GRS differ by more than 7% compared with MCNP5 calculations by CEA. Such differences could have occurred in the definition of input data for the codes, from either CEA or GRS, possibly due to a misunderstanding in the benchmark definition as it was asked to consider the sum of all BUC nuclides of cases 1 to 25 with the corresponding concentrations. A possible mistake could have occurred with ^{235}U, which was asked to replace the initial fuel concentration of 1.764E-4 by 6.900E-4, and not to be added. Nevertheless, errors observed on this case are not so important as this kind of fuel is non-physical due to the impossibility of manufacturing a fuel that contains such a sum of BUC nuclides (the corresponding density is higher than what is possible to achieve), not even in pile-oscillation experiments. The idea behind this case was to test the limit of calculation codes in situations where self-shielding effects are maximised with interactions between several nuclides. The conclusions is that VUJE calculations based on SCALE6 and CEA calculations based on APOLLO2 are still in good agreement with TRIPOLI4.

For the case 28, where the central fuel is replaced by an equivalent volume of air, DORTOREST, CASMO5 and APOLLO2 calculations give the best results with an agreement better than 1% with TRIPOLI4. Quite good results are also obtained with DRAGON3 and GMVP-II which are overestimated by around 3%. SCALE6 calculations are in less good agreement with TRIPOLI4 as they overestimate the reactivity worth, as calculated using TRIPOLI4, by more than 4%.

The same trends are observed in case 29 where the fuel is substituted by light water: only APOLLO2 and CASMO5 are able to calculate the reactivity worth within 2%. Concerning the comparison between DRAGON3 and GMVP-II, it seems that the use of Monte Carlo improves the agreement with TRIPOLI4 which means that apart from the energy group structure of the library which is used, there is a clear dependency of the kind of solver which is used on the calculated value for the reactivity worth. Other codes overestimate the reactivity worth by around 7%, when compared with TRIPOLI4 results.

Figure 27. Relative difference in the reactivity worth by the eigen-value difference method for cases 1 to 15 of sub-phase 2

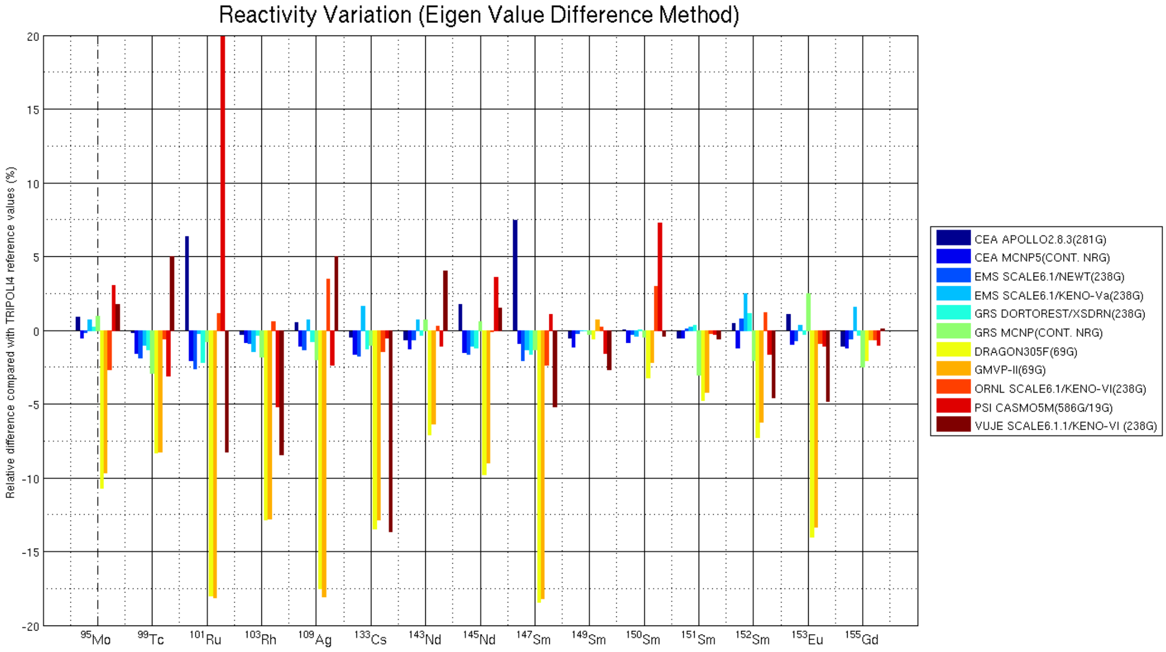


Figure 28. Relative difference in the reactivity worth by the eigen-value difference method for cases 16 to 29 of sub-phase 2

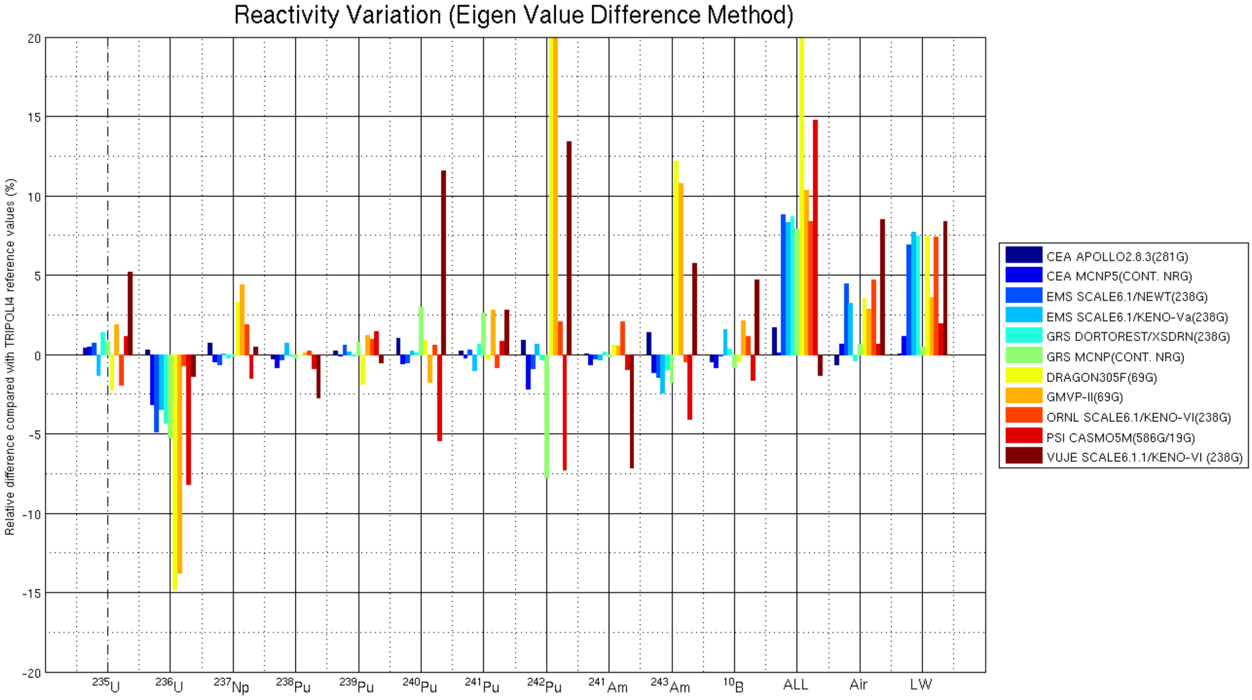


Table 34. Reactivity worth by the eigen-value difference method in pcm (sub-phase 2)

Case	CEA APOLLO2 281G	CEA TRIPOLI4 Cont. Energy	CEA MCNP5 Cont. Energy	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS DORTOREST 238G	GRS MCNP5 Cont. Energy	DRAGON305F 69G	GMVP-II 69G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G
^{95}Mo	-226.2	-224.1(2.0)	-223.0(0.4)	-223.8	-225.8(4.5)	-224.6	-226.2(5.2)	-200.2	-202.5(1.4)	-218.2(7.4)	-231	-228.0(23.1)
^{99}Tc	-270.9	-271.4(2.0)	-267.1(0.4)	-266.4	-268.5(4.5)	-267.8	-263.4(5.2)	-248.8	-248.9(1.4)	-269.8(7.4)	-263	-285.0(22.5)
^{101}Ru	-280.5	-263.8(2.0)	-258.5(0.4)	-256.9	-263.3(4.5)	-258	-261.8(5.2)	-216.3	-215.9(1.4)	-266.8(7.4)	-352	-242.0(23.1)
^{103}Rh	-343	-343.9(2.0)	-341.1(0.4)	-340.9	-338.9(4.5)	-342.7	-337.8(5.2)	-299.8	-299.8(1.4)	-346.0(7.4)	-326	-315.0(24.2)
^{109}Ag	-232.6	-231.5(2.0)	-229.0(0.4)	-228.5	-233.1(4.5)	-229.7	-226.8(5.2)	-190.9	-189.7(1.4)	-239.5(7.4)	-226	-243.0(23.1)
^{133}Cs	-250.1	-251.2(2.0)	-247.2(0.4)	-246.8	-255.3(4.5)	-248.1	-248.7(5.2)	-217.4	-218.9(1.4)	-247.6(7.4)	-250	-217.0(22.8)
^{143}Nd	-371.4	-373.9(2.0)	-369.2(0.4)	-371.6	-376.5(4.5)	-372.7	-376.6(5.2)	-347.5	-350.2(1.4)	-375.0(7.4)	-370	-389.0(23.9)
^{145}Nd	-343.7	-337.8(2.0)	-332.7(0.4)	-332.5	-334.1(4.5)	-333.7	-339.9(5.2)	-304.8	-307.4(1.4)	-337.6(7.4)	-350	-343.0(24.2)
^{147}Sm	-292.4	-272.1(2.0)	-269.7(0.4)	-266.6	-268.5(4.5)	-267.7	-268.6(5.2)	-222	-222.7(1.4)	-265.7(7.4)	-275	-258.0(23.8)
^{149}Sm	-353.6	-355.5(2.0)	-351.5(0.4)	-354.7	-355.3(4.5)	-355.4	-354.6(5.2)	-353.4	-358.0(1.4)	-356.3(7.4)	-350	-346.0(23.2)
^{150}Sm	-367.6	-367.4(2.0)	-364.4(0.4)	-366.3	-365.9(4.5)	-367.5	-365.6(5.2)	-355.6	-359.4(1.4)	-378.2(7.4)	-394	-366.0(25.0)
^{151}Sm	-382.3	-384.2(2.0)	-382.1(0.4)	-384.5	-385.0(4.5)	-385.5	-372.4(5.2)	-365.8	-368.0(1.4)	-383.3(7.4)	-383	-382.0(23.2)
^{152}Sm	-205.3	-204.3(2.0)	-201.8(0.4)	-205.8	-209.4(4.5)	-206.6	-200.1(5.2)	-189.5	-191.6(1.4)	-206.8(7.4)	-201	-195.0(22.8)
^{153}Eu	-378.1	-374.1(2.0)	-370.6(0.4)	-371.6	-375.5(4.5)	-373.1	-383.5(5.2)	-321.8	-324.3(1.4)	-370.8(7.4)	-370	-356.0(23.5)
^{155}Gd	-367.8	-371.8(2.0)	-367.3(0.4)	-369.6	-377.6(4.5)	-370.5	-362.5(5.2)	-364.2	-369.3(1.4)	-369.3(7.4)	-368	-372.0(23.9)
^{235}U	222.4	221.5(2.0)	222.5(0.4)	223.1	218.6(4.4)	224.5	223.3(5.1)	216.6	225.7(1.4)	217.2(7.3)	224	233.0(22.6)
^{236}U	-117.9	-117.6(2.0)	-113.9(0.4)	-111.9	-113.5(4.5)	-112.5	-111.4(5.2)	-100.2	-101.4(1.4)	-116.8(7.4)	-108	-116.0(23.1)
^{237}Np	-353.7	-351.3(2.0)	-349.8(0.4)	-349	-351.3(4.5)	-350.5	-350.9(5.2)	-362.9	-366.7(1.4)	-357.8(7.4)	-346	-353.0(23.5)
^{238}Pu	-386.5	-387.5(2.0)	-384.4(0.4)	-386.2	-390.2(4.5)	-387.1	-386.6(5.2)	-387.3	-387.9(1.4)	-388.2(7.4)	-384	-377.0(22.8)
^{239}Pu	306.2	305.5(2.0)	305.3(0.4)	307.3	306.0(4.4)	305.3	307.9(5.1)	299.8	309.2(1.4)	308.4(7.3)	310	304.0(23.3)
^{240}Pu	-190.2	-188.2(2.0)	-187.1(0.4)	-187.2	-188.6(4.5)	-188.4	-193.8(5.2)	-189.9	-184.9(1.4)	-189.3(7.4)	-178	-210.0(24.2)
^{241}Pu	351.8	351.1(2.0)	350.4(0.4)	352.2	347.6(4.4)	353.5	360.4(5.1)	350.2	360.9(1.4)	348.2(7.3)	354	361.0(23.6)
^{242}Pu	-121.9	-120.8(2.0)	-118.2(0.4)	-119.7	-121.5(4.5)	-120.4	-111.4(5.2)	-202.6	-197.8(1.4)	-123.3(7.4)	-112	-137.0(23.4)
^{241}Am	-336.3	-336.1(2.0)	-334.0(0.4)	-335.2	-335.0(4.5)	-336.7	-335.7(5.2)	-338	-337.8(1.4)	-343.1(7.4)	-333	-312.0(22.5)
^{243}Am	-268.5	-264.9(2.0)	-261.8(0.4)	-261	-258.5(4.5)	-262.4	-260.3(5.2)	-297.1	-293.3(1.4)	-263.7(7.4)	-254	-280.0(23.5)
^{10}B	-282.3	-283.6(2.0)	-281.3(0.4)	-283.4	-288.1(4.5)	-284.5	-281.2(5.2)	-282.2	-289.6(1.4)	-286.8(7.4)	-279	-297.0(23.5)
ALL	-2598.7	-2555.4(2.1)	-2558.3(0.5)	-2780	-2768.0(4.6)	-2777	-2757.0(5.3)	-3124	-2819.8(1.8)	-2770.0(7.6)	-2932	-2521.0(25.0)
Air	317.7	319.8(2.0)	321.9(0.4)	334.1	330.2(4.4)	318.5	321.8(5.1)	331	329.0(1.4)	334.9(7.3)	322	347.0(22.9)
LW	360	359.8(2.0)	363.8(0.4)	384.6	387.6(4.4)	386.7	361.4(5.1)	386.5	372.7(1.4)	386.4(7.3)	367	390.0(22.6)

3.2.4.2 Perturbation method

Comparisons of reactivity worth calculation based on perturbation are illustrated in Figures 29 and 30 while the calculated values are reported in Table 35. Comparisons are still performed relative to TRIPOLI4 calculations based on the eigen value difference method.

Compared with sub-phase 1, a less good agreement is observed for GRS calculations based on the MCNP5 differential operator method. While in the case of thermal absorbers like ^{149}Sm and ^{155}Gd where the agreement is better than 2%, other cases are underestimated by 5 to 15%. Moreover, results were not provided for cases 28 and 29, probably because the method is not adapted to evaluate reactivity worth in the case of material substitution. The same is observed for SCALE6 calculations by EMS, which are even more discrepant compared with TRIPOLI4 in sub-phase 2 than in sub-phase 1, with underestimations ranging from 5 to 20%. The best agreement is still obtained from APOLLO2 exact perturbation calculations. For some BUC nuclides, an overestimation of a few percents remain, especially for ^{101}Ru and ^{147}Sm, but this trend was already observed on the eigen value difference method which means that it is not linked to use of the perturbation method. DRAGON3 and GMVP-II calculations show quite satisfactory results for actinides where the agreement is mostly under 4% but still underestimate the fission product reactivity worth by more than 10%. However, like for APOLLO2, the same trend was observed in the eigen value difference method which means that given a finest group structure for the input library, calculations based on GMVP-II and DRAGON3 would lead to equivalent accuracy than APOLLO2.

Figure 29. Relative difference in the reactivity worth by the perturbation method for cases 1 to 15 of sub-phase 2

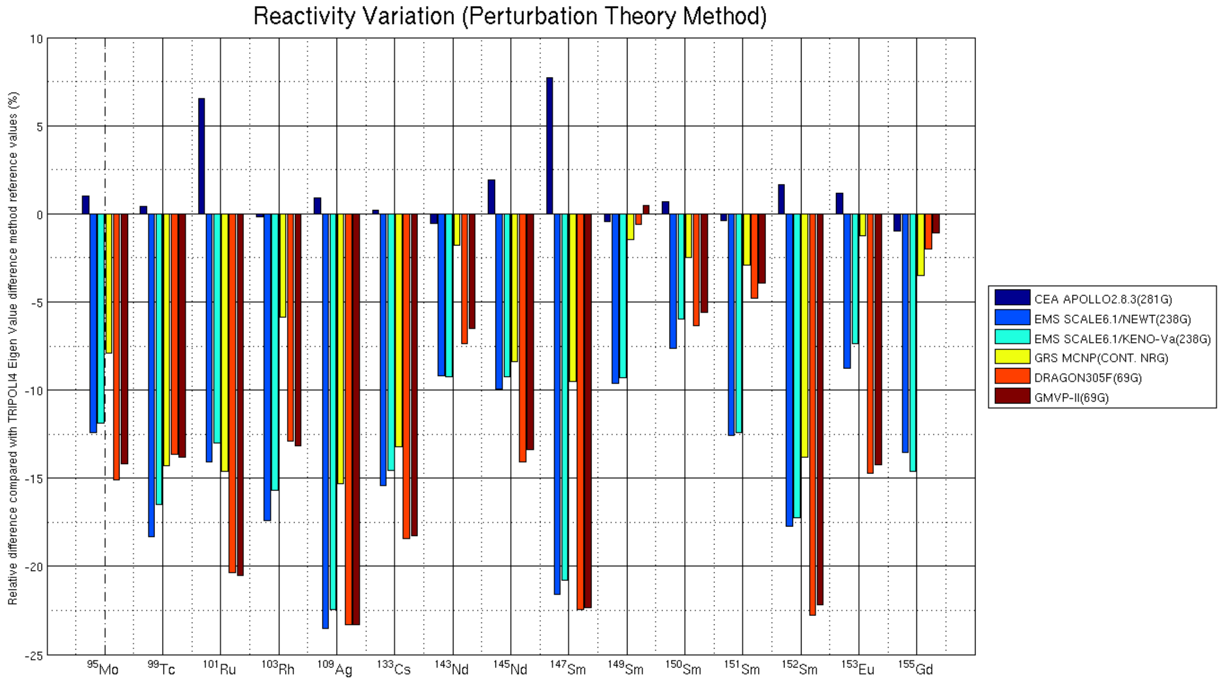
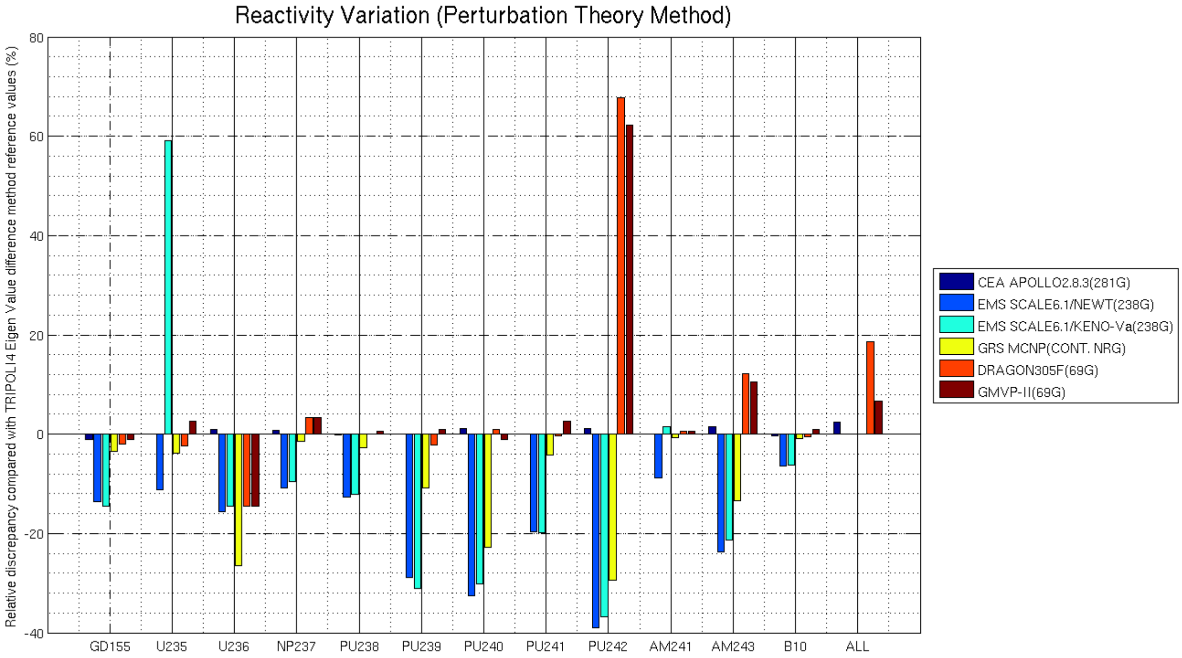


Figure 30. Relative difference in the reactivity worth by the perturbation method for cases 16 to 29 of sub-phase 2



3.2.4.3 Individual components

Like in sub-phase 1, comparisons of reactivity worth components are separated in two different parts, depending on the definition used for the reactivity perturbation. Illustrations are shown in Figures 31 and 32 for the cases of ^{235}U, ^{239}Pu, ^{241}Pu, AIR and LW where absorption, production and scattering effects occur. The complete list of provided results is given in Tables 36 and 37.

Comparisons between APOLLO2, GMVP-II and DRAGON3 calculations, which all use an exact perturbation formulation, show an excellent agreement for the cases of ^{235}U, ^{239}Pu and ^{241}Pu, like in sub-phase 1. The large differences observed on case 28 where UO_2 is substituted by air, is due to a problem of sign on the individual components. The production term should be negative as the fission component is included in the reference case 0 which is used to evaluate the reactivity worth. After a renormalisation of the values obtained by DRAGON3 and GMVP-II, we find a 6% overestimation of the DRAGON3 individual components compared with APOLLO2 and less than 3% using GMVP-II. The remaining disagreement may come from the scattering component which is given almost negligible in both DRAGON3 and GMVP-II calculations while it contributes to more than 20% of the total reactivity worth in APOLLO2 calculations. The difference could be due to the Legendre polynomial order for the treatment of scattering.

Comparisons between CEA, EMS and GRS calculations, projected on capture and fission components show an excellent agreement between APOLLO2 and MCNP5, contrary to what was shown on sub-phase 1 where a systematic underprediction of the MCNP5 components of 4 to 10% was identified. This may be due to the better agreement observed on the total reactivity worth obtained by the perturbation capabilities of MCNP5 than the ones of SCALE6 in this benchmark. It is likely that the first order perturbation theory shows some limitations to treat the situation of sub-phase 2 where the higher concentration of added isotopes involve a much larger flux depression inside the fuel.

Table 35. Reactivity worth by the perturbation method in pcm (sub-phase 2)

Case	CEA APOLLO2 281G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	DRAGON305 F 69G	GMVP-II 69G
^{95}Mo	-226.4	-196.3	-197.5	-206.4	-190.3	-192.3
^{99}Tc	-272.5	-221.6	-226.6	-232.6	-234.4	-233.9
^{101}Ru	-281	-226.7	-229.4	-225.3	-210.1	-209.6
^{103}Rh	-343.3	-284	-290	-323.7	-299.6	-298.8
^{109}Ag	-233.5	-177	-179.5	-196	-177.5	-177.5
^{133}Cs	-251.8	-212.5	-214.7	-218	-205	-205.3
^{143}Nd	-371.8	-339.6	-339.3	-367.2	-346.3	-349.6
^{145}Nd	-344.3	-304.3	-306.7	-309.6	-290.3	-292.6
^{147}Sm	-293.1	-213.3	-215.6	-246.2	-211.1	-211.3
^{149}Sm	-353.9	-321.3	-322.4	-350.4	-353.4	-357.1
^{150}Sm	-369.9	-339.4	-345.4	-358.3	-344	-346.8
^{151}Sm	-382.6	-335.9	-336.6	-373	-365.8	-369
^{152}Sm	-207.7	-168	-169.1	-176.1	-157.8	-158.9
^{153}Eu	-378.5	-341.3	-346.5	-369.4	-319.1	-320.9
^{155}Gd	-368.1	-321.4	-317.5	-358.8	-364.3	-367.7
^{235}U	221.7	196.6	352.3	212.9	216.2	227.3
^{236}U	-118.7	-99.3	-100.5	-86.4	-100.5	-100.5
^{237}Np	-354	-313.4	-317.9	-346.2	-363	-362.9
^{238}Pu	-386.8	-338.6	-340.3	-376.7	-387.5	-389.6
^{239}Pu	305.7	217.1	210.7	272.7	299	308.6
^{240}Pu	-190.5	-126.9	-131.5	-145.4	-190	-186.2
^{241}Pu	351.3	282	281.6	336.6	349.8	360.1
^{242}Pu	-122.2	-73.7	-76.5	-85.4	-202.7	-196
^{241}Am	-336.5	-306.4	-341.4	-333.6	-338.1	-338.4
^{243}Am	-268.9	-202.2	-208.3	-229.5	-297.3	-292.8
^{10}B	-282.6	-265.6	-265.9	-281.2	-282.1	-286.2
ALL	-2615.7	N.R.	N.R.	N.R.	-3031	-2724.2
Air	321.5	N.R.	N.R.	N.R.	353	353
LW	358.1	N.R.	N.R.	N.R.	415.3	400.8

Figure 31. Comparison of reactivity worth components due to absorption and production for cases 15, 19, 21 of sub-phase

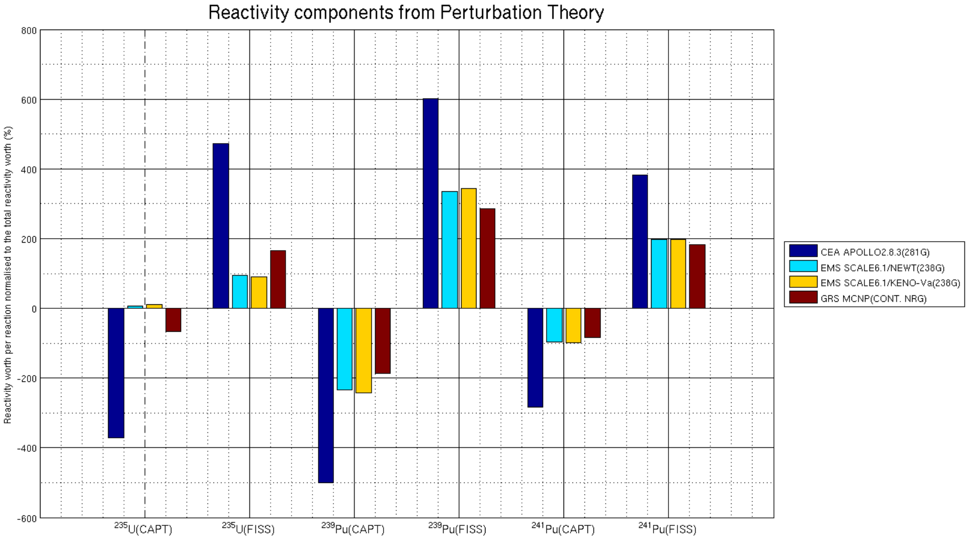


Figure 32. Comparison of reactivity worth components due to capture and fission for cases 15, 19, 21 of sub-phase 2

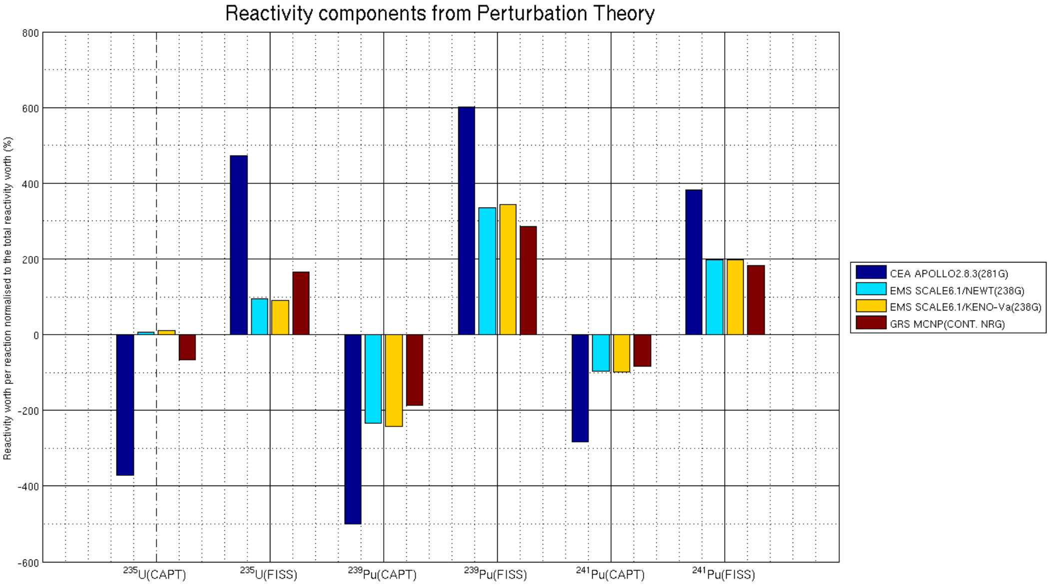


Table 36. Components of the reactivity worth due to capture, fission and scattering in percents of the total reactivity worth (sub-phase 2)

	Capture / Total				Fission / Total				Scattering / Total			
Case	CEA APOLLO2 281G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	CEA APOLLO2 281G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy	CEA APOLLO2 281G	EMS SCALE6.1 NEWT 238G	EMS SCALE6.1 KENO-Va 238G	GRS MCNP5 Cont. Energy
^{95}Mo	99.49	102.247	102.02	103.295	-0.001	0	0	0	0.61	-1.792	-	0.55
^{99}Tc	99.664	99.725	99.643	100	-0.001	0	0	0	0.186	0.272	0.357	-0.448
^{101}Ru	95.256	98.84	98.784	101.642	-0.001	0	0	0	0.576	1.159	1.218	-2.778
^{103}Rh	100.072	99.947	99.945	99.846	0	0	0	0	0.034	0.053	0.057	0.161
^{109}Ag	100.153	100.616	100.418	100.561	0	0	0	0	0.052	-0.618	-0.416	-0.532
^{133}Cs	99.776	99.765	99.669	100.459	0	0	0	0	0.146	0.233	0.339	-0.957
^{143}Nd	100.027	100.124	100.003	100	0	0	0	0	0.044	-0.125	-0.002	-0.427
^{145}Nd	98.913	100.283	100.163	101.873	-0.001	0	0	0	0.214	-0.281	-0.161	-3.036
^{147}Sm	94.065	105.189	105.051	103.168	-0.002	0	0	0	0.069	-5.186	-5.051	-4.236
^{149}Sm	100.107	100.003	100	100.143	0	0	0	0	0	-0.001	0	0
^{150}Sm	99.972	99.823	99.615	101.312	0	0	0	0	-0.08	0.176	0.384	-1.603
^{151}Sm	100.081	100	99.997	100	0	0	0	0	-0.001	-0.001	0.001	0
^{152}Sm	98.907	103.654	102.555	105.054	0	0	0	0	0.948	-3.688	-2.586	-5.327
^{153}Eu	99.567	99.974	99.931	99.838	-0.001	0	0	0	0.014	0.028	0.044	0.141
^{155}Gd	100.083	100	99.997	100	0	0	0	0	0	0.001	0.001	0
^{235}U	-62.664	6.333	10.329	-68.859	162.796	93.657	89.723	174.213	-0.061	-0.009	0.053	0
^{236}U	105.587	107.016	106.746	115.66	-6.8	-8.411	-8.355	-9.639	0.539	1.394	1.608	-7.831
^{237}Np	101.037	101.433	101.419	101.069	-1.193	-1.369	-1.367	-1.207	0.022	-0.063	-0.05	0.151
^{238}Pu	104.717	106.185	106.177	105.256	-4.892	-6.115	-6.125	-5.41	0.01	-0.071	-0.051	0
^{239}Pu	-164.045	-234.869	-243.441	-210.048	264.026	334.942	343.498	322.956	-0.031	-0.061	-0.058	0.19
^{240}Pu	100.794	101.064	100.669	101.444	-0.44	0.679	-0.666	-0.717	0.003	-0.385	0.001	-0.358
^{241}Pu	-74.474	-96.759	-97.564	-86.334	174.529	196.802	197.607	189.869	-0.018	-0.042	-0.042	0.154
^{242}Pu	104.437	110.156	109.398	107.919	-4.433	-7.457	-7.323	-6.707	0.138	-2.699	-2.075	-1.829
^{241}Am	101.058	101.097	90.307	100.929	-0.946	-1.098	-0.994	-0.939	0.005	0.004	0.009	0.157
^{243}Am	101.036	102.087	101.993	102.048	-1.421	-1.934	-1.911	-1.591	0.024	-0.154	-0.082	-0.227
^{10}B	100.093	100	100	100	0	0	0	0	0.001	0.002	0.002	0
ALL	137.192	N.R.	N.R.	N.R.	-37.518	N.R.	N.R.	N.R.	0.356	N.R.	N.R.	N.R.
Air	163.006	N.R.	N.R.	N.R.	-73.603	N.R.	N.R.	N.R.	22.81	N.R.	N.R.	N.R.
LW	155.87	N.R.	N.R.	N.R.	-59.065	N.R.	N.R.	N.R.	-6.264	N.R.	N.R.	N.R.

Table 37. Components of the reactivity worth due to absorption, production and scattering in percents of the total reactivity worth (sub-phase 2)

	Absorption / Total			Production / Total			Scattering / Total		
Case	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G	CEA APOLLO2 281G	DRAGON305F 69G	GMVP-II 69G
^{95}Mo	99.492	99.448	99.444	-0.003	0	0	0.61	0.55	0.557
^{99}Tc	99.665	99.774	99.769	-0.001	-0.001	-0.001	0.186	0.225	0.232
^{101}Ru	95.258	99.343	99.327	-0.003	0	0	0.576	0.655	0.674
^{103}Rh	100.072	99.967	99.967	0	0	0	0.034	0.033	0.034
^{109}Ag	100.153	99.944	99.938	-0.001	-0.002	-0.002	0.052	0.061	0.062
^{133}Cs	99.776	99.815	99.81	-0.001	-0.002	-0.001	0.146	0.188	0.193
^{143}Nd	100.027	99.974	99.971	-0.001	0	0	0.044	0.028	0.028
^{145}Nd	98.914	99.817	99.812	-0.002	-0.002	-0.002	0.214	0.184	0.188
^{147}Sm	94.068	99.901	99.896	-0.005	0	0	0.069	0.098	0.101
^{149}Sm	100.107	100	100	0	0	0	0	0	0
^{150}Sm	99.973	99.869	99.867	-0.001	0	0	-0.08	0.131	0.133
^{151}Sm	100.081	99.997	100	0	0	0	-0.001	0.001	0.001
^{152}Sm	98.907	99.93	99.931	0	-0.003	-0.003	0.948	0.074	0.076
^{153}Eu	99.568	99.978	99.978	-0.001	0	0	0.014	0.021	0.022
^{155}Gd	100.083	100	100	0	0	0	0	0	0
^{235}U	-372.332	-386.057	-362.928	472.463	486.127	462.994	-0.061	-0.06	-0.058
^{236}U	113.357	120.058	120.169	-14.569	-20.68	-20.806	0.539	0.624	0.641
^{237}Np	102.092	102.223	102.237	-2.248	-2.242	-2.257	0.022	0.019	0.02
^{238}Pu	109.763	110.047	110.124	-9.937	-10.055	-10.131	0.01	0.008	0.008
^{239}Pu	-500.5	-519.882	-482.585	600.481	619.912	582.602	-0.031	-0.027	-0.027
^{240}Pu	101.154	100.811	100.827	-0.8	-0.814	-0.836	0.003	0.006	0.007
^{241}Pu	-283.197	-288.578	-274.642	383.252	388.62	374.67	-0.018	-0.017	-0.017
^{242}Pu	107.921	104.834	105.035	-7.917	-4.897	-5.104	0.138	0.062	0.068
^{241}Am	101.904	101.789	101.803	-1.791	-1.792	-1.807	0.005	0.005	0.005
^{243}Am	101.96	102.16	102.206	-2.345	-2.179	-2.225	0.024	0.019	0.02
^{10}B	100.093	100	100	0	0	0	0.001	0	0
ALL	182.726	173.59	172.774	-83.052	-73.84	-73.056	0.356	0.253	0.28
Air	294.251	155.807	161.19	-204.848	102.266	109.065	22.81	1.856	1.955
LW	259.52	220.329	243.597	-162.715	-152.246	-174.514	-6.264	31.918	30.919

3.3 Sub-phase 3 results

The calculation results for sub-phases 3 and their analysis are presented in Sections 3.3.1 to 3.3.4.

3.3.1 Effective multiplication factor

Calculations of the k_{eff} are presented in Figures 33 and 34. Corresponding values are given in Table 38.

Like in sub-phases 1 and 2, differences mainly depend on the code system and not on the case number. GMVP-II calculations overestimate the k_{eff} by more than 2000 pcm, maybe due to an incorrect account for neutron leakage. SCALE6 calculations by EMS, ORNL and VUJE agree in the underestimation of the k_{eff} by around 500 pcm, in agreement with the values obtained in sub-phase 2. APOLLO2 and CASMO5 calculations show quite the same behaviour, with an underestimation of 500-600 pcm, to be compared to less than 100 pcm in sub-phase 2.

