WIMS-D Library Update

Final report of a coordinated research project

D. Lopez Aldama
F. Leszczynski
A. Trkov

INTERNATIONAL ATOMIC ENERGY AGENCY

L O G O

December 2003

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FINAL REPORT OF A COORDINATED RESEARCH PROJECT
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FOREWORD

WIMS-D is one of few reactor lattice codes in the public domain, and therefore is available on non-commercial terms. Recently, WIMSD-5B has been released from the OECD/NEA Data Bank, with major improvements in machine portability and a few minor corrections. This version supersedes WIMS-D/4, which was released from Winfrith for IBM machines and has been adapted for various other computer platforms in different laboratories. The main weakness of the WIMS-D package is the multi-group constants library, which is based on very old data. Relatively good performance of WIMS-D is attributed to a series of empirical adjustments to the multi-group data. However, the adjustments are not always justified on the basis of more accurate and recent experimental measurements.

Following the release of new and revised evaluated nuclear data files, it was felt that the performance of WIMS-D could be improved by updating the associated library. The WIMS-D Library Update Project (WLUP) was initiated in the early 1990s, supported by the International Atomic Energy Agency (IAEA). This project consisted of voluntary contributions from a large number of participants. Several benchmarks for testing the library were identified and analyzed, the WIMSR module of the NJOY code system was upgraded, and the author of NJOY accepted the proposed updates for the official code system distribution. A detailed parametric study was performed to investigate the effects of various data processing input options on the integral results. In addition, the data processing methods for the main reactor materials were optimized. Several partially updated libraries were produced for testing purposes.

The final stage of WLUP was organised as a coordinated research project (CRP) in order to speed up completion of the fully updated library. Research coordination meetings were held in Vienna, Austria (1999 and 2001), and Bariloche, Argentina (2000). During the last years, intensive work was performed and all of the objectives were achieved. The present publication refers to the final results of WLUP.

The final product includes:

- WIMSD-IAEA 69 group library prepared from the selected evaluated data files.
- WIMSD-IAEA 172 group library prepared from the selected evaluated data files.
- IAEA-document with detailed description.
- Data processing inputs for NJOY and WILLIE.
- Benchmark inputs models for WIMS.
- System of auxiliary codes developed under the CRP.

The IAEA officers responsible for this publication were B. Dodd, S. Basu, S. Paranjpe, and A. Trkov.

EDITORIAL NOTE

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1. INTRODUCTION AND SUMMARY OF THE PROJECT

1.1. Requirements for updated WIMS-D libraries

The WIMS-D/4 code is a freely available thermal reactor physics lattice-cell code [1.1], and is widely used in many laboratories for thermal research reactor and power reactor calculations. It should be noted that the WIMS library associated with the WIMS/D-4 package is the "1981" 69-group library generated in the United Kingdom using evaluated nuclear data from the early sixties.

The WIMSD-5B version of the code was released from Winfrith in 1998 [1.2] for distribution by the OECD/NEA Data Bank. An important improvement of this version lies in the inclusion of the "1986" WIMS-library. Halsall has summarised several compelling reasons, which justify the adjustments in the 1986 library [1.3]. These changes represent a significant improvement over the older version used by many WIMS-D/4 users, but it must be borne in mind that these libraries are essentially based on nuclear data files from the sixties. Since 1986, the WIMS nuclear data libraries had been extensively updated by the authors at Winfrith, but the improved versions are only available on commercial terms.

The objective of the WIMS-D Library Update Project (WLUP) was to provide updated working libraries compatible with the WIMS-D family of codes or equivalent lattice cell codes. This aim would enable scientists and reactor designers to make use of the most recent evaluated nuclear data files for research and power thermal reactor calculations.

1.2. History of the project

The project to update the multi-group nuclear data library in WIMS-D format grew out of discussions between the participants, lecturers and directors of the Joint IAEA/ICTP Workshop on Reactor Physics Calculations for Applications in Nuclear Technology held from 12 February to 16 March 1990. This workshop is organised in cooperation with the International Atomic Energy Agency (IAEA) and held biennially at the International Centre for Theoretical Physics (ICTP).

WLUP started officially in the early 1990s [1.4-1.6] when the idea was promoted within the International Atomic Energy Agency (referred to as the IAEA from hereon). The IAEA was responsible for the coordination, creation, formulation and execution of this project during 1990-94 and through informal contacts for 1995-96.

The planned project was in line with the relevant conclusions and recommendations of the Technical Committee Meeting on In-core Fuel Management held by the IAEA in Vienna, 4-7 December 1989, and the International Nuclear Data Committee (INDC) endorsed the continuation of the WIMS-D Library Update Project in March 1993 to provide updated multi-group constants in WIMS-D format for research and power thermal reactor applications. WLUP was also recommended by specialists from developing countries at the IAEA/ICTP Workshop (1994) and by the participants of the IAEA consultants meeting held in 1993 on the processing of nuclear data.

Andrej Trkov from the Jožef Stefan Institute coordinated the technical work and was supported by the IAEA through a research contract. Apart from the coordination activities under contract, the participants contributed all other work on a voluntary basis.

Need for a CRP on the final stage of WLUP: A Coordinated Research Project (CRP) was initiated in 1996, with the primary aim of speeding up the work to complete the updated WIMS-D Library, and to provide users with a product that would improve the quality of thermal reactor lattice calculations. A Consultants' Meeting was held at the IAEA in Vienna, from 29 to 31 July 1996 [1.8] to plan for the final stage of the IAEA WIMS-D Library Update Project. The final stage of WLUP as a Coordinated Research Project (CRP) began in December 1998, with the issue of research contracts to participants. Research Coordination Meetings were held in Vienna, Austria (1999 and 2001), and Bariloche, Argentina (2000). The present document refers to the final results of WLUP.

1.3. Summary of work

1.3.1. Work before the CRP

From the beginning, the project was divided into several stages:

Stage 1 – Benchmark Definition
Stage 2 – Data Processing Codes
Stage 3 – Major Reactor Materials Replacement
Stage 4 – Actinides and Fission Products
Stage 5 – Structural Materials
Stage 6 – Other Moderators and Missing Materials
Stage 7 – Final Benchmarking and Documentation

Stage 1: Extensive work was performed to define the benchmarks [1.5, 1.7]. This was a crucial step in the project in which more than 20 laboratories participated. The work was coordinated from the Jožef Stefan Institute in Slovenia. Five light water moderated uranium metal and uranium oxide lattices were specified, and the participants were asked to provide results for:

- Standard WIMS input: the purpose of the exercise was to identify possible differences between different versions of the WIMS-D/4 code. Note that WIMSD-5B was not available at the time.
- Optimised input: the participants were asked to prepare WIMS inputs that would model the selected benchmarks as accurately as possible.