Figure 33. Absolute difference in the effective multiplication factor k_{eff} for cases 0 to 14 of sub-phase 3

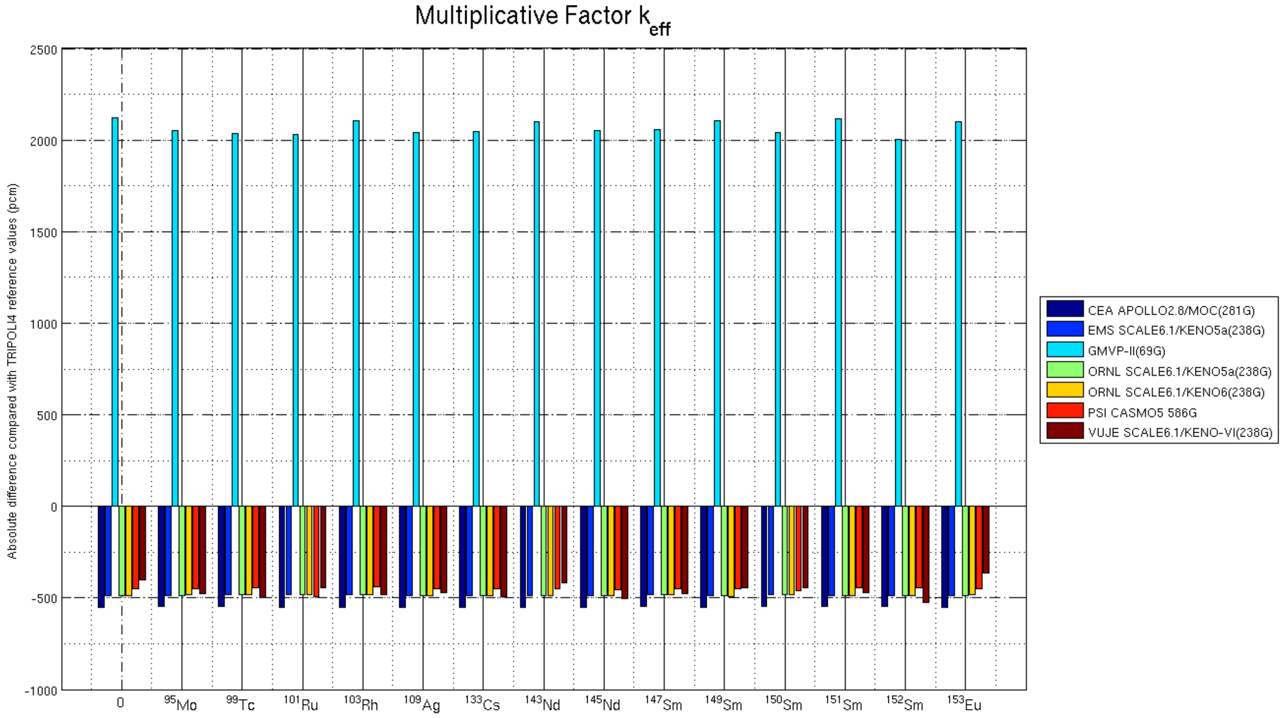


Figure 34. Absolute difference in the effective multiplication factor k_{eff} for cases 15 to 29 of sub-phase 3

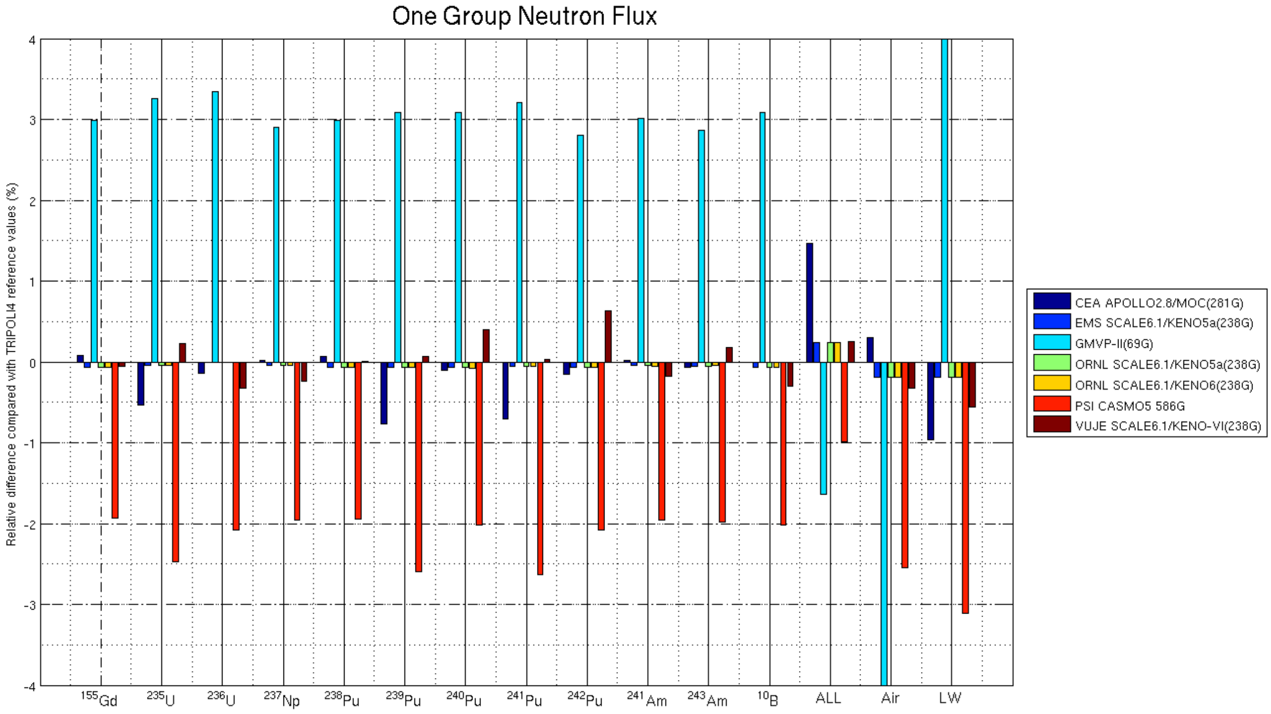


Table 38. k_{eff} calculations (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	1.28063	1.28124(10)	1.30732(16)	1.281240(10)	1.28126(10)	1.28162	1.28211(370)	1.28613(24)
^{95}Mo	1.27951	1.280130(10)	1.305510(16)	1.280130(10)	1.280160(10)	1.280491	1.280210(370)	1.284980(24)
^{99}Tc	1.27927	1.279910(10)	1.305120(16)	1.279910(10)	1.279920(10)	1.280319	1.279750(390)	1.284740(24)
^{101}Ru	1.2793	1.279990(10)	1.305120(16)	1.279990(10)	1.279970(10)	1.279898	1.280370(390)	1.284810(24)
^{103}Rh	1.27889	1.279550(10)	1.305450(16)	1.279550(10)	1.279550(10)	1.279996	1.279580(380)	1.284390(24)
^{109}Ag	1.27945	1.280110(10)	1.305420(16)	1.280110(10)	1.280110(10)	1.280496	1.280290(390)	1.284990(24)
^{133}Cs	1.27937	1.280020(10)	1.305340(16)	1.280020(10)	1.280020(10)	1.28038	1.279920(400)	1.284870(24)
^{143}Nd	1.27876	1.279370(10)	1.305290(16)	1.279370(10)	1.279400(10)	1.279779	1.280080(380)	1.284270(24)
^{145}Nd	1.27892	1.279590(10)	1.304980(16)	1.279590(10)	1.279600(10)	1.27989	1.279410(340)	1.284450(24)
^{147}Sm	1.27924	1.279930(10)	1.305280(16)	1.279930(10)	1.279930(10)	1.280254	1.279990(360)	1.284730(24)
^{149}Sm	1.27884	1.279480(10)	1.305410(16)	1.279480(10)	1.279460(10)	1.279872	1.279930(350)	1.284380(24)
^{150}Sm	1.27878	1.279430(10)	1.304640(16)	1.279430(10)	1.279440(10)	1.279667	1.279790(340)	1.284250(24)
^{151}Sm	1.27869	1.279320(10)	1.305310(16)	1.279320(10)	1.279320(10)	1.279711	1.279480(350)	1.284170(24)
^{152}Sm	1.27959	1.280220(10)	1.305090(16)	1.280220(10)	1.280220(10)	1.280617	1.279840(350)	1.285070(24)
^{153}Eu	1.27873	1.279400(10)	1.305260(16)	1.279400(10)	1.279410(10)	1.279775	1.280590(360)	1.284250(24)
^{155}Gd	1.27876	1.279390(10)	1.305400(16)	1.279390(10)	1.279420(10)	1.279782	1.279390(360)	1.284260(25)
^{235}U	1.28178	1.282450(10)	1.308550(15)	1.282450(10)	1.282420(10)	1.282775	1.282890(410)	1.287320(24)
^{236}U	1.28005	1.280710(10)	1.306800(16)	1.280710(10)	1.280700(10)	1.281102	1.280940(340)	1.285520(24)
^{237}Np	1.27885	1.279520(10)	1.305440(15)	1.279520(10)	1.279510(10)	1.2799	1.279410(400)	1.284320(24)
^{238}Pu	1.27868	1.279310(10)	1.305280(16)	1.279310(10)	1.279320(10)	1.27971	1.279770(340)	1.284190(24)
^{239}Pu	1.28225	1.282880(10)	1.308980(16)	1.282880(10)	1.282870(10)	1.283223	1.283290(370)	1.287780(24)
^{240}Pu	1.27965	1.280330(10)	1.306270(16)	1.280330(10)	1.280320(10)	1.280733	1.280900(380)	1.285170(24)
^{241}Pu	1.28247	1.283110(10)	1.309250(16)	1.283110(10)	1.283110(10)	1.283433	1.282710(420)	1.287960(24)
^{242}Pu	1.28001	1.280670(10)	1.306310(16)	1.280670(10)	1.280660(10)	1.28107	1.281070(350)	1.285570(24)
^{241}Am	1.27893	1.279600(10)	1.305600(16)	1.279600(10)	1.279580(10)	1.27996	1.279570(350)	1.284490(24)
^{243}Am	1.27927	1.279960(10)	1.305770(16)	1.279960(10)	1.279950(10)	1.280356	1.280180(350)	1.284790(24)
^{10}B	1.27921	1.279830(10)	1.305850(16)	1.279830(10)	1.279840(10)	1.28023	1.279930(390)	1.284700(24)
ALL	1.26677	1.268740(10)	1.291640(16)	1.268740(10)	1.268760(10)	1.267341	1.268830(410)	1.273480(24)
Air	1.28186	1.282850(10)	1.308650(16)	1.282850(10)	1.282870(10)	1.282819	1.282990(430)	1.287630(23)
LW	1.28246	1.283350(10)	1.309030(16)	1.283350(10)	1.283350(10)	1.283601	1.283220(430)	1.288140(23)

3.3.2 Neutron flux

Comparisons of the integrated neutron flux over the central fuel cell are illustrated in Figures 35 and 36, and calculation results are reported in Table 39.

All of them succeed in the calculation of this parameter within less than 0.5%, except GMVP-II calculations which overestimate the neutron flux by 3% and CASMO5 which underestimate it by 2%. In the case 27, where all BUC nuclides have been added to the central fuel cell, APOLLO2 calculations are at bit more discrepant (~1.5%) compared with TRIPOLI4. Much more discrepant results are observed for cases 28 and 29, especially for GMVP-II calculations which are out of the plotted range in Figure 36, with differences as high as 20% for the substitution of UO_2 by air for instance (case 28).

Figure 35. Relative difference in the neutron flux for cases 0 to 14 of sub-phase 3

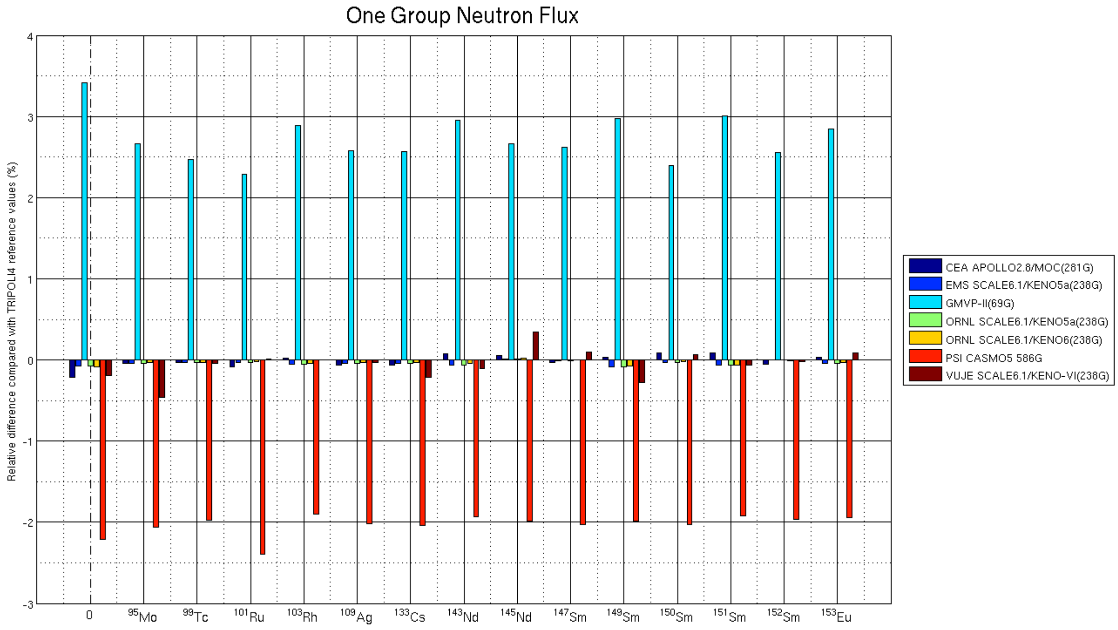


Figure 36. Relative difference in the neutron flux for cases 15 to 29 of sub-phase 3

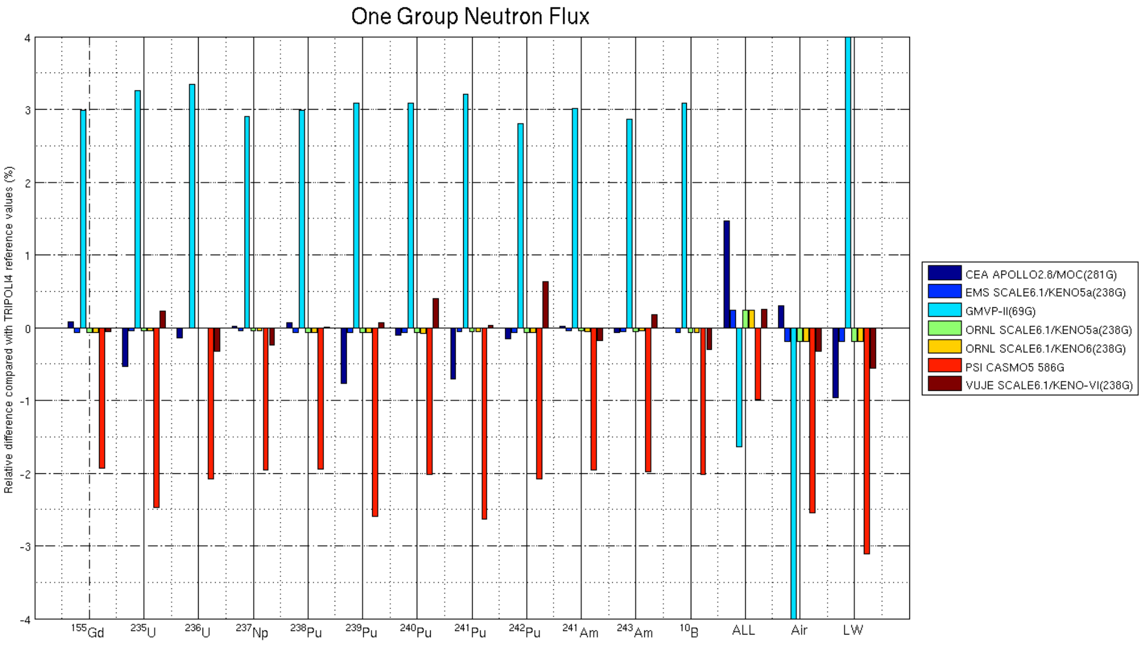


Table 39. Neutron flux in cm^{-2}.s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	5.318E-02	5.325E-02	5.511E-02	5.325E-02	5.325E-02	5.211E-02	5.319E-02	5.329E-02
^{95}Mo	5.265E-02	5.266E-02	5.408E-02	5.266E-02	5.266E-02	5.159E-02	5.244E-02	5.268E-02
^{99}Tc	5.257E-02	5.257E-02	5.389E-02	5.257E-02	5.257E-02	5.155E-02	5.257E-02	5.259E-02
^{101}Ru	5.259E-02	5.262E-02	5.384E-02	5.262E-02	5.262E-02	5.137E-02	5.264E-02	5.264E-02
^{103}Rh	5.243E-02	5.239E-02	5.393E-02	5.239E-02	5.240E-02	5.142E-02	5.242E-02	5.242E-02
^{109}Ag	5.266E-02	5.267E-02	5.405E-02	5.267E-02	5.267E-02	5.163E-02	5.267E-02	5.269E-02
^{133}Cs	5.261E-02	5.262E-02	5.399E-02	5.262E-02	5.262E-02	5.157E-02	5.253E-02	5.264E-02
^{143}Nd	5.230E-02	5.223E-02	5.380E-02	5.223E-02	5.224E-02	5.125E-02	5.220E-02	5.226E-02
^{145}Nd	5.240E-02	5.238E-02	5.376E-02	5.238E-02	5.238E-02	5.133E-02	5.255E-02	5.237E-02
^{147}Sm	5.257E-02	5.258E-02	5.396E-02	5.258E-02	5.259E-02	5.152E-02	5.264E-02	5.259E-02
^{149}Sm	5.236E-02	5.230E-02	5.389E-02	5.230E-02	5.230E-02	5.130E-02	5.219E-02	5.234E-02
^{150}Sm	5.231E-02	5.226E-02	5.352E-02	5.226E-02	5.226E-02	5.121E-02	5.230E-02	5.227E-02
^{151}Sm	5.225E-02	5.217E-02	5.377E-02	5.217E-02	5.217E-02	5.120E-02	5.217E-02	5.220E-02
^{152}Sm	5.268E-02	5.271E-02	5.405E-02	5.271E-02	5.270E-02	5.167E-02	5.270E-02	5.271E-02
^{153}Eu	5.234E-02	5.230E-02	5.382E-02	5.230E-02	5.231E-02	5.131E-02	5.237E-02	5.232E-02
^{155}Gd	5.228E-02	5.220E-02	5.379E-02	5.220E-02	5.220E-02	5.122E-02	5.220E-02	5.223E-02
^{235}U	5.301E-02	5.327E-02	5.504E-02	5.327E-02	5.328E-02	5.198E-02	5.342E-02	5.330E-02
^{236}U	5.291E-02	5.298E-02	5.475E-02	5.298E-02	5.298E-02	5.188E-02	5.281E-02	5.298E-02
^{237}Np	5.240E-02	5.236E-02	5.391E-02	5.236E-02	5.237E-02	5.137E-02	5.227E-02	5.239E-02
^{238}Pu	5.223E-02	5.216E-02	5.375E-02	5.216E-02	5.216E-02	5.118E-02	5.220E-02	5.219E-02
^{239}Pu	5.276E-02	5.312E-02	5.480E-02	5.312E-02	5.312E-02	5.178E-02	5.320E-02	5.316E-02
^{240}Pu	5.276E-02	5.278E-02	5.444E-02	5.278E-02	5.277E-02	5.175E-02	5.303E-02	5.281E-02
^{241}Pu	5.315E-02	5.350E-02	5.525E-02	5.350E-02	5.350E-02	5.212E-02	5.355E-02	5.353E-02
^{242}Pu	5.290E-02	5.295E-02	5.447E-02	5.295E-02	5.295E-02	5.189E-02	5.332E-02	5.299E-02
^{241}Am	5.243E-02	5.239E-02	5.400E-02	5.239E-02	5.239E-02	5.139E-02	5.232E-02	5.242E-02
^{243}Am	5.261E-02	5.261E-02	5.415E-02	5.261E-02	5.261E-02	5.160E-02	5.273E-02	5.264E-02
^{10}B	5.251E-02	5.248E-02	5.414E-02	5.248E-02	5.248E-02	5.146E-02	5.236E-02	5.252E-02
ALL	4.600E-02	4.545E-02	4.459E-02	4.545E-02	4.544E-02	4.489E-02	4.545E-02	4.534E-02
Air	5.459E-02	5.432E-02	4.310E-02	5.432E-02	5.432E-02	5.303E-02	5.424E-02	5.442E-02
LW	5.459E-02	5.501E-02	5.744E-02	5.501E-02	5.501E-02	5.340E-02	5.481E-02	5.511E-02

3.3.3 Reaction rates

Comparisons of reaction rate calculations performed on ^{235}U, ^{238}U and ^{16}O are illustrated in Figure 37, for the first case (case 0 without BUC nuclide) as the same conclusions can be observed for cases 1 to 27. All calculation results are reported in Table 40 to Table 50.

Most of the conclusions drawn in sub-phase 2 are similar in sub-phase 3. The only difference concerns GMVP-II calculations which show a higher difference compared with TRIPOLI4: for instance on absorption and production rate on ^{235}U, an overestimation of 4% is observed while it was only 2% for sub-phase 2. It may be explained by the ~3% overestimation of the neutron flux in the central cell, as mentioned in the previous section. The same trend is observed on the scattering rate of ^{235}U and ^{238}U which are less underestimated (respectively 8% and 11%, to be compared with 10% and 12.5% in sub-phase 2), due to an incorrect normalisation of the neutron flux.

Comparisons of reaction rate calculations on the BUC nuclide are illustrated in Figure 38 to Figure 42, with the full list of results in Table 48 to Table 50.

Results on absorption rate are also similar to the ones of sub-phase 2, with differences to TRIPOLI4 calculations by a few percent, except for GMVP-II calculations which are overestimated by more than 20% for several fission products, while there were not in sub-phase 2. These results are not confirmed on production rate on the BUC nuclide, where GMVP-II calculations are in quite the same agreement with TRIPOLI4 than in sub-phase 2. The other calculations are in good agreement with TRIPOLI4 within less than 3% (except Ru101 for CASMO5 which is overestimate like it was discussed in sub-phase 2) with similar trends compared with sub-phase 2. Only the APOLLO2 calculations show a significant difference with an overestimation of around 30% of the production rate.

For scattering rates, very close results to sub-phase 2 can be observed, except for GMVP-II calculations, which show differences larger than 30% on ^{145}Nd, ^{147}Sm, ^{150}Sm, ^{152}Sm, while they are consistent with previous results on other isotopes.

Figure 37. Relative difference in the reaction rates of ^{235}U, ^{238}U and ^{16}O of sub-phase 3 (case 0)

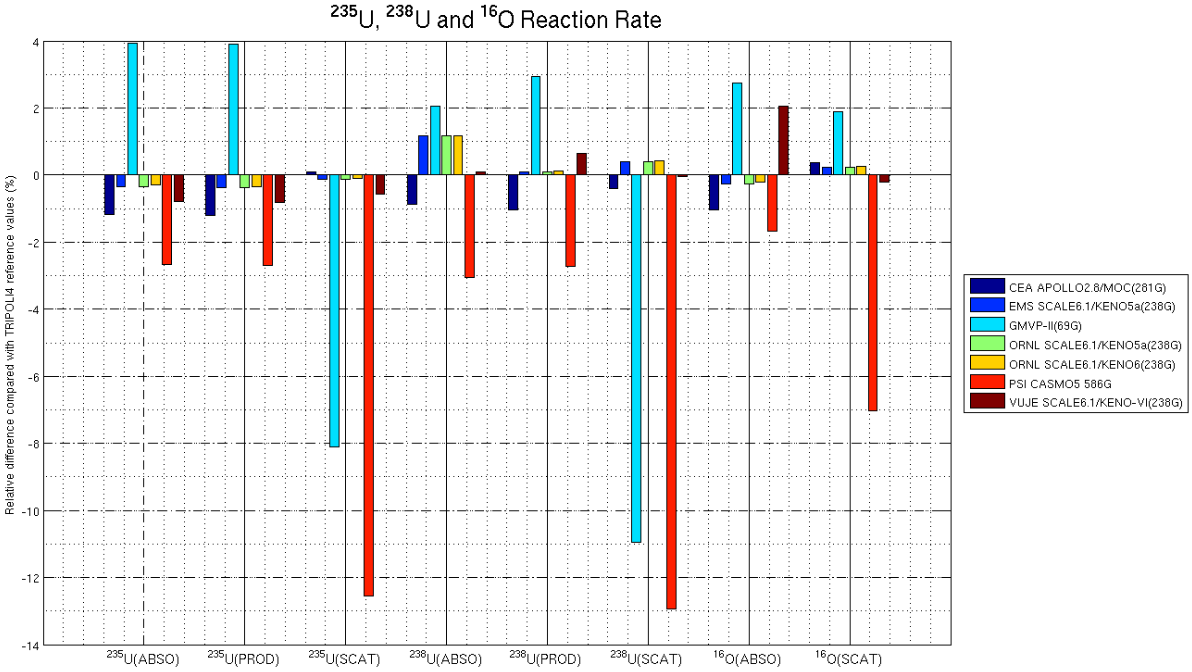


Table 40. Absorption rate on ^{235}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	8.815E-04	8.891E-04	9.367E-04	8.891E-04	8.887E-04	8.702E-04	8.898E-04	8.922E-04
^{95}Mo	8.450E-04	8.522E-04	8.886E-04	8.522E-04	8.525E-04	8.322E-04	8.483E-04	8.551E-04
^{99}Tc	8.485E-04	8.559E-04	8.885E-04	8.559E-04	8.560E-04	8.384E-04	8.511E-04	8.586E-04
^{101}Ru	8.572E-04	8.647E-04	8.983E-04	8.647E-04	8.648E-04	8.413E-04	8.705E-04	8.682E-04
^{103}Rh	8.359E-04	8.432E-04	8.812E-04	8.432E-04	8.435E-04	8.244E-04	8.440E-04	8.460E-04
^{109}Ag	8.533E-04	8.605E-04	8.957E-04	8.605E-04	8.607E-04	8.415E-04	8.530E-04	8.634E-04
^{133}Cs	8.497E-04	8.572E-04	8.925E-04	8.572E-04	8.570E-04	8.375E-04	8.555E-04	8.599E-04
^{143}Nd	8.033E-04	8.101E-04	8.457E-04	8.101E-04	8.104E-04	7.897E-04	8.118E-04	8.126E-04
^{145}Nd	8.271E-04	8.345E-04	8.687E-04	8.345E-04	8.343E-04	8.137E-04	8.407E-04	8.370E-04
^{147}Sm	8.506E-04	8.576E-04	8.942E-04	8.576E-04	8.578E-04	8.383E-04	8.657E-04	8.608E-04
^{149}Sm	8.162E-04	8.232E-04	8.595E-04	8.232E-04	8.236E-04	8.034E-04	8.231E-04	8.269E-04
^{150}Sm	8.086E-04	8.156E-04	8.459E-04	8.156E-04	8.156E-04	7.942E-04	8.163E-04	8.183E-04
^{151}Sm	7.874E-04	7.940E-04	8.306E-04	7.940E-04	7.937E-04	7.732E-04	7.923E-04	7.963E-04
^{152}Sm	8.519E-04	8.595E-04	8.931E-04	8.595E-04	8.595E-04	8.404E-04	8.602E-04	8.619E-04
^{153}Eu	8.275E-04	8.345E-04	8.725E-04	8.345E-04	8.345E-04	8.147E-04	8.339E-04	8.378E-04
^{155}Gd	7.892E-04	7.958E-04	8.319E-04	7.958E-04	7.957E-04	7.747E-04	7.941E-04	7.985E-04
^{235}U	2.803E-03	2.850E-03	2.959E-03	2.850E-03	2.850E-03	2.744E-03	2.859E-03	2.861E-03
^{236}U	8.709E-04	8.786E-04	9.234E-04	8.786E-04	8.784E-04	8.597E-04	8.822E-04	8.816E-04
^{237}Np	8.325E-04	8.400E-04	8.774E-04	8.400E-04	8.402E-04	8.203E-04	8.355E-04	8.431E-04
^{238}Pu	7.867E-04	7.937E-04	8.290E-04	7.937E-04	7.936E-04	7.727E-04	7.941E-04	7.962E-04
^{239}Pu	6.265E-04	6.429E-04	6.595E-04	6.429E-04	6.429E-04	6.128E-04	6.432E-04	6.452E-04
^{240}Pu	8.606E-04	8.681E-04	9.105E-04	8.681E-04	8.681E-04	8.492E-04	8.784E-04	8.716E-04
^{241}Pu	6.983E-04	7.129E-04	7.383E-04	7.129E-04	7.129E-04	6.842E-04	7.154E-04	7.151E-04
^{242}Pu	8.708E-04	8.785E-04	9.192E-04	8.785E-04	8.783E-04	8.598E-04	8.883E-04	8.813E-04
^{241}Am	8.281E-04	8.357E-04	8.732E-04	8.357E-04	8.354E-04	8.159E-04	8.308E-04	8.381E-04
^{243}Am	8.572E-04	8.649E-04	9.041E-04	8.649E-04	8.649E-04	8.461E-04	8.626E-04	8.675E-04
^{10}B	8.225E-04	8.294E-04	8.693E-04	8.294E-04	8.295E-04	8.029E-04	8.241E-04	8.327E-04
ALL	1.159E-03	1.194E-03	1.101E-03	1.194E-03	1.194E-03	3.041E-04	1.188E-03	1.194E-03

Table 41. Production rate on ^{235}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	1.789E-03	1.804E-03	1.900E-03	1.804E-03	1.804E-03	1.766E-03	1.805E-03	1.811E-03
^{95}Mo	1.714E-03	1.728E-03	1.802E-03	1.728E-03	1.729E-03	1.688E-03	1.720E-03	1.735E-03
^{99}Tc	1.721E-03	1.736E-03	1.803E-03	1.736E-03	1.736E-03	1.700E-03	1.726E-03	1.742E-03
^{101}Ru	1.740E-03	1.755E-03	1.824E-03	1.755E-03	1.756E-03	1.709E-03	1.767E-03	1.763E-03
^{103}Rh	1.695E-03	1.710E-03	1.785E-03	1.710E-03	1.710E-03	1.671E-03	1.712E-03	1.716E-03
^{109}Ag	1.732E-03	1.746E-03	1.818E-03	1.746E-03	1.747E-03	1.707E-03	1.732E-03	1.753E-03
^{133}Cs	1.724E-03	1.739E-03	1.811E-03	1.739E-03	1.739E-03	1.699E-03	1.736E-03	1.745E-03
^{143}Nd	1.627E-03	1.641E-03	1.711E-03	1.641E-03	1.641E-03	1.599E-03	1.645E-03	1.646E-03
^{145}Nd	1.677E-03	1.692E-03	1.761E-03	1.692E-03	1.692E-03	1.649E-03	1.705E-03	1.698E-03
^{147}Sm	1.726E-03	1.741E-03	1.814E-03	1.741E-03	1.741E-03	1.701E-03	1.758E-03	1.748E-03
^{149}Sm	1.653E-03	1.667E-03	1.739E-03	1.667E-03	1.668E-03	1.627E-03	1.667E-03	1.676E-03
^{150}Sm	1.638E-03	1.652E-03	1.714E-03	1.652E-03	1.652E-03	1.609E-03	1.654E-03	1.658E-03
^{151}Sm	1.594E-03	1.607E-03	1.680E-03	1.607E-03	1.607E-03	1.565E-03	1.604E-03	1.613E-03
^{152}Sm	1.729E-03	1.744E-03	1.812E-03	1.744E-03	1.744E-03	1.704E-03	1.744E-03	1.749E-03
^{153}Eu	1.679E-03	1.693E-03	1.768E-03	1.693E-03	1.693E-03	1.652E-03	1.691E-03	1.700E-03
^{155}Gd	1.597E-03	1.611E-03	1.682E-03	1.611E-03	1.611E-03	1.567E-03	1.608E-03	1.617E-03
^{235}U	5.668E-03	5.764E-03	5.981E-03	5.764E-03	5.764E-03	5.547E-03	5.782E-03	5.787E-03
^{236}U	1.768E-03	1.783E-03	1.873E-03	1.783E-03	1.783E-03	1.744E-03	1.791E-03	1.790E-03
^{237}Np	1.688E-03	1.703E-03	1.778E-03	1.703E-03	1.704E-03	1.663E-03	1.694E-03	1.710E-03
^{238}Pu	1.593E-03	1.607E-03	1.677E-03	1.607E-03	1.607E-03	1.563E-03	1.607E-03	1.612E-03
^{239}Pu	1.261E-03	1.295E-03	1.326E-03	1.295E-03	1.295E-03	1.233E-03	1.296E-03	1.300E-03
^{240}Pu	1.746E-03	1.761E-03	1.846E-03	1.761E-03	1.761E-03	1.722E-03	1.783E-03	1.769E-03
^{241}Pu	1.410E-03	1.440E-03	1.489E-03	1.440E-03	1.440E-03	1.381E-03	1.445E-03	1.445E-03
^{242}Pu	1.767E-03	1.783E-03	1.864E-03	1.783E-03	1.782E-03	1.744E-03	1.803E-03	1.789E-03
^{241}Am	1.679E-03	1.694E-03	1.769E-03	1.694E-03	1.694E-03	1.654E-03	1.684E-03	1.700E-03
^{243}Am	1.739E-03	1.755E-03	1.834E-03	1.755E-03	1.755E-03	1.717E-03	1.750E-03	1.761E-03
^{10}B	1.667E-03	1.681E-03	1.760E-03	1.681E-03	1.681E-03	1.626E-03	1.670E-03	1.688E-03
ALL	2.291E-03	2.365E-03	2.195E-03	2.365E-03	2.365E-03	6.023E-04	2.352E-03	2.367E-03

Table 42. Scattering rate on ^{235}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	9.485E-05	9.477E-05	8.813E-05	9.477E-05	9.475E-05	8.297E-05	9.473E-05	9.490E-05
^{95}Mo	9.362E-05	9.344E-05	8.596E-05	9.344E-05	9.345E-05	8.180E-05	9.300E-05	9.354E-05
^{99}Tc	9.346E-05	9.328E-05	8.560E-05	9.328E-05	9.328E-05	8.172E-05	9.318E-05	9.338E-05
^{101}Ru	9.357E-05	9.344E-05	8.559E-05	9.344E-05	9.345E-05	8.143E-05	9.350E-05	9.353E-05
^{103}Rh	9.304E-05	9.280E-05	8.559E-05	9.280E-05	9.281E-05	8.132E-05	9.275E-05	9.292E-05
^{109}Ag	9.365E-05	9.350E-05	8.596E-05	9.350E-05	9.350E-05	8.187E-05	9.336E-05	9.360E-05
^{133}Cs	9.356E-05	9.340E-05	8.583E-05	9.340E-05	9.340E-05	8.176E-05	9.329E-05	9.350E-05
^{143}Nd	9.268E-05	9.238E-05	8.524E-05	9.238E-05	9.240E-05	8.088E-05	9.226E-05	9.251E-05
^{145}Nd	9.300E-05	9.278E-05	8.528E-05	9.278E-05	9.279E-05	8.115E-05	9.310E-05	9.284E-05
^{147}Sm	9.348E-05	9.331E-05	8.574E-05	9.331E-05	9.331E-05	8.163E-05	9.352E-05	9.338E-05
^{149}Sm	9.280E-05	9.252E-05	8.541E-05	9.252E-05	9.252E-05	8.098E-05	9.240E-05	9.267E-05
^{150}Sm	9.274E-05	9.247E-05	8.472E-05	9.247E-05	9.247E-05	8.083E-05	9.250E-05	9.257E-05
^{151}Sm	9.256E-05	9.224E-05	8.518E-05	9.224E-05	9.224E-05	8.076E-05	9.216E-05	9.237E-05
^{152}Sm	9.374E-05	9.360E-05	8.595E-05	9.360E-05	9.359E-05	8.200E-05	9.359E-05	9.366E-05
^{153}Eu	9.288E-05	9.265E-05	8.538E-05	9.265E-05	9.265E-05	8.109E-05	9.282E-05	9.275E-05
^{155}Gd	9.262E-05	9.230E-05	8.522E-05	9.230E-05	9.229E-05	8.080E-05	9.232E-05	9.243E-05
^{235}U	3.604E-04	3.615E-04	3.313E-04	3.615E-04	3.615E-04	3.125E-04	3.625E-04	3.620E-04
^{236}U	9.425E-05	9.419E-05	8.737E-05	9.419E-05	9.419E-05	8.247E-05	9.385E-05	9.426E-05
^{237}Np	9.297E-05	9.275E-05	8.553E-05	9.275E-05	9.276E-05	8.120E-05	9.261E-05	9.287E-05
^{238}Pu	9.244E-05	9.215E-05	8.501E-05	9.215E-05	9.214E-05	8.062E-05	9.227E-05	9.227E-05
^{239}Pu	8.984E-05	9.036E-05	8.178E-05	9.036E-05	9.035E-05	7.727E-05	9.039E-05	9.048E-05
^{240}Pu	9.384E-05	9.369E-05	8.670E-05	9.369E-05	9.368E-05	8.211E-05	9.419E-05	9.383E-05
^{241}Pu	9.187E-05	9.233E-05	8.424E-05	9.233E-05	9.232E-05	7.946E-05	9.240E-05	9.244E-05
^{242}Pu	9.421E-05	9.410E-05	8.678E-05	9.410E-05	9.410E-05	8.244E-05	9.478E-05	9.423E-05
^{241}Am	9.300E-05	9.278E-05	8.565E-05	9.278E-05	9.277E-05	8.121E-05	9.268E-05	9.288E-05
^{243}Am	9.350E-05	9.335E-05	8.608E-05	9.335E-05	9.335E-05	8.177E-05	9.352E-05	9.346E-05
^{10}B	9.321E-05	9.297E-05	8.597E-05	9.297E-05	9.297E-05	8.152E-05	9.264E-05	9.310E-05
ALL	2.895E-04	2.863E-04	2.370E-04	2.863E-04	2.863E-04	6.217E-05	2.862E-04	2.857E-04