Proposed input models were evaluated on the basis of the results from the participants. An independent study on the sensitivity of the results to different input options was performed [1.9]. This study was supported by the IAEA with a fellowship for work to be undertaken at the Jožef Stefan Institute in Slovenia in 1994. WIMS inputs to model the benchmarks were then finalised. Additional benchmarks were added later.

Stage 2: The objective was to check the definitions of the multi-group constants in the WIMS-D library and to upgrade the data processing codes. Note that at the start of the project there were no validated codes, which could process the evaluated nuclear data files to prepare a WIMS-D library. One could find a few attempts at improving the library in the literature, but these efforts could not provide a complete and reliable solution to the problem. The use of various data processing codes was investigated to analyse their capability in the preparation of multi-group constants for WIMS. Seven laboratories participated, each with their own code system. The overall conclusion was that none of the codes was adequate, and required extensive updates to meet all the requirements for the preparation of multi-group constants for the WIMS-D library. At that same time the NJOY-91 code system was released, which

included the WIMSR module. The decision was taken to adopt NJOY as the data processing system and to upgrade the WIMSR module as necessary because:

- NJOY is a "state of the art" data processing system.
- Extensions due to format changes in the evaluated nuclear data fil es are maintained by the author.
- NJOY is a widely used system - feedback from the users helps the author to quickly eliminate possible errors in the code.
- Upgrades to the existing codes were necessary anyway, therefore there was no disadvantage in adopting WIMSR of the NJOY-91 code system as a starting point to prepare the multi-group constants for the WIMS-D library.

The IAEA issued a "Special Service Agreement" to upgrade the WIMSR module of the NJOY-91 code system as necessary. Experience from the inter-comparison of the processed data resulting from Stage 2 of the project and discussions with the participants were fully taken into account. The task was completed and checked independently by participants from KAERI, Republic of Korea. Unfortunately, the next version of the NJOY-94 code was released with major changes to the WIMSR module source code, so the updates based on NJOY-91 were not compatible. After careful examination of the changes in the source code, a new set of updates of NJOY-94 for WIMSR was produced. Eventually, the author of NJOY accepted these updates, and they now form a standard part of NJOY-97 and later versions of the NJOY data processing system.

Fission product yield and decay data are not handled by the NJOY code system. In fact, there is no generally available standard code to provide the necessary information for the WIMS-D library. The AVRFPY code was developed, which has the capability to produce the appropriate fission product yields from the independent or cumulative yields and extract decay data from the ENDF files, as well as perform checking and data inter-comparisons. Also, a set of criteria can be entered on input to identify the most important fission products that need to be treated explicitly. Except for a few additions, the list of fission product nuclides defined in the "1986" WIMS-D library was found to be sufficient.

As a by-product of the data inter-comparison task the WILLIE code for WIMS-D library maintenance was developed, based on the WILIT2 code of Holubar. The code allows various operations on the data in the WIMS-D library such as material deletion, insertion, replacement, library conversion to binary and vice-versa, consistency checking, etc.

Stage 3: The objective was to replace the main reactor materials in the existing WIMS-D library for testing purposes. These materials are H bound in water, O, Al, ^{235}U and ^{238}U. After an extensive parametric study to investigate the effects of various data processing options on the integral benchmark results and extensive discussions with other participants and the author of the code, the NJOY inputs for the main reactor materials were finalized. Optimisation of the data processing options was based on numerical benchmarks available in the literature, based mainly on ENDF/B-IV data since the ENDF/B-V was restricted and ENDF/B-VI did not exist at that time.

Stage 4: The objective was to replace the actinide and fission-product cross sections, fission product yields, decay and burnup data. The IAEA sponsored work undertaken for three months at the Jožef Stefan Institute in Slovenia, in which the Burnup Credit Criticality Benchmark model for WIMS was developed, and the multi-group constants for all actinides

and fission products were replaced. Some decay constants and burnup chains were also corrected [1.10]. Preliminary results indicated a marked improvement in modelling the reactivity changes, compared to the original WIMS-D library [1.11]. Fission product yields were generated with the AVRFPY code for all major actinides, while the decay and burnup data were added to the NJOY inputs. The energy release per fission was extracted from the ENDF files for all fissile materials. A number of simplifying assumptions were made, which were later refined by more accurate procedures (see Chapter 8). This allowed the replacement or insertion of all the data in the WIMS-D library in a single processing sequence with the WILLIE code, using the "1986" version of the WIMS-D library as a starter file. The problem of the lumped fission products was not addressed in Stage 4.

Stage 5: The objective was to address the data needs for structural materials. NJOY inputs were approximately defined for some of the structural materials. Appropriate input instructions for WILLIE were defined to merge the isotopic cross sections for elements and/or mixtures. Careful checking was required, particularly for structural materials with significant resonant behaviour.

Stage 6: The objective was to process data for other moderators and to add data for missing materials to be used in different applications. NJOY inputs had to be defined, and additional materials had to be identified for special applications.

Stage 7: The objective was to complete benchmark testing and prepare the library documentation. Underlying materials on the work completed so far were available, but a concise final document needed to be produced for the end-user.

Data processing procedures: The objective was to simplify the data processing task and input file maintenance. This was achieved by producing several DOS batch procedures and auxiliary programs, developed during different stages of the project.

1.3.2. Work during the CRP

The main objective was to produce the following products:

(1) A fully updated WIMS-D library, compatible with the WIMSD-5B code.
(2) A user guide, providing necessary documentation for the updated library.

Furthermore, the updating procedure needs to be easily repeated, based on data from any evaluated data library, and therefore the following products were also required:

(3) NJOY input instructions for one or more of the major evaluated nuclear data libraries.
(4) Automatic procedures for updating the WIMS-D library under one or more computer platforms.
(5) Documentation describing the data processing methods and assumptions.

A secondary objective was to remove the restriction in the WIMS-D code, which limits the data to 69 energy groups. The library could then be reassembled with a larger number of groups.

Due to different interests, the final product of the project was not only a single recommended WIMS-D library, but also a set of recommended inputs for data processing, library updating, verification and validation. The inputs are applicable to a variety of available (and future

releases) of the basic evaluated nuclear data files and to different applications of the WIMS code. An additional by-product, of course, is a set of libraries based on the various data files.

A summary of the WLUP coordination meeting is given below:

FIRST RESEARCH COORDINATION MEETING OF THE
FINAL STAGE OF WIMS-D LIBRARY UPDATE PROJECT
15-18 February 1999, IAEA, Vienna, Austria [1.12]

Twelve participants attended the meeting. The WLUP work programme consisted of contributions from several laboratories participating in the CRP. A WLUP web page was set up, where participants of the CRP could find and exchange up-to-date information on the current status and results of the project.

An interesting and crucial discussion about various important issues took place during this meeting. The topics were:

CODES (WIMSD-5B, NJOY97);

NUCLEAR DATA PROCESSING FOR WIMS-D (evaluated-library-specific NJOY inputs, Goldstein-Cohen λ factors, flux calculator parameters, weighting flux, weighting current, self shielding, source data checking prior to processing, source data for fission product yields and decay);

UPDATED LIBRARY FEATURES (number of explicitly represented fission products, treatment of the (*n, 2n*) reaction and capture branching ratios, lumped fission products, P_1 scattering matrices, resonance integral tables for structural materials, structural materials - elements vs. compounds, new materials, fission spectrum, energy release per fission, boron in high concentration in fuel, material identification numbers);

BENCHMARKS (collection of additional benchmarks, provision of spectra with benchmark output, WIMS input options, comparison with other codes);

WIMS CODE UPGRADE (increase the number of groups, isotope-dependent fission spectra, number of resonance groups, treatment of the (*n, 2n*) reaction products and capture branching ratios, increase the limits on the number of fission products).

SECOND RESEARCH COORDINATION MEETING
FINAL STAGE OF WIMS-D LIBRARY UPDATE PROJECT
14-17 August 2000, San Carlos de Bariloche, Argentina [1.13]

The purpose of the second meeting was to discuss and assess the current status of the project, define the final goals and determine the actions required to achieve these goals. A total of ten participants attended the meeting. Although three contract holders were unable to attend because of administrative problems, presentations of their work were made on the basis of material they had supplied.

FINAL RESEARCH COORDINATION MEETING
FINAL STAGE OF WIMS-D LIBRARY UPDATE PROJECT
19-23 November 2001, IAEA, Vienna, Austria [1.14]

An intensive programme of work was successfully completed in the last year of the CRP. The minimum, medium and extra ("nice to have") objectives were achieved. All agreed actions to close the CRP were also assigned; 13 participants attended the meeting.

The IAEA invited two specialists (F. Leszczynski and D. Lopez Aldama) to the IAEA Headquarters in April 2002 to draft the documentation for the new library, and to upload the libraries, codes, benchmark results and other documentation onto the Agency web server.

Further work was performed at the Jožef Stefan Institute (sponsored by the institute) in the summer of 2002 to validate the new library for PWR design calculations. Problems were encountered and a last-minute change of the selected data for ^{235}U was found to be necessary. All benchmarks were re-analysed and corrections were made to the documentation.

Finally, the library documentation was ready for printing by December 2003, and the updated WIMSD-IAEA libraries were publicised and made available from the Agency.

1.3.3. Maintenance and promotion of the final product

The official generic name of the library is WIMSD-IAEA.

The library exists in two group structures: WIMSD-IAEA-69 in 69 energy groups and WIMSD-IAEA-172 in 172 energy groups.

The IAEA packages and distributes the CRP final product to users in Member States – includes libraries and documentation.

The IAEA collects feedback from users and provides for future updates of the libraries to fulfil the requirements of users or when new evaluated data become available.

1.4. Overview of the present publication

This technical report summarises the results of the CRP and presents the libraries produced for general use. Both the contents and details of production of each type of data included on the WIMSD-libraries are described in Chapters 2-11.

Details of WIMSD-5B extensions made during the CRP are included in Chapter 12. These extensions are mainly related to the increased number of materials, resonant nuclides and the use of the new 172-group WIMD-libraries generated by the CRP.

A summary of the evaluated nuclear data processing options is given in Chapter 13, with a description of the data processing sequence using the NJOY code system, further data processing procedures and special issues.

Chapter 14 contains the types, organization, index and results of the benchmarks implemented for testing the new WIMSD-libraries. Conclusions from test cases are also given.

General conclusions of all the work performed on the project and suggestions for future activities on this subject are given in Chapter 15.

Details of the programs used to display predicted effective multiplication factors and spectral indices of criticality benchmarks are included in Appendix I. Appendix II is an index of all benchmark cases with a summary of the main parameters. A list of WIMSD-IAEA library materials tested with the benchmarks is included in Appendix III, while detailed descriptions of each benchmark are given in Appendix IV (standard benchmarks) and Appendix V (supplementary benchmarks). Finally, Appendix VI includes tabulated summary results of all standard and supplementary benchmarks from WIMSD-5B calculations with all WIMS-D libraries.

The WIMSD-IAEA and other libraries generated by WLUP and all materials related to the generation of libraries and benchmarks are available from the Web server at http://www-nds.iaea.org/wimsd/. A CD-ROM with all this material and additional valuable information is also available upon request (contents of this CD-ROM are listed at the end of this document).

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[1.14] Final Research Co-ordination Meeting, Final Stage of WIMS-D Library Update Project, Summary Report, IAEA, Vienna, Austria, 19-23 November 2001.

2. MAIN PARAMETERS OF THE LIBRARY

Definitions of the constants included in the WIMS-D library are given here. Details of the format of the library can be found elsewhere (e.g., Ref. [2.1] or in the comments of the FORTRAN source of the WILLIE program included on WLUP CD-ROM). Data processing methods implemented in the NJOY code system and the associated WIMSR module are described in Ref. [2.2].

When necessary in the WIMS-D libraries, the cross sections in the thermal energy range are tabulated at several temperatures. At higher energies the cross sections and other parameters are given at a single temperature, except for the resonance integrals which can be tabulated at several temperatures and dilutions for the resonant nuclides. Contrary to the approach in the original WIMS-D libraries, where all cross sections (apart from resonance integrals) are defined at infinite dilution the cross-sections in the WIMSD-IAEA libraries are all given at some reference dilution most typically used for that material in practical applications (see parameter XS0 in Table 6.2.1). Details of the resonance treatment and weighting spectra are given in Chapter 3 and Chapter 10, respectively.

2.1. Transport cross section

The transport cross section for an energy group *g* is:

$$\sigma_{tr,g} = \sigma_{t,g} - \sigma_{s1,g} \tag{2.1}$$

where

$\sigma_{t,g}$ is the total cross section (sum of absorption and scattering cross sections), and

$\sigma_{s1,g}$ is the transport correction [2.2, 2.3], namely the P_1 scattering component.