Table 43. Absorption rate on ^{238}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	1.351E-03	1.379E-03	1.430E-03	1.379E-03	1.380E-03	1.324E-03	1.376E-03	1.366E-03
^{95}Mo	1.329E-03	1.356E-03	1.368E-03	1.356E-03	1.356E-03	1.300E-03	1.342E-03	1.341E-03
^{99}Tc	1.311E-03	1.339E-03	1.337E-03	1.339E-03	1.338E-03	1.299E-03	1.340E-03	1.325E-03
^{101}Ru	1.331E-03	1.355E-03	1.372E-03	1.355E-03	1.355E-03	1.300E-03	1.362E-03	1.340E-03
^{103}Rh	1.324E-03	1.350E-03	1.391E-03	1.350E-03	1.350E-03	1.298E-03	1.336E-03	1.337E-03
^{109}Ag	1.327E-03	1.355E-03	1.347E-03	1.355E-03	1.355E-03	1.308E-03	1.352E-03	1.340E-03
^{133}Cs	1.314E-03	1.343E-03	1.347E-03	1.343E-03	1.342E-03	1.291E-03	1.339E-03	1.327E-03
^{143}Nd	1.309E-03	1.333E-03	1.372E-03	1.333E-03	1.333E-03	1.279E-03	1.336E-03	1.319E-03
^{145}Nd	1.318E-03	1.341E-03	1.350E-03	1.341E-03	1.341E-03	1.290E-03	1.345E-03	1.327E-03
^{147}Sm	1.329E-03	1.355E-03	1.367E-03	1.355E-03	1.355E-03	1.298E-03	1.361E-03	1.341E-03
^{149}Sm	1.314E-03	1.339E-03	1.380E-03	1.339E-03	1.340E-03	1.286E-03	1.347E-03	1.327E-03
^{150}Sm	1.292E-03	1.311E-03	1.342E-03	1.311E-03	1.312E-03	1.279E-03	1.319E-03	1.300E-03
^{151}Sm	1.298E-03	1.324E-03	1.365E-03	1.324E-03	1.324E-03	1.271E-03	1.333E-03	1.310E-03
^{152}Sm	1.320E-03	1.350E-03	1.345E-03	1.350E-03	1.350E-03	1.293E-03	1.358E-03	1.332E-03
^{153}Eu	1.313E-03	1.339E-03	1.372E-03	1.339E-03	1.340E-03	1.287E-03	1.331E-03	1.327E-03
^{155}Gd	1.300E-03	1.326E-03	1.367E-03	1.326E-03	1.325E-03	1.272E-03	1.314E-03	1.312E-03
^{235}U	1.268E-03	1.303E-03	1.344E-03	1.303E-03	1.303E-03	1.242E-03	1.295E-03	1.289E-03
^{236}U	1.340E-03	1.369E-03	1.415E-03	1.369E-03	1.369E-03	1.317E-03	1.357E-03	1.355E-03
^{237}Np	1.317E-03	1.343E-03	1.385E-03	1.343E-03	1.343E-03	1.291E-03	1.334E-03	1.330E-03
^{238}Pu	1.299E-03	1.325E-03	1.365E-03	1.325E-03	1.325E-03	1.270E-03	1.310E-03	1.312E-03
^{239}Pu	1.229E-03	1.268E-03	1.301E-03	1.268E-03	1.268E-03	1.204E-03	1.272E-03	1.253E-03
^{240}Pu	1.338E-03	1.365E-03	1.410E-03	1.365E-03	1.365E-03	1.312E-03	1.377E-03	1.352E-03
^{241}Pu	1.260E-03	1.296E-03	1.338E-03	1.296E-03	1.297E-03	1.234E-03	1.303E-03	1.283E-03
^{242}Pu	1.344E-03	1.371E-03	1.414E-03	1.371E-03	1.372E-03	1.317E-03	1.378E-03	1.357E-03
^{241}Am	1.319E-03	1.346E-03	1.387E-03	1.346E-03	1.346E-03	1.293E-03	1.338E-03	1.332E-03
^{243}Am	1.329E-03	1.357E-03	1.400E-03	1.357E-03	1.356E-03	1.304E-03	1.348E-03	1.343E-03
^{10}B	1.317E-03	1.344E-03	1.387E-03	1.344E-03	1.344E-03	1.284E-03	1.344E-03	1.331E-03
ALL	9.355E-04	9.418E-04	7.967E-04	9.418E-04	9.415E-04	9.529E-04	9.324E-04	9.200E-04

Table 44. Production rate on ^{238}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	3.192E-04	3.235E-04	3.336E-04	3.235E-04	3.235E-04	3.144E-04	3.200E-04	3.233E-04
^{95}Mo	3.173E-04	3.209E-04	3.300E-04	3.209E-04	3.210E-04	3.119E-04	3.227E-04	3.206E-04
^{99}Tc	3.179E-04	3.215E-04	3.303E-04	3.215E-04	3.214E-04	3.129E-04	3.209E-04	3.210E-04
^{101}Ru	3.170E-04	3.206E-04	3.292E-04	3.206E-04	3.206E-04	3.115E-04	3.217E-04	3.204E-04
^{103}Rh	3.182E-04	3.214E-04	3.303E-04	3.214E-04	3.213E-04	3.133E-04	3.238E-04	3.211E-04
^{109}Ag	3.185E-04	3.221E-04	3.308E-04	3.221E-04	3.222E-04	3.137E-04	3.242E-04	3.217E-04
^{133}Cs	3.182E-04	3.217E-04	3.307E-04	3.217E-04	3.218E-04	3.130E-04	3.190E-04	3.214E-04
^{143}Nd	3.175E-04	3.205E-04	3.297E-04	3.205E-04	3.206E-04	3.125E-04	3.203E-04	3.203E-04
^{145}Nd	3.175E-04	3.208E-04	3.296E-04	3.208E-04	3.208E-04	3.123E-04	3.222E-04	3.204E-04
^{147}Sm	3.184E-04	3.219E-04	3.308E-04	3.219E-04	3.219E-04	3.134E-04	3.228E-04	3.215E-04
^{149}Sm	3.179E-04	3.210E-04	3.301E-04	3.210E-04	3.209E-04	3.130E-04	3.211E-04	3.207E-04
^{150}Sm	3.173E-04	3.204E-04	3.289E-04	3.204E-04	3.205E-04	3.122E-04	3.245E-04	3.201E-04
^{151}Sm	3.174E-04	3.204E-04	3.292E-04	3.204E-04	3.203E-04	3.125E-04	3.187E-04	3.202E-04
^{152}Sm	3.186E-04	3.222E-04	3.311E-04	3.222E-04	3.222E-04	3.137E-04	3.234E-04	3.218E-04
^{153}Eu	3.181E-04	3.212E-04	3.302E-04	3.212E-04	3.212E-04	3.132E-04	3.206E-04	3.210E-04
^{155}Gd	3.174E-04	3.204E-04	3.293E-04	3.204E-04	3.204E-04	3.125E-04	3.209E-04	3.201E-04
^{235}U	3.476E-04	3.533E-04	3.645E-04	3.533E-04	3.533E-04	3.423E-04	3.579E-04	3.529E-04
^{236}U	3.184E-04	3.225E-04	3.323E-04	3.225E-04	3.225E-04	3.134E-04	3.224E-04	3.222E-04
^{237}Np	3.183E-04	3.215E-04	3.304E-04	3.215E-04	3.214E-04	3.134E-04	3.192E-04	3.211E-04
^{238}Pu	3.183E-04	3.213E-04	3.306E-04	3.213E-04	3.213E-04	3.135E-04	3.219E-04	3.212E-04
^{239}Pu	3.717E-04	3.781E-04	3.868E-04	3.781E-04	3.781E-04	3.681E-04	3.808E-04	3.779E-04
^{240}Pu	3.188E-04	3.226E-04	3.316E-04	3.226E-04	3.225E-04	3.140E-04	3.253E-04	3.223E-04
^{241}Pu	3.560E-04	3.623E-04	3.742E-04	3.623E-04	3.624E-04	3.517E-04	3.627E-04	3.621E-04
^{242}Pu	3.190E-04	3.230E-04	3.323E-04	3.230E-04	3.230E-04	3.141E-04	3.269E-04	3.228E-04
^{241}Am	3.183E-04	3.215E-04	3.307E-04	3.215E-04	3.215E-04	3.134E-04	3.200E-04	3.213E-04
^{243}Am	3.188E-04	3.223E-04	3.315E-04	3.223E-04	3.223E-04	3.140E-04	3.230E-04	3.220E-04
^{10}B	3.180E-04	3.215E-04	3.309E-04	3.215E-04	3.214E-04	3.124E-04	3.222E-04	3.212E-04
ALL	3.604E-04	3.572E-04	3.559E-04	3.572E-04	3.572E-04	3.452E-04	3.571E-04	3.569E-04

Table 45. Scattering rate on ^{238}U in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	1.252E-02	1.264E-02	1.134E-02	1.264E-02	1.264E-02	1.096E-02	1.265E-02	1.259E-02
^{95}Mo	1.241E-02	1.251E-02	1.109E-02	1.251E-02	1.251E-02	1.084E-02	1.245E-02	1.246E-02
^{99}Tc	1.240E-02	1.250E-02	1.108E-02	1.250E-02	1.250E-02	1.084E-02	1.250E-02	1.245E-02
^{101}Ru	1.239E-02	1.249E-02	1.105E-02	1.249E-02	1.249E-02	1.078E-02	1.249E-02	1.243E-02
^{103}Rh	1.236E-02	1.245E-02	1.109E-02	1.245E-02	1.245E-02	1.081E-02	1.244E-02	1.240E-02
^{109}Ag	1.241E-02	1.252E-02	1.111E-02	1.252E-02	1.252E-02	1.086E-02	1.250E-02	1.247E-02
^{133}Cs	1.240E-02	1.250E-02	1.110E-02	1.250E-02	1.250E-02	1.085E-02	1.249E-02	1.245E-02
^{143}Nd	1.234E-02	1.242E-02	1.106E-02	1.242E-02	1.242E-02	1.078E-02	1.239E-02	1.237E-02
^{145}Nd	1.235E-02	1.244E-02	1.104E-02	1.244E-02	1.244E-02	1.078E-02	1.248E-02	1.238E-02
^{147}Sm	1.240E-02	1.249E-02	1.107E-02	1.249E-02	1.249E-02	1.082E-02	1.251E-02	1.244E-02
^{149}Sm	1.234E-02	1.243E-02	1.109E-02	1.243E-02	1.243E-02	1.079E-02	1.239E-02	1.239E-02
^{150}Sm	1.233E-02	1.242E-02	1.100E-02	1.242E-02	1.242E-02	1.077E-02	1.243E-02	1.237E-02
^{151}Sm	1.232E-02	1.240E-02	1.106E-02	1.240E-02	1.240E-02	1.077E-02	1.240E-02	1.236E-02
^{152}Sm	1.241E-02	1.252E-02	1.112E-02	1.252E-02	1.251E-02	1.086E-02	1.250E-02	1.246E-02
^{153}Eu	1.234E-02	1.243E-02	1.106E-02	1.243E-02	1.243E-02	1.078E-02	1.246E-02	1.238E-02
^{155}Gd	1.233E-02	1.241E-02	1.107E-02	1.241E-02	1.241E-02	1.077E-02	1.241E-02	1.236E-02
^{235}U	1.242E-02	1.258E-02	1.116E-02	1.258E-02	1.258E-02	1.079E-02	1.260E-02	1.253E-02
^{236}U	1.247E-02	1.259E-02	1.126E-02	1.259E-02	1.259E-02	1.091E-02	1.253E-02	1.253E-02
^{237}Np	1.235E-02	1.244E-02	1.108E-02	1.244E-02	1.244E-02	1.080E-02	1.243E-02	1.239E-02
^{238}Pu	1.231E-02	1.240E-02	1.105E-02	1.240E-02	1.240E-02	1.076E-02	1.240E-02	1.235E-02
^{239}Pu	1.231E-02	1.249E-02	1.099E-02	1.249E-02	1.249E-02	1.064E-02	1.249E-02	1.245E-02
^{240}Pu	1.243E-02	1.253E-02	1.120E-02	1.253E-02	1.253E-02	1.088E-02	1.259E-02	1.249E-02
^{241}Pu	1.244E-02	1.261E-02	1.116E-02	1.261E-02	1.261E-02	1.079E-02	1.262E-02	1.257E-02
^{242}Pu	1.246E-02	1.257E-02	1.120E-02	1.257E-02	1.257E-02	1.091E-02	1.267E-02	1.253E-02
^{241}Am	1.236E-02	1.245E-02	1.110E-02	1.245E-02	1.245E-02	1.081E-02	1.244E-02	1.240E-02
^{243}Am	1.239E-02	1.250E-02	1.113E-02	1.250E-02	1.249E-02	1.085E-02	1.253E-02	1.245E-02
^{10}B	1.238E-02	1.247E-02	1.114E-02	1.247E-02	1.247E-02	1.084E-02	1.244E-02	1.243E-02
ALL	1.084E-02	1.077E-02	8.719E-03	1.077E-02	1.077E-02	9.085E-03	1.076E-02	1.067E-02

Table 46. Absorption rate on ^{16}O in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	5.995E-06	6.056E-06	6.252E-06	6.056E-06	6.056E-06	5.972E-06	5.847E-06	6.069E-06
^{95}Mo	5.953E-06	6.000E-06	6.181E-06	6.000E-06	6.004E-06	5.916E-06	6.139E-06	6.016E-06
^{99}Tc	5.967E-06	6.015E-06	6.181E-06	6.015E-06	6.014E-06	5.936E-06	5.986E-06	6.022E-06
^{101}Ru	5.947E-06	5.992E-06	6.160E-06	5.992E-06	5.995E-06	5.903E-06	6.095E-06	6.006E-06
^{103}Rh	5.972E-06	6.013E-06	6.189E-06	6.013E-06	6.008E-06	5.944E-06	6.097E-06	6.021E-06
^{109}Ag	5.980E-06	6.025E-06	6.191E-06	6.025E-06	6.028E-06	5.954E-06	6.111E-06	6.034E-06
^{133}Cs	5.971E-06	6.014E-06	6.192E-06	6.014E-06	6.019E-06	5.938E-06	5.887E-06	6.033E-06
^{143}Nd	5.957E-06	5.992E-06	6.167E-06	5.992E-06	5.992E-06	5.925E-06	6.021E-06	6.002E-06
^{145}Nd	5.958E-06	5.998E-06	6.170E-06	5.998E-06	6.001E-06	5.922E-06	6.017E-06	6.009E-06
^{147}Sm	5.976E-06	6.021E-06	6.185E-06	6.021E-06	6.023E-06	5.950E-06	5.986E-06	6.030E-06
^{149}Sm	5.965E-06	6.003E-06	6.175E-06	6.003E-06	6.002E-06	5.938E-06	6.114E-06	6.011E-06
^{150}Sm	5.954E-06	5.990E-06	6.152E-06	5.990E-06	5.993E-06	5.922E-06	6.047E-06	6.001E-06
^{151}Sm	5.954E-06	5.989E-06	6.168E-06	5.989E-06	5.988E-06	5.925E-06	5.899E-06	5.999E-06
^{152}Sm	5.981E-06	6.030E-06	6.191E-06	6.030E-06	6.025E-06	5.955E-06	6.023E-06	6.039E-06
^{153}Eu	5.969E-06	6.010E-06	6.184E-06	6.010E-06	6.011E-06	5.943E-06	5.985E-06	6.022E-06
^{155}Gd	5.954E-06	5.993E-06	6.165E-06	5.993E-06	5.990E-06	5.926E-06	6.099E-06	6.007E-06
^{235}U	6.514E-06	6.597E-06	6.814E-06	6.597E-06	6.596E-06	6.482E-06	6.666E-06	6.605E-06
^{236}U	5.981E-06	6.039E-06	6.232E-06	6.039E-06	6.035E-06	5.957E-06	5.983E-06	6.048E-06
^{237}Np	5.974E-06	6.015E-06	6.183E-06	6.015E-06	6.014E-06	5.948E-06	5.996E-06	6.024E-06
^{238}Pu	5.973E-06	6.010E-06	6.192E-06	6.010E-06	6.011E-06	5.945E-06	5.991E-06	6.025E-06
^{239}Pu	7.064E-06	7.153E-06	7.237E-06	7.153E-06	7.156E-06	7.169E-06	7.222E-06	7.165E-06
^{240}Pu	5.986E-06	6.033E-06	6.207E-06	6.033E-06	6.034E-06	5.962E-06	6.114E-06	6.046E-06
^{241}Pu	6.757E-06	6.848E-06	6.996E-06	6.848E-06	6.849E-06	6.876E-06	6.900E-06	6.862E-06
^{242}Pu	5.991E-06	6.043E-06	6.223E-06	6.043E-06	6.046E-06	5.967E-06	6.256E-06	6.057E-06
^{241}Am	5.975E-06	6.014E-06	6.192E-06	6.014E-06	6.015E-06	5.948E-06	5.980E-06	6.028E-06
^{243}Am	5.986E-06	6.028E-06	6.210E-06	6.028E-06	6.031E-06	5.961E-06	6.016E-06	6.043E-06
^{10}B	5.969E-06	6.014E-06	6.200E-06	6.014E-06	6.014E-06	5.928E-06	6.025E-06	6.025E-06
ALL	6.801E-06	6.722E-06	6.614E-06	6.722E-06	6.717E-06	6.709E-06	6.689E-06	6.720E-06

Table 47. Scattering rate on ^{16}O in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	8.985E-03	8.986E-03	9.211E-03	8.986E-03	8.984E-03	8.321E-03	8.980E-03	8.967E-03
^{95}Mo	8.893E-03	8.881E-03	9.028E-03	8.881E-03	8.883E-03	8.236E-03	8.841E-03	8.860E-03
^{99}Tc	8.875E-03	8.864E-03	8.992E-03	8.864E-03	8.864E-03	8.225E-03	8.859E-03	8.841E-03
^{101}Ru	8.883E-03	8.877E-03	8.988E-03	8.877E-03	8.878E-03	8.201E-03	8.884E-03	8.854E-03
^{103}Rh	8.847E-03	8.830E-03	9.000E-03	8.830E-03	8.831E-03	8.200E-03	8.832E-03	8.809E-03
^{109}Ag	8.889E-03	8.880E-03	9.021E-03	8.880E-03	8.881E-03	8.237E-03	8.869E-03	8.859E-03
^{133}Cs	8.882E-03	8.872E-03	9.011E-03	8.872E-03	8.873E-03	8.228E-03	8.859E-03	8.851E-03
^{143}Nd	8.823E-03	8.799E-03	8.975E-03	8.799E-03	8.801E-03	8.169E-03	8.786E-03	8.779E-03
^{145}Nd	8.843E-03	8.828E-03	8.970E-03	8.828E-03	8.829E-03	8.186E-03	8.864E-03	8.802E-03
^{147}Sm	8.874E-03	8.865E-03	9.004E-03	8.865E-03	8.866E-03	8.217E-03	8.868E-03	8.840E-03
^{149}Sm	8.833E-03	8.812E-03	8.992E-03	8.812E-03	8.813E-03	8.179E-03	8.789E-03	8.794E-03
^{150}Sm	8.826E-03	8.806E-03	8.926E-03	8.806E-03	8.806E-03	8.164E-03	8.797E-03	8.783E-03
^{151}Sm	8.812E-03	8.788E-03	8.970E-03	8.788E-03	8.788E-03	8.158E-03	8.791E-03	8.768E-03
^{152}Sm	8.894E-03	8.887E-03	9.021E-03	8.887E-03	8.886E-03	8.244E-03	8.881E-03	8.862E-03
^{153}Eu	8.831E-03	8.814E-03	8.978E-03	8.814E-03	8.814E-03	8.179E-03	8.823E-03	8.792E-03
^{155}Gd	8.818E-03	8.794E-03	8.974E-03	8.794E-03	8.793E-03	8.162E-03	8.786E-03	8.774E-03
^{235}U	8.873E-03	8.902E-03	9.096E-03	8.902E-03	8.903E-03	8.194E-03	8.916E-03	8.882E-03
^{236}U	8.938E-03	8.939E-03	9.148E-03	8.939E-03	8.939E-03	8.284E-03	8.901E-03	8.913E-03
^{237}Np	8.840E-03	8.824E-03	8.995E-03	8.824E-03	8.825E-03	8.189E-03	8.820E-03	8.803E-03
^{238}Pu	8.806E-03	8.784E-03	8.962E-03	8.784E-03	8.784E-03	8.152E-03	8.793E-03	8.764E-03
^{239}Pu	8.761E-03	8.806E-03	8.985E-03	8.806E-03	8.806E-03	8.075E-03	8.817E-03	8.788E-03
^{240}Pu	8.907E-03	8.899E-03	9.091E-03	8.899E-03	8.898E-03	8.257E-03	8.931E-03	8.880E-03
^{241}Pu	8.879E-03	8.923E-03	9.107E-03	8.923E-03	8.922E-03	8.194E-03	8.924E-03	8.903E-03
^{242}Pu	8.934E-03	8.930E-03	9.095E-03	8.930E-03	8.931E-03	8.282E-03	8.986E-03	8.911E-03
^{241}Am	8.846E-03	8.829E-03	9.010E-03	8.829E-03	8.828E-03	8.192E-03	8.812E-03	8.808E-03
^{243}Am	8.879E-03	8.869E-03	9.037E-03	8.869E-03	8.870E-03	8.230E-03	8.878E-03	8.849E-03
^{10}B	8.862E-03	8.845E-03	9.034E-03	8.845E-03	8.845E-03	8.203E-03	8.823E-03	8.826E-03
ALL	7.542E-03	7.443E-03	7.180E-03	7.443E-03	7.442E-03	6.923E-03	7.437E-03	7.398E-03

Figure 38. Relative difference in the BUC absorption rate for cases 1 to 14 of sub-phase 3

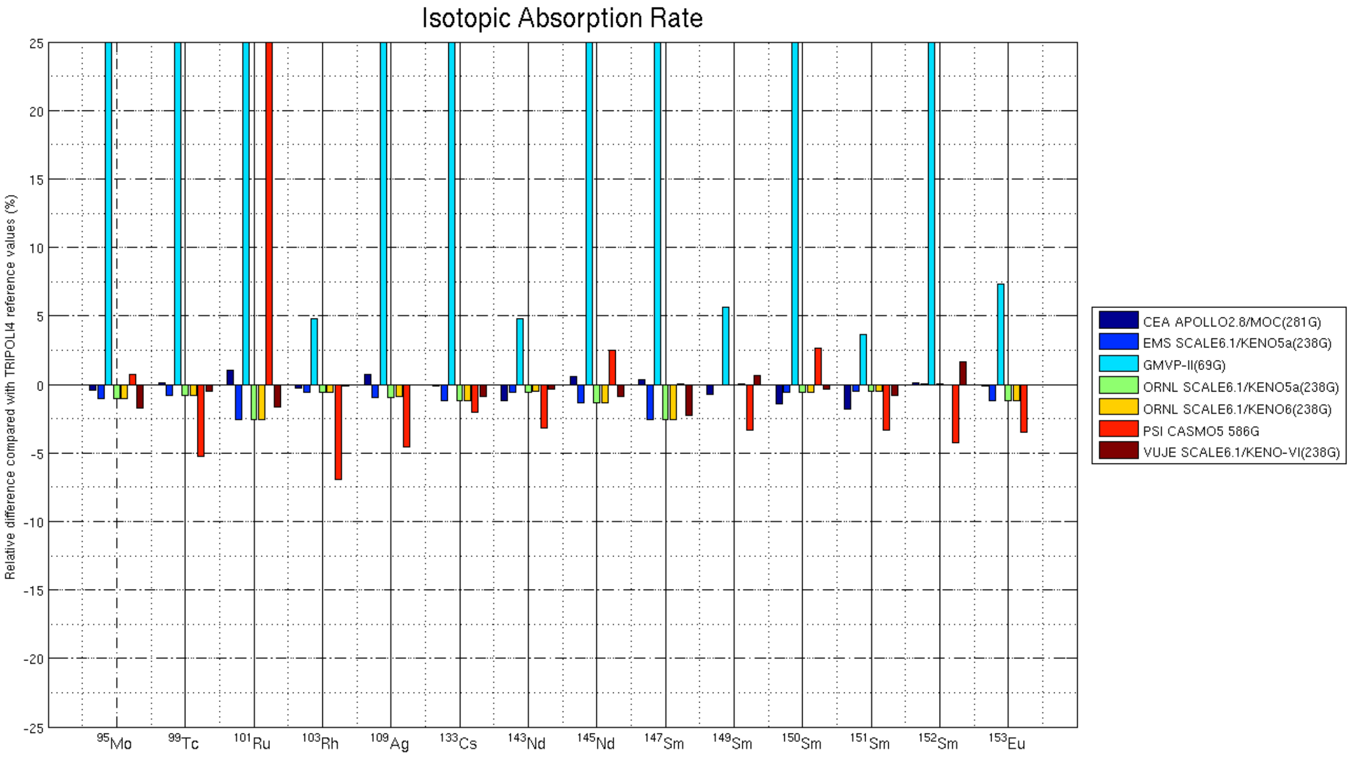


Figure 39. Relative difference in the BUC absorption rate for cases 15 to 27 of sub-phase 3

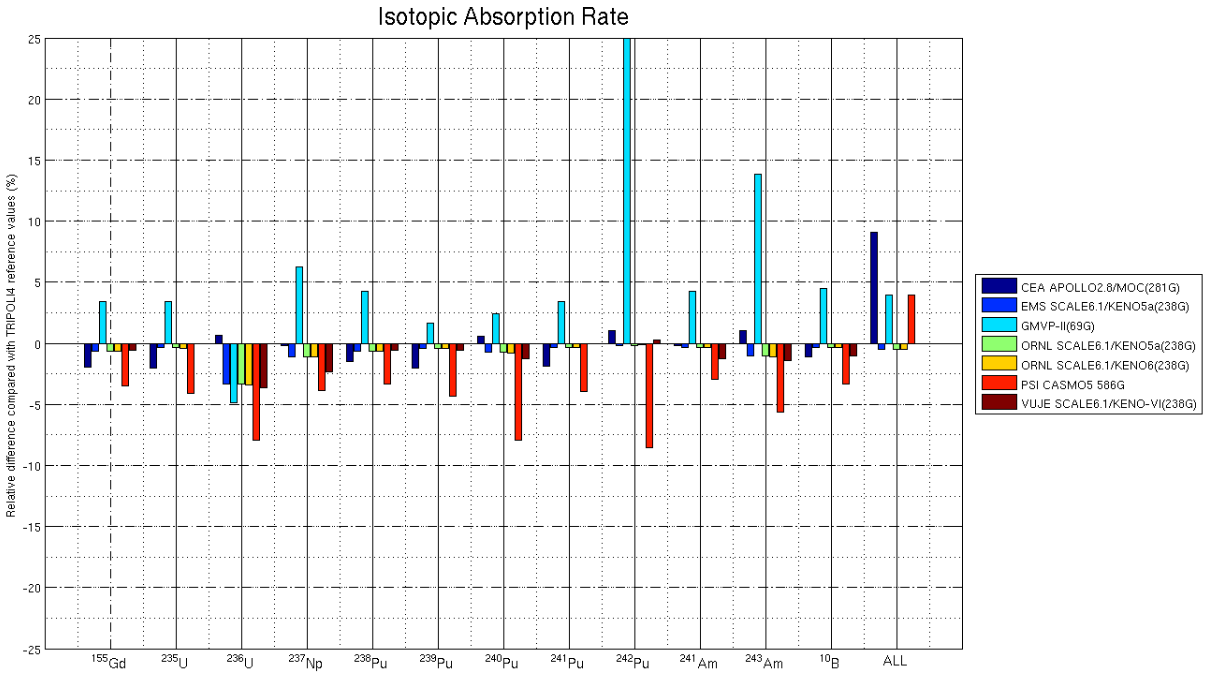


Figure 40. Relative difference in the BUC production rate for cases 16 to 27 of sub-phase 3

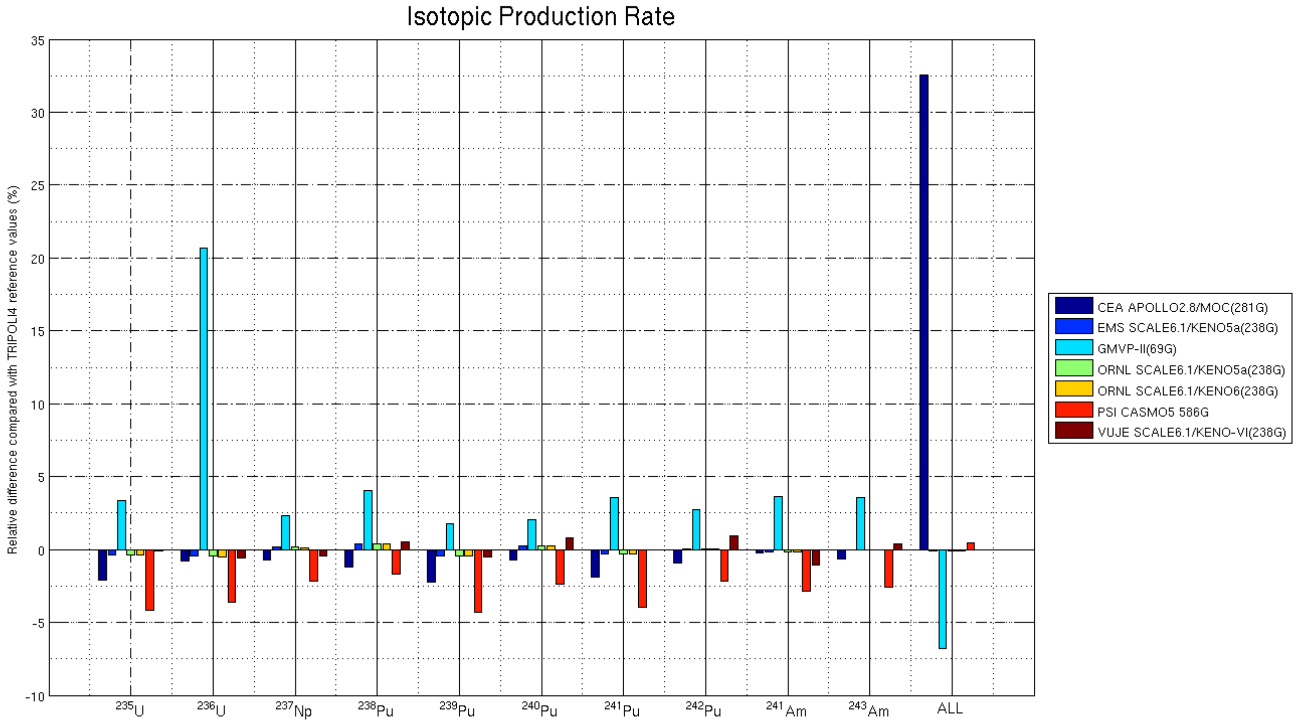


Figure 41. Relative difference in the BUC scattering rate for cases 1 to 14 of sub-phase 3

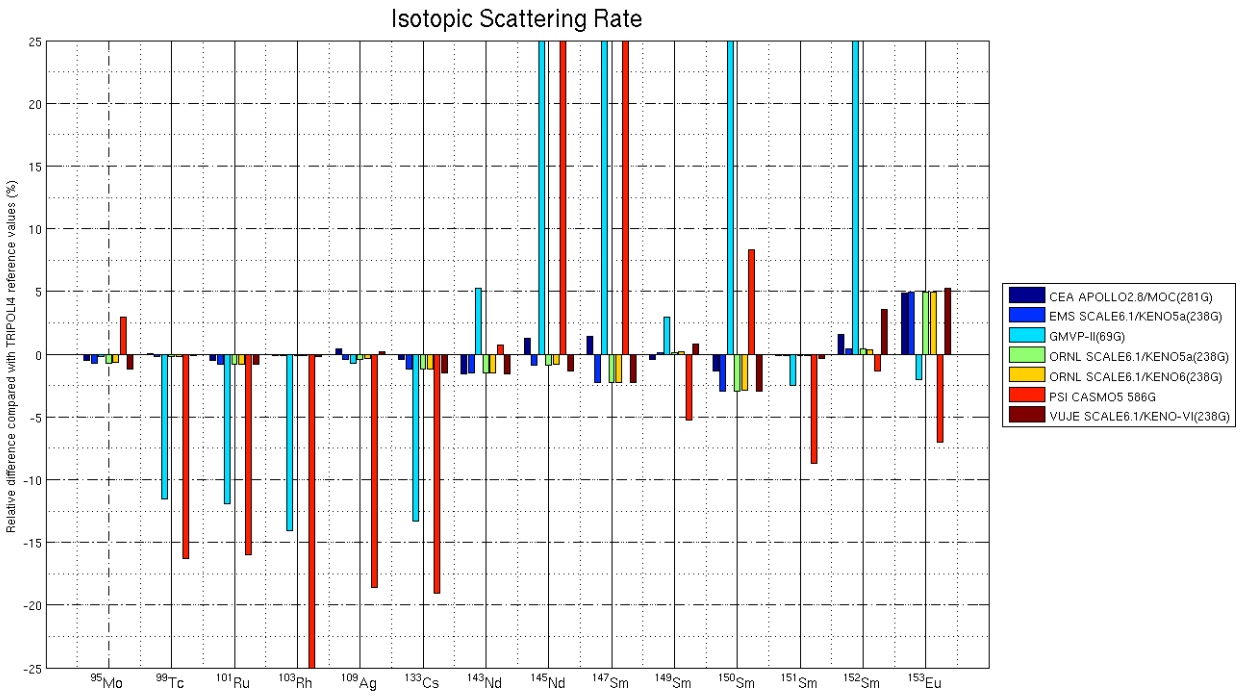


Figure 42. Relative difference in the BUC scattering rate for cases 15 to 27 of sub-phase 3

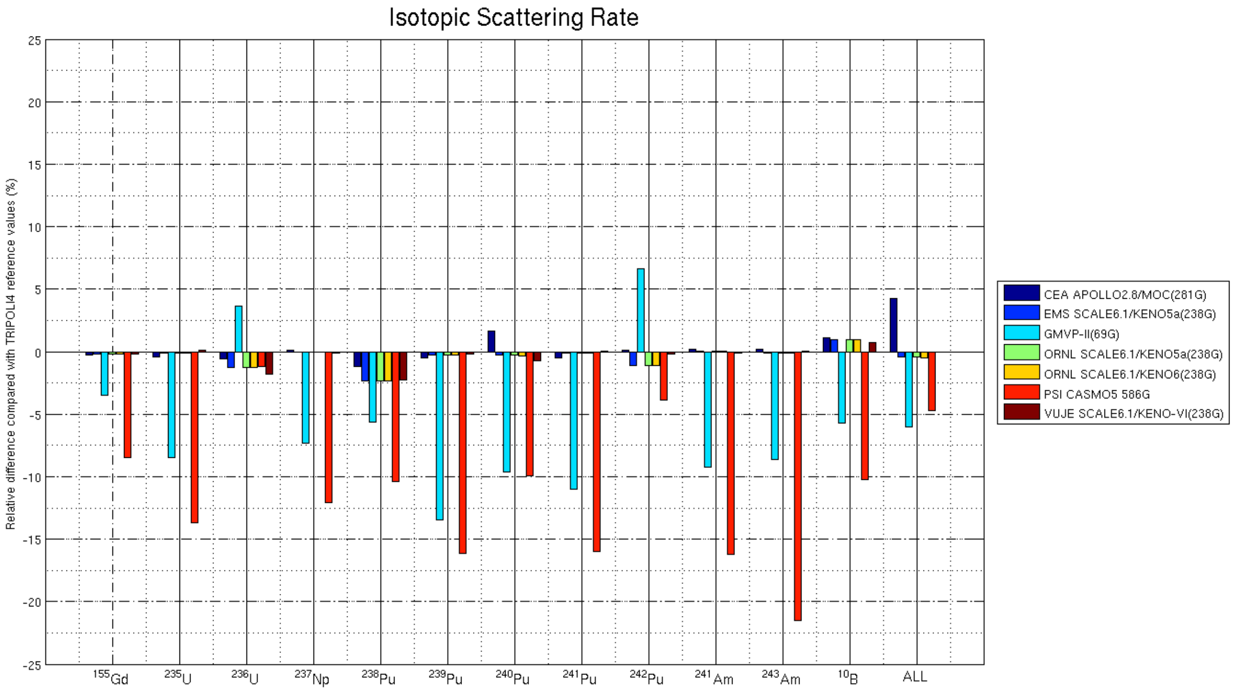


Table 48. Absorption rate on the BUC nuclide in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	5.885E-04	5.848E-04	8.899E-04	5.848E-04	5.849E-04	5.952E-04	5.806E-04	5.909E-04
^{99}Tc	7.218E-04	7.154E-04	1.078E-03	7.154E-04	7.154E-04	6.833E-04	7.174E-04	7.211E-04
^{101}Ru	7.332E-04	7.074E-04	1.133E-03	7.074E-04	7.074E-04	9.491E-04	7.137E-04	7.258E-04
^{103}Rh	8.586E-04	8.559E-04	9.017E-04	8.559E-04	8.557E-04	8.008E-04	8.598E-04	8.607E-04
^{109}Ag	6.047E-04	5.945E-04	9.052E-04	5.945E-04	5.949E-04	5.729E-04	6.000E-04	6.002E-04
^{133}Cs	6.688E-04	6.620E-04	9.828E-04	6.620E-04	6.621E-04	6.561E-04	6.640E-04	6.698E-04
^{143}Nd	9.346E-04	9.405E-04	9.911E-04	9.405E-04	9.408E-04	9.160E-04	9.427E-04	9.458E-04
^{145}Nd	8.737E-04	8.571E-04	1.129E-03	8.571E-04	8.572E-04	8.902E-04	8.610E-04	8.686E-04
^{147}Sm	7.263E-04	7.050E-04	1.008E-03	7.050E-04	7.052E-04	7.238E-04	7.070E-04	7.236E-04
^{149}Sm	8.837E-04	8.898E-04	9.400E-04	8.898E-04	8.903E-04	8.600E-04	8.956E-04	8.900E-04
^{150}Sm	9.515E-04	9.591E-04	1.298E-03	9.591E-04	9.594E-04	9.906E-04	9.617E-04	9.648E-04
^{151}Sm	9.659E-04	9.788E-04	1.020E-03	9.788E-04	9.785E-04	9.508E-04	9.758E-04	9.835E-04
^{152}Sm	5.468E-04	5.466E-04	8.623E-04	5.466E-04	5.463E-04	5.232E-04	5.553E-04	5.464E-04
^{153}Eu	9.719E-04	9.616E-04	1.044E-03	9.616E-04	9.614E-04	9.391E-04	9.727E-04	9.728E-04
^{155}Gd	9.269E-04	9.396E-04	9.778E-04	9.396E-04	9.396E-04	9.130E-04	9.400E-04	9.458E-04
^{235}U	2.803E-03	2.850E-03	2.959E-03	2.850E-03	2.850E-03	2.744E-03	2.859E-03	2.861E-03
^{236}U	3.627E-04	3.483E-04	3.429E-04	3.483E-04	3.482E-04	3.319E-04	3.473E-04	3.605E-04
^{237}Np	9.270E-04	9.185E-04	9.866E-04	9.185E-04	9.187E-04	8.926E-04	9.066E-04	9.287E-04
^{238}Pu	1.074E-03	1.083E-03	1.137E-03	1.083E-03	1.083E-03	1.054E-03	1.084E-03	1.090E-03
^{239}Pu	3.786E-03	3.850E-03	3.930E-03	3.850E-03	3.849E-03	3.697E-03	3.844E-03	3.866E-03
^{240}Pu	4.814E-04	4.754E-04	4.903E-04	4.754E-04	4.750E-04	4.409E-04	4.725E-04	4.787E-04
^{241}Pu	2.491E-03	2.529E-03	2.625E-03	2.529E-03	2.529E-03	2.437E-03	2.537E-03	2.538E-03
^{242}Pu	3.368E-04	3.328E-04	5.442E-04	3.328E-04	3.329E-04	3.048E-04	3.343E-04	3.334E-04
^{241}Am	8.613E-04	8.597E-04	8.994E-04	8.597E-04	8.594E-04	8.372E-04	8.514E-04	8.626E-04
^{243}Am	7.042E-04	6.895E-04	7.935E-04	6.895E-04	6.892E-04	6.579E-04	6.869E-04	6.969E-04
^{10}B	7.121E-04	7.175E-04	7.526E-04	7.175E-04	7.175E-04	6.959E-04	7.128E-04	7.201E-04
ALL	1.196E-02	1.091E-02	1.140E-02	1.091E-02	1.091E-02	1.140E-02	N.R.	1.096E-02