A conventional "row-transport correction" is used for thermal groups *g*:

$$\sigma_{s1,g} = \sum_{h=1}^{NG} \sigma_{s1,g\to h} \tag{2.2}$$

while "column-transport correction" is applied for epithermal groups *g*:

$$\sigma_{s1,g} = \frac{\sum_{h=1}^{NG} \sigma_{s1,h\to g}\, J_h}{\sum_{h=1}^{NG} J_h} \tag{2.3}$$

where

NG is the total number of energy groups,

$\sigma_{s1,i\to j}$ is the P_1 scattering matrix element for scattering from group *i* into *j*, and

J_i is the neutron current in group *i* (see Chapter 10).

2.2. Absorption cross section

The absorption cross section for an energy group *g* is modified to preserve neutron balance by correcting for the (*n ,2n*) and (*n, 3n*) reactions, which are not explicitly included in WIMS-D

libraries [2.3]:

$$\sigma'_{a,g} = \sigma_{a,g} - \sigma_{(n,2n),g} - 2\sigma_{(n,3n),g} \tag{2.4}$$

2.3. P_1 transport-corrected p_0 scattering matrix

The scattering cross section for an energy group *g* is modified to include the (*n, 2n*) and (*n, 3n*) reactions, consistent with the definition of the absorption cross section given above. The general expression for P_0-scattering matrix terms is [2.3]:

$$\sigma'_{s0,g\to h} = \sigma_{s0,g\to h} + 2\sigma_{(n,2n),g\to h} + 3\sigma_{(n,3n),g\to h} \tag{2.5}$$

If the P_1-scattering matrix is not given explicitly for a particular material, the transport correction is included in the self-scattering term (see Section 2.1):

$$\sigma'_{s0,g\to g} = \sigma_{s0,g\to g} + 2\sigma_{(n,2n),g\to g} + 3\sigma_{(n,3n),g\to g} - \sigma_{s1,g} \tag{2.6}$$

2.4. Other parameters

The following parameters are also needed to update a WIMS-D formatted library. They are discussed in the chapters that follow:

- Resonance integrals (see Chapter 3).
- Potential cross section σ_p (see Chapter 6).
- Slowing-down power per unit lethargy ($\xi\sigma_s/\tau$), where ξ is the average lethargy decrement per collision, σ_s is the scattering cross section at infinite dilution and τ is the lethargy width of the group.
- Fission neutron production cross section $(\nu\sigma_f)_g$.
- Fission cross section $\sigma_{f,g}$.
- Fission product yields, burnup and decay chain data (see Chapters 4-6, 8).
- Fission spectrum (see Chapter 10).
- P_1-scattering matrix $\sigma_{s1,g\to h}$ (see Chapter 6).

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3. RESONANCE TREATMENT AND GOLDSTEIN-COHEN λ FACTORS

The resonance treatment in the WIMS-D family of codes is based on the intermediate resonance approximation and the equivalence theorems [3.1, 3.2].

Resonance integrals are calculated by solving the slowing-down transport equation for a homogeneous mixture of the resonant absorber with non-resonant nuclides. The resulting neutron spectrum is used to calculate the multigroup cross sections and the corresponding resonance integrals in a consistent way in the formulation of the WIMS-D formatted library.

Assuming that the intermediate resonance approximation is valid for all non-resonant nuclides, the resonance integrals can be tabulated as a function of temperature and a lumped parameter σ_o called the Bondarenko cross section (in units of barns per resonant atom). The tabulations can be used to obtain the resonance integral of the resonant absorber in any mixture by interpolating over temperature and σ_o values. Applying the equivalence theorems, the resonance integrals of a heterogeneous system can also be computed from a set of calculated resonance integrals for a homogeneous mixture.

σ_o depends on the formalism used to approximate the scattering kernel of the non-resonant materials. In the case of the intermediate resonance approximation (IR), the Goldstein-Cohen intermediate resonance λ factors are needed to obtain the σ_o value of the actual system. The background cross section σ_b is used instead of the Bondarenko cross section σ_o as the independent variable for resonance integral tabulations in WIMS-D formatted libraries. The λ factor of the resonant absorber is also needed in order to compute σ_b from the corresponding σ_o. As a consequence of this feature, the resonance tabulations and the λ values are inter-related in a WIMS-D library.

A brief description of the resonance treatment outlined above is presented in Section 3.1. Section 3.2 gives a summary of the main features and methods of the NRSC code system, which was developed to estimate the Goldstein-Cohen λ factors following the WIMS-D conventions. λ values included on the WIMS-D formatted libraries are given in Section 3.3 as a function of atomic number.

3.1. Brief description of resonance treatment

A detailed description of the resonance and slowing down theory can be found elsewhere [3.1, 3.2], but a brief summary is given below for convenience and a better understanding of the methods used for generating the WIMS-D formatted library resonance data.

3.1.1.Resonance in a homogeneous medium

If elastic scattering can be considered isotropic in the centre of mass system, the slowing down equation in the resonance range for a homogeneous mixture of nuclides in an infinite medium can be defined as:

$$\Sigma\Phi = \sum_i K_i(\Sigma_s^i \Phi)\,, \tag{3.1}$$

where, Φ is the neutron flux as a function of energy, Σ is the macroscopic total cross section of the mixture, and Σ_s^i is the macroscopic scattering cross section of the i-th nuclide in the mixture. The slowing down operator K_i for the i-th nuclide is defined as:

$$K_i(\Sigma_s^i\Phi) = \frac{1}{1-\alpha_i}\int_E^{E/\alpha_i}\Sigma_s^i(E')\Phi(E')\frac{dE'}{E'}\ , \tag{3.2}$$

where

$$\alpha_i = \left(\frac{A_i-1}{A_i+1}\right)^2 \tag{3.3}$$

is the well known slowing down parameter of nuclide i with mass A_i given in neutron mass units, and the term $(1-\alpha_i)$ represents the maximum fractional energy loss by a neutron per collision with nuclide i.

Equation (3.1) can be further simplified by introducing three assumptions that are generally valid in the resonance range for reactor lattices. The first assumption states that the resonances of the mixture are well separated and that the flux can be approximated by a smooth function $\Psi(E)$ between resonances, which is proportional to $1/E$ in the resonance range. Only one resonant isotope is assumed in the mixture with a constant potential scattering cross section σ_p^r, a resonance scattering cross-section $\sigma_{s,r}^r(E)$ and a resonance absorption cross section $\sigma_a^r(E)$. Finally, the non-resonant nuclides are considered to have a negligible absorption cross section and a constant potential scattering cross section σ_p^i. Under these conditions equation (3.1) can be written as:

$$\left(\sigma_t^r + \sum_{i\neq r}\sigma_0^i\right)\Phi = K_r(\sigma_s^r\Phi) + \sum_{i\neq r}K_i(\sigma_o^i\Phi) \tag{3.4}$$

where

$\sigma_s^r = \sigma_{s,r}^r(E) + \sigma_p^r$ is the microscopic scattering cross section of the resonant nuclide,

$\sigma_t^r = \sigma_s^r(E) + \sigma_a^r(E)$ is the microscopic total cross section of the resonant nuclide,

$\sigma_o^i = \frac{N_i}{N_r}\sigma_p^i$ is the potential scattering cross section of the i-th nuclide per resonant atom,

and N_i and N_r are the nuclear densities of the nuclide i and the resonant isotope, respectively.

Equation (3.4) can be solved numerically for any mixture of isotopes, but if the intermediate resonance approximation is applied for all non-resonant nuclides [3.2], the resulting equation for a given resonant nuclide depends only on the temperature (implicit in the cross sections) and on the lumped Bondarenko σ_o parameter. The IR approximation simplifies the slowing down kernel K_i to the expression:

$$K_i(\sigma_0^i\Phi) = \lambda_i\sigma_0^i\Psi + (1-\lambda_i)\sigma_0^i\Phi \tag{3.5}$$

where λ_i is the Goldstein-Cohen intermediate resonance factor of nuclide i, and the other symbols have the same meaning as before. Note that $\lambda_I = 1$ for the narrow resonance approximation (NR), and $\lambda_I = 0$ for the wide resonance or infinite mass approximation (WR, IA). After introducing the IR approximation, equation (3.4) becomes:

$$\left(\sigma_t^r + \sigma_0\right)\Phi = K_r(\sigma_s^r\Phi) + \sigma_0\Psi \tag{3.6}$$

where

$$\sigma_0 = \sum_{i \neq r} \lambda_i \sigma_0^i = \sum_{i \neq r} \frac{N_i}{N_r} \lambda_i \sigma_p^i \tag{3.7}$$

If the IR approximation is also valid for the resonant isotope, the resonance flux can be written as:

$$\Phi = \frac{\lambda_r \sigma_p^r + \sigma_0}{\sigma_a^r + \lambda_r \sigma_{s,r}^r + \lambda_r \sigma_p^r + \sigma_0} \Psi \tag{3.8}$$

The background cross-section σ_b can be defined by:

$$\sigma_b = \lambda_r \sigma_p^r + \sigma_0 \tag{3.9}$$

and equation (3.8) becomes:

$$\Phi = \frac{\sigma_b}{\sigma_a^r + \lambda_r \sigma_{s,r}^r + \sigma_b} \Psi \tag{3.10}$$

Note that if NR approximation is used for all nuclides, the well-known NR expression for the flux is obtained:

$$\Phi = \frac{\sigma_p^r + \sigma_0}{\sigma_t^r + \sigma_0} \Psi \tag{3.11}$$

where σ_o is calculated with $\lambda_I = 1$ for all isotopes. Thus, from equation (3.11),the flux can be seen to be inversely proportional to the total cross section of the resonant nuclide.

Equation (3.6) was solved in the low energy range for all resonant nuclides using the flux calculator option of the GROUPR module of the NJOY code system. At higher energies the NR approximation was applied. The multigroup cross sections and resonance integrals were computed for different temperatures and σ_o values. An important point to note is that the background cross-section σ_b is used instead of the Bondarenko σ_o to tabulate the resonance integrals in the WIMS-D code.

3.1.2. Resonances in a heterogeneous medium

The solution of the slowing-down equation in an heterogeneous medium is a more complicated problem than for an homogeneous medium. However, under some simplifying assumptions the equivalence theorems are valid and the resonance integrals of a heterogeneous system can be obtained from a set of homogenously-calculated resonance integrals. This feature is used in most of the lattice codes including WIMS-D. A detailed derivation of the equivalence theorems will not be presented here and can be found elsewhere [3.2], but the main assumptions and the final expressions are given below for completeness.

Applying the collision probability method in a two region (fuel/moderator) pin cell [3.2] under the same three assumptions as before, and considering the flat flux approximation as well as the one term rational expansion of the escape probability from the fuel to be valid, the slowing-down equation in the fuel can be written as:

$$\left(\Sigma_t^f + \Sigma_e\right)\Phi^f = \sum_{i\in f} K_i(\Sigma_s^i \Phi^f) + \frac{\Sigma_e}{\Sigma_t^m}\sum_{i\in m} K_i(\Sigma_s^i \Phi^m) \tag{3.12}$$

where Σ_t^k, Σ_s^k are the macroscopic total and scattering cross section respectively in the region k, Σ_e denotes the escape cross section, and the superscripts f and m are used for the fuel and moderator respectively. All other parameters have the same meaning as before.

Two further assumptions have to be made in order to obtain the equivalence relationship. The first assumption is that the IR approximation is valid for all non-resonant isotopes in the fuel. The second one is applied to the moderator region, where the IR approximation is also assumed to be valid for all nuclides, but neglecting the term proportional to $(1 - \lambda_i)\Phi^m$ (implying that the quantity $\sum_{i\in m}\lambda_i\Sigma_p^i$ should be used for the moderator potential cross section).

Equation (3.12) then becomes:

$$\left(\sigma_t^r + \sigma_0\right)\Phi_f = K_r(\sigma_s^r \Phi_f) + \sigma_0 \Psi \tag{3.13}$$

where

$$\sigma_0 = \sigma_e + \sum_{i\neq r, i\in f}\lambda_i\sigma_0^i = \sigma_e + \sum_{i\neq r, i\in f}\frac{N_i}{N_r}\lambda_i\sigma_p^i \tag{3.14}$$

$$\sigma_e = \frac{\Sigma_e}{N_r} \tag{3.15}$$

are the heterogeneous Bondarenko (σ_o) and the microscopic escape cross section (σ_e), respectively.

An equivalence theorem can be deduced by comparing equations (3.6) and (3.13). The neutron spectrum in the fuel region of a heterogeneous medium is the same as that in a homogeneous medium, with the potential scattering cross section augmented by σ_e.

Similar equivalence theorems can be deduced for multiregion problems. The escape cross section σ_e takes into account the heterogeneity of the medium, and depends on the geometry. Bell and Dancoff factors for the lattice are introduced and other approximations are used to calculate the escape probability from the fuel, but their derivation and justification are beyond the scope of the present review.

The resonance integrals of a heterogeneous medium can be obtained in a WIMS-D code by a linear combination of homogeneously calculated resonance integrals [3.3].