Table 49. Production rate on the BUC nuclide in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{235}U	5.668E-03	5.764E-03	5.981E-03	5.764E-03	5.764E-03	5.547E-03	5.782E-03	5.787E-03
^{236}U	7.178E-05	7.204E-05	8.735E-05	7.204E-05	7.203E-05	6.974E-05	7.195E-05	7.237E-05
^{237}Np	3.291E-05	3.320E-05	3.392E-05	3.320E-05	3.320E-05	3.244E-05	3.299E-05	3.315E-05
^{238}Pu	1.558E-04	1.584E-04	1.641E-04	1.584E-04	1.584E-04	1.551E-04	1.586E-04	1.577E-04
^{239}Pu	7.316E-03	7.450E-03	7.612E-03	7.450E-03	7.449E-03	7.161E-03	7.442E-03	7.482E-03
^{240}Pu	6.316E-06	6.376E-06	6.491E-06	6.376E-06	6.375E-06	6.208E-06	6.413E-06	6.361E-06
^{241}Pu	5.416E-03	5.500E-03	5.716E-03	5.500E-03	5.501E-03	5.300E-03	5.517E-03	5.518E-03
^{242}Pu	4.028E-05	4.068E-05	4.176E-05	4.068E-05	4.068E-05	3.977E-05	4.103E-05	4.065E-05
^{241}Am	2.442E-05	2.445E-05	2.538E-05	2.445E-05	2.444E-05	2.379E-05	2.423E-05	2.448E-05
^{243}Am	2.595E-05	2.611E-05	2.704E-05	2.611E-05	2.611E-05	2.543E-05	2.621E-05	2.611E-05
ALL	8.588E-03	6.474E-03	6.037E-03	6.474E-03	6.475E-03	6.508E-03	N.R.	6.479E-03

Table 50. Scattering rate on the BUC nuclide in s^{-1} (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	1.704E-03	1.700E-03	1.709E-03	1.700E-03	1.701E-03	1.763E-03	1.692E-03	1.712E-03
^{99}Tc	7.690E-04	7.671E-04	6.795E-04	7.671E-04	7.671E-04	6.432E-04	7.675E-04	7.684E-04
^{101}Ru	2.042E-03	2.036E-03	1.808E-03	2.036E-03	2.036E-03	1.724E-03	2.035E-03	2.052E-03
^{103}Rh	1.413E-04	1.413E-04	1.215E-04	1.413E-04	1.413E-04	1.060E-04	1.411E-04	1.415E-04
^{109}Ag	1.605E-04	1.592E-04	1.587E-04	1.592E-04	1.593E-04	1.301E-04	1.602E-04	1.599E-04
^{133}Cs	5.027E-04	4.988E-04	4.375E-04	4.988E-04	4.989E-04	4.085E-04	4.974E-04	5.048E-04
^{143}Nd	7.322E-04	7.331E-04	7.834E-04	7.331E-04	7.332E-04	7.493E-04	7.324E-04	7.441E-04
^{145}Nd	1.538E-03	1.505E-03	1.954E-03	1.505E-03	1.506E-03	1.940E-03	1.498E-03	1.518E-03
^{147}Sm	7.207E-04	6.948E-04	9.237E-04	6.948E-04	6.949E-04	9.060E-04	6.948E-04	7.107E-04
^{149}Sm	8.062E-06	8.106E-06	8.335E-06	8.106E-06	8.109E-06	7.667E-06	8.158E-06	8.094E-06
^{150}Sm	1.071E-03	1.054E-03	1.371E-03	1.054E-03	1.054E-03	1.176E-03	1.053E-03	1.085E-03
^{151}Sm	1.316E-05	1.316E-05	1.285E-05	1.316E-05	1.316E-05	1.203E-05	1.313E-05	1.318E-05
^{152}Sm	5.827E-04	5.763E-04	1.161E-03	5.763E-04	5.755E-04	5.659E-04	5.943E-04	5.737E-04
^{153}Eu	1.363E-04	1.364E-04	1.274E-04	1.364E-04	1.364E-04	1.208E-04	1.367E-04	1.300E-04
^{155}Gd	2.692E-06	2.694E-06	2.605E-06	2.694E-06	2.694E-06	2.471E-06	2.696E-06	2.700E-06
^{235}U	3.604E-04	3.615E-04	3.313E-04	3.615E-04	3.615E-04	3.125E-04	3.625E-04	3.620E-04
^{236}U	1.367E-03	1.357E-03	1.426E-03	1.357E-03	1.357E-03	1.358E-03	1.351E-03	1.375E-03
^{237}Np	2.437E-04	2.433E-04	2.256E-04	2.433E-04	2.434E-04	2.140E-04	2.431E-04	2.434E-04
^{238}Pu	2.273E-04	2.247E-04	2.171E-04	2.247E-04	2.247E-04	2.062E-04	2.250E-04	2.301E-04
^{239}Pu	2.325E-04	2.331E-04	2.022E-04	2.331E-04	2.331E-04	1.960E-04	2.332E-04	2.337E-04
^{240}Pu	6.402E-05	6.282E-05	5.692E-05	6.282E-05	6.279E-05	5.672E-05	6.251E-05	6.299E-05
^{241}Pu	1.278E-04	1.284E-04	1.144E-04	1.284E-04	1.284E-04	1.079E-04	1.285E-04	1.285E-04
^{242}Pu	3.753E-04	3.707E-04	3.998E-04	3.707E-04	3.707E-04	3.604E-04	3.741E-04	3.750E-04
^{241}Am	6.027E-05	6.017E-05	5.460E-05	6.017E-05	6.017E-05	5.038E-05	6.010E-05	6.014E-05
^{243}Am	1.846E-04	1.841E-04	1.684E-04	1.841E-04	1.841E-04	1.446E-04	1.844E-04	1.843E-04
^{10}B	3.336E-06	3.332E-06	3.112E-06	3.332E-06	3.332E-06	2.961E-06	3.324E-06	3.300E-06
ALL	1.135E-02	1.083E-02	1.022E-02	1.083E-02	1.083E-02	1.037E-02	N.R.	1.088E-02

3.3.4 Reactivity worth

3.3.4.1 Eigen-value difference method

Reactivity worth calculated by the eigen value difference method are presented in Figures 43 and 44 , with the calculated values reported in Table 51.

As observed in sub-phase 2, most of the trends on reactivity worth are similar to the ones observed for the absorption and production rate of the BUC nuclide.

The best agreement with TRIPOLI4 is obtained by SCALE6.1 calculations from ORNL and EMS, and also APOLLO2 calculations from CEA with differences within 3% for most cases. Most of VUJE calculations fail to evaluate correctly the reactivity worth, due to the convergence of the k-effective of each case at around 40 pcm, which correspond to the magnitude of the reactivity worth of each added nuclide.

More complications are observed for the calculation of the case 28 where large differences are observed between all code systems. Even if the reactivity worth is smaller than in sub-phase 2 (around 100 pcm), the TRIPOLI4 reference calculation is converged enough to identify significant differences from participants. It seems that calculations of reactivity worth in the case of large scattering effects are not well predicted by participants. Deterministic solutions may be limited to the evaluation of a large local variation of the diffusion coefficient which may affect the axial leakage close to the central cell (streaming effect). In the case of Monte-Carlo solutions though, it is more complicated to explain the differences as neutron leakage are treated explicitly. A possible explanation could come from the processing of multi-group cross-sections which are based on a 1D formalism, which is unable to correctly account for the local perturbation due to the voided cell. The same kind of conclusions can be drawn for the case 29 where the fuel is substituted by light water.

Figure 43. Relative difference in the reactivity worth by the eigen-value difference method for cases 1 to 15 of sub-phase 3 (y-axis scaled from -20% to 20% difference)

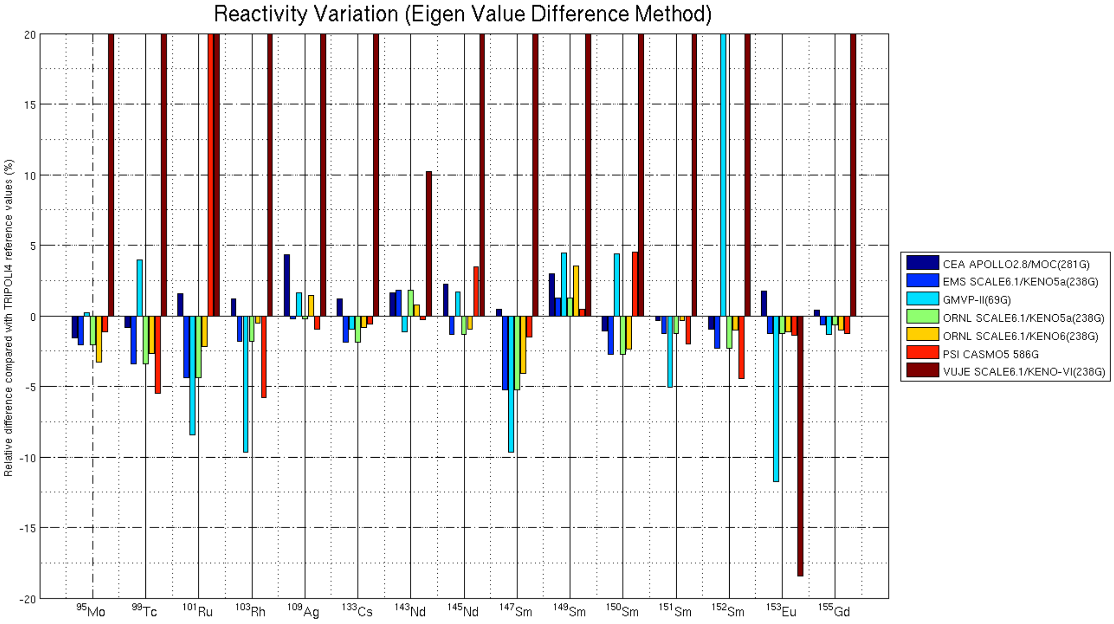


Figure 44. Relative difference in the reactivity worth by the eigen-value difference method for cases 16 to 29 of sub-phase 3 (y-axis scaled from -20% to 20% difference)

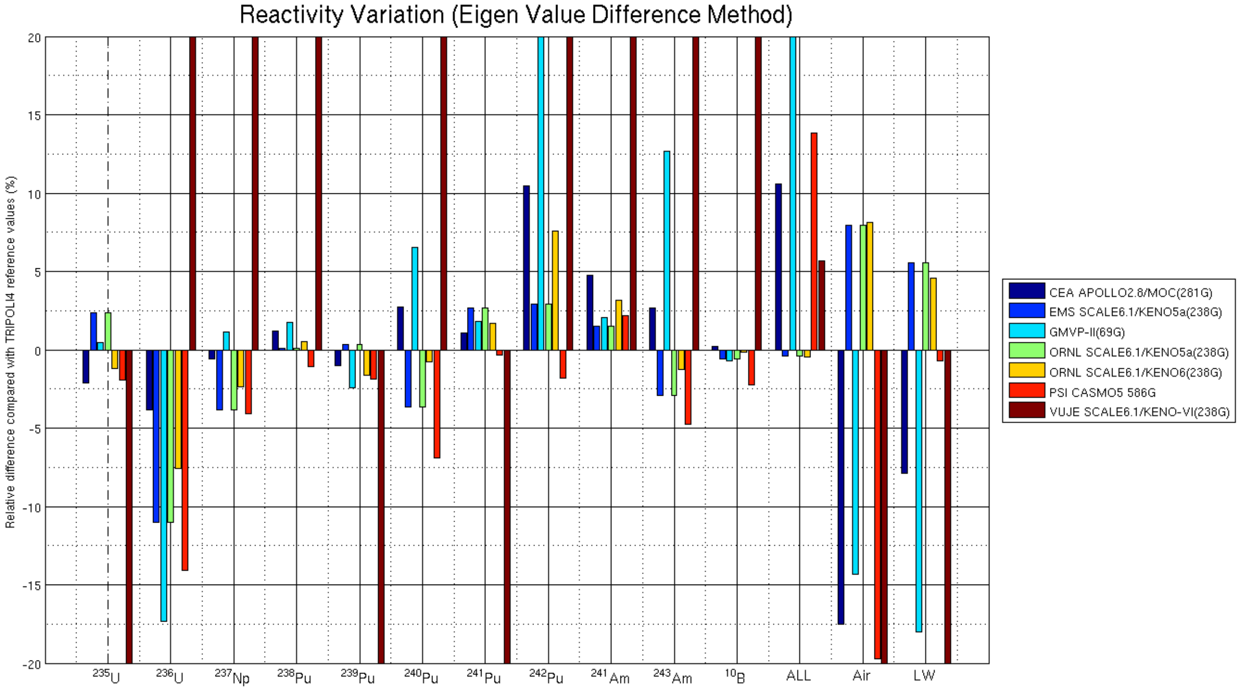


Table 51. Reactivity worth by the eigen-value difference method in pcm (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	-68.5	-68.2(0.6)	-69.8(0.9)	-68.2(0.6)	-67.3(0.6)	-68.8	-116.0(22.5)	-69.6(1.5)
^{99}Tc	-83.2	-81.0(0.6)	-87.2(0.9)	-81.0(0.6)	-81.7(0.6)	-79.3	-144.0(23.8)	-83.9(1.5)
^{101}Ru	-81.5	-76.6(0.6)	-73.4(0.9)	-76.6(0.6)	-78.4(0.6)	-105	-106.0(23.8)	-80.2(1.5)
^{103}Rh	-106.3	-103.2(0.6)	-94.9(0.9)	-103.2(0.6)	-104.5(0.6)	-99	-154.0(23.2)	-105.1(1.5)
^{109}Ag	-72.2	-69.0(0.6)	-70.3(0.9)	-69.0(0.6)	-70.1(0.6)	-68.5	-111.0(23.8)	-69.2(1.5)
^{133}Cs	-77	-74.6(0.6)	-75.4(0.9)	-74.6(0.6)	-75.4(0.6)	-75.6	-133.0(24.4)	-76.1(1.5)
^{143}Nd	-114.3	-114.5(0.6)	-111.2(0.9)	-114.5(0.6)	-113.4(0.6)	-112.2	-124.0(23.2)	-112.5(1.5)
^{145}Nd	-104.2	-100.6(0.6)	-103.7(0.9)	-100.6(0.6)	-101.0(0.6)	-105.5	-165.0(20.7)	-101.9(1.5)
^{147}Sm	-84.9	-80.1(0.6)	-76.3(0.9)	-80.1(0.6)	-81.0(0.6)	-83.2	-129.0(21.9)	-84.5(1.5)
^{149}Sm	-109.3	-107.5(0.6)	-110.9(0.9)	-107.5(0.6)	-109.9(0.6)	-106.6	-133.0(21.3)	-106.1(1.5)
^{150}Sm	-112.7	-110.8(6.1)	-118.9(0.9)	-110.8(6.1)	-111.2(6.1)	-119.1	-141.0(20.7)	-113.9(1.5)
^{151}Sm	-118.4	-117.3(0.6)	-112.8(0.9)	-117.3(0.6)	-118.3(0.6)	-116.4	-160.0(21.3)	-118.7(1.5)
^{152}Sm	-63.3	-62.5(0.6)	-87.8(0.9)	-62.5(0.6)	-63.3(0.6)	-61.1	-138.0(21.3)	-64.0(1.5)
^{153}Eu	-116	-112.6(0.6)	-100.6(0.9)	-112.6(0.6)	-112.8(0.6)	-112.5	-93.0(21.9)	-114.1(1.5)
^{155}Gd	-114	-112.8(0.6)	-112.0(0.9)	-112.8(0.6)	-112.4(0.6)	-112.1	-166.0(21.9)	-113.5(1.5)
^{235}U	70	73.3(0.6)	71.9(0.9)	73.3(0.6)	70.7(0.6)	70.2	47.0(24.9)	71.6(1.4)
^{236}U	-35.4	-32.7(0.6)	-30.4(0.9)	-32.7(0.6)	-34.0(0.6)	-31.6	-71.0(20.7)	-36.8(1.5)
^{237}Np	-108.7	-105.2(0.6)	-110.6(0.9)	-105.2(0.6)	-106.8(0.6)	-104.9	-165.0(24.4)	-109.3(1.5)
^{238}Pu	-119.1	-117.8(0.6)	-119.7(0.9)	-117.8(0.6)	-118.2(0.6)	-116.4	-143.0(20.7)	-117.6(1.5)

Table 51. Reactivity worth by the eigen-value difference method in pcm (sub-phase 3) (continued)

^{239}Pu	98.4	99.7(0.6)	97.0(0.9)	99.7(0.6)	97.8(0.6)	97.5	72.0(22.5)	99.4(1.4)
^{240}Pu	-59.6	-55.9(0.6)	-61.8(0.9)	-55.9(0.6)	-57.6(0.6)	-54	-74.0(23.1)	-58.0(1.5)
^{241}Pu	111.8	113.6(0.6)	112.6(0.9)	113.6(0.6)	112.5(0.6)	110.2	36.0(25.5)	110.6(1.4)
^{242}Pu	-37.7	-35.1(0.6)	-59.5(0.9)	-35.1(0.6)	-36.7(0.6)	-33.5	-63.0(21.3)	-34.1(1.5)
^{241}Am	-103.7	-100.5(0.6)	-101.0(0.9)	-100.5(0.6)	-102.2(0.6)	-101.2	-155.0(21.3)	-99.0(1.5)
^{243}Am	-83	-78.5(0.6)	-91.1(0.9)	-78.5(0.6)	-79.8(0.6)	-77	-118.0(21.3)	-80.9(1.5)
^{10}B	-86.9	-86.2(0.6)	-86.1(0.9)	-86.2(0.6)	-86.5(0.6)	-84.7	-133.0(23.8)	-86.7(1.5)
ALL	-854.1	-769.2(0.6)	-928.5(0.9)	-769.2(0.6)	-768.6(0.6)	-879.1	-816.0(25.2)	-772.2(1.5)
Air	74.9	98.0(0.6)	77.8(0.9)	98.0(0.6)	98.2(0.6)	72.9	53.0(26.1)	90.8(1.4)
LW	111.7	128.0(0.6)	99.5(0.9)	128.0(0.6)	126.8(0.6)	120.4	67.0(26.1)	121.3(1.4)

3.3.4.2 Perturbation method

Comparisons of reactivity worth calculation based on perturbation are illustrated in Figures 45 and 46 while the calculated values are reported in Table 52. Comparisons are still performed relatively to TRIPOLI4 calculations based on the eigen value difference method.

A reasonably good agreement is observed for TRIPOLI4 calculations based on the correlated sample method on most of fission products (except ^{152}Sm) with differences of less than 5% compared with the eigen value difference method. This is not the case for the actinide nuclides where differences larger than 5% for several of them, and even more for the case of fuel substitution by air and light water where the method fails to correctly predict the reactivity worth. Like in sub-phase 2, the best agreement is still obtained from APOLLO2 exact perturbation calculations, with differences of less than 3% for most of the nuclides. The only exception concerns ^{242}Pu which is overestimated by more than 10%, consistently with the eigen value difference method, while it was not in sub-phase 2. Nevertheless, it should be noted that the uncertainty on the reference value provided by TRIPOLI4 is almost 5%, due to the fact that the reactivity worth of this case is only 35 pcm. Moreover, the calculation of the absorption rate on ^{242}Pu does not show any significant error arising from APOLLO2, so it can be concluded that at least a part of the observed discrepancy can come from the convergence of the TRIPOLI4 calculation. GMVP-II calculations show similar results to APOLLO2 for actinide nuclides where the agreement is mostly under 5% but still underestimate the fission product reactivity worth by more than 10%. This trend is even higher than the one observed in the eigen-value difference method, which means that a potential bias could come from the adjoint flux calculation, taking into account the reasonably good agreement observed on the calculation of the absorption rate on the BUC nuclide.

Figure 45. Relative difference in the reactivity worth by the perturbation method for cases 1 to 15 of sub-phase 3

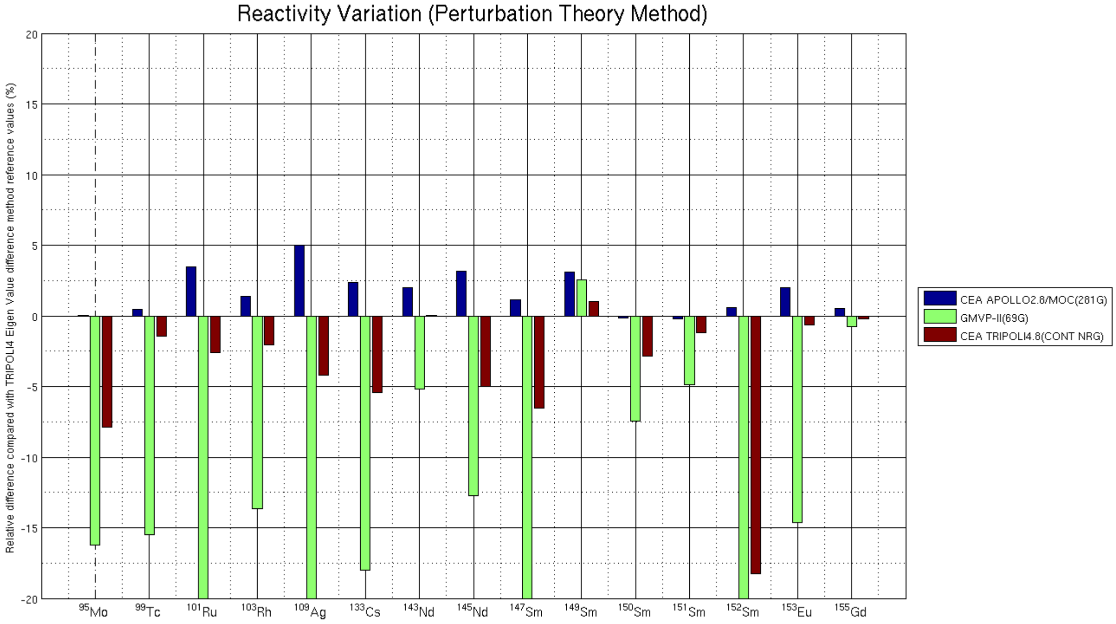


Figure 46. Relative difference in the reactivity worth by the perturbation method for cases 16 to 29 of sub-phase 3

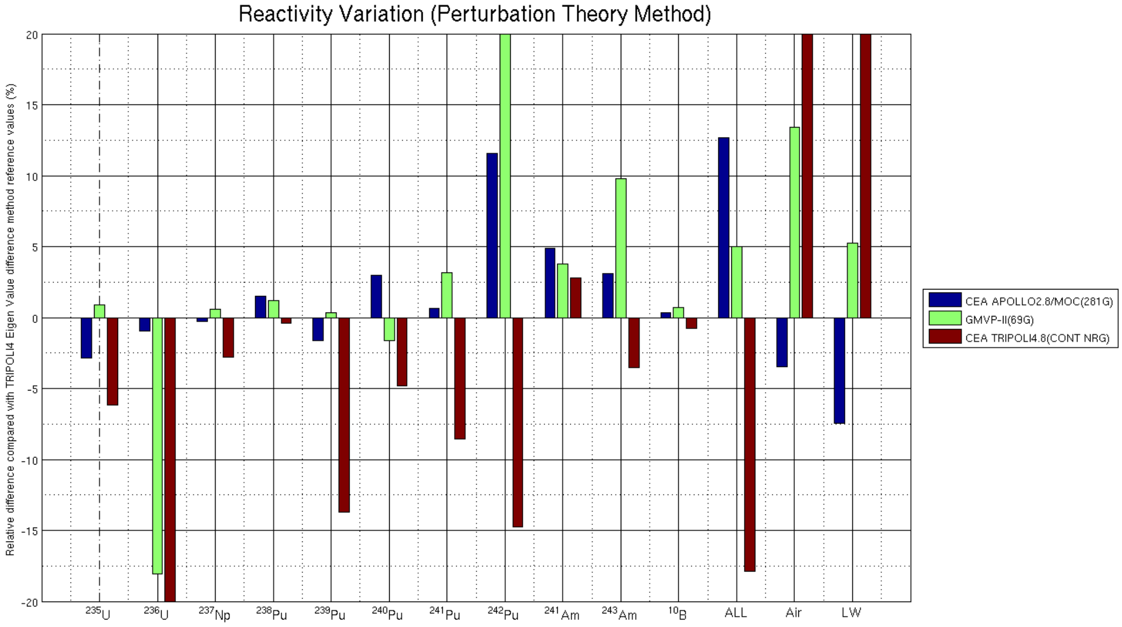


Table 52. Reactivity worth by the perturbation method in pcm (sub-phase 3)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	-69.6	N.R.	-58.3	N.R.	N.R.	N.R.	N.R.	-64.1(0.8)
^{99}Tc	-84.3	N.R.	-70.9	N.R.	N.R.	N.R.	N.R.	-82.7(3.4)
^{101}Ru	-83	N.R.	-63.1	N.R.	N.R.	N.R.	N.R.	-78.1(0.5)
^{103}Rh	-106.6	N.R.	-90.7	N.R.	N.R.	N.R.	N.R.	-102.9(0.3)
^{109}Ag	-72.6	N.R.	-54	N.R.	N.R.	N.R.	N.R.	-66.3(0.5)
^{133}Cs	-77.9	N.R.	-62.4	N.R.	N.R.	N.R.	N.R.	-71.9(0.6)
^{143}Nd	-114.7	N.R.	-106.7	N.R.	N.R.	N.R.	N.R.	-112.5(0.3)
^{145}Nd	-105.2	N.R.	-88.9	N.R.	N.R.	N.R.	N.R.	-96.8(0.6)
^{147}Sm	-85.4	N.R.	-64.2	N.R.	N.R.	N.R.	N.R.	-79.0(0.4)
^{149}Sm	-109.4	N.R.	-108.9	N.R.	N.R.	N.R.	N.R.	-107.2(0.3)
^{150}Sm	-113.8	N.R.	-105.5	N.R.	N.R.	N.R.	N.R.	-110.7(0.7)
^{151}Sm	-118.5	N.R.	-113	N.R.	N.R.	N.R.	N.R.	-117.3(0.3)
^{152}Sm	-64.3	N.R.	-48.3	N.R.	N.R.	N.R.	N.R.	-52.3(0.8)
^{153}Eu	-116.4	N.R.	-97.4	N.R.	N.R.	N.R.	N.R.	-113.3(0.3)
^{155}Gd	-114.1	N.R.	-112.6	N.R.	N.R.	N.R.	N.R.	-113.3(0.3)
^{235}U	69.6	N.R.	72.2	N.R.	N.R.	N.R.	N.R.	67.1(0.3)
^{236}U	-36.4	N.R.	-30.1	N.R.	N.R.	N.R.	N.R.	-28.8(0.4)
^{237}Np	-109.1	N.R.	-110	N.R.	N.R.	N.R.	N.R.	-106.3(0.3)
^{238}Pu	-119.4	N.R.	-119	N.R.	N.R.	N.R.	N.R.	-117.2(0.3)
^{239}Pu	97.8	N.R.	99.7	N.R.	N.R.	N.R.	N.R.	85.8(0.4)
^{240}Pu	-59.7	N.R.	-57.1	N.R.	N.R.	N.R.	N.R.	-55.2(1.4)
^{241}Pu	111.3	N.R.	114.1	N.R.	N.R.	N.R.	N.R.	101.1(0.3)
^{242}Pu	-38.1	N.R.	-60	N.R.	N.R.	N.R.	N.R.	-29.1(0.4)
^{241}Am	-103.9	N.R.	-102.8	N.R.	N.R.	N.R.	N.R.	-101.8(0.3)
^{243}Am	-83.3	N.R.	-88.7	N.R.	N.R.	N.R.	N.R.	-78.0(0.3)
^{10}B	-87	N.R.	-87.3	N.R.	N.R.	N.R.	N.R.	-86.0(0.3)
ALL	-870.1	N.R.	-810.8	N.R.	N.R.	N.R.	N.R.	-634.3(18.0)
Air	87.7	N.R.	103	N.R.	N.R.	N.R.	N.R.	1335.0(8.6)
LW	112.2	N.R.	127.6	N.R.	N.R.	N.R.	N.R.	300.1(73.6)

3.3.4.3 Individual components

In this sub-phase, only GMVP-II and APOLLO2 were able to provide the different components in the reactivity breakdown. They are illustrated in Figure 47, with the values reported in Table 53.

Comparisons still show an excellent agreement for the cases of ^{235}U, ^{239}Pu and ^{241}Pu, like in sub-phase 2. Even the scattering components, which are very small for all nuclides, are in quite good agreement (except in the case of ^{150}Sm, which may be due partly to the overestimation by 30% of the scattering rate by GMVP).

Figure 47. Comparison of reactivity worth components due to absorption and production for cases 15, 19, 21 of sub-phase 3

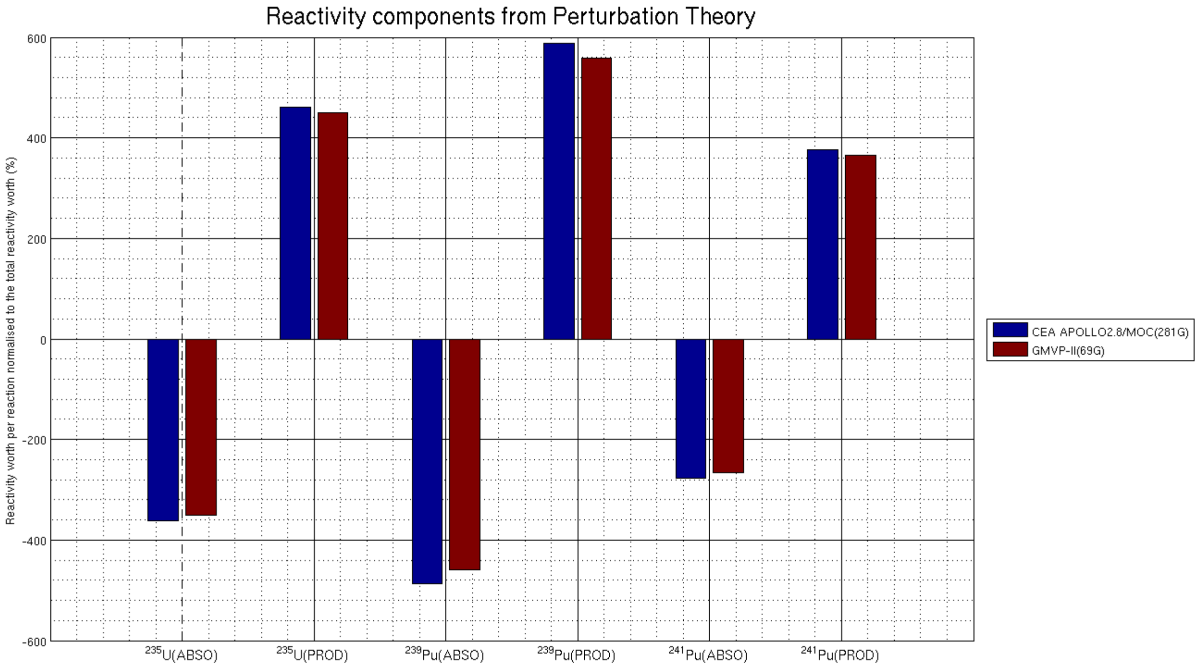


Table 53. Components of the reactivity worth due to absorption, production and scattering in percents of the total reactivity worth (sub-phase 3)

Case	Absorption / Total		Production / Total		Scattering / Total	
Case	CEA APOLLO2 281G	GMVP-II 69G	CEA APOLLO2 281G	GMVP-II 69G	CEA APOLLO2 281G	GMVP-II 69G
^{95}Mo	99.986	99.968	-0.003	0	0.017	0.033
^{99}Tc	100.079	99.998	-0.002	-0.001	-0.078	0.003
^{101}Ru	100.203	100.09	-0.003	0	-0.2	-0.089
^{103}Rh	100.006	100	0	0	-0.006	0
^{109}Ag	100.009	100	-0.001	-0.002	-0.009	0.002
^{133}Cs	100.034	99.976	-0.001	-0.001	-0.032	0.025
^{143}Nd	99.991	100.001	-0.001	0	0.009	-0.001
^{145}Nd	99.967	99.976	-0.002	-0.002	0.035	0.026
^{147}Sm	100.033	99.999	-0.006	0	-0.027	0.001
^{149}Sm	100	100	0	0	0	0
^{150}Sm	100.21	99.969	-0.001	0	-0.209	0.031
^{151}Sm	100.002	100	0	0	-0.002	0
^{152}Sm	99.085	99.962	0	-0.003	0.915	0.041
^{153}Eu	100.014	100.002	-0.001	0	-0.013	-0.002
^{155}Gd	100	100	0	0	0	0
^{235}U	-361.596	-350.39	461.58	450.39	0.016	-0.001
^{236}U	115.57	121.181	-15.404	-21.2	-0.166	0.018
^{237}Np	102.344	102.265	-2.334	-2.262	-0.009	-0.003
^{238}Pu	110.143	110.109	-10.141	-10.108	-0.002	-0.001

Table 53. Components of the reactivity worth due to absorption, production and scattering in percents of the total reactivity worth (sub-phase 3) (continued)

^{239}Pu	-487.155	-459.254	587.149	559.253	0.006	0.001
^{240}Pu	100.83	100.832	-0.825	-0.832	-0.005	0
^{241}Pu	-276.495	-266.255	376.492	366.256	0.002	-0.001
^{242}Pu	108.251	105.094	-8.249	-5.095	-0.002	0.001
^{241}Am	101.819	101.812	-1.816	-1.811	-0.003	-0.001
^{243}Am	102.436	102.239	-2.425	-2.235	-0.011	-0.004
^{10}B	100	100	0	0	0	0
ALL	184.468	171.754	-84.449	-71.769	-0.019	0.015

3.4. Sub-phase 4 results

The calculation results for sub-phases 4 and their analysis are presented in Sections 3.4.1 to 3.4.4

3.4.1 Effective multiplication factor

Calculations of the k_{eff} are presented in Figures 48 and 49. Corresponding values are given in Table 54.

Like in sub-phases 3, GMVP-II calculations overestimate the k_{eff} by several thousands of pcm, maybe due to an incorrect account for neutron leakage. SCALE6 calculations by EMS, ORNL and VUJE just like CASMO5 calculations agree in the overestimation of the k_{eff} by 300-400 pcm compared with TRIPOLI4, while they all underestimate it by around 500 pcm in sub-phase 3. The best agreement with TRIPOLI4 is observed with APOLLO2 where the k_{eff} is within 100 pcm. The same remark can be made with these calculations as they both underestimate the k_{eff} by 400 to 500 pcm whereas they are in good agreement with TRIPOLI4 in this sub-phase. A possible explanation could come from the account of radial leakage which is explicitly treated in this sub-phase, while the axial leakage in sub-phase 3 is treated using a B1 homogeneous model.

Figure 48. Absolute difference in the effective multiplication factor k_{eff} for cases 0 to 14 of sub-phase 4

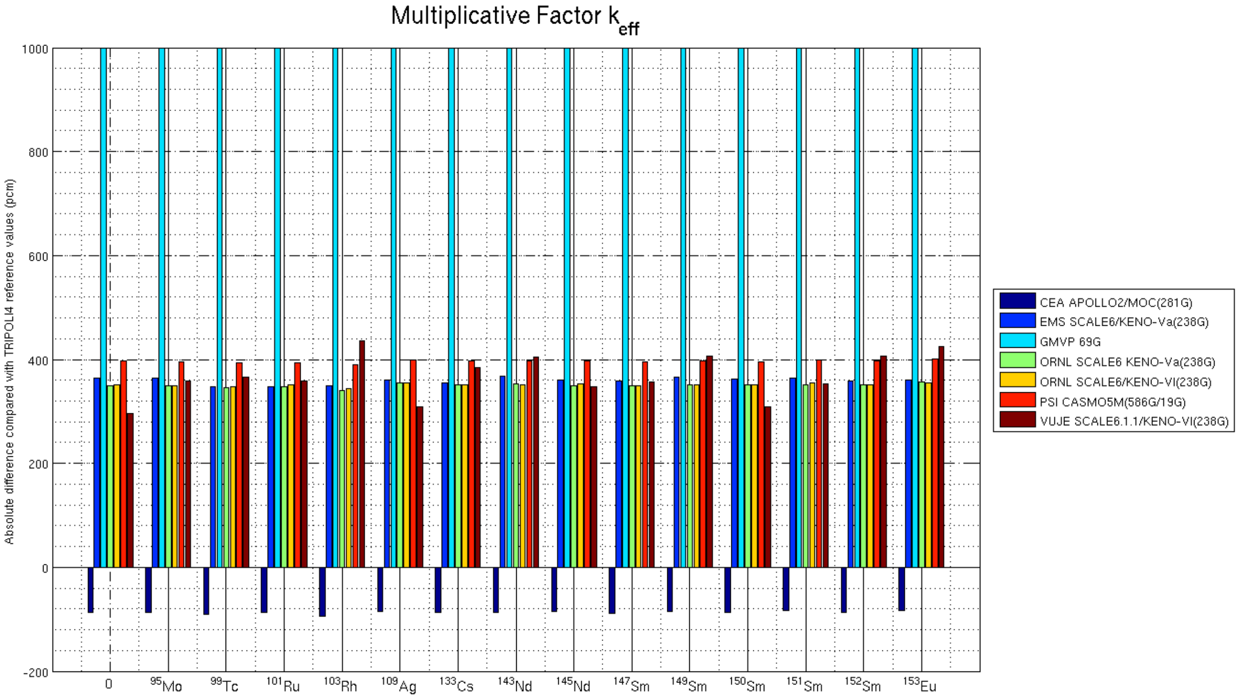


Figure 49. Absolute difference in the effective multiplication factor k_{eff} for cases 15 to 29 of sub-phase 4

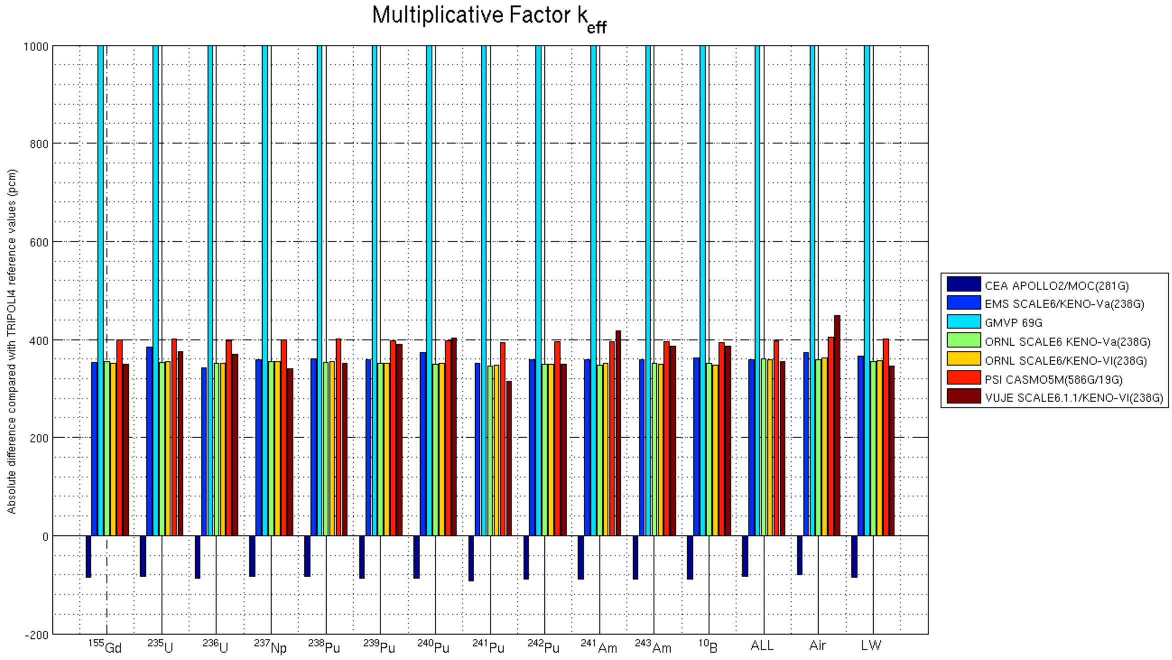


Table 54. k_{eff} calculations (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	1.09504	1.09954(6)	1.174780(18)	1.099407(12)	1.099411(10)	1.09981	1.09886(43)	1.095909(32)
^{95}Mo	1.09498	1.09950(6)	1.174500(18)	1.099350(12)	1.099340(10)	1.0998	1.09943(48)	1.095850(23)
^{99}Tc	1.09496	1.09933(6)	1.174350(18)	1.099320(12)	1.099340(10)	1.09977	1.09952(51)	1.095860(23)
^{101}Ru	1.09496	1.09930(6)	1.174490(18)	1.099310(12)	1.099350(10)	1.09978	1.09941(43)	1.095830(23)
^{103}Rh	1.09494	1.09938(6)	1.174660(18)	1.099290(12)	1.099320(10)	1.09981	1.10024(47)	1.095880(23)
^{109}Ag	1.09497	1.09942(6)	1.174420(18)	1.099360(12)	1.099360(10)	1.0998	1.09890(46)	1.095820(23)
^{133}Cs	1.09497	1.09938(6)	1.174400(18)	1.099350(10)	1.099350(10)	1.09977	1.09967(49)	1.095830(23)
^{143}Nd	1.09493	1.09947(6)	1.174550(18)	1.099320(10)	1.099300(10)	1.09977	1.09984(40)	1.095790(23)
^{145}Nd	1.09494	1.09939(6)	1.174320(18)	1.099290(10)	1.099320(10)	1.0998	1.09926(46)	1.095790(23)
^{147}Sm	1.09496	1.09943(6)	1.174420(18)	1.099350(12)	1.099340(10)	1.09977	1.09941(48)	1.095850(23)
^{149}Sm	1.09494	1.09945(6)	1.174600(18)	1.099310(12)	1.099310(10)	1.09976	1.09985(42)	1.095790(23)
^{150}Sm	1.09494	1.09942(6)	1.174420(18)	1.099310(12)	1.099320(10)	1.09976	1.09889(43)	1.095800(23)
^{151}Sm	1.09493	1.09941(6)	1.174620(18)	1.099290(12)	1.099310(10)	1.09982	1.09930(40)	1.095770(23)
^{152}Sm	1.09498	1.09942(6)	1.174070(18)	1.099360(12)	1.099350(10)	1.09977	1.09991(42)	1.095840(23)
^{153}Eu	1.09493	1.09937(6)	1.174590(18)	1.099330(12)	1.099310(10)	1.09977	1.10002(46)	1.095770(23)
^{155}Gd	1.09493	1.09931(6)	1.174640(18)	1.099320(12)	1.099290(10)	1.09995	1.09927(49)	1.095780(23)
^{235}U	1.0951	1.09979(6)	1.174830(18)	1.099470(12)	1.099490(10)	1.09985	1.09969(46)	1.095940(23)
^{236}U	1.09501	1.09930(6)	1.174660(18)	1.099400(12)	1.099400(10)	1.09977	1.09957(42)	1.095880(23)
^{237}Np	1.09494	1.09936(6)	1.174620(18)	1.099320(12)	1.099320(10)	1.09976	1.09919(49)	1.095780(23)
^{238}Pu	1.09493	1.09936(6)	1.174630(18)	1.099290(12)	1.099310(10)	1.09998	1.09928(47)	1.095760(23)
^{239}Pu	1.09513	1.09958(6)	1.174850(18)	1.099520(12)	1.099520(10)	1.09982	1.09990(42)	1.096000(23)
^{240}Pu	1.09498	1.09958(6)	1.174660(18)	1.099340(12)	1.099360(10)	1.09999	1.09987(47)	1.095850(23)
^{241}Pu	1.09514	1.09957(6)	1.174870(18)	1.099520(12)	1.099540(10)	1.09984	1.09921(48)	1.096060(23)
^{242}Pu	1.095	1.09948(6)	1.174730(18)	1.099390(12)	1.099380(10)	1.09978	1.09939(45)	1.095890(23)
^{241}Am	1.09494	1.09941(6)	1.174580(18)	1.099300(12)	1.099340(10)	1.0998	1.09999(41)	1.095820(23)
^{243}Am	1.09496	1.09944(6)	1.174620(18)	1.099360(10)	1.099350(10)	1.09979	1.09972(47)	1.095850(23)
^{10}B	1.09496	1.09948(6)	1.174720(18)	1.099360(12)	1.099320(10)	1.09907	1.09971(41)	1.095850(23)
ALL	1.09425	1.09867(7)	1.171950(18)	1.098700(12)	1.098680(10)	1.09994	1.09864(43)	1.095090(23)
Air	1.09509	1.09963(6)	1.174500(18)	1.099480(12)	1.099510(10)	1.10001	1.10037(52)	1.095890(34)
LW	1.09515	1.09966(6)	1.174400(18)	1.099550(12)	1.099570(10)	1.09981	1.09945(46)	1.096000(34)

3.4.2 Neutron flux

Comparisons of the integrated neutron flux over the central fuel cell are illustrated in Figures 50 and 51, and calculation results are reported in Table 55.

All of them succeed in the calculation of this parameter within less than 2%, except CASMO5 which underestimate the neutron flux by 1.5% and GMVP-II calculations which overestimate it by more than 11%. It seems that this bias is correlated to the one on the k_{eff}, as in sub-phase 3, the 2000 pcm overestimation of the k_{eff} was associated to a 3% overestimation of the neutron flux. VUJE results show differences between cases which may be not linked to the kind of isotope but more to the convergence of the calculation: as the k_{eff} is reported at ±45 pcm, it is likely that not enough neutrons have reached the central cell to produce a correct evaluation of the 1-group neutron flux.

Figure 50. Relative difference in the neutron flux for cases 0 to 14 of sub-phase 4

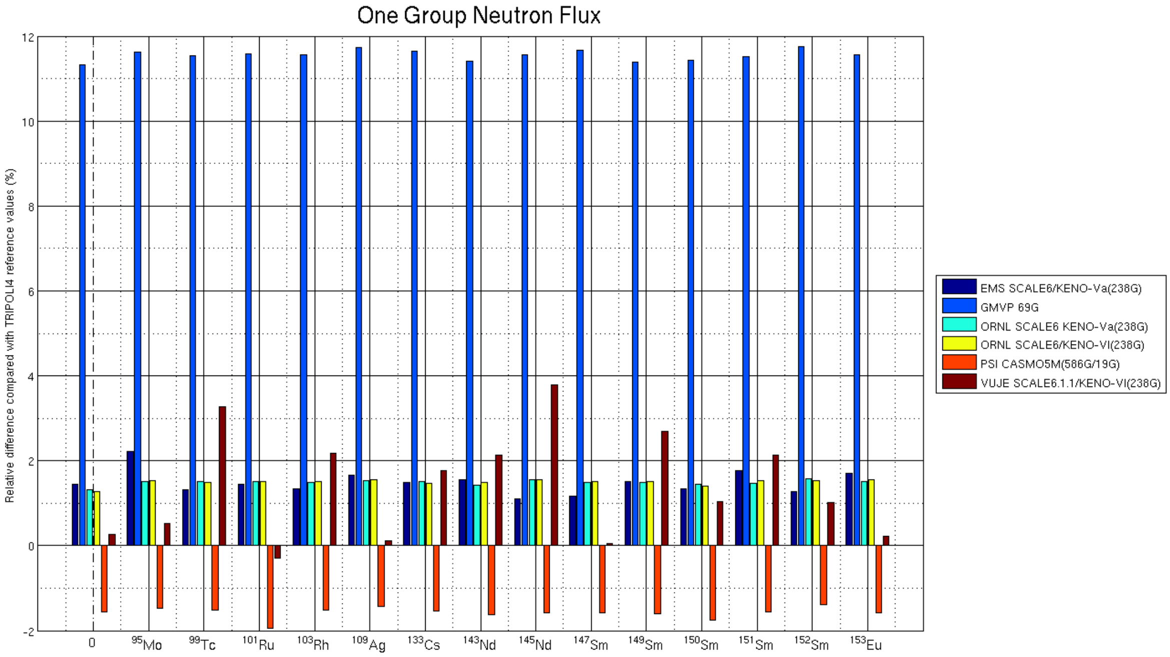


Figure 51. Relative difference in the neutron flux for cases 15 to 29 of sub-phase 4

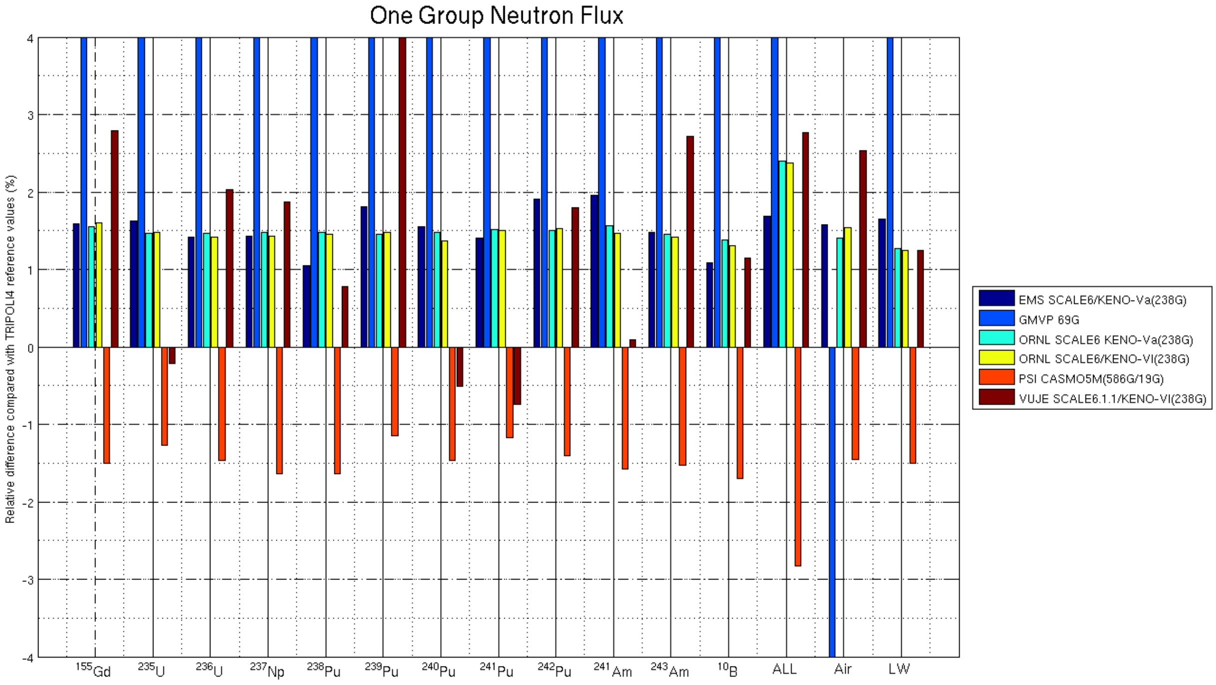


Table 55. Neutron flux in cm^{-2}.s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	2.1050E-03	2.3100E-03	2.1030E-03	2.1010E-03	2.0430E-03	2.0810E-03	2.0750E-03
^{95}Mo	N.R.	2.0950E-03	2.2880E-03	2.0800E-03	2.0810E-03	2.0190E-03	2.0600E-03	2.0500E-03
^{99}Tc	N.R.	2.0750E-03	2.2840E-03	2.0790E-03	2.0790E-03	2.0170E-03	2.1150E-03	2.0480E-03
^{101}Ru	N.R.	2.0790E-03	2.2870E-03	2.0800E-03	2.0800E-03	2.0100E-03	2.0430E-03	2.0490E-03
^{103}Rh	N.R.	2.0690E-03	2.2780E-03	2.0730E-03	2.0730E-03	2.0110E-03	2.0860E-03	2.0420E-03
^{109}Ag	N.R.	2.0840E-03	2.2900E-03	2.0820E-03	2.0820E-03	2.0210E-03	2.0520E-03	2.0500E-03
^{133}Cs	N.R.	2.0800E-03	2.2880E-03	2.0810E-03	2.0800E-03	2.0180E-03	2.0860E-03	2.0500E-03
^{143}Nd	N.R.	2.0680E-03	2.2690E-03	2.0650E-03	2.0670E-03	2.0030E-03	2.0800E-03	2.0360E-03
^{145}Nd	N.R.	2.0610E-03	2.2750E-03	2.0710E-03	2.0710E-03	2.0070E-03	2.1160E-03	2.0390E-03
^{147}Sm	N.R.	2.0720E-03	2.2870E-03	2.0790E-03	2.0790E-03	2.0160E-03	2.0490E-03	2.0480E-03
^{149}Sm	N.R.	2.0690E-03	2.2700E-03	2.0680E-03	2.0690E-03	2.0050E-03	2.0930E-03	2.0380E-03
^{150}Sm	N.R.	2.0650E-03	2.2700E-03	2.0670E-03	2.0660E-03	2.0010E-03	2.0590E-03	2.0370E-03
^{151}Sm	N.R.	2.0690E-03	2.2660E-03	2.0620E-03	2.0640E-03	2.0010E-03	2.0760E-03	2.0320E-03
^{152}Sm	N.R.	2.0770E-03	2.2920E-03	2.0830E-03	2.0820E-03	2.0220E-03	2.0710E-03	2.0510E-03
^{153}Eu	N.R.	2.0730E-03	2.2730E-03	2.0690E-03	2.0700E-03	2.0060E-03	2.0430E-03	2.0380E-03
^{155}Gd	N.R.	2.0650E-03	2.2670E-03	2.0640E-03	2.0650E-03	2.0020E-03	2.0890E-03	2.0320E-03
^{235}U	N.R.	2.1150E-03	2.3180E-03	2.1120E-03	2.1120E-03	2.0550E-03	2.0770E-03	2.0810E-03
^{236}U	N.R.	2.0920E-03	2.3000E-03	2.0930E-03	2.0920E-03	2.0330E-03	2.1050E-03	2.0630E-03
^{237}Np	N.R.	2.0710E-03	2.2680E-03	2.0720E-03	2.0710E-03	2.0090E-03	2.0800E-03	2.0420E-03
^{238}Pu	N.R.	2.0550E-03	2.2650E-03	2.0640E-03	2.0640E-03	2.0010E-03	2.0500E-03	2.0340E-03
^{239}Pu	N.R.	2.1200E-03	2.3090E-03	2.1130E-03	2.1140E-03	2.0590E-03	2.1730E-03	2.0830E-03
^{240}Pu	N.R.	2.0880E-03	2.2870E-03	2.0860E-03	2.0840E-03	2.0260E-03	2.0460E-03	2.0560E-03
^{241}Pu	N.R.	2.1210E-03	2.3270E-03	2.1230E-03	2.1230E-03	2.0670E-03	2.0760E-03	2.0920E-03
^{242}Pu	N.R.	2.1010E-03	2.2890E-03	2.0930E-03	2.0930E-03	2.0330E-03	2.0990E-03	2.0610E-03
^{241}Am	N.R.	2.0810E-03	2.2690E-03	2.0730E-03	2.0710E-03	2.0090E-03	2.0430E-03	2.0410E-03
^{243}Am	N.R.	2.0810E-03	2.2750E-03	2.0800E-03	2.0800E-03	2.0190E-03	2.1060E-03	2.0500E-03
^{10}B	N.R.	2.0690E-03	2.2780E-03	2.0750E-03	2.0740E-03	2.0120E-03	2.0710E-03	2.0470E-03
ALL	N.R.	1.8270E-03	1.9200E-03	1.8400E-03	1.8400E-03	1.7460E-03	1.8470E-03	1.7970E-03
Air	N.R.	2.1350E-03	2.0100E-03	2.1320E-03	2.1340E-03	2.0710E-03	2.1550E-03	2.1020E-03
LW	N.R.	2.1730E-03	2.4030E-03	2.1650E-03	2.1650E-03	2.1060E-03	2.1650E-03	2.1380E-03

3.4.3 Reaction rates

Comparisons of reaction rate calculations performed on ^{235}U, ^{238}U and ^{16}O are illustrated in Figure 48, for the first case (case 0 without BUC nuclide) as the same conclusions can be observed for cases 1 to 27. The calculation results are reported in Table 56 to Table 63.

Most of the conclusions drawn in sub-phase 3 are similar in sub-phases 4. As discussed in the previous section, the bias of more than 10% on the 1-group neutron flux in GMVP-II calculations affects the reaction rates of ^{235}U, ^{238}U and ^{16}O in the same way. Other results are consistent with sub-phase 3 and show a good agreement with TRIPOLI4, with differences lower than 2% compared to TRIPOLI4.

Comparisons of reaction rate calculations on the BUC nuclide are illustrated in Figure 53 to Figure 57, with the full list of results in Table 64 to Table 66.

Results on absorption rate are also similar to the ones of sub-phase 3, with differences to TRIPOLI4 calculations by a few percent, except for GMVP-II calculations, which are overestimated by more than 20% for several fission products, while there were not in sub-phase 2. These results are not confirmed on production rate on the BUC nuclide, where GMVP-II calculations are in quite the same agreement with TRIPOLI4 than in sub-phase 2. The other calculations are in good agreement with TRIPOLI4 within less than 3%, with similar trends compared with sub-phase 2.

Figure 52. Relative difference in the reaction rates of ^{235}U, ^{238}U and ^{16}O of sub-phase 4 (case 0)

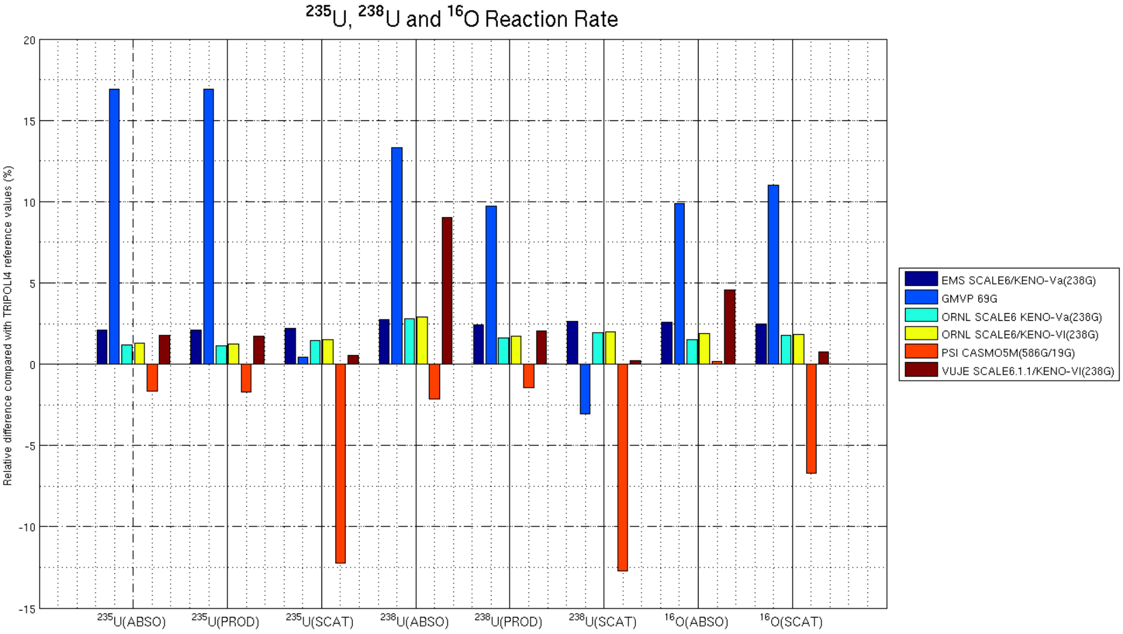


Table 56. Absorption rate on ^{235}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	3.3910E-05	3.8520E-05	3.3830E-05	3.3790E-05	3.2960E-05	3.2390E-05	3.3320E-05
^{95}Mo	N.R.	3.2700E-05	3.7450E-05	3.2400E-05	3.2440E-05	3.1500E-05	3.2600E-05	3.2030E-05
^{99}Tc	N.R.	3.2920E-05	3.7430E-05	3.2650E-05	3.2630E-05	3.1730E-05	3.3990E-05	3.2080E-05
^{101}Ru	N.R.	3.3160E-05	3.7810E-05	3.2930E-05	3.2950E-05	3.1840E-05	3.3530E-05	3.2470E-05
^{103}Rh	N.R.	3.1880E-05	3.6770E-05	3.2140E-05	3.2140E-05	3.1180E-05	3.2540E-05	3.1640E-05
^{109}Ag	N.R.	3.2540E-05	3.7650E-05	3.2760E-05	3.2760E-05	3.1850E-05	3.2940E-05	3.2230E-05
^{133}Cs	N.R.	3.3000E-05	3.7540E-05	3.2640E-05	3.2640E-05	3.1690E-05	3.1950E-05	3.2060E-05
^{143}Nd	N.R.	3.0930E-05	3.5150E-05	3.0870E-05	3.0900E-05	2.9860E-05	3.0820E-05	3.0340E-05
^{145}Nd	N.R.	3.1700E-05	3.6580E-05	3.1810E-05	3.1800E-05	3.0780E-05	3.2810E-05	3.1270E-05
^{147}Sm	N.R.	3.2750E-05	3.7610E-05	3.2660E-05	3.2710E-05	3.1720E-05	3.2790E-05	3.2280E-05
^{149}Sm	N.R.	3.1450E-05	3.5530E-05	3.1420E-05	3.1400E-05	3.0380E-05	3.1590E-05	3.0960E-05
^{150}Sm	N.R.	3.0900E-05	3.5980E-05	3.1080E-05	3.1110E-05	3.0030E-05	3.2050E-05	3.0610E-05
^{151}Sm	N.R.	3.0420E-05	3.4440E-05	3.0230E-05	3.0270E-05	2.9240E-05	3.0940E-05	2.9780E-05
^{152}Sm	N.R.	3.2770E-05	3.7740E-05	3.2750E-05	3.2730E-05	3.1800E-05	3.3240E-05	3.2190E-05
^{153}Eu	N.R.	3.1710E-05	3.6450E-05	3.1840E-05	3.1840E-05	3.0820E-05	3.1710E-05	3.1270E-05
^{155}Gd	N.R.	3.0350E-05	3.4530E-05	3.0300E-05	3.0360E-05	2.9300E-05	3.1320E-05	2.9830E-05
^{235}U	N.R.	1.1230E-04	1.2220E-04	1.0840E-04	1.0840E-04	1.0440E-04	1.0800E-04	1.0660E-04
^{236}U	N.R.	3.3340E-05	3.8090E-05	3.3440E-05	3.3420E-05	3.2560E-05	3.3800E-05	3.2990E-05
^{237}Np	N.R.	3.2140E-05	3.6300E-05	3.2050E-05	3.2030E-05	3.1030E-05	3.2110E-05	3.1530E-05
^{238}Pu	N.R.	2.9990E-05	3.4200E-05	3.0260E-05	3.0260E-05	2.9220E-05	2.9930E-05	2.9800E-05
^{239}Pu	N.R.	2.4420E-05	2.7080E-05	2.4470E-05	2.4450E-05	2.3370E-05	2.4840E-05	2.4050E-05
^{240}Pu	N.R.	3.3090E-05	3.7420E-05	3.3100E-05	3.3040E-05	3.2140E-05	3.3490E-05	3.2570E-05
^{241}Pu	N.R.	2.7080E-05	3.0330E-05	2.7090E-05	2.7110E-05	2.6060E-05	2.6500E-05	2.6690E-05
^{242}Pu	N.R.	3.3500E-05	3.7870E-05	3.3450E-05	3.3430E-05	3.2560E-05	3.3940E-05	3.3010E-05
^{241}Am	N.R.	3.2090E-05	3.5910E-05	3.1870E-05	3.1800E-05	3.0860E-05	3.1400E-05	3.1300E-05
^{243}Am	N.R.	3.3190E-05	3.7190E-05	3.2950E-05	3.2950E-05	3.2020E-05	3.1720E-05	3.2500E-05
^{10}B	N.R.	3.1640E-05	3.5840E-05	3.1620E-05	3.1590E-05	3.0370E-05	3.1630E-05	3.1140E-05
ALL	N.R.	N.R.	4.6250E-05	4.6240E-05	4.6270E-05	1.1490E-05	4.7030E-05	1.2430E-05

Table 57. Production rate on ^{235}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	6.8840E-05	7.8100E-05	6.8630E-05	6.8540E-05	6.6860E-05	6.5730E-05	6.7620E-05
^{95}Mo	N.R.	6.6300E-05	7.5930E-05	6.5690E-05	6.5770E-05	6.3850E-05	6.6080E-05	6.4950E-05
^{99}Tc	N.R.	6.6770E-05	7.5920E-05	6.6190E-05	6.6160E-05	6.4320E-05	6.9010E-05	6.5060E-05
^{101}Ru	N.R.	6.7280E-05	7.6720E-05	6.6800E-05	6.6860E-05	6.4640E-05	6.8090E-05	6.5910E-05
^{103}Rh	N.R.	6.4600E-05	7.4480E-05	6.5150E-05	6.5140E-05	6.3180E-05	6.6060E-05	6.4150E-05
^{109}Ag	N.R.	6.6020E-05	7.6350E-05	6.6440E-05	6.6450E-05	6.4570E-05	6.6900E-05	6.5390E-05
^{133}Cs	N.R.	6.6940E-05	7.6140E-05	6.6190E-05	6.6190E-05	6.4250E-05	6.4800E-05	6.5020E-05
^{143}Nd	N.R.	6.2600E-05	7.1100E-05	6.2500E-05	6.2550E-05	6.0430E-05	6.2310E-05	6.1430E-05
^{145}Nd	N.R.	6.4240E-05	7.4130E-05	6.4460E-05	6.4460E-05	6.2360E-05	6.6400E-05	6.3380E-05
^{147}Sm	N.R.	6.6440E-05	7.6280E-05	6.6250E-05	6.6360E-05	6.4340E-05	6.6460E-05	6.5500E-05
^{149}Sm	N.R.	6.3660E-05	7.1870E-05	6.3610E-05	6.3560E-05	6.1490E-05	6.3970E-05	6.2700E-05
^{150}Sm	N.R.	6.2570E-05	7.2900E-05	6.2940E-05	6.2990E-05	6.0810E-05	6.4880E-05	6.2000E-05
^{151}Sm	N.R.	6.1590E-05	6.9640E-05	6.1170E-05	6.1250E-05	5.9150E-05	6.2650E-05	6.0270E-05
^{152}Sm	N.R.	6.6470E-05	7.6530E-05	6.6410E-05	6.6380E-05	6.4470E-05	6.7330E-05	6.5310E-05
^{153}Eu	N.R.	6.4280E-05	7.3840E-05	6.4570E-05	6.4570E-05	6.2450E-05	6.4440E-05	6.3410E-05
^{155}Gd	N.R.	6.1430E-05	6.9810E-05	6.1300E-05	6.1440E-05	5.9250E-05	6.3300E-05	6.0360E-05
^{235}U	N.R.	2.2710E-04	2.4700E-04	2.1910E-04	2.1920E-04	2.1090E-04	2.1830E-04	2.1550E-04
^{236}U	N.R.	6.7630E-05	7.7240E-05	6.7830E-05	6.7790E-05	6.6040E-05	6.8530E-05	6.6950E-05
^{237}Np	N.R.	6.5160E-05	7.3530E-05	6.4970E-05	6.4920E-05	6.2880E-05	6.5070E-05	6.3920E-05
^{238}Pu	N.R.	6.0690E-05	6.9130E-05	6.1240E-05	6.1220E-05	5.9110E-05	6.0530E-05	6.0310E-05
^{239}Pu	N.R.	4.9150E-05	5.4430E-05	4.9270E-05	4.9230E-05	4.6990E-05	4.9900E-05	4.8420E-05
^{240}Pu	N.R.	6.7100E-05	7.5830E-05	6.7130E-05	6.7000E-05	6.5160E-05	6.7950E-05	6.6060E-05
^{241}Pu	N.R.	5.4660E-05	6.1150E-05	5.4680E-05	5.4720E-05	5.2570E-05	5.3580E-05	5.3890E-05
^{242}Pu	N.R.	6.7960E-05	7.6770E-05	6.7840E-05	6.7820E-05	6.6020E-05	6.8770E-05	6.6970E-05
^{241}Am	N.R.	6.5010E-05	7.2700E-05	6.4580E-05	6.4440E-05	6.2520E-05	6.3640E-05	6.3440E-05
^{243}Am	N.R.	6.7310E-05	7.5400E-05	6.6830E-05	6.6840E-05	6.4930E-05	6.4160E-05	6.5940E-05
^{10}B	N.R.	6.4070E-05	7.2540E-05	6.4040E-05	6.3990E-05	6.1500E-05	6.4170E-05	6.3080E-05
ALL	N.R.	N.R.	9.2140E-05	9.1510E-05	9.1560E-05	2.2740E-05	9.3050E-05	2.4650E-05

Table 58. Scattering rate on ^{235}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	3.7180E-06	3.6720E-06	3.7130E-06	3.7100E-06	3.2180E-06	3.6620E-06	3.6640E-06
^{95}Mo	N.R.	3.6900E-06	3.6260E-06	3.6640E-06	3.6640E-06	3.1680E-06	3.6290E-06	3.6110E-06
^{99}Tc	N.R.	3.6600E-06	3.6180E-06	3.6610E-06	3.6610E-06	3.1650E-06	3.7220E-06	3.6080E-06
^{101}Ru	N.R.	3.6660E-06	3.6260E-06	3.6660E-06	3.6660E-06	3.1530E-06	3.6290E-06	3.6120E-06
^{103}Rh	N.R.	3.6360E-06	3.6010E-06	3.6430E-06	3.6440E-06	3.1480E-06	3.6680E-06	3.5910E-06
^{109}Ag	N.R.	3.6690E-06	3.6320E-06	3.6660E-06	3.6670E-06	3.1710E-06	3.6100E-06	3.6120E-06
^{133}Cs	N.R.	3.6700E-06	3.6260E-06	3.6650E-06	3.6630E-06	3.1660E-06	3.6750E-06	3.6100E-06
^{143}Nd	N.R.	3.6330E-06	3.5780E-06	3.6260E-06	3.6290E-06	3.1300E-06	3.6270E-06	3.5750E-06
^{145}Nd	N.R.	3.6220E-06	3.5980E-06	3.6410E-06	3.6400E-06	3.1410E-06	3.7260E-06	3.5850E-06
^{147}Sm	N.R.	3.6550E-06	3.6250E-06	3.6600E-06	3.6610E-06	3.1610E-06	3.6080E-06	3.6080E-06
^{149}Sm	N.R.	3.6320E-06	3.5780E-06	3.6320E-06	3.6330E-06	3.1340E-06	3.6840E-06	3.5790E-06
^{150}Sm	N.R.	3.6290E-06	3.5850E-06	3.6300E-06	3.6290E-06	3.1280E-06	3.6370E-06	3.5780E-06
^{151}Sm	N.R.	3.6290E-06	3.5720E-06	3.6190E-06	3.6220E-06	3.1240E-06	3.6610E-06	3.5670E-06
^{152}Sm	N.R.	3.6650E-06	3.6350E-06	3.6710E-06	3.6700E-06	3.1760E-06	3.6530E-06	3.6150E-06
^{153}Eu	N.R.	3.6420E-06	3.5930E-06	3.6370E-06	3.6390E-06	3.1380E-06	3.5880E-06	3.5830E-06
^{155}Gd	N.R.	3.6250E-06	3.5770E-06	3.6220E-06	3.6250E-06	3.1260E-06	3.6770E-06	3.5680E-06
^{235}U	N.R.	1.4300E-05	1.3870E-05	1.4210E-05	1.4210E-05	1.2200E-05	1.4060E-05	1.4000E-05
^{236}U	N.R.	3.6890E-06	3.6530E-06	3.6920E-06	3.6910E-06	3.1970E-06	3.7360E-06	3.6400E-06
^{237}Np	N.R.	3.6420E-06	3.5840E-06	3.6430E-06	3.6420E-06	3.1430E-06	3.6640E-06	3.5910E-06
^{238}Pu	N.R.	3.6070E-06	3.5630E-06	3.6190E-06	3.6180E-06	3.1200E-06	3.5740E-06	3.5670E-06
^{239}Pu	N.R.	3.5720E-06	3.4220E-06	3.5610E-06	3.5620E-06	3.0320E-06	3.6660E-06	3.5100E-06
^{240}Pu	N.R.	3.6830E-06	3.6220E-06	3.6760E-06	3.6720E-06	3.1810E-06	3.6220E-06	3.6230E-06
^{241}Pu	N.R.	3.6310E-06	3.5230E-06	3.6310E-06	3.6300E-06	3.1110E-06	3.5290E-06	3.5780E-06
^{242}Pu	N.R.	3.7070E-06	3.6280E-06	3.6910E-06	3.6910E-06	3.1960E-06	3.7040E-06	3.6370E-06
^{241}Am	N.R.	3.6600E-06	3.5790E-06	3.6440E-06	3.6400E-06	3.1430E-06	3.6020E-06	3.5880E-06
^{243}Am	N.R.	3.6650E-06	3.5960E-06	3.6620E-06	3.6620E-06	3.1670E-06	3.7120E-06	3.6110E-06
^{10}B	N.R.	3.6390E-06	3.6000E-06	3.6490E-06	3.6460E-06	3.1560E-06	3.6240E-06	3.6000E-06
ALL	N.R.	N.R.	1.0150E-05	1.1500E-05	1.1500E-05	2.3970E-06	1.1500E-05	2.8940E-06