3.1.3. Resonance cross sections and resonance integrals

The relation between the self-shielded cross sections and the resonance integrals is given by:

$$\sigma_x(T,\sigma_b) = \frac{I_x(T,\sigma_b)}{1 - \frac{I_a(T,\sigma_b)}{\sigma_b} - \frac{\lambda I_{er}(T,\sigma_b)}{\sigma_b}} \approx \frac{I_x(T,\sigma_b)}{1 - \frac{I_a(T,\sigma_b)}{\sigma_b}} \tag{3.16}$$

where σ_x is the self-shielded cross section for reaction type x, and I_x is the corresponding resonance integral; subscript a stands for absorption and er for resonance scattering.

The approximate expression is used in WIMS-D, which is valid only if the resonance contribution to elastic scattering is negligible. Although this criterion is only true for predominantly absorbing resonances and wide resonances ($\lambda \approx 0$), consistency with WIMS-D is achieved by calculating the resonance integrals for WIMS-D from the self-shielded cross sections by the equation:

$$I_x(T,\sigma_b) = \frac{\sigma_x(T,\sigma_b)\cdot\sigma_b}{\sigma_a(T,\sigma_b)+\sigma_b} \tag{3.17}$$

which is exactly the inverse formula of the approximate expression in equation (3.16). This can be done because the resonance integrals in WIMS-D are not directly used, except to calculate the corresponding self shielded cross sections.

Only the absorption and the fission ($\nu\sigma_f$) resonance integrals are supplied in a WIMS-D formatted library. The self-shielded removal cross section is corrected within the WIMS-D code by the self-shielded absorption cross sections.

3.2. Method of obtaining the Goldstein-Cohen λ factors

As mentioned above, the Goldtein-Cohen λ factors are part of the library data. They are needed for the interpolation of data in the resonance tables and to correct the removal cross section in the resonance range. The method used to compute the λ factors follows the work of Aldous [3.4]. As defined in equation (3.6) for a given resonant isotope, the shape of the resonance flux will be the same if the background cross section σ_o (or σ_b) is the same.

A good approximation for hydrogen is to take $\lambda = 1$, because all resonances can be considered narrow compared to the maximum energy loss from scattering on hydrogen atoms. λ values can be obtained by comparing the exact solution of equation (3.4) for a mixture of the main resonant isotope ^{238}U and pure hydrogen with the corresponding equation in which hydrogen has been replaced by another nuclide. These λ values are commonly called “hydrogen equivalent” λ values.

Assume that a tabulation of σ_a and I_a is available as a function of σ_b for a mixture of the main resonance absorber and hydrogen (H), and solve equation (3.4) for a mixture in which hydrogen is replaced by a nuclide of interest (X). Values of $I_a(\sigma_b(H+X))$ can be calculated in the resonance range and converted to the corresponding self-shielded cross section $\sigma_a(\sigma_b(H+X))$. If the IR approximation is valid, equations (3.6) and (3.7) should also be valid and according to the equivalence theorem both mixtures should have the same resonance absorption on the assumption that:

$$\sigma_b(H+X) = \sigma_b(H) \tag{3.18}$$

where H and X represent the hydrogen and the extra nuclide, respectively.

Adopting this expression and $\lambda_H = 1$ gives the following:

$$\lambda_x = \frac{\sigma_b(H) - \left(\frac{N_H}{N_r}\right)_{H+x} \sigma_{pH} - \lambda_r \sigma_{pr}}{\left(\frac{N_x}{N_r}\right)_{H+x} \sigma_{px}} \tag{3.19}$$

or by taking into account the relationship between σ_b and σ_o:

$$\lambda_x = \frac{\sigma_0(H) - \left(\frac{N_H}{N_r}\right)_{H+x} \sigma_{pH}}{\left(\frac{N_x}{N_r}\right)_{H+x} \sigma_{px}} \tag{3.20}$$

The last expression shows for a given resonant isotope that the values of λ depend on the relative concentration of hydrogen and the extra nuclide with respect to the main resonant nuclide. Relative concentrations should be selected according to the typical concentrations in the lattice cell. However, there is no dependence on λ_r, because the contribution of the resonant isotope cancels.

Additionally, λ values depend on the energy, therefore equations (3.19) and (3.20) should be applied group by group. However, in practice the resonance absorption over all resonance groups can be collapsed into one group, and the resulting average λ value can be used for all groups. This approximation has the advantage that the one group λ value is less dependent on the main resonant nuclide cross section shapes than the energy-dependent λ values.

3.3. Final λ factor values for WIMS-D libraries

The method outlined in Section 3.2 to estimate λ values for different elements in typical lattices has been implemented in the RMET21 and ALAMBDA programs of the NRSC system [3.5, 3.6, 3.7]. Computation of σ_a in several mixtures of the main resonance absorber ^{238}U, hydrogen and different isotopes X were obtained in different runs of NRSC/RMET21. λ values were calculated with the NRSC/ALAMBDA program and using the results of the NRSC/RMET21 calculations.

Selected isotopes for which λ factors were calculated explicitly are ^{16}O, ^{27}Al, ^{56}Fe and ^{91}Zr. An estimate of λ for ^{238}U was derived from an additional calculation in which isotope X was a fictitious nuclide with A=238 and the potential cross section of ^{238}U.

Hydrogen atom densities in these calculations corresponded to typical heterogeneous PWR cells. Values of the relative atom densities N_i/N_U for the selected nuclides were taken as follows:

- A typical value of the N_O/N_U ratio in UO_2 fuel was selected for oxygen.
- Selected values for Al, Fe and Zr correspond to cladding made from these elements, with the atom density ratios calculated from the following formula:

$$\frac{N_i}{N_u} = \frac{N_i^* \cdot Vclad}{N_u^* \cdot Vfuel} \tag{3.21}$$

where N_i^* is the atom density in the cladding for nuclide i, N_u^* is the atom density of ^{238}U

in the fuel, and V_{clad} and V_{fuel} are the cladding and fuel volumes, respectively.

- The selected ratio N_H / N_U for all the cases was 1.219, and corresponds to a typical light water reactor cell.

Adopted values of N_i/N_U are shown in Table 3.1, while one-group λ factors are listed in Table 3.2. Figure 3.1 shows a plot of the values from Table 3.2 as a function of atomic weight. The resulting curve has been drawn through the points by adopting a cubic spline interpolation. One-group λ factors for all nuclides can be taken from this graph. Final recommended λ factors for all isotopes are given in Table 3.3, as included in the WIMS libraries, and the NRSC system is included on the WLUP CD-ROM.