Table 59. Absorption rate on ^{238}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	5.3750E-05	5.9400E-05	5.3500E-05	5.3440E-05	5.1110E-05	4.9970E-05	5.2420E-05
^{95}Mo	N.R.	5.2620E-05	5.8020E-05	5.2650E-05	5.2690E-05	5.0110E-05	5.5840E-05	5.1200E-05
^{99}Tc	N.R.	5.1920E-05	5.7210E-05	5.1960E-05	5.2020E-05	5.0060E-05	5.1340E-05	5.0550E-05
^{101}Ru	N.R.	5.3050E-05	5.8290E-05	5.2670E-05	5.2640E-05	5.0100E-05	5.2640E-05	5.1170E-05
^{103}Rh	N.R.	5.2580E-05	5.8320E-05	5.2510E-05	5.2510E-05	5.0000E-05	5.0610E-05	5.1050E-05
^{109}Ag	N.R.	5.2600E-05	5.7640E-05	5.2650E-05	5.2630E-05	5.0410E-05	5.4850E-05	5.1110E-05
^{133}Cs	N.R.	5.2820E-05	5.7550E-05	5.2210E-05	5.2110E-05	4.9760E-05	5.1900E-05	5.0650E-05
^{143}Nd	N.R.	5.2230E-05	5.7470E-05	5.1750E-05	5.1880E-05	4.9270E-05	5.1860E-05	5.0290E-05
^{145}Nd	N.R.	5.2660E-05	5.7160E-05	5.2190E-05	5.2060E-05	4.9680E-05	5.3640E-05	5.0640E-05
^{147}Sm	N.R.	5.2720E-05	5.8010E-05	5.2650E-05	5.2600E-05	5.0010E-05	5.4000E-05	5.1130E-05
^{149}Sm	N.R.	5.1750E-05	5.7580E-05	5.2150E-05	5.2090E-05	4.9550E-05	5.1040E-05	5.0680E-05
^{150}Sm	N.R.	5.0650E-05	5.7040E-05	5.0890E-05	5.0990E-05	4.9280E-05	5.1040E-05	4.9680E-05
^{151}Sm	N.R.	5.2060E-05	5.7020E-05	5.1440E-05	5.1470E-05	4.8940E-05	5.1660E-05	5.0070E-05
^{152}Sm	N.R.	5.2320E-05	5.7730E-05	5.2380E-05	5.2460E-05	4.9850E-05	5.2740E-05	5.0860E-05
^{153}Eu	N.R.	5.1650E-05	5.7600E-05	5.1980E-05	5.2090E-05	4.9590E-05	4.8960E-05	5.0640E-05
^{155}Gd	N.R.	5.0980E-05	5.7090E-05	5.1580E-05	5.1550E-05	4.9010E-05	5.3710E-05	5.0190E-05
^{235}U	N.R.	4.9710E-05	5.6140E-05	5.0610E-05	5.0670E-05	4.8270E-05	4.9810E-05	4.9210E-05
^{236}U	N.R.	5.3750E-05	5.9000E-05	5.3250E-05	5.3090E-05	5.0810E-05	5.2980E-05	5.1590E-05
^{237}Np	N.R.	5.2200E-05	5.7830E-05	5.2270E-05	5.2150E-05	4.9760E-05	5.3160E-05	5.0820E-05
^{238}Pu	N.R.	5.1150E-05	5.6940E-05	5.1590E-05	5.1450E-05	4.8950E-05	4.9740E-05	5.0130E-05
^{239}Pu	N.R.	4.9980E-05	5.4130E-05	4.9380E-05	4.9360E-05	4.6980E-05	5.0070E-05	4.7970E-05
^{240}Pu	N.R.	5.2640E-05	5.8690E-05	5.3020E-05	5.2990E-05	5.0590E-05	5.2210E-05	5.1570E-05
^{241}Pu	N.R.	5.0460E-05	5.5720E-05	5.0350E-05	5.0360E-05	4.8050E-05	4.6290E-05	4.9050E-05
^{242}Pu	N.R.	5.2530E-05	5.8930E-05	5.3260E-05	5.3200E-05	5.0810E-05	5.6010E-05	5.1980E-05
^{241}Am	N.R.	5.2310E-05	5.7830E-05	5.2310E-05	5.2270E-05	4.9820E-05	4.9250E-05	5.1040E-05
^{243}Am	N.R.	5.3170E-05	5.8270E-05	5.2640E-05	5.2590E-05	5.0260E-05	5.2150E-05	5.1360E-05
^{10}B	N.R.	5.2350E-05	5.7820E-05	5.2230E-05	5.2180E-05	4.9480E-05	5.0860E-05	5.0850E-05
ALL	N.R.	N.R.	3.3990E-05	3.7300E-05	3.7320E-05	3.6570E-05	3.9480E-05	3.6310E-05

Table 60. Production rate on ^{238}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	1.2970E-05	1.4040E-05	1.3040E-05	1.3040E-05	1.2680E-05	1.2840E-05	1.2870E-05
^{95}Mo	N.R.	1.3030E-05	1.3960E-05	1.2930E-05	1.2950E-05	1.2540E-05	1.2980E-05	1.2730E-05
^{99}Tc	N.R.	1.2890E-05	1.3990E-05	1.2960E-05	1.2960E-05	1.2580E-05	1.2750E-05	1.2760E-05
^{101}Ru	N.R.	1.2890E-05	1.3960E-05	1.2920E-05	1.2940E-05	1.2520E-05	1.2540E-05	1.2740E-05
^{103}Rh	N.R.	1.2970E-05	1.3980E-05	1.2960E-05	1.2960E-05	1.2590E-05	1.3540E-05	1.2770E-05
^{109}Ag	N.R.	1.3100E-05	1.3980E-05	1.2980E-05	1.2990E-05	1.2620E-05	1.3300E-05	1.2800E-05
^{133}Cs	N.R.	1.2900E-05	1.4000E-05	1.2980E-05	1.2970E-05	1.2590E-05	1.3030E-05	1.2800E-05
^{143}Nd	N.R.	1.2990E-05	1.3940E-05	1.2920E-05	1.2930E-05	1.2540E-05	1.3330E-05	1.2750E-05
^{145}Nd	N.R.	1.3000E-05	1.3950E-05	1.2940E-05	1.2950E-05	1.2540E-05	1.2960E-05	1.2740E-05
^{147}Sm	N.R.	1.2820E-05	1.3990E-05	1.3000E-05	1.2980E-05	1.2600E-05	1.2250E-05	1.2780E-05
^{149}Sm	N.R.	1.3050E-05	1.3960E-05	1.2950E-05	1.2950E-05	1.2570E-05	1.3410E-05	1.2760E-05
^{150}Sm	N.R.	1.2850E-05	1.3950E-05	1.2910E-05	1.2920E-05	1.2530E-05	1.2950E-05	1.2760E-05
^{151}Sm	N.R.	1.3020E-05	1.3940E-05	1.2920E-05	1.2900E-05	1.2540E-05	1.2970E-05	1.2730E-05
^{152}Sm	N.R.	1.2900E-05	1.3990E-05	1.2990E-05	1.2990E-05	1.2620E-05	1.2930E-05	1.2780E-05
^{153}Eu	N.R.	1.3080E-05	1.3950E-05	1.2970E-05	1.2950E-05	1.2570E-05	1.3270E-05	1.2770E-05
^{155}Gd	N.R.	1.2900E-05	1.3900E-05	1.2900E-05	1.2910E-05	1.2540E-05	1.3120E-05	1.2710E-05
^{235}U	N.R.	1.3770E-05	1.5470E-05	1.4360E-05	1.4370E-05	1.3980E-05	1.3850E-05	1.4160E-05
^{236}U	N.R.	1.3060E-05	1.3970E-05	1.3010E-05	1.3000E-05	1.2630E-05	1.3160E-05	1.2810E-05
^{237}Np	N.R.	1.2980E-05	1.3900E-05	1.2990E-05	1.2960E-05	1.2590E-05	1.2750E-05	1.2770E-05
^{238}Pu	N.R.	1.2820E-05	1.3980E-05	1.2970E-05	1.2970E-05	1.2590E-05	1.3090E-05	1.2790E-05
^{239}Pu	N.R.	1.5470E-05	1.6420E-05	1.5440E-05	1.5450E-05	1.5150E-05	1.5750E-05	1.5220E-05
^{240}Pu	N.R.	1.2820E-05	1.3990E-05	1.3020E-05	1.3000E-05	1.2640E-05	1.2470E-05	1.2810E-05
^{241}Pu	N.R.	1.4750E-05	1.5890E-05	1.4750E-05	1.4750E-05	1.4420E-05	1.5160E-05	1.4520E-05
^{242}Pu	N.R.	1.3060E-05	1.4010E-05	1.3030E-05	1.3020E-05	1.2650E-05	1.3020E-05	1.2820E-05
^{241}Am	N.R.	1.3040E-05	1.3920E-05	1.2980E-05	1.2980E-05	1.2590E-05	1.2700E-05	1.2790E-05
^{243}Am	N.R.	1.2960E-05	1.4010E-05	1.3000E-05	1.3000E-05	1.2630E-05	1.2860E-05	1.2810E-05
^{10}B	N.R.	1.2890E-05	1.3940E-05	1.2980E-05	1.2960E-05	1.2550E-05	1.3010E-05	1.2770E-05
ALL	N.R.	N.R.	1.5380E-05	1.4760E-05	1.4760E-05	1.3720E-05	1.5200E-05	1.4120E-05

Table 61. Scattering rate on ^{238}U in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	4.9910E-04	4.7410E-04	4.9800E-04	4.9780E-04	4.2750E-04	4.9360E-04	4.8960E-04
^{95}Mo	N.R.	4.9640E-04	4.6890E-04	4.9310E-04	4.9320E-04	4.2220E-04	4.8470E-04	4.8360E-04
^{99}Tc	N.R.	4.9250E-04	4.6870E-04	4.9320E-04	4.9320E-04	4.2210E-04	5.0160E-04	4.8370E-04
^{101}Ru	N.R.	4.9260E-04	4.6870E-04	4.9300E-04	4.9280E-04	4.1980E-04	4.8520E-04	4.8300E-04
^{103}Rh	N.R.	4.9090E-04	4.6770E-04	4.9160E-04	4.9160E-04	4.2080E-04	4.9300E-04	4.8190E-04
^{109}Ag	N.R.	4.9430E-04	4.7010E-04	4.9350E-04	4.9370E-04	4.2290E-04	4.8770E-04	4.8410E-04
^{133}Cs	N.R.	4.9360E-04	4.6950E-04	4.9340E-04	4.9310E-04	4.2230E-04	4.9210E-04	4.8380E-04
^{143}Nd	N.R.	4.9150E-04	4.6570E-04	4.9010E-04	4.9040E-04	4.1920E-04	4.9070E-04	4.8090E-04
^{145}Nd	N.R.	4.8900E-04	4.6640E-04	4.9070E-04	4.9070E-04	4.1950E-04	5.0070E-04	4.8090E-04
^{147}Sm	N.R.	4.9180E-04	4.6890E-04	4.9280E-04	4.9300E-04	4.2110E-04	4.8330E-04	4.8350E-04
^{149}Sm	N.R.	4.9000E-04	4.6600E-04	4.9070E-04	4.9070E-04	4.1970E-04	4.9570E-04	4.8100E-04
^{150}Sm	N.R.	4.9000E-04	4.6570E-04	4.9030E-04	4.9010E-04	4.1880E-04	4.8720E-04	4.8120E-04
^{151}Sm	N.R.	4.9030E-04	4.6520E-04	4.8930E-04	4.8960E-04	4.1880E-04	4.9230E-04	4.7990E-04
^{152}Sm	N.R.	4.9250E-04	4.7050E-04	4.9350E-04	4.9340E-04	4.2300E-04	4.8900E-04	4.8400E-04
^{153}Eu	N.R.	4.9110E-04	4.6650E-04	4.9050E-04	4.9080E-04	4.1950E-04	4.8200E-04	4.8100E-04
^{155}Gd	N.R.	4.8920E-04	4.6570E-04	4.8970E-04	4.8990E-04	4.1900E-04	4.9650E-04	4.8020E-04
^{235}U	N.R.	4.9680E-04	4.6850E-04	4.9710E-04	4.9720E-04	4.2390E-04	4.8950E-04	4.8770E-04
^{236}U	N.R.	4.9620E-04	4.7220E-04	4.9630E-04	4.9610E-04	4.2530E-04	4.9990E-04	4.8680E-04
^{237}Np	N.R.	4.9130E-04	4.6570E-04	4.9120E-04	4.9110E-04	4.2010E-04	4.9420E-04	4.8210E-04
^{238}Pu	N.R.	4.8810E-04	4.6470E-04	4.8960E-04	4.8940E-04	4.1850E-04	4.8120E-04	4.8020E-04
^{239}Pu	N.R.	4.9730E-04	4.6170E-04	4.9500E-04	4.9520E-04	4.1990E-04	5.1010E-04	4.8590E-04
^{240}Pu	N.R.	4.9540E-04	4.6950E-04	4.9440E-04	4.9400E-04	4.2390E-04	4.8480E-04	4.8520E-04
^{241}Pu	N.R.	4.9910E-04	4.6850E-04	4.9900E-04	4.9880E-04	4.2500E-04	4.8370E-04	4.8950E-04
^{242}Pu	N.R.	4.9770E-04	4.6990E-04	4.9590E-04	4.9590E-04	4.2530E-04	4.9790E-04	4.8640E-04
^{241}Am	N.R.	4.9290E-04	4.6570E-04	4.9160E-04	4.9120E-04	4.2040E-04	4.8460E-04	4.8220E-04
^{243}Am	N.R.	4.9340E-04	4.6660E-04	4.9300E-04	4.9280E-04	4.2230E-04	5.0290E-04	4.8400E-04
^{10}B	N.R.	4.9090E-04	4.6770E-04	4.9210E-04	4.9180E-04	4.2200E-04	4.8790E-04	4.8330E-04
ALL	N.R.	N.R.	3.7430E-04	4.3420E-04	4.3410E-04	3.5130E-04	4.3420E-04	4.2240E-04

Table 62. Absorption rate on ^{16}O in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	2.3570E-07	2.5880E-07	2.4020E-07	2.4070E-07	2.3780E-07	2.2890E-07	2.3800E-07
^{95}Mo	N.R.	2.4060E-07	2.5780E-07	2.3810E-07	2.3900E-07	2.3500E-07	2.4530E-07	2.3460E-07
^{99}Tc	N.R.	2.3780E-07	2.5760E-07	2.3890E-07	2.3940E-07	2.3570E-07	2.3460E-07	2.3550E-07
^{101}Ru	N.R.	2.4090E-07	2.5800E-07	2.3810E-07	2.3920E-07	2.3430E-07	2.4140E-07	2.3590E-07
^{103}Rh	N.R.	2.3360E-07	2.5900E-07	2.3930E-07	2.3880E-07	2.3590E-07	2.6540E-07	2.3660E-07
^{109}Ag	N.R.	2.4100E-07	2.5820E-07	2.3910E-07	2.3970E-07	2.3650E-07	2.8080E-07	2.3680E-07
^{133}Cs	N.R.	2.3760E-07	2.5790E-07	2.3920E-07	2.3960E-07	2.3580E-07	2.3820E-07	2.3690E-07
^{143}Nd	N.R.	2.3900E-07	2.5770E-07	2.3860E-07	2.3850E-07	2.3490E-07	2.3610E-07	2.3520E-07
^{145}Nd	N.R.	2.4120E-07	2.5710E-07	2.3850E-07	2.3860E-07	2.3490E-07	2.3320E-07	2.3440E-07
^{147}Sm	N.R.	2.3760E-07	2.5780E-07	2.4040E-07	2.3940E-07	2.3630E-07	2.1270E-07	2.3560E-07
^{149}Sm	N.R.	2.3970E-07	2.5860E-07	2.3900E-07	2.3890E-07	2.3550E-07	2.5180E-07	2.3520E-07
^{150}Sm	N.R.	2.3750E-07	2.5820E-07	2.3800E-07	2.3860E-07	2.3480E-07	2.6860E-07	2.3670E-07
^{151}Sm	N.R.	2.4190E-07	2.5900E-07	2.3820E-07	2.3770E-07	2.3480E-07	2.3050E-07	2.3430E-07
^{152}Sm	N.R.	2.4020E-07	2.5860E-07	2.4040E-07	2.3950E-07	2.3660E-07	2.4020E-07	2.3660E-07
^{153}Eu	N.R.	2.3800E-07	2.5810E-07	2.3920E-07	2.3890E-07	2.3570E-07	2.4690E-07	2.3700E-07
^{155}Gd	N.R.	2.3620E-07	2.5590E-07	2.3780E-07	2.3750E-07	2.3490E-07	2.6390E-07	2.3480E-07
^{235}U	N.R.	2.4010E-07	2.8510E-07	2.6470E-07	2.6540E-07	2.6190E-07	2.3500E-07	2.6090E-07
^{236}U	N.R.	2.4200E-07	2.5890E-07	2.4030E-07	2.4040E-07	2.3710E-07	2.4950E-07	2.3600E-07
^{237}Np	N.R.	2.4200E-07	2.5760E-07	2.3970E-07	2.3930E-07	2.3600E-07	2.5050E-07	2.3540E-07
^{238}Pu	N.R.	2.3130E-07	2.5940E-07	2.3870E-07	2.3980E-07	2.3580E-07	2.5400E-07	2.3740E-07
^{239}Pu	N.R.	2.9050E-07	3.0290E-07	2.8950E-07	2.8940E-07	2.9230E-07	2.9380E-07	2.8520E-07
^{240}Pu	N.R.	2.3440E-07	2.5760E-07	2.4000E-07	2.3970E-07	2.3700E-07	2.4400E-07	2.3690E-07
^{241}Pu	N.R.	2.7370E-07	2.9290E-07	2.7580E-07	2.7560E-07	2.7920E-07	2.7510E-07	2.7090E-07
^{242}Pu	N.R.	2.4170E-07	2.5820E-07	2.4080E-07	2.3960E-07	2.3740E-07	2.4440E-07	2.3650E-07
^{241}Am	N.R.	2.4180E-07	2.5670E-07	2.3970E-07	2.3970E-07	2.3600E-07	2.3610E-07	2.3660E-07
^{243}Am	N.R.	2.3770E-07	2.5920E-07	2.3950E-07	2.3960E-07	2.3680E-07	2.5440E-07	2.3680E-07
^{10}B	N.R.	2.3690E-07	2.5740E-07	2.3980E-07	2.3890E-07	2.3530E-07	2.4090E-07	2.3450E-07
ALL	N.R.	N.R.	2.8360E-07	2.7420E-07	2.7490E-07	2.6420E-07	2.8990E-07	2.6360E-07

Table 63. Scattering rate on ^{16}O in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
0	N.R.	3.5510E-04	3.8590E-04	3.5400E-04	3.5390E-04	3.2490E-04	3.4960E-04	3.4840E-04
^{95}Mo	N.R.	3.5270E-04	3.8190E-04	3.5030E-04	3.5030E-04	3.2110E-04	3.4670E-04	3.4410E-04
^{99}Tc	N.R.	3.4910E-04	3.8120E-04	3.4980E-04	3.4980E-04	3.2060E-04	3.5730E-04	3.4360E-04
^{101}Ru	N.R.	3.5040E-04	3.8180E-04	3.5020E-04	3.5020E-04	3.1960E-04	3.4390E-04	3.4400E-04
^{103}Rh	N.R.	3.4770E-04	3.7990E-04	3.4860E-04	3.4870E-04	3.1940E-04	3.4950E-04	3.4250E-04
^{109}Ag	N.R.	3.5010E-04	3.8230E-04	3.5030E-04	3.5030E-04	3.2110E-04	3.4560E-04	3.4390E-04
^{133}Cs	N.R.	3.5040E-04	3.8190E-04	3.5010E-04	3.5000E-04	3.2070E-04	3.5260E-04	3.4390E-04
^{143}Nd	N.R.	3.4730E-04	3.7830E-04	3.4730E-04	3.4750E-04	3.1810E-04	3.4880E-04	3.4130E-04
^{145}Nd	N.R.	3.4660E-04	3.7950E-04	3.4830E-04	3.4830E-04	3.1890E-04	3.5750E-04	3.4200E-04
^{147}Sm	N.R.	3.4880E-04	3.8160E-04	3.4970E-04	3.4980E-04	3.2030E-04	3.4750E-04	3.4360E-04
^{149}Sm	N.R.	3.4770E-04	3.7850E-04	3.4780E-04	3.4790E-04	3.1850E-04	3.5080E-04	3.4170E-04
^{150}Sm	N.R.	3.4750E-04	3.7860E-04	3.4760E-04	3.4750E-04	3.1790E-04	3.4580E-04	3.4160E-04
^{151}Sm	N.R.	3.4750E-04	3.7780E-04	3.4670E-04	3.4700E-04	3.1760E-04	3.4740E-04	3.4070E-04
^{152}Sm	N.R.	3.4990E-04	3.8260E-04	3.5050E-04	3.5040E-04	3.2140E-04	3.4850E-04	3.4410E-04
^{153}Eu	N.R.	3.4830E-04	3.7930E-04	3.4790E-04	3.4810E-04	3.1860E-04	3.4240E-04	3.4160E-04
^{155}Gd	N.R.	3.4720E-04	3.7800E-04	3.4700E-04	3.4720E-04	3.1780E-04	3.5360E-04	3.4080E-04
^{235}U	N.R.	3.5540E-04	3.8260E-04	3.5200E-04	3.5200E-04	3.2240E-04	3.4700E-04	3.4590E-04
^{236}U	N.R.	3.5220E-04	3.8430E-04	3.5240E-04	3.5230E-04	3.2330E-04	3.5470E-04	3.4640E-04
^{237}Np	N.R.	3.4810E-04	3.7840E-04	3.4850E-04	3.4840E-04	3.1900E-04	3.5130E-04	3.4260E-04
^{238}Pu	N.R.	3.4580E-04	3.7740E-04	3.4700E-04	3.4690E-04	3.1750E-04	3.4490E-04	3.4080E-04
^{239}Pu	N.R.	3.5080E-04	3.7810E-04	3.4930E-04	3.4930E-04	3.1920E-04	3.5870E-04	3.4330E-04
^{240}Pu	N.R.	3.5220E-04	3.8170E-04	3.5110E-04	3.5070E-04	3.2200E-04	3.4480E-04	3.4510E-04
^{241}Pu	N.R.	3.5260E-04	3.8320E-04	3.5310E-04	3.5310E-04	3.2320E-04	3.4280E-04	3.4690E-04
^{242}Pu	N.R.	3.5340E-04	3.8200E-04	3.5220E-04	3.5230E-04	3.2320E-04	3.5380E-04	3.4610E-04
^{241}Am	N.R.	3.5000E-04	3.7850E-04	3.4870E-04	3.4840E-04	3.1910E-04	3.4680E-04	3.4230E-04
^{243}Am	N.R.	3.5070E-04	3.7940E-04	3.5000E-04	3.4990E-04	3.2080E-04	3.5410E-04	3.4390E-04
^{10}B	N.R.	3.4850E-04	3.8000E-04	3.4910E-04	3.4890E-04	3.1960E-04	3.4800E-04	3.4340E-04
ALL	N.R.	N.R.	3.0900E-04	3.0060E-04	3.0050E-04	2.6830E-04	3.0200E-04	2.9340E-04

Figure 53. Relative difference in the BUC absorption rate for cases 1 to 14 of sub-phase 4

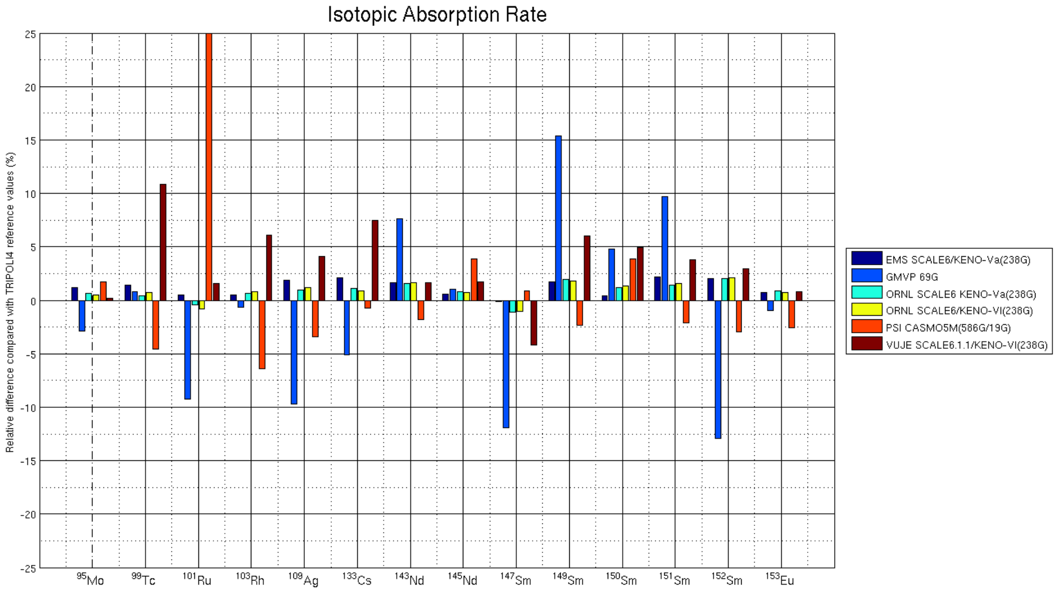


Figure 54. Relative difference in the BUC absorption rate for cases 15 to 27 of sub-phase 4

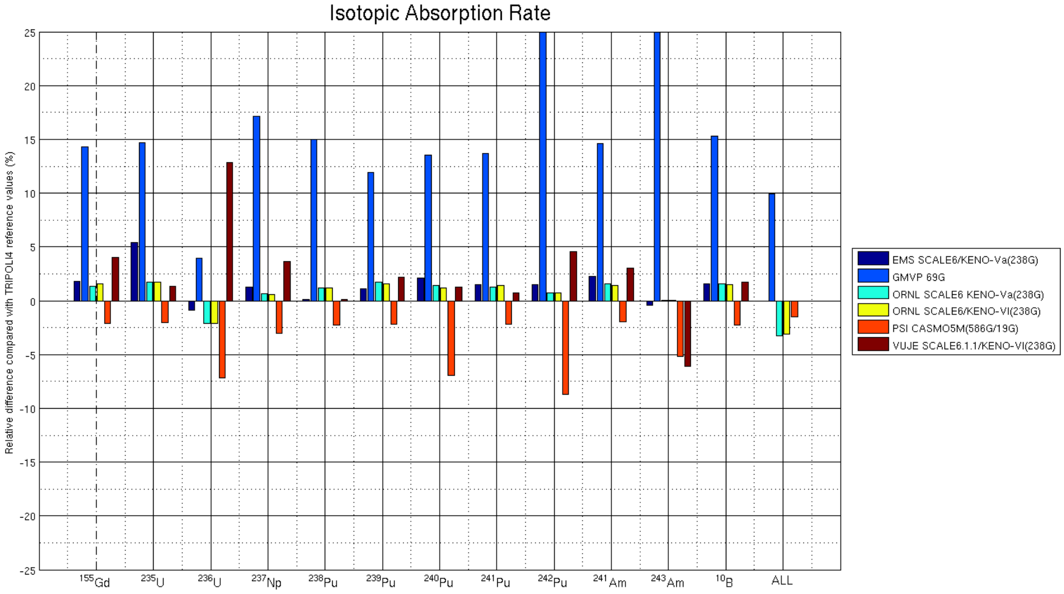


Figure 55. Relative difference in the BUC production rate for cases 16 to 27 of sub-phase 4

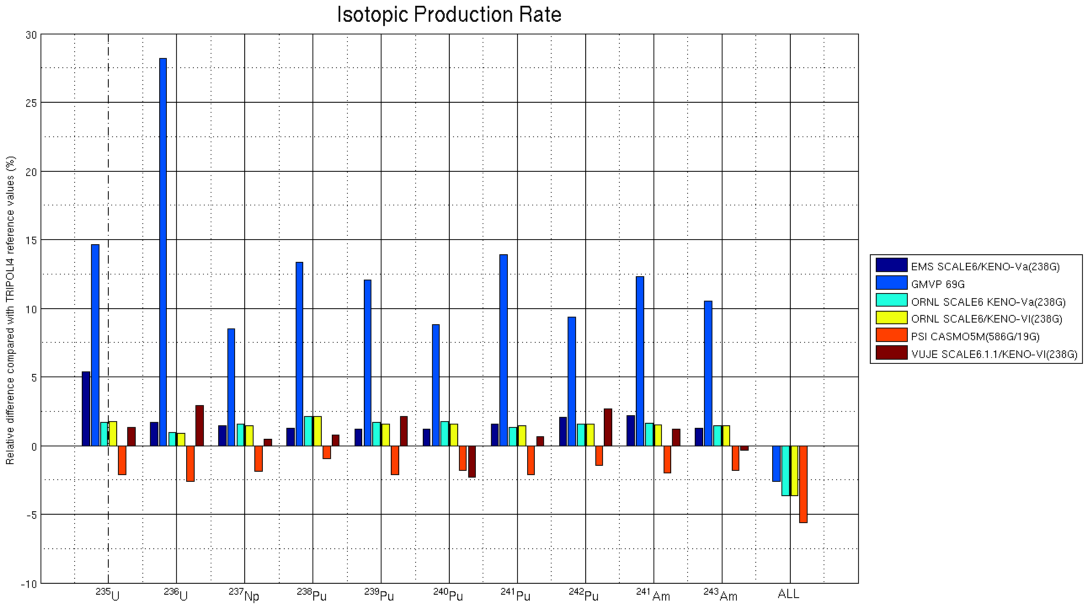


Figure 56. Relative difference in the BUC scattering rate for cases 1 to 14 of sub-phase 4

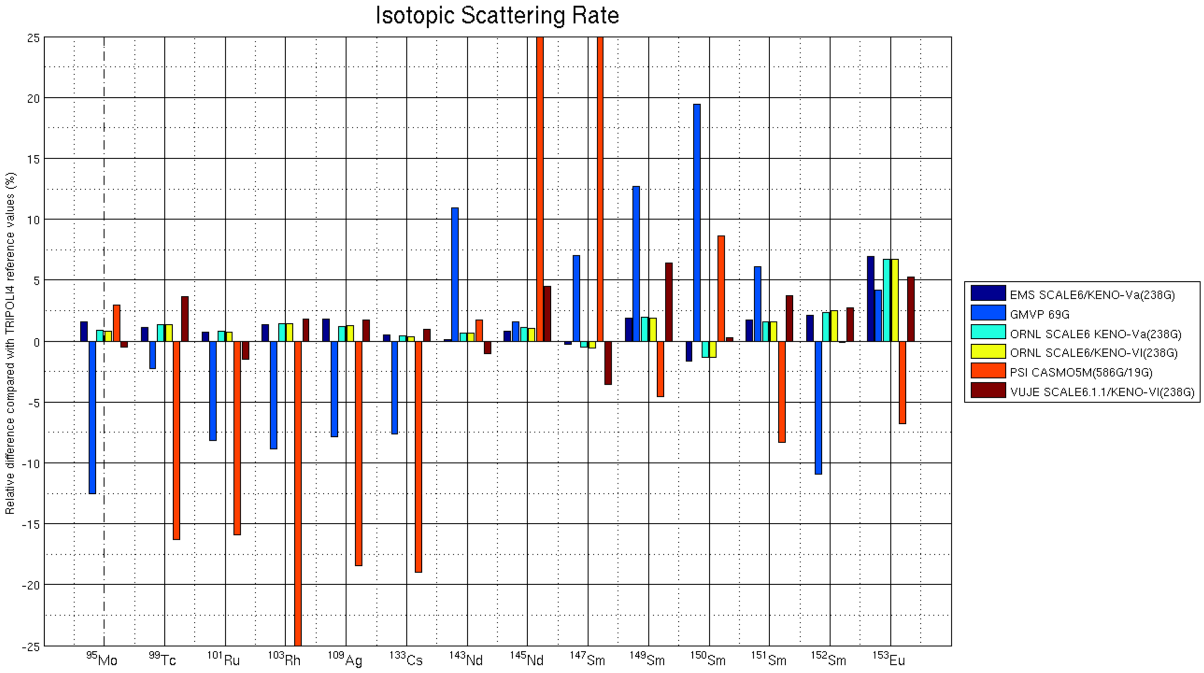


Figure 57. Relative difference in the BUC scattering rate for cases 15 to 27 of sub-phase 4

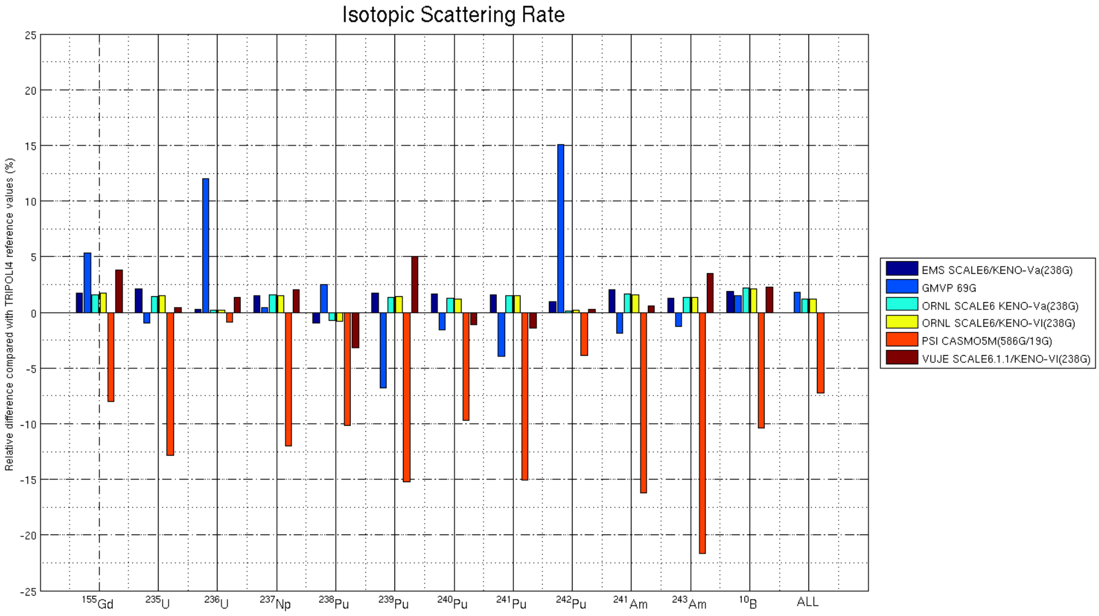


Table 64. Absorption rate on the BUC nuclide in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	5.885E-04	2.2550E-05	2.1650E-05	2.2430E-05	2.2400E-05	2.2670E-05	2.2340E-05	2.2290E-05
^{99}Tc	7.218E-04	2.7730E-05	2.7560E-05	2.7460E-05	2.7530E-05	2.6090E-05	3.0300E-05	2.7340E-05
^{101}Ru	7.332E-04	2.7730E-05	2.5050E-05	2.7480E-05	2.7380E-05	3.6490E-05	2.8040E-05	2.7600E-05
^{103}Rh	8.586E-04	3.2600E-05	3.2230E-05	3.2660E-05	3.2700E-05	3.0360E-05	3.4430E-05	3.2450E-05
^{109}Ag	6.047E-04	2.3000E-05	2.0380E-05	2.2800E-05	2.2850E-05	2.1820E-05	2.3500E-05	2.2580E-05
^{133}Cs	6.688E-04	2.5740E-05	2.3930E-05	2.5490E-05	2.5430E-05	2.5020E-05	2.7100E-05	2.5210E-05
^{143}Nd	9.346E-04	3.5820E-05	3.7920E-05	3.5790E-05	3.5820E-05	3.4590E-05	3.5810E-05	3.5230E-05
^{145}Nd	8.737E-04	3.2740E-05	3.2900E-05	3.2830E-05	3.2800E-05	3.3830E-05	3.3130E-05	3.2560E-05
^{147}Sm	7.263E-04	2.7400E-05	2.4160E-05	2.7140E-05	2.7150E-05	2.7670E-05	2.6280E-05	2.7430E-05
^{149}Sm	8.837E-04	3.3780E-05	3.8310E-05	3.3850E-05	3.3810E-05	3.2430E-05	3.5200E-05	3.3210E-05
^{150}Sm	9.515E-04	3.6270E-05	3.7850E-05	3.6560E-05	3.6620E-05	3.7520E-05	3.7900E-05	3.6120E-05
^{151}Sm	9.659E-04	3.7430E-05	4.0190E-05	3.7160E-05	3.7210E-05	3.5880E-05	3.8050E-05	3.6650E-05
^{152}Sm	5.468E-04	2.0920E-05	1.7860E-05	2.0920E-05	2.0930E-05	1.9900E-05	2.1120E-05	2.0500E-05
^{153}Eu	9.719E-04	3.6900E-05	3.6290E-05	3.6950E-05	3.6890E-05	3.5710E-05	3.6930E-05	3.6640E-05
^{155}Gd	9.269E-04	3.5790E-05	4.0190E-05	3.5630E-05	3.5720E-05	3.4420E-05	3.6590E-05	3.5160E-05
^{235}U	2.803E-03	1.1230E-04	1.2220E-04	1.0840E-04	1.0840E-04	1.0440E-04	1.0800E-04	1.0660E-04
^{236}U	3.627E-04	1.3640E-05	1.4310E-05	1.3480E-05	1.3480E-05	1.2780E-05	1.5530E-05	1.3770E-05
^{237}Np	9.270E-04	3.5450E-05	4.0990E-05	3.5220E-05	3.5210E-05	3.3930E-05	3.6290E-05	3.5000E-05
^{238}Pu	1.074E-03	4.0820E-05	4.6860E-05	4.1260E-05	4.1260E-05	3.9840E-05	4.0800E-05	4.0760E-05
^{239}Pu	3.786E-03	1.4560E-04	1.6120E-04	1.4650E-04	1.4630E-04	1.4090E-04	1.4720E-04	1.4400E-04
^{240}Pu	4.814E-04	1.8380E-05	2.0440E-05	1.8260E-05	1.8210E-05	1.6750E-05	1.8220E-05	1.8000E-05
^{241}Pu	2.491E-03	9.6220E-05	1.0780E-04	9.6040E-05	9.6120E-05	9.2760E-05	9.5530E-05	9.4810E-05
^{242}Pu	3.368E-04	1.2970E-05	2.2720E-05	1.2870E-05	1.2870E-05	1.1660E-05	1.3360E-05	1.2780E-05
^{241}Am	8.613E-04	3.3080E-05	3.7070E-05	3.2860E-05	3.2800E-05	3.1710E-05	3.3310E-05	3.2340E-05
^{243}Am	7.042E-04	2.6340E-05	3.3070E-05	2.6460E-05	2.6470E-05	2.5080E-05	2.4840E-05	2.6450E-05
^{10}B	7.121E-04	2.7300E-05	3.1010E-05	2.7310E-05	2.7290E-05	2.6290E-05	2.7350E-05	2.6890E-05
ALL	1.196E-02	N.R.	4.8100E-04	4.2350E-04	4.2390E-04	4.3100E-04	N.R.	4.3760E-04