TABLE 3.1. N_i / N_U FOR λ CALCULATIONS

Nuclide	N_i/N_U
O-16	2.0
Al-27	0.345
Fe-56	0.9
Zr-91	0.5

TABLE 3.2. ONE-GROUP λ FACTORS FOR H, O, Al, Fe, Zr AND ^{238}U

Nuclide	**One-Group λ**
H-1	1.000
O-16	0.957
Al-27	0.809
Fe-56	0.524
Zr-91	0.372
U-238	0.206

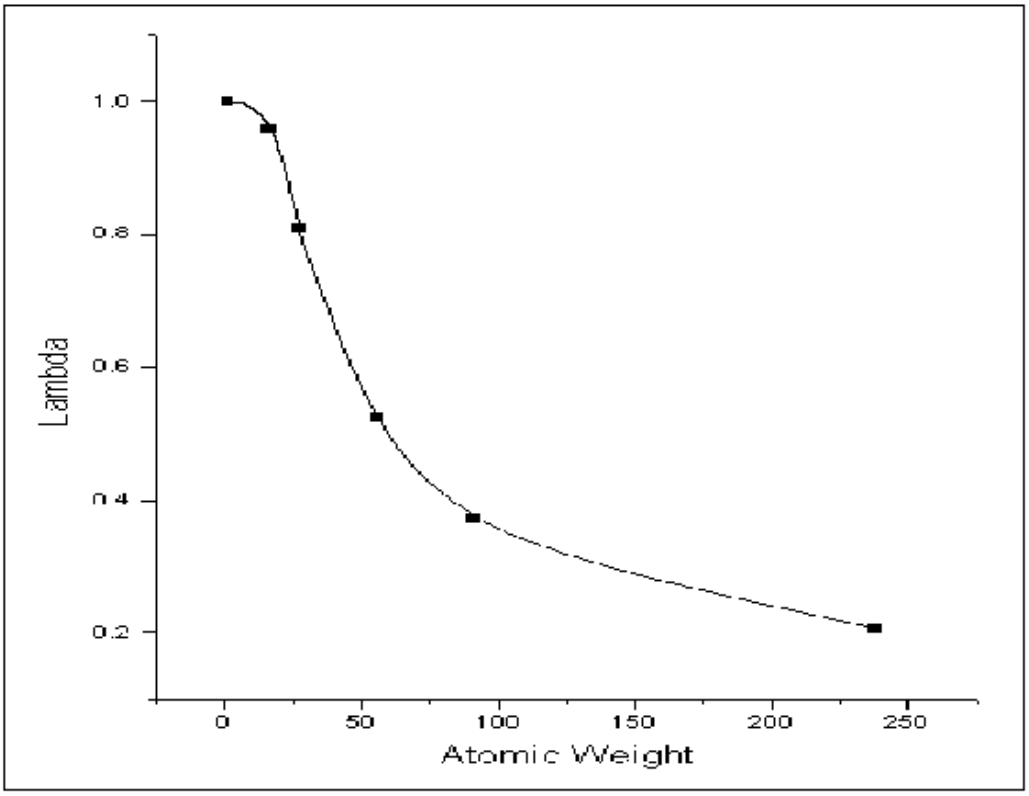

FIG. 3.1. One-group λ plotted against atomic weight.

TABLE 3.3. FINAL ESTIMATES OF λ FACTORS AS A FUNCTION OF MASS NUMBER (A)

A	λ	A	λ	A	λ	A	λ
1-2	1.00	31	0.75	52	0.55	94-96	0.36
3-6	0.99	32	0.74	53,54	0.54	97-100	0.35
7-11	0.98	33	0.72	55	0.53	101-103	0.34
12-14	0.97	34	0.71	56,57	0.52	104-107	0.33
15,16	0.96	35	0.70	58,59	0.51	108-111	0.32
17	0.95	36	0.69	60,61	0.50	112-116	0.31
18	0.94	37	0.68	62	0.49	117-120	0.30
19	0.93	38	0.67	63,64	0.48	121-125	0.29
20	0.91	39	0.66	65,66	0.47	126-131	0.28
21	0.90	40	0.65	67-69	0.46	132-137	0.27
22	0.89	41	0.64	70,71	0.45	138-144	0.26
23	0.87	42	0.63	72,73	0.44	145-152	0.25
24	0.85	43	0.62	74,75	0.43	153-161	0.24
25	0.84	44	0.61	76-78	0.42	162-172	0.23
26	0.82	45	0.60	79-81	0.41	173-188	0.22
27	0.81	46,47	0.59	82-84	0.40	189-214	0.21
28	0.79	48	0.58	85,86	0.39	215-	0.20
29	0.78	49	0.57	87-90	0.38		
30	0.76	50,51	0.56	91-93	0.37		

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4. SELECTION OF EXPLICITLY REPRESENTED AND LUMPED FISSION PRODUCT MATERIALS

The nuclear fission process in the fuel of a nuclear reactor core causes the accumulation of fission products. Some of them have a significant impact on the nuclear properties of the core and must be treated explicitly. Although individually unimportant, others have a cumulative effect that cannot be neglected; usually they are lumped together and called a **pseudo fission product**.

A set of criteria was developed to select the fission product candidates for the WIMS-D Library Update Project (WLUP). As a consequence of the implementation of these criteria, 56 nuclides were explicitly represented in the library and 79 nuclides were lumped into a pseudo fission product. The following sub-sections describe the selection criteria, the evaluated nuclear data processing options and the main procedures applied in the preparation of the WIMS-D fission product data.

4.1. Selection criteria

Based on the analytical equations that govern the buildup and decay of the fission products, a set of quantitative criteria was developed. The detailed derivation of the expression is described in ref. [4.1] in which the following definitions and criteria are given:

- **Short-lived nuclides** are those which satisfy the condition:

  $\sigma_p H_p < 1.16\times10^{19} \cdot \varepsilon_1 \ln 2 / \Phi$

  where σ_p is the capture cross section [*barns*] and H_p is the half-life [*days*]. The scaling constant 1.16×10^{19} is used to convert $[cm^2 \cdot s]$ to *[barn days]*. Parameter ε_1 represents the fraction of neutrons removed by absorption, and Φ is the flux level. These nuclides can be lumped with their daughter products.

- **Nearly stable nuclides** are those which satisfy the condition:

  $\sigma_p H_p > 1.16\times10^{19} \cdot \ln 2 / (\varepsilon_2 \Phi)$

  where ε_2 represents the fraction by which radioactive decay affects the equilibrium concentration. The decay products of such nuclides can be ignored.

- **Highly absorbing fission products** are those which satisfy the criterion:

  $\gamma_p \sigma_p > 1.16\times10^{19} \cdot 2\ \varepsilon_3 / (\Phi T)$

  where γ_p is the fission yield, T is the fuel residence time in the core, and ε_3 represents the fraction of the capture reactions compared to the fission reactions during fuel irradiation. All nuclides that satisfy this criterion must be treated explicitly.