Table 65. Production rate on the BUC nuclide in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{235}U	N.R.	2.2710E-04	2.4700E-04	2.1910E-04	2.1920E-04	2.1090E-04	2.1830E-04	2.1550E-04
^{236}U	N.R.	2.9160E-06	3.6760E-06	2.8940E-06	2.8930E-06	2.7940E-06	2.9520E-06	2.8680E-06
^{237}Np	N.R.	1.3420E-06	1.4350E-06	1.3440E-06	1.3420E-06	1.2980E-06	1.3290E-06	1.3230E-06
^{238}Pu	N.R.	6.1100E-06	6.8380E-06	6.1590E-06	6.1600E-06	5.9750E-06	6.0780E-06	6.0330E-06
^{239}Pu	N.R.	2.8200E-04	3.1230E-04	2.8340E-04	2.8310E-04	2.7290E-04	2.8450E-04	2.7870E-04
^{240}Pu	N.R.	2.5590E-07	2.7520E-07	2.5730E-07	2.5690E-07	2.4830E-07	2.4710E-07	2.5290E-07
^{241}Pu	N.R.	2.0930E-04	2.3470E-04	2.0890E-04	2.0910E-04	2.0170E-04	2.0740E-04	2.0610E-04
^{242}Pu	N.R.	1.6550E-06	1.7730E-06	1.6470E-06	1.6470E-06	1.5990E-06	1.6650E-06	1.6220E-06
^{241}Am	N.R.	9.6230E-07	1.0570E-06	9.5700E-07	9.5560E-07	9.2260E-07	9.5280E-07	9.4160E-07
^{243}Am	N.R.	1.0480E-06	1.1450E-06	1.0500E-06	1.0500E-06	1.0170E-06	1.0320E-06	1.0350E-06
ALL	N.R.	N.R.	2.5380E-04	2.5110E-04	2.5120E-04	2.4600E-04	N.R.	2.6060E-04

Table 66. Scattering rate on the BUC nuclide in s^{-1} (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	N.R.	6.7640E-05	5.8240E-05	6.7180E-05	6.7150E-05	6.8570E-05	6.6250E-05	6.6600E-05
^{99}Tc	N.R.	3.0320E-05	2.9300E-05	3.0370E-05	3.0370E-05	2.5090E-05	3.1070E-05	2.9980E-05
^{101}Ru	N.R.	8.0520E-05	7.3390E-05	8.0580E-05	8.0560E-05	6.7220E-05	7.8780E-05	7.9950E-05
^{103}Rh	N.R.	5.5960E-06	5.0350E-06	5.6010E-06	5.6010E-06	4.1320E-06	5.6240E-06	5.5230E-06
^{109}Ag	N.R.	6.3390E-06	5.7330E-06	6.2980E-06	6.3020E-06	5.0770E-06	6.3330E-06	2.3670E-07
^{133}Cs	N.R.	1.9780E-05	1.8190E-05	1.9770E-05	1.9750E-05	1.5940E-05	1.9880E-05	1.9680E-05
^{143}Nd	N.R.	2.8280E-05	3.1340E-05	2.8430E-05	2.8420E-05	2.8740E-05	2.7960E-05	2.8250E-05
^{145}Nd	N.R.	5.8810E-05	5.9260E-05	5.8990E-05	5.8920E-05	7.4970E-05	6.0960E-05	5.8330E-05
^{147}Sm	N.R.	2.7400E-05	2.9390E-05	2.7330E-05	2.7300E-05	3.5110E-05	2.6480E-05	2.7460E-05
^{149}Sm	N.R.	3.1060E-07	3.4350E-07	3.1090E-07	3.1060E-07	2.9110E-07	3.2430E-07	3.0490E-07
^{150}Sm	N.R.	4.1160E-05	4.9970E-05	4.1260E-05	4.1260E-05	4.5430E-05	4.1950E-05	4.1830E-05
^{151}Sm	N.R.	5.1350E-07	5.3580E-07	5.1270E-07	5.1300E-07	4.6290E-07	5.2380E-07	5.0490E-07
^{152}Sm	N.R.	2.2280E-05	1.9440E-05	2.2330E-05	2.2370E-05	2.1800E-05	2.2430E-05	2.1830E-05
^{153}Eu	N.R.	5.3830E-06	5.2430E-06	5.3710E-06	5.3720E-06	4.6910E-06	5.2980E-06	5.0340E-06
^{155}Gd	N.R.	1.0480E-07	1.0840E-07	1.0460E-07	1.0480E-07	9.4760E-08	1.0690E-07	1.0300E-07
^{235}U	N.R.	1.4300E-05	1.3870E-05	1.4210E-05	1.4210E-05	1.2200E-05	1.4060E-05	1.4000E-05
^{236}U	N.R.	5.3520E-05	5.9790E-05	5.3500E-05	5.3480E-05	5.2910E-05	5.4080E-05	5.3380E-05
^{237}Np	N.R.	9.5560E-06	9.4570E-06	9.5600E-06	9.5580E-06	8.2860E-06	9.6040E-06	9.4150E-06
^{238}Pu	N.R.	8.7890E-06	9.0930E-06	8.8050E-06	8.8020E-06	7.9660E-06	8.5890E-06	8.8710E-06
^{239}Pu	N.R.	9.2530E-06	8.4790E-06	9.2190E-06	9.2220E-06	7.7080E-06	9.5500E-06	9.0960E-06
^{240}Pu	N.R.	2.4690E-06	2.3900E-06	2.4600E-06	2.4580E-06	2.1930E-06	2.4030E-06	2.4290E-06
^{241}Pu	N.R.	5.0580E-06	4.7850E-06	5.0530E-06	5.0530E-06	4.2280E-06	4.9100E-06	4.9800E-06
^{242}Pu	N.R.	1.4720E-05	1.6770E-05	1.4600E-05	1.4610E-05	1.4020E-05	1.4610E-05	1.4580E-05
^{241}Am	N.R.	2.3780E-06	2.2860E-06	2.3690E-06	2.3670E-06	1.9520E-06	2.3450E-06	2.3300E-06
^{243}Am	N.R.	7.2410E-06	7.0580E-06	7.2500E-06	7.2480E-06	5.6040E-06	7.4010E-06	7.1510E-06
^{10}B	N.R.	1.3150E-07	1.3100E-07	1.3190E-07	1.3180E-07	1.1570E-07	1.3200E-07	1.23073E-07
ALL	N.R.	N.R.	4.3770E-04	4.3510E-04	4.3510E-04	3.9900E-04	N.R.	4.3010E-04

3.4.4 Reactivity worth

3.4.4.1 Eigen-value difference method

Reactivity worth calculated by the eigen value difference method is presented in Figures 58 and 59, with the calculated values reported in Table 67.

It should be noted that due to the small reactivity effect of each case (typically less than 10 pcm), the “reference” TRIPOLI4 calculation is limited by a convergence of 2 pcm on the reactivity worth, which means that most of the difference plotted in Figures 43 and 44 are affected by an uncertainty of at least 20%. This is why we have added a blue line which represents the 1σ uncertainty on the reference calculation.

Considering the differences between each participant, it is difficult to draw any conclusion on the different code systems: most of calculations show differences with TRIPOLI4 within 2σ uncertainty. It should be mentioned that the uncertainty on each Monte-Carlo solution (SCALE6 and GMVP-II) should also be included when considering the differences with TRIPOLI: for instance, large differences observed between VUJE calculations and TRIPOLI4 are due to convergence limitations (uncertainty of ±40 pcm on reactivity worth of less than 10 pcm). Nevertheless, we should remark that deterministic solutions provided by CEA and PSI are in good agreement, with differences of a few percent on most of the nuclides. Considering that these deterministic calculations have shown a great consistency with TRIPOLI4 calculation in sub-phase 2 and 3, we should consider these calculations as the reference solution in this sub-phase, as the deterministic solution is less limited by the convergence of each eigen value: the remaining error on the numerical convergence is typically 0.1 pcm in an APOLLO2/MOC calculation, while it is more than 1 pcm in a TRIPOLI4 Monte-Carlo calculation.

Figure 58. Relative difference in the reactivity worth by the eigen-value difference method for cases 1 to 15 of sub-phase 4 (y-axis scaled from -80% to 80% difference, the blue line is the 1σ uncertainty on TRIPOLI4 calculations)

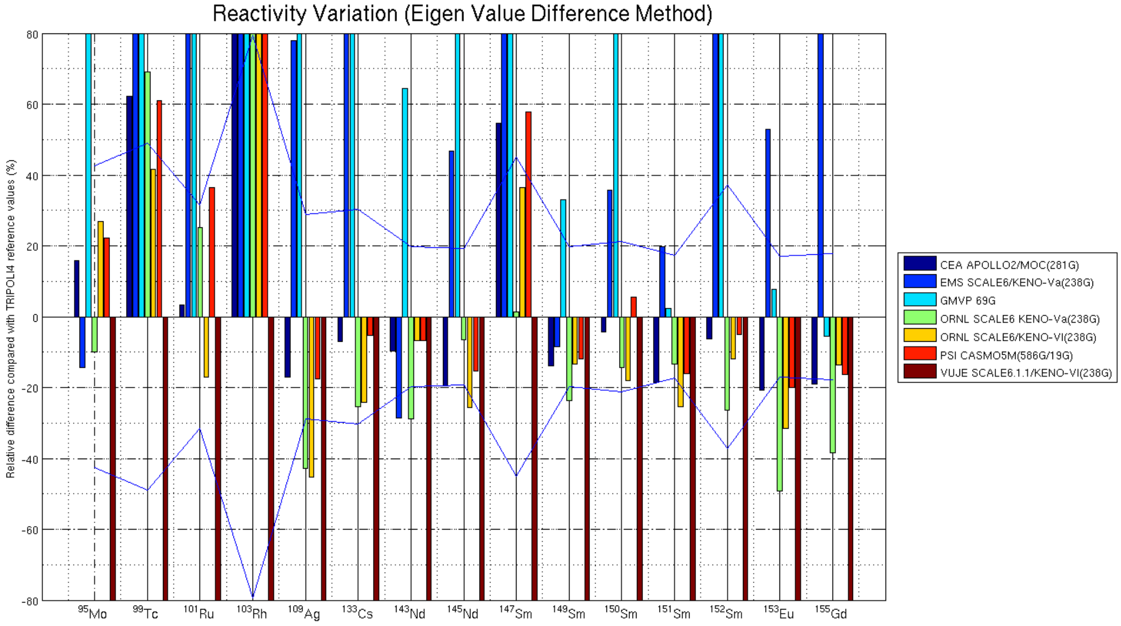


Figure 59. Relative difference in the reactivity worth by the eigen-value difference method for cases 16 to 29 of sub-phase 4 (y-axis scaled from -300% to 300% difference, the blue line is the 1σ uncertainty on TRIPOLI4 calculations)

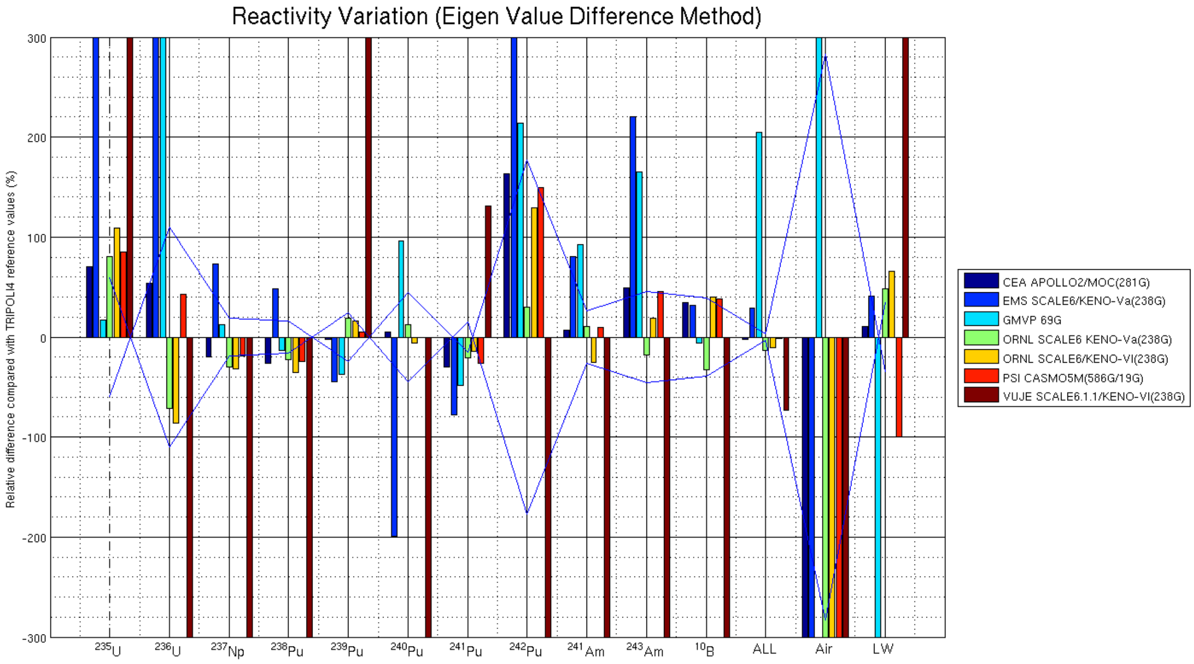


Table 67. Reactivity worth by the eigen-value difference method in pcm (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	-5.2	-3.9(5.0)	-17.6(1.3)	-4.1(1.0)	-5.7(0.8)	-5.5	47.0(39.7)	-4.5(1.9)
^{99}Tc	-6.4	-21.4(5.0)	-27.5(1.3)	-6.6(1.0)	-5.5(0.8)	-6.3	55.0(42.2)	-3.9(1.9)
^{101}Ru	-6.3	-24.4(5.0)	-16.7(1.3)	-7.6(1.0)	-5.0(0.8)	-8.3	46.0(35.6)	-6.1(1.9)
^{103}Rh	-8.1	-16.0(5.0)	-7.5(1.3)	-9.4(1.0)	-7.4(0.8)	-7.9	114.0(38.9)	-2.4(1.9)
^{109}Ag	-5.5	-11.8(5.0)	-22.7(1.3)	-3.8(1.0)	-3.6(0.8)	-5.5	3.0(38.1)	-6.7(1.9)
^{133}Cs	-5.9	-15.9(5.0)	-24.5(1.3)	-4.7(0.8)	-4.8(0.8)	-6	67.0(40.6)	-6.3(1.9)
^{143}Nd	-8.7	-6.9(5.0)	-15.9(1.3)	-6.9(0.8)	-9.0(0.8)	-9	81.0(33.1)	-9.7(1.9)
^{145}Nd	-8	-14.6(5.0)	-30.5(1.3)	-9.3(0.8)	-7.4(0.8)	-8.4	33.0(38.1)	-9.9(1.9)
^{147}Sm	-6.6	-10.9(5.0)	-22.2(1.3)	-4.3(1.0)	-5.8(0.8)	-6.7	46.0(39.7)	-4.2(1.9)
^{149}Sm	-8.3	-8.8(5.0)	-12.8(1.3)	-7.4(1.0)	-8.4(0.8)	-8.5	82.0(34.8)	-9.7(1.9)
^{150}Sm	-8.6	-12.2(5.0)	-22.9(1.3)	-7.7(1.0)	-7.4(0.8)	-9.5	2.0(35.6)	-9.0(1.9)
^{151}Sm	-9	-13.2(5.0)	-11.3(1.3)	-9.6(1.0)	-8.3(0.8)	-9.3	36.0(33.1)	-11.1(1.9)
^{152}Sm	-4.8	-12.5(5.0)	-48.1(1.3)	-3.8(1.0)	-4.6(0.8)	-4.9	87.0(34.7)	-5.2(1.9)
^{153}Eu	-8.9	-17.2(5.0)	-12.1(1.3)	-5.7(1.0)	-7.7(0.8)	-9	96.0(38.1)	-11.2(1.9)
^{155}Gd	-8.7	-23.5(5.0)	-10.2(1.3)	-6.6(1.0)	-9.3(0.8)	-9	34.0(40.6)	-10.7(1.9)
^{235}U	5.5	25.2(5.0)	3.8(1.3)	5.9(1.0)	6.8(0.8)	6	69.0(38.1)	3.2(1.9)
^{236}U	-2.7	-23.6(5.0)	-8.7(1.3)	-0.5(1.0)	-0.2(0.8)	-2.5	59.0(34.8)	-1.7(1.9)
^{237}Np	-8.3	-17.9(5.0)	-11.6(1.3)	-7.2(1.0)	-7.0(0.8)	-8.4	27.0(40.6)	-10.3(1.9)
^{238}Pu	-9.1	-18.2(5.0)	-10.6(1.3)	-9.4(1.0)	-7.9(0.8)	-9.3	35.0(38.9)	-12.2(1.9)
^{239}Pu	7.8	4.5(5.0)	5.0(1.3)	9.5(1.0)	9.3(0.8)	8.4	86.0(34.7)	8.0(1.9)
^{240}Pu	-4.6	4.3(5.0)	-8.5(1.3)	-4.9(1.0)	-4.1(0.8)	-4.3	84.0(38.9)	-4.3(1.9)
^{241}Pu	8.8	2.9(5.0)	6.5(1.3)	10.0(1.0)	10.8(0.8)	9.3	29.0(39.7)	12.6(1.9)
^{242}Pu	-2.8	-6.0(5.0)	-3.4(1.3)	-1.4(1.0)	-2.5(0.8)	-2.7	44.0(37.2)	-1.1(1.9)
^{241}Am	-7.9	-13.3(5.0)	-14.3(1.3)	-8.2(1.0)	-5.5(0.8)	-8.1	93.0(33.9)	-7.4(1.9)
^{243}Am	-6.3	-13.6(5.0)	-11.2(1.3)	-3.5(0.8)	-5.0(0.8)	-6.2	71.0(38.9)	-4.2(1.9)
^{10}B	-6.6	-6.4(5.0)	-4.6(1.3)	-3.3(1.0)	-6.9(0.8)	-6.8	70.0(33.9)	-4.9(1.9)
ALL	-65.8	-87.4(5.8)	-205.7(1.3)	-58.4(1.0)	-60.4(0.8)	-66.7	-18.0(35.6)	-67.6(1.9)
Air	4.3	4.7(5.0)	-20.6(1.3)	6.8(1.0)	8.2(0.8)	5.1	125.0(43.0)	-1.0(2.8)
LW	9.1	9.8(5.0)	-27.6(1.3)	12.2(1.0)	13.6(0.8)	11.4	49.0(38.1)	8.2(2.8)

3.4.4.2 Perturbation method

Comparisons of reactivity worth calculation based on perturbation are illustrated in Figures 60 and 61 while the calculated values are reported in Table 68. Comparisons are still performed relatively to TRIPOLI4 calculations based on the eigen value difference method. As explained in the previous section, we have plotted a blue line on these figures to represent the 1σ uncertainty on the reference eigen value difference obtained from TRIPOLI4.

Due to the large uncertainty on the reference values, no conclusion can be made on the relative advantage or drawback of each method. Nevertheless, it should be noted that the APOLLO2 calculations are in good agreement with most of SCALE6 calculations, with differences of a few percent . GMVP-II calculations have quite the same trends, but with larger differences, maybe due to convergence limitations.

Figure 60. Relative difference in the reactivity worth by the perturbation method for cases 1 to 15 of sub-phase 4 (y-axis scaled from -80% to 80% difference, the blue line is the 1σ uncertainty on TRIPOLI4 calculations)

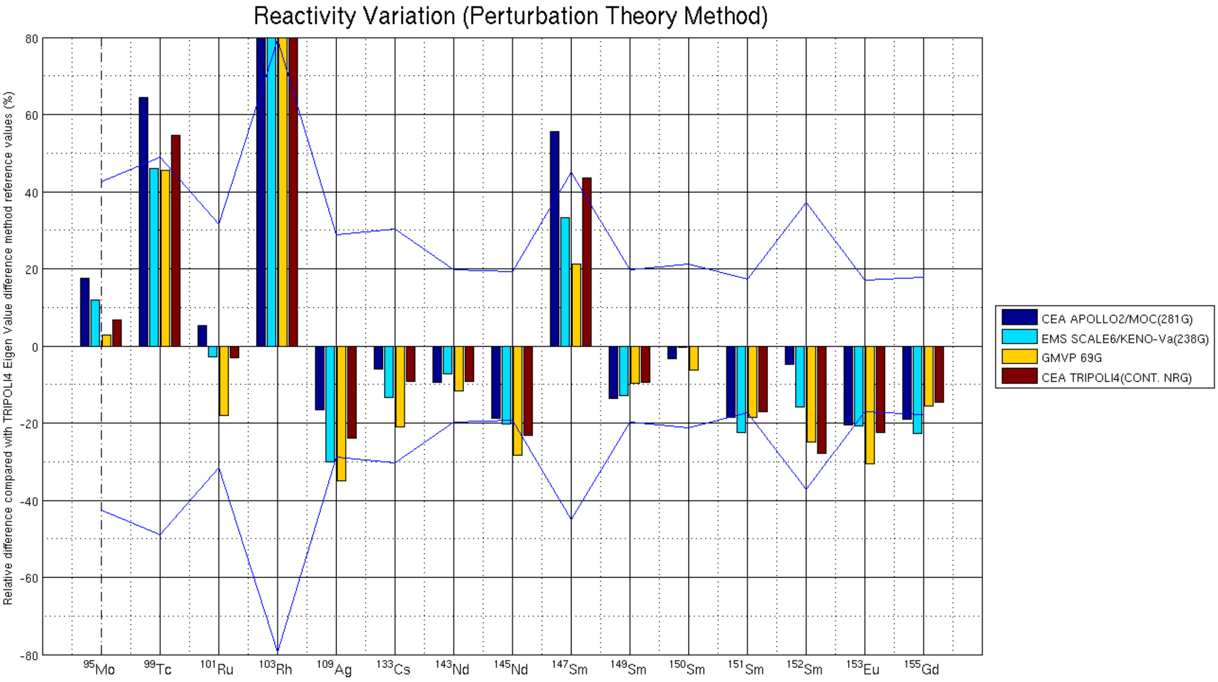


Figure 61. Relative difference in the reactivity worth by the perturbation method for cases 16 to 29 of sub-phase 4 (y-axis scaled from -300% to 300% difference, the blue line is the 1σ uncertainty on TRIPOLI4 calculations)

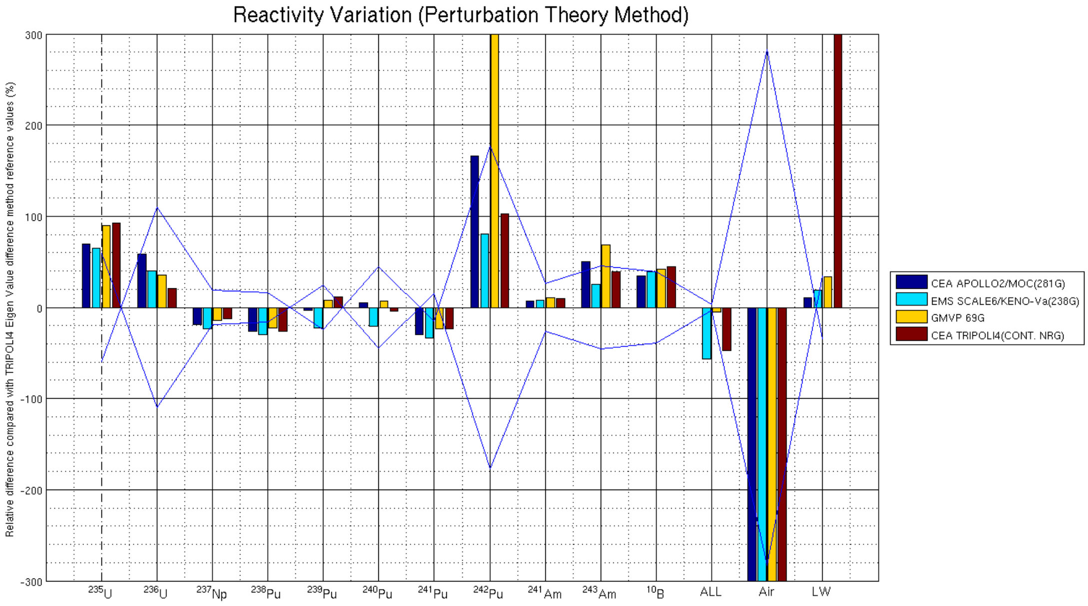


Table 68. Reactivity worth by the perturbation method in pcm (sub-phase 4)

Case	CEA APOLLO2 281G	EMS SCALE6.1 KENO-Va 238G	GMVP-II 69G	ORNL SCALE6.1 KENO-Va 238G	ORNL SCALE6.1 KENO-VI 238G	PSI CASMO5 586/19G	VUJE SCALE6.1 KENO-VI 238G	CEA TRIPOLI4 Cont. Energy
^{95}Mo	-5.3	-5	-4.6	N.R.	N.R.	N.R.	N.R.	-4.8(0.2)
^{99}Tc	-6.4	-5.7	-5.7	N.R.	N.R.	N.R.	N.R.	-6(0.2)
^{101}Ru	-6.4	-5.9	-5	N.R.	N.R.	N.R.	N.R.	-5.9(0.2)
^{103}Rh	-8.1	-7.4	-7.3	N.R.	N.R.	N.R.	N.R.	-8.5(0.3)
^{109}Ag	-5.6	-4.7	-4.3	N.R.	N.R.	N.R.	N.R.	-5.1(0.2)
^{133}Cs	-6	-5.5	-5	N.R.	N.R.	N.R.	N.R.	-5.8(0.2)
^{143}Nd	-8.8	-9	-8.5	N.R.	N.R.	N.R.	N.R.	-8.8(0.3)
^{145}Nd	-8.1	-7.9	-7.1	N.R.	N.R.	N.R.	N.R.	-7.6(0.2)
^{147}Sm	-6.6	-5.7	-5.1	N.R.	N.R.	N.R.	N.R.	-6.1(0.2)
^{149}Sm	-8.3	-8.4	-8.7	N.R.	N.R.	N.R.	N.R.	-8.7(0.3)
^{150}Sm	-8.7	-9	-8.4	N.R.	N.R.	N.R.	N.R.	-9(0.3)
^{151}Sm	-9	-8.6	-9	N.R.	N.R.	N.R.	N.R.	-9.2(0.3)
^{152}Sm	-4.9	-4.3	-3.9	N.R.	N.R.	N.R.	N.R.	-3.7(0.1)
^{153}Eu	-8.9	-8.9	-7.8	N.R.	N.R.	N.R.	N.R.	-8.7(0.3)
^{155}Gd	-8.7	-8.3	-9.1	N.R.	N.R.	N.R.	N.R.	-9.2(0.3)
^{235}U	5.5	5.3	6.2	N.R.	N.R.	N.R.	N.R.	6.3(0.2)
^{236}U	-2.8	-2.4	-2.4	N.R.	N.R.	N.R.	N.R.	-2.1(0.1)
^{237}Np	-8.3	-7.9	-8.9	N.R.	N.R.	N.R.	N.R.	-9(0.3)
^{238}Pu	-9.1	-8.6	-9.5	N.R.	N.R.	N.R.	N.R.	-9.1(0.3)
^{239}Pu	7.7	6.2	8.6	N.R.	N.R.	N.R.	N.R.	8.9(0.3)
^{240}Pu	-4.6	-3.4	-4.6	N.R.	N.R.	N.R.	N.R.	-4.2(0.1)
^{241}Pu	8.8	8.3	9.6	N.R.	N.R.	N.R.	N.R.	9.7(0.3)
^{242}Pu	-2.9	-2	-4.9	N.R.	N.R.	N.R.	N.R.	-2.2(0.1)
^{241}Am	-7.9	-8	-8.2	N.R.	N.R.	N.R.	N.R.	-8.2(0.2)
^{243}Am	-6.4	-5.3	-7.2	N.R.	N.R.	N.R.	N.R.	-5.9(0.2)
^{10}B	-6.6	-6.9	-7	N.R.	N.R.	N.R.	N.R.	-7.1(0.2)
ALL	-67.1	-29.6	-64.4	N.R.	N.R.	N.R.	N.R.	-35.8(0.2)
Air	5	11.5	7.4	N.R.	N.R.	N.R.	N.R.	126(1)
LW	9.1	9.1	11	N.R.	N.R.	N.R.	N.R.	107(4)

3.4.4.3 Individual components

Not enough results were provided to allow a comparison between participants.

4. Recommendations for the calculation of small-sample reactivity experiments

One of the goals of this benchmark was to demonstrate that treating the whole core model is not necessary for an accurate analysis of small sample reactivity experiments. Most of the time, these experiments are calibrated against reference samples containing nuclides with well-known neutronic properties (reference cross-sections). As a consequence, we can show that a simplified 2D model can be considered to treat the measured data without involving significant calculation bias.

To do so, we have chosen to renormalise all the reactivity worth data of sub-phase 2 and sub-phase 4 with respect to the reactivity worth of boron. In order to evaluate the calculation bias due to the simplified 2D 7x7 lattice model without leakage used in sub-phase 2, compared to the full 3D core model including axial and radial leakage in sub-phase 4, we have evaluated the following ε factor:

$$\varepsilon_i = \delta\rho = \frac{\left[\frac{\delta\rho_i}{\delta\rho_{B10}}\right]_{sub-phase\ VIII.2}}{\left[\frac{\delta\rho_i}{\delta\rho_{B10}}\right]_{sub-phase\ VIII.4}} - 1 \qquad (1)$$

Calculations of ε have been made with the eigen value difference method and with the perturbation method. Results are presented in Table 69.

This table shows consistent results, both between calculation codes for the eigen value difference method, and between the 2 methods for APOLLO2 calculations. Most of the errors for thermal absorbers are very small, typically less than 1%. Slightly higher errors are observed for resonant absorbers like ^{101}Ru and ^{147}Sm, resulting from spectral shift between the infinite lattice model, where the fast component is much higher, and the critical configuration. There are also higher errors for fissile isotopes ^{235}U, ^{239}Pu and ^{241}Pu. This is due to the higher reactivity worth of the central cell in the 7x7 lattice compared to the full 3D core model. Indeed, the modification denominator term in the reactivity worth of the perturbation formulation is overestimated by the fact that the integral of production is calculated over a reduced lattice whereas it should be done on the whole core calculation. To avoid this error, we should calculate only the nominator term of the perturbation formulation as the actual modification of the denominator is negligible in experiments where the sample reactivity worth remains below a few tens of pcm.

As a consequence, the recommended calculation route for the analysis of small sample reactivity worth experiments is a reduced 2D model of the core configuration. A 7x7 lattice seems to be large enough in the current benchmark, which is close to the core configuration loaded in most of MINERVE experiments. For small reactivity worths (typically 10 pcm or lower), exact perturbation calculations are preferred to eigen value difference method calculations because the first one is not limited by convergence concerns for low reactivity worths to be evaluated. The only remaining question concerns the treatment of fissile nuclides.

For the latter, the use of reduced lattice should be questionable as the increase of the fast neutron component linked to additional fissions in the lattice involves perturbations through longer distances which necessitate increasing the model size of the core configuration. Moreover, it should be necessary to calculate only the nominator term of the perturbation formulation to avoid an overestimation of the fission term modification linked to the perturbed cell. One recommendation would be to prefer the calibration of reactivity worth by absorbing nuclides like ^{10}B, instead of fissile nuclides like ^{235}U, in order to keep a simple model for the analysis of reactivity experiments. However, this difficulty could be overcome with a larger model, typically 19x19, involving a negligible variation of the fission integral in the case of fissile nuclides.

Table 69. Evaluation of calculation bias on the reactivity worth ratio due to the use of an infinite 2D model, compared to the 3D full core model

Case	Eigen-Value Difference Method		Perturbation Method	
	PSI CASMO5 586/19G	CEA APOLLO2 281G	PSI CASMO5 586/19G	CEA APOLLO2 281G
^{95}Mo	1.9%	2.0%	0.4%	1.5%
^{99}Tc	0.0%	1.6%	-0.7%	0.4%
^{101}Ru	4.8%	2.4%	3.1%	2.7%
^{103}Rh	-0.9%	-0.5%	-0.9%	0.0%
^{109}Ag	-1.2%	-0.2%	-1.4%	-0.1%
^{133}Cs	-0.3%	-0.3%	-0.8%	0.2%
^{143}Nd	-0.1%	-0.5%	-0.3%	0.1%
^{145}Nd	1.0%	0.7%	0.3%	0.8%
^{147}Sm	4.4%	0.0%	4.0%	0.4%
^{149}Sm	-0.4%	-0.5%	-0.4%	0.1%
^{150}Sm	0.2%	0.5%	-0.1%	0.5%
^{151}Sm	-0.7%	-0.3%	-0.7%	-0.2%
^{152}Sm	-0.5%	-0.6%	-0.8%	0.1%
^{153}Eu	-0.4%	-0.5%	-0.5%	0.3%
^{155}Gd	-0.7%	0.0%	-0.7%	-0.9%
^{235}U	-5.9%	-9.2%	-5.5%	-10.0%
^{236}U	2.8%	6.8%	0.5%	3.3%
^{237}Np	-0.2%	0.7%	-0.4%	0.2%
^{238}Pu	0.1%	1.0%	0.0%	0.2%
^{239}Pu	-7.7%	-10.9%	-7.2%	-12.3%
^{240}Pu	-2.0%	0.0%	-2.0%	-1.7%
^{241}Pu	-6.7%	-8.8%	-6.3%	-8.3%
^{242}Pu	0.3%	2.6%	-0.3%	-1.4%
^{241}Am	-0.4%	0.4%	-0.5%	0.5%
^{243}Am	-0.7%	-0.3%	-0.9%	-0.2%

5. Conclusions

Several calculation methods and codes have been compared through the EGBUC Benchmark, dedicated to the analysis of small-sample reactivity experiments.

Considering the calculation of the k_{eff}, flux and reaction rates, comparisons between different codes were relevant to identify calculation bias due to the different approximations used in the deterministic approach. The treatment of the self-shielding effect due to the addition of BUC nuclide in a UO_2 fuel has been identified as the key-point of these comparisons. It was shown that the use of more than two hundred energy groups, like in the SCALE6, CASMO5 and APOLLO2 calculations is required to evaluate the reaction rate of BUC nuclides within a few percent. To reach this agreement is more problematic for resonant absorbers like ^{240}Pu or ^{101}Ru which require more energy groups or an appropriate model to account for the flux depression inside large resonances.

For the calculation of a small reactivity worth (typically 10 pcm or less) due to a BUC nuclide, it was concluded that the exact perturbation calculations should be preferred to standard eigen-value difference methods, as it is not limited by convergence concerns. Comparisons between a full 3D core model and an infinite, 2D 7x7 lattice have shown that considering ratio of reactivity worth, only small errors (typically less than 1%) are introduced by the simplified geometry model. This is especially true for neutron absorbers like fission products. This conclusion should not be generalised to all nuclides, especially for fissile actinide nuclides where the modification of the production rate integrated over the whole geometry is overestimated in the reduced geometry compared to the full core geometry. One solution should be to consider only the numerator term of the perturbation formulation to avoid the evaluation of the denominator modifications which is generally small (less than 0.1%) for reactivity-worth of less than 100 pcm on the full core geometry.

6. References

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Appendix A: Benchmark specifications

1. Geometry data

1.1 Benchmark Sub-phase I – single cell calculation

Sub-phase I of the benchmark concerns the analysis of a single fuel cell from a standard 17x17 PWR assembly with an infinite axial dimension. The main geometrical characteristics are described below (see Figure 62):

PWR cell

Fuel material	UO_2
Fuel enrichment in ^{235}U	3% w/o
Lattice square pitch	1.26 cm
Fuel radius	0.41 cm
Cladding material	Zircaloy-4
Cladding inner radius	0.418 cm
Cladding outer radius	0.475 cm
Fuel/clad inter-space material	Air
Moderator material	Light water
Material Temperature	300 K
Radial boundary conditions	Reflective

1.2 Benchmark Sub-phase II – 7x7 pattern calculation (axially infinite)

Sub-phase II of the benchmark concerns the analysis of a natural UO_2 fuel cell with an infinite axial dimension, centered in a 7x7 lattice of PWR UO_2 fuel cells (same as sub-phase I). Reflexive conditions are imposed at boundaries. The main geometrical characteristics are described below (see Figure 63):

Central cell

Fuel material	UO_2
Fuel enrichment	0.7% w/o
Lattice square pitch	1.26 cm

Fuel radius	0.41 cm
Cladding material	Zircaloy-4
Cladding inner radius	0.418 cm
Cladding outer radius	0.475 cm
Fuel/clad inter-space material	Air
Moderator material	Water
Material Temperature	300 K
Surrounding cells	PWR cell (same as Sub-phase I)
Lattice	
Number of cells	7x7
Radial boundary conditions	Reflective

1.3 Benchmark Sub-phase III – 7x7 pattern calculation (axially finite)

Sub-phase III of the benchmark concerns the analysis of a natural UO_2 fuel sample centered between aluminum cylinders, in a 7x7 lattice of PWR UO_2 fuel cells (same as sub-phase I). Leakage conditions are imposed on the lower and upper plans of the 7x7 pattern. The main geometrical characteristics are described below (see Figure 64):

Central cell	Same as Sub-phase II except:
Fuel and clad length	10 cm
Spacer material	AG-3
Spacer radius	0.475
Spacer length	27 cm
Surrounding cells	Same as Sub-phase II except:
Fuel length	64 cm
Cladding length	64 cm
Lattice	Same as Sub-phase II except:
Axial boundary conditions	Leakage (null flux)

1.4 Benchmark Sub-phase IV – 49x49 pattern calculation (axially finite)

Sub-phase IV of the benchmark concerns the analysis of a natural UO_2 fuel sample centred between aluminum cylinders, surrounded by a core built with a 49x49 lattice of PWR UO_2 fuel cells (same as Sub-phase I) with leakage conditions on each boundary (null flux). The main geometrical characteristics are described below (see Figure 65):

Central cell	Same as Sub-phase III
Surrounding cells	Same as Sub-phase III

Lattice	Same as Sub-phase III except:
Number of cells	49x49
Radial boundary conditions	Leakage (null flux)
Axial boundary conditions	Leakage (null flux)

2. Material data

2.1 Benchmark Sub-phase I – single cell calculation

Concentrations associated to the PWR fuel cell materials are given below (temperature = 300K):

PWR cell

Fuel	Atomic density (atoms/barn.cm)
(UO_2 – 3%)	U-234 6.160E-06
U-235 6.900E-04	
	U-238 2.200E-02
	O-16 4.540E-02

Fuel-clad space	Atomic density (atoms/barn.cm)
(Air)	N-14 4.000E-05
	O-16 1.000E-05

Clad	Atomic density (atoms/barn.cm)
(Zircaloy-4)	Zr 4.247E-02
	Fe 1.486E-04
	Cr 7.598E-05

Moderator	Atomic density (atoms/barn.cm)
(Light Water)	H-1 6.664E-02
	O-16 3.332E-02

Concentrations of each BUC nuclide to be added to the fuel correspond to a burn-up of 40 GWd/t, for a cooling time of one year (temperature = 300K) :

Poisons to be added to the fuel	Atomic density (atoms/barn.cm)
Case I.0	Reference case (UO_2-3%) without BUC nuclide
Case I.1	Mo-95 5.300E-05
Case I.2	Tc-99 5.200E-05
Case I.3	Ru-101 5.100E-05
Case I.4	Rh-103 3.000E-05
Case I.5	Ag-109 4.000E-06
Case I.6	Cs-133 5.600E-05
Case I.7	Nd-143 3.700E-05
Case I.8	Nd-145 3.100E-05
Case I.9	Sm-147 4.900E-06
Case I.10	Sm-149 1.780E-07
Case I.11	Sm-150 1.400E-05
Case I.12	Sm-151 6.700E-07
Case I.13	Sm-152 5.400E-06
Case I.14	Eu-153 4.800E-06
Case I.15	Gd-155 1.000E-07
Case I.16	U-235 1.800E-04 (replace ^{235}U density of UO_2)
Case I.17	U-236 1.000E-04
Case I.18	Np-237 1.500E-05
Case I.19	Pu-238 5.600E-06
Case I.20	Pu-239 1.400E-04
Case I.21	Pu-240 5.500E-05
Case I.22	Pu-241 3.600E-05
Case I.23	Pu-242 1.400E-05
Case I.24	Am-241 2.800E-06
Case I.25	Am-243 3.400E-06
Case I.26	B-10 2.700E-06 (calibration nuclide)
Case I.27	Sum of all the 25 BUC nuclides (cases 1 to 25)

2.2 Benchmark Sub-phase II – 7x7 pattern cell calculation (axially infinite)

Concentrations associated to the PWR fuel cells of the 7x7 lattice are identical to the ones of Sub-phase I. Concentrations of the central cell materials are given below (temperature = 300K):

PWR cells	Same as Sub-phase I

Central UO_2 cell

Fuel	Atomic density (atoms/barn.cm)
(UO_2 – 0.7%)	^{234}U 1.575E-06
^{235}U1.764E-04	
	^{238}U 2.375E-02
	O-16 4.785E-02
Fuel-clad space	Same as PWR cells
Clad	Same as PWR cells
Moderator	Same as PWR cells

Concentrations of the BUC nuclides to be added to the central UO_2 fuel are typical values encountered in small sample reactivity experiments, to provide reactivity effects of a few tens of pcm on the whole core (temperature = 300K). Concerning the main FP absorbers, they are about 10 times higher than FP concentrations in LWR spent fuels:

Poisons to be added to the central fuel	Atomic density (atoms/barn.cm)
Case II.0	Reference case (UO_2-0.7%) without BUC nuclide
Case II.1	Mo-95 4.300E-03
Case II.2	Tc-99 2.100E-03
Case II.3	Ru-101 6.000E-03
Case II.4	Rh-103 4.300E-04
Case II.5	Ag-109 4.400E-04
Case II.6	Cs-133 1.600E-03
Case II.7	Nd-143 4.400E-04
Case II.8	Nd-145 1.800E-03
Case II.9	Sm-147 7.400E-04
Case II.10	Sm-149 1.900E-06
Case II.11	Sm-150 1.300E-03
Case II.12	Sm-151 1.300E-05
Case II.13	Sm-152 2.100E-04
Case II.14	Eu-153 2.700E-04
Case II.15	Gd-155 3.600E-06
Case II.16	U-235 6.900E-04 (replace U-235 density of UO_2)

Case II.17	U-236 2.400E-03
Case II.18	Np-237 4.400E-04
Case II.19	Pu-238 3.300E-04
Case II.20	Pu-239 4.900E-04
Case II.21	Pu-240 7.400E-05
Case II.22	Pu-241 2.600E-04
Case II.23	Pu-242 6.300E-04
Case II.24	Am-241 1.200E-04
Case II.25	Am-243 3.500E-04
Case II.26	B-10 2.700E-05 (calibration nuclide)
Case II.27	Sum of all the 25 BUC nuclides (cases 1 to 25)

In addition to BUC nuclides, air and light water are substituted to the central UO2 fuel to test the ability to predict the 'absolute' reactivity effect of UO_2 and to take into account scattering effects in the reactivity worth.

Materials to be substituted to the central fuel			Atomic density (atoms/barn.cm)
Case II.28	Air	N-14	4.000E-05
		O-16	1.000E-05
Case II.29	Light Water	H-1	6.662E-02
		O-16	3.331E-02

2.3 Benchmark Sub-phase III – 7x7 pattern cell calculation (axially finite)

Concentrations associated to the PWR fuel cells of the 7x7 lattice are identical to the ones of Sub-phase I. Concentrations of the central cell materials are given below (temperature = 300K):

PWR cells	Same as Sub-phase I
Central UO_2 cell	
Fuel (UO_2 – 0.7%)	Same as Sub-phase II
Spacer (AG-3)	Atomic density (atoms/barn.cm) Al 5.457E-02 Mg 1.959E-03
Fuel-clad space	Same as PWR cells

Clad	Same as PWR cells
Moderator	Same as PWR cells

Concentrations of the BUC nuclides to be added to the central UO_2 fuel are typical values encountered in small sample reactivity experiments, to provide reactivity effects of a few tens of pcm on the whole core (temperature = 300K):

Poisons to be added to the central fuel	
Case III.1 to III.27	Same as Sub-phase II

In addition to BUC nuclides, air and light water are substituted to the central UO2 fuel to test the ability to predict the 'absolute' reactivity effect of UO_2 and to take into account scattering effects in the reactivity worth.

Materials to be substituted to the central fuel	
Case III.28 to III.29	Same as Sub-phase II

2.4 Benchmark Sub-phase IV – 49x49 pattern cell calculation

Concentrations associated to the PWR fuel cells of the 49x49 lattice are identical to the ones of Sub-phase I. Concentrations of the central cell materials are given below (temperature = 300K):

PWR cells	Same as Sub-phase I	
Central UO_2 cell		
Fuel (UO_2 – 0.7%)	Same as Sub-phase II	
Spacer (AG-3)	Atomic density (atoms/barn.cm)	
	Al	5.457E-02
	Mg	1.959E-03
Fuel-clad space	Same as PWR cells	
Clad	Same as PWR cells	
Moderator	Same as PWR cells	

Concentrations of the BUC nuclides to be added to the central UO_2 fuel are typical values encountered in small sample reactivity experiments, to provide reactivity effects of a few tens of pcm on the whole core (temperature = 300K):

Poisons to be added to the central fuel	
Case III.1 to III.27	Same as Sub-phase II

In addition to BUC nuclides, air and light water are substituted to the central UO2 fuel to test the ability to predict the ‘absolute’ reactivity effect of UO_2 and to take into account scattering effects in the reactivity worth.

Materials to be substituted to the central fuel	
Case III.28 to III.29	Same as Sub-phase II

Concentrations associated to the PWR fuel cells of the 7x7 lattice are identical to the ones of Sub-phase I. Concentrations of the central cell materials are given below (temperature = 300K):

3. Nuclear data file

As the main objective of this benchmark is to compare numerical methods and models from different codes to emphasize specific problems associated with the analysis of reactivity-worth measurements, calculations should be performed with the same nuclear data library. It is recommended to use the ENDF-VII.0 library for this benchmark. Otherwise, JEFF-3.1.1 should be preferred to other libraries. Any change in the library should be explained in the result file.

4. Case numbers

Each sub-phase of the benchmark can be treated independently from the others. Case numbers are defined as follows:

4.1 Benchmark sub-phase I – single cell calculation

- Case I.0 represents the nominal case without any BUC nuclide into the fuel.
- Cases I.1 to I.25 describe the addition of each BUC nuclide into the fuel following the concentrations given in §3.1.
- Case I.26 describes the addition of B-10 into the fuel as a calibration isotope for small-sample reactivity experiments with the concentration given in §3.1.
- Case I.27 describes the addition of all the 25 BUC nuclides (cases 1 to 25) into the fuel following the concentrations given in §3.1.

4.2 Benchmark sub-phase II – 7x7 pattern cell calculation (axially infinite)

- Case II.0 represents the nominal case without any BUC nuclide into the central fuel of the 7x7 pattern.
- Cases II.1 to II.25 describe the addition of BUC nuclides into the fuel following the concentrations given in §3.2.
- Case II.26 describes the addition of B-10 into the fuel as a calibration isotope for small-sample reactivity experiments with the concentration given in §3.2.
- Case II.27 describes the addition of all the 25 BUC nuclides (cases 1 to 25) into the fuel following the concentrations given in §3.2.
- Cases II.28 and II.29 describe the substitution of UO_2 fuel by respectively air and light water.

4.3 Benchmark sub-phase III – 7x7 pattern cell calculation (axially finite)

- Case III.0 represents the nominal case without any BUC nuclide into the central fuel of the 7x7 pattern.
- Cases III.1 to III.25 describe the addition of BUC nuclides into the fuel following the concentrations given in §3.3.
- Case III.26 describes the addition of B-10 into the fuel as a calibration isotope for small-sample reactivity experiments with the concentration given in §3.3.
- Case III.27 describes the addition of all the 25 BUC nuclides (cases 1 to 25) into the fuel following the concentrations given in §3.2.
- Cases II.28 and II.29 describe the substitution of UO_2 fuel by respectively air and light water.

4.4 Benchmark sub-phase IV – 49x49 pattern cell calculation

- Case IV.0 represents the nominal case without any BUC nuclide into the central fuel of the 49x49 pattern.
- Cases IV.1 to IV.25 describe the addition of BUC nuclides into the fuel following the concentrations given in §3.2.

- Case IV.26 describes the addition of B-10 into the fuel as a calibration isotope for small-sample reactivity experiments with the concentration given in §3.2.
- Case IV.27 describes the addition of all the 25 BUC nuclides (cases 1 to 25) into the fuel following the concentrations given in §3.2.
- Cases IV.28 and IV.29 describe the substitution of UO_2 fuel by respectively air and light water.

5. Parameters

Parameters of interest in this benchmark are given below. All integrations are defined over the central fuel volume (except for the denominator term in perturbation theory which is integrated over the whole geometry) and over 4π directions for solid angle. They are all normalized to the central fuel volume and to 1 source neutron (the consequence is the equality of the production rate over the whole geometry to k_{eff}). The bra-ket notation <A, B> corresponds to the integration of the product A.B in the phase space, e.g. over energy, space and direction.

- - neutron flux $F = \int\int\int \Phi(E,\vec{r},\vec{\Omega})dEd\vec{r}d\vec{\Omega}$
- - absorption rate $A = \int\int\int \Sigma_a(E,\vec{r})\Phi(E,\vec{r},\vec{\Omega})dEd\vec{r}d\vec{\Omega}$
- - scattering rate (elastic and inelastic) $S = \int\int\int \Sigma_s(E,\vec{r})\Phi(E,\vec{r},\vec{\Omega})dEd\vec{r}d\vec{\Omega}$
- - production rate $P = \int\int\int \nu\Sigma_f(E,\vec{r})\Phi(E,\vec{r},\vec{\Omega})dEd\vec{r}d\vec{\Omega}$
- - reactivity worth (EigenValue-difference method) $\rho_{EV} = \dfrac{k - k_o}{kk_o}$
- - reactivity worth (Exact Perturbation Theory) $\rho_{EPT} = \dfrac{< \Phi_o^+, \delta H\Phi >}{< \Phi_o^+, P\Phi >}$
- - reactivity worth (Taylor Expansion Method) ρ_{TEM}
- - reactivity worth (Multiple Estimation Method) ρ_{MEM} (also named “correlated-sample theory”)
- - absorption effects in the reactivity worth $\rho_A = \left.\dfrac{< \Phi_o^+, \delta H\Phi >}{< \Phi_o^+, P\Phi >}\right|_{\Sigma_a}$
- - production effects due to fission in the reactivity worth $\rho_P = \left.\dfrac{< \Phi_o^+, \delta H\Phi >}{< \Phi_o^+, P\Phi >}\right|_{\nu\Sigma_f}$
- - scattering effects (in and out contributions) in the reactivity worth $$\rho_S = \left.\frac{< \Phi_o^+, \delta H\Phi >}{< \Phi_o^+, P\Phi >}\right|_{\Sigma_s}$$

- \- leakage effects in the reactivity worth $$\rho_L = \left.\frac{<\Phi_o^+, \delta H \Phi>}{<\Phi_o^+, P\Phi>}\right|_{leakage}$$

Parameter definitions:

$\Phi(E,\vec{r},\vec{\Omega})$ is the perturbed neutron flux,

$\Phi_o^+(E,\vec{r},\vec{\Omega})$ is the unperturbed adjoint flux,

$\Sigma_a, \Sigma_c, \Sigma_f, \Sigma_s$ are respectively the macroscopic absorption, capture, fission and scattering cross-sections,

ν is the number of neutrons emitted per fission,

k and k_o are the effective multiplication factor of respectively the perturbed case and nominal case.

H is the Boltzmann operator.

An accurate definition of ρ_{MEM} and ρ_{TEM} can be founded in the following paper:

B. Morillon, *On the Use of Monte Carlo Perturbation in neutron transport problems*, Annals of Nuclear Energy, Volume 25, Issue 14, September 1998, Pages 1095-1117.

Guidances:

Each parameter is defined as "exactly" as possible. Nevertheless, the participants are invited to provide their results even in the case of simplified models, like for instance diffusion theory, anisotropy of scattering effects… Flux, Absorption Rates, Production Rates and Reactivity Worth from Eigenvalue difference method is the minimal set of results to be provided by the participants.

For users of Monte Carlo calculations, reactivity worth from Taylor Expansion of Multiple Estimate method should be given (if available).

For users of deterministic codes, reactivity worth from the Exact Perturbation Theory should be given (if available) including the decomposition between absorption cross section ($\Sigma_a = \Sigma_c + \Sigma_f$) and production cross section ($\nu\Sigma_f$). Exact Perturbation Theory, which means using unperturbated adjoint flux and perturbated flux, corresponds to the real problem related to the measurement of reactivity-worth effects and should be preferred. Nevertheless, first-order perturbation theory could be provided if perturbated flux cannot be used in the perturbation analysis.

If leakage effects could not be explicitly calculated, a simplified expression could be used within the framework of the diffusion theory, leading to:

$$\rho_L = \frac{\int\int \nabla\Phi_o^+(E,\vec{r})\delta D(E)\nabla\Phi(E,\vec{r})dEd\vec{r}}{<\Phi_o^+, P\Phi>}$$ where D is the diffusion coefficient

Another approximation could consist in the assumption of the fundamental mode (independency between energy and space) where flux and adjoint flux could be simplified like this: $\Phi(E,\vec{r},\vec{\Omega}) = f(E)J_o(\alpha r)\cos(\beta z)$. In addition, in the heterogeneous P$_1$ model, the diffusion coefficient can be expressed as $D = 1/(3\Sigma_{tr})$

6. Requested information and results

Please forward the results by electronic mail to CEA Cadarache (pierre.leconte@cea.fr) , one file per sub-phase of the benchmark. Results must be presented as follows:

Line No.	Contents	
1	*** BENCHMARK – SUB-PHASE I***	
2	Date	
3	Institute and Country	
4	Contact person	
5	E-mail address of the contact person	
6	Participants	
7	Computer Code	
8	Neutron data processing code or method	
9	Number of energy groups (NEG), supply 1 for continuous energy	
10	Upper energy Limit, in the sens from High to Low (i=1..NEG)	
11	Geometry modeling	
12	Omitted nuclides if any	
13	Numerical solver (Pij, MOC, Sn, Monte Carlo…)	
14	Employed convergence limit or statistical errors for eigenvalues	
15	* Results of Case I.0 *	
16	Multiplication Factor (for Monte Carlo: Number of histories, Deviation)	
17	- Reaction rates – (Total over all energy groups)	
18	Neutron flux	*F*
19	U-235 absorption rate	*A*
20	U-235 production rate	*P*
21	U-235 scattering rate	*S*
22	U-238 absorption rate	*A*
23	U-238 production rate	*P*
24	U-238 scattering rate	*S*
25	O-16 absorption rate	*A*
26	O-16 scattering rate	*S*
27	* Results of Case I.1 *	
28	Multiplication Factor (for Monte Carlo: Number of histories, Deviation)	
29	- Reaction rates – (Total over all energy groups)	
30	Neutron flux	*F*
31	U-235 absorption rate	*A*
32	U-235 production rate	*P*
33	U-235 scattering rate	*S*
34	U-238 absorption rate	*A*
35	U-238 production rate	*P*
36	U-238 scattering rate	*S*
37	O-16 absorption rate	*A*
38	O-16 scattering rate	*S*
39	Added isotope absorption rate	*A*
40	Added isotope production rate	*P*
41	Added isotope scattering rate	*S*

42	Total reactivity variation	ρ_{EV}
43	Total reactivity variation from Perturbation Theory	ρ_{EPT} (for a deterministic calculation) ρ_{TEM} or ρ_{MEM} (for a probabilistic calculation)
44	Reactivity variation due to absorption	ρ_A
45	Reactivity variation due to production	ρ_P
46	Reactivity variation due to scattering	ρ_S
47	Reactivity variation due to leakage	ρ_L

Lines 27 to 47 are repeated for cases 2 to 28 (or 26 for Sub-phase I).
If participants are not able to provide the full set of results, they can send a reduced file leaving blank spaces for parameters which cannot be obtained. The minimal set should contain results for:

- lines 18, 19, 20, 22, 23, 30, 31, 32, 34, 35, 39, 40, 42 for a deterministic calculation (with results in lines 43, 44 and 45 if perturbation theory is available)
- lines 18, 19, 20, 22, 23, 30, 31, 32, 34, 35, 39, 40, 42 for a probabilistic calculations (with results in lines 43, 44 and 45 if perturbation theory is available)

Participants who have the ability to perform both deterministic and probabilistic calculations should send their results in separated files.

7. Schedule

The following schedule is proposed:

- mid-September 2010: distribution of the draft specification;
- mid-December 2010: comments on available nuclides and parameters;
- end December 2010: distribution of final specification;
- end June 2011: final results on sub-phases 1 and 2 from WPNCS/BUC participants to CEA;
- September 2011: presentation of the results of sub-phases 1 and 2 at the WPNCS meeting;
- end June 2012 : final results on sub-phases 3 and 4 from WPNCS/BUC participants to CEA;
- September 2012: presentation of results of sub-phases 1 to 4 at the WPNCS meeting.

Figure 62. Sub-phase 1 – PWR cell (radial cross-section)

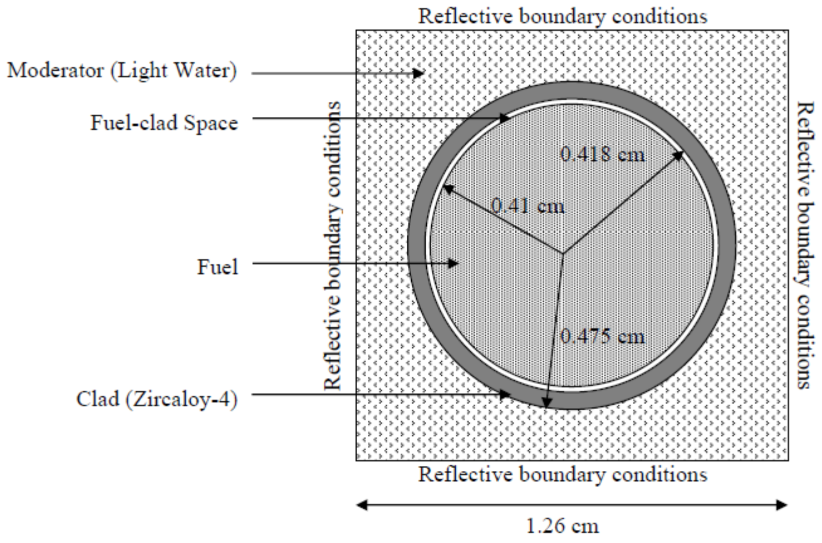


Figure 63. Sub-phase 2 – axially infinite 7x7 lattice (radial cross-section)

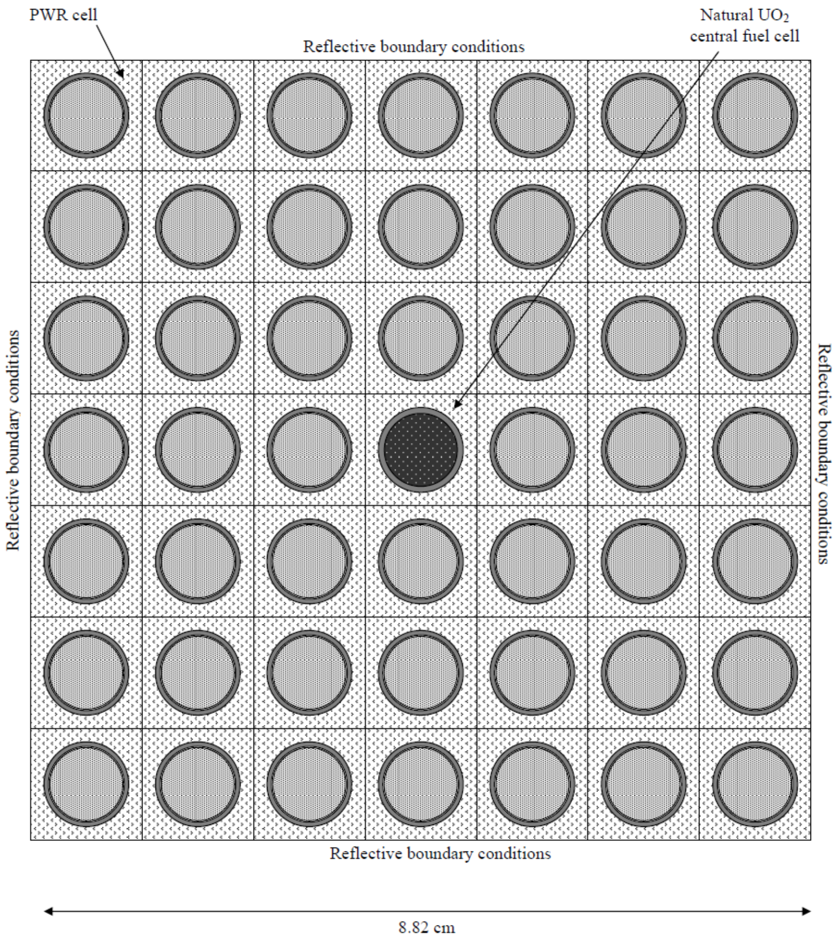


Figure 64. Sub-phase 3 – axially finite 7x7 lattice (axial cross-section, non to scale)

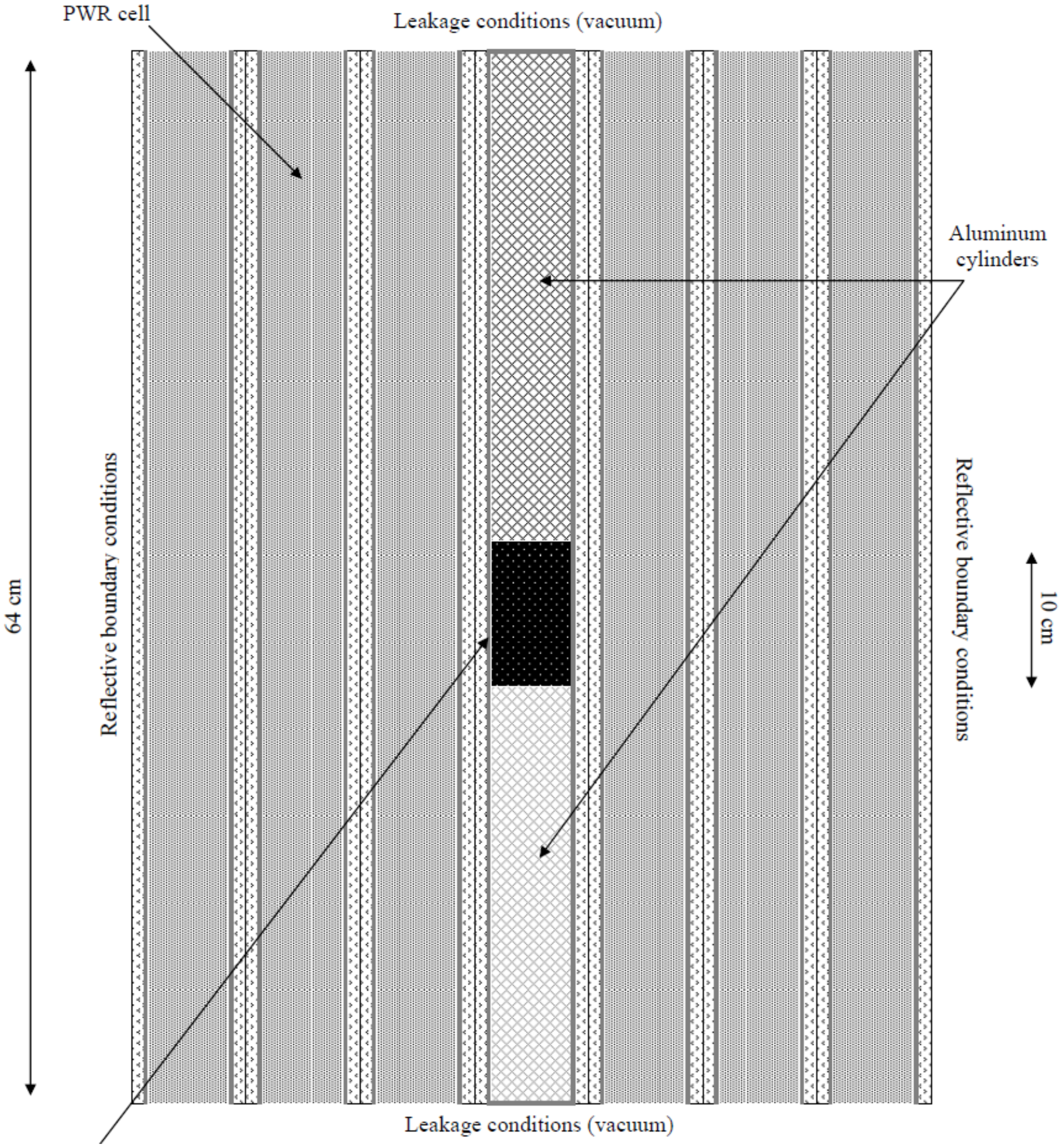
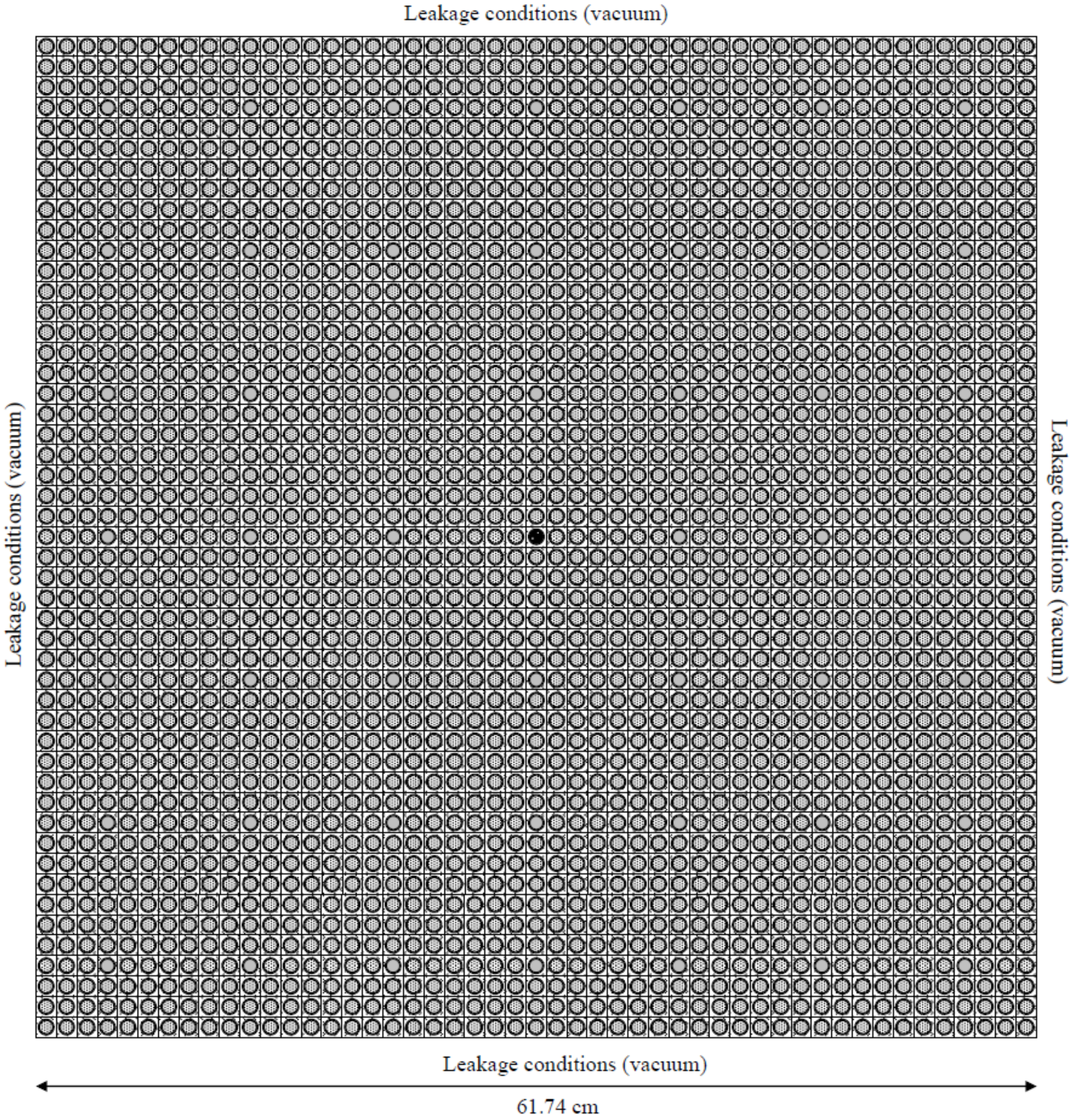


Figure 65. Sub-phase 4 – axially and radially finite 49x49 lattice (radial cross-section)



Appendix B: Participants and methods of analysis

1. VUJE a.s., Slovak Republic

Country: Slovak Republic

Organisation: Nuclear Power Plant Research Institute Trnava Inc (VUJE a.s.)

Participant: Vladimír Chrapčiak

Description of the code system: SCALE6.1.1/KENO-VI

Nuclear data library: SCALE6 ENDF/B-VII.0 238 group library (v7-238)

Calculation method: Multi-group Monte-Carlo

Other related information:

k_{eff} calculations are converged at ±30 to ±40 pcm (4 million histories per case).

2. Paul Scherrer Institute (PSI), Switzerland

Country: Switzerland

Organisation: Paul Scherrer Institute (PSI)

Participant: Peter Grimm

Description of the code system: CASMO-5M Version 1.07.01

Neutron data library: ENDF/B-VII.0 with proprietary Studsvik modifications, processed with NJOY-99.227 and NJOY-94.105

Calculation method: 19 Energy Group Method of Characteristics with 100 iterations.

Other related information:

^{99}Tc and ^{103}Rh in CASMO5 nuclear data library are from the JEFF-3.1.1 evaluations instead of ENDF/B-VII.0.

3. E. Mennerdahl Systems, Sweden

Country: Sweden

Organisation: E. Mennerdahl Systems

Participant: Dennis Mennerdahl

Description of the code system: SCALE6.1 with NEWT, XSDRN and KENO-Va.

Neutron data library: ENDF/B-VII.0, 238 group library (v7-238)

Calculation method: 1D Discrete Ordinate (S32) in XSDRN, 2D Discrete Ordinate (S32) in NEWT, Multigroup Monte-Carlo in KENO-Va.

Other related information:

k_{eff} calculations were converged at ±6 pcm (100 to 200 million histories per case).

The TSAR module is used for perturbation calculations.

4. Commissariat à l'énergie atomique et aux énergies alternatives, France

Country: France

Organisation: Commissariat à l'énergie atomique et aux énergies alternatives (CEA)

Participant: Pierre Leconte

Description of the code system: APOLLO2.8-3, TRIPOLI4.9, MCNP5.

Neutron data library: ENDF/B-VII.0, Continuous Energy for TRIPOLI4 and MCNP5, 281 energy groups for APOLLO2

Calculation method: 281 Energy Group Method of Characteristics in APOLLO2, Continuous Energy Monte-Carlo in TRIPOLI4 and MCNP5.

Other related information:

k_{eff} calculations are converged at ±1 to ±2 pcm in TRIPOLI4 and MCNP5 (5 to 8 billion histories per case).

The correlated sampling method was used in TRIPOLI4 for perturbation calculations

The CLIO module is used for perturbations calculations in APOLLO2

5. Oak Ridge National Laboratory, United States

Country: United States

Organisation: Oak Ridge National Laboratory (ORNL)

Participant: Don Mueller, Adam Caswell and Sam Morris

Description of the code system: SCALE6.1 with KENO-Va and KENO-VI.

Neutron data library: ENDF/B-VII.0, 238 group library (v7-238)

Calculation method: Multi-group Monte-Carlo

Other related information:

k_{eff} calculations are converged at ±10 pcm in forward simulations (35 million histories per case), ±50 pcm in adjoint simulations for sub-phases 1 and 2, at ±1 pcm in forward simulations (5 billion histories per case) for sub-phases 3 and 4.

The TSUNAMI and TSAR modules are used for perturbation calculations.

6. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Germany

Country: Germany

Organisation: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

Participants: Markus Wagner and Volker Hannstein

Description of the code system: DORTOREST and MCNP5

Neutron data library: ENDF/B-VII.0, 238 group library.

Calculation method: Cartesian discrete ordinate method (Sn) in DORTOREST, Continuous Energy Monte-Carlo in MCNP5

Other related information:

k_{eff} calculations are converged at ±7pcm in MCNP5 (50 million histories per case).

7. Japan

Country: Japan

Organisation: Japan Nuclear Energy Safety Organisation (JNES)

Participant: Toshihisa Yamamoto

Description of the code system: DRAGON-305F and GMVP-II

Neutron data library: ENDF/B-VII.0, 69 group library, processed by WIMSD

Calculation method: Pij (2D) forward flux calculations for DRAGON3, Multi-group Monte-Carlo for GMVP-II.

Other related information:

The pseudo-adjoint flux option is used for perturbation calculations.