- **Highly absorbing capture products** are those which satisfy the criterion:

  $\gamma_p \sigma_p \sigma_c > [1.16\times10^{19}]^2 \cdot 6\ \varepsilon_4 / (\Phi T)^2$

where σ_c is the capture product absorption cross section, and the other parameters are defined as before. These nuclides must also be treated explicitly.

AVRFPY code [4.1] was developed so that the above criteria could be applied. The fission product yield and evaluated nuclear decay data files are processed on the basis of the ENDF-6 conventions. Cross-section data are extracted from an INTER output file [4.2] and the criteria defined above are taken into account. The code produces effective fission product cumulative yields for the selected fission products, subtracting the yields of precursors to avoid double counting.

Assuming:

- Φ of the order 10^{13} $n.cm^{-2}s^{-1}$
- $\varepsilon_1=\varepsilon_2=0.002$, $\varepsilon_3=\varepsilon_4=0.0005$
- $T=1000$ days

the specified criteria reduce to:

- $\sigma_p H_p < 1600$ [*barn.days*]
- $\sigma_p H_p > 4 \cdot 10^8$ [*barn.days*]
- $\gamma_p \sigma_p > 0.12$ [*barns*]
- $\gamma_p \sigma_p \sigma_c > 400$ [$barns^2$]

Additionally, a qualitative criterion was also considered: if a nuclide is a candidate burnable poison that can be mixed with the fuel and could also be produced by fission, that nuclide is treated as an explicitly-represented fission product.

A total of 56 fission products were identified as important from the above conditions for the major actinides; they are explicitly represented in the library and are listed in Table 4.1. A full list of candidate fission products was obtained by relaxing the condition for highly absorbing fission products to $\gamma_p \sigma_p > 10^{-8}$ [*barns*], $\varepsilon_3=4 \times 10^{-12}$: altogether 135 nuclides were identified. Excluding the 56 explicitly represented nuclides, 79 were lumped into the "pseudo fission product", as shown in Table 4.2. All of these nuclides were found to be stable or nearly stable, therefore there was no need to define a decaying pseudo fission product separately.

TABLE 4.1. EXPLICITLY REPRESENTED FISSION PRODUCTS

No.	Nuclide	WIMS ID	Reso. Table	No. Temp.	Description
1	36-Kr- 83	4083	0	1	Krypton-83
2	42-Mo- 95	4095	0	1	Molybdenum-95
3	43-Tc- 99	4099	1	3	Technetium-99
4	44-Ru-101	4101	0	1	Ruthenium-101
5	44-Ru-103	5103	0	1	Ruthenium-103
6	44-Ru-106	4106	0	1	Ruthenium-106
7	45-Rh-103	4103	0	1	Rhodium-103
8	45-Rh-105	4105	0	1	Rhodium-105
9	46-Pd-105	5105	0	1	Palladium-105
10	46-Pd-107	4107	0	1	Palladium-107
11	46-Pd-108	4108	0	1	Palladium-108
12	47-Ag-109	4109	1	3	Silver-109
13	48-Cd-113	4113	0	1	Cadmium-113
14	49-In-115	4115	0	1	Indium-115
15	51-Sb-125	4125	0	1	Antimony-125
16	52-Te-127	5127	0	1	Tellurium-127m
17	53-I -127	4127	0	1	Iodine-127
18	54-Xe-131	4131	0	1	Xenon-131
19	55-Cs-133	4133	1	3	Cesium-133
20	55-Cs-134	4134	0	1	Cesium-134
21	55-Cs-137	4137	0	1	Cesium-137
22	53-I -135	6135	0	1	Iodine-135
23	54-Xe-134	5134	0	1	Xenon-134
24	54-Xe-135	4135	0	1	Xenon-135
25	55-Cs-135	5135	0	1	Cesium-135
26	54-Xe-136	4136	0	1	Xenon-136
27	60-Nd-143	4143	0	1	Neodynium-143
28	60-Nd-145	4145	0	1	Neodynium-145
29	61-Pm-147	4147	0	1	Promethium-147 (+n-->Pm-148)
	61-Pm-147	5147	0	1	Promethium-147 (+n-->Pm-148m)
30	62-Sm-147	6147	0	1	Samarium-147
31	61-Pm-148m	4148	0	1	Promethium-148m
32	61-Pm-148	5148	0	1	Promethium-148
33	62-Sm-148	6148	0	1	Samarium-148
34	61-Pm-149	5149	0	1	Promethium-149
35	62-Sm-149	4149	0	1	Samarium-149
36	62-Sm-150	4150	0	1	Samarium-150
37	62-Sm-151	4151	0	1	Samarium-151
38	62-Sm-152	4152	0	1	Samarium-152
39	63-Eu-151	5151	0	1	Europium-151
40	63-Eu-152	5152	0	1	Europium-152
41	63-Eu-153	4153	0	1	Europium-153
42	63-Eu-154	4154	0	1	Europium-154
43	63-Eu-155	4155	0	1	Europium-155
44	64-Gd-154	2154	1	3	Gadolinium-154
45	64-Gd-155	2155	1	3	Gadolinium-155
46	64-Gd-156	2156	1	3	Gadolinium-156
47	64-Gd-157	2157	1	3	Gadolinium-157
48	64-Gd-158	2158	1	3	Gadolinium-158

No.	Nuclide	WIMS ID	Reso. Table	No. Temp.	Description
49	66-Dy-160	160	0	1	Dysprosium-160
50	66-Dy-161	161	0	1	Dysprosium-161
51	66-Dy-162	162	0	1	Dysprosium-162
52	66-Dy-163	163	0	1	Dysprosium-163
53	66-Dy-164	164	0	1	Dysprosium-164
54	67-Ho-165	165	0	1	Holmium-165
55	68-Er-166	2166	1	3	Erbium-166
56	68-Er-167	2167	1	3	Erbium-167

TABLE 4.2. FISSION PRODUCT NUCLIDES LUMPED INTO A PSEUDO FISSION PRODUCT

No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide
1	32-Ge- 72	21	38-Sr- 88	41	48-Cd-114	61	54-Xe-132
2	32-Ge- 73	22	39-Y – 89	42	48-Cd-116	62	56-Ba-134
3	32-Ge- 74	23	40-Zr- 90	43	49-In-113	63	56-Ba-135
4	32-Ge- 76	24	40-Zr- 91	44	50-Sn-115	64	56-Ba-136
5	33-As- 75	25	40-Zr- 92	45	50-Sn-117	65	56-Ba-137
6	34-Se- 76	26	40-Zr- 93	46	50-Sn-118	66	56-Ba-138
7	34-Se- 77	27	40-Zr- 94	47	50-Sn-119	67	58-Ce-140
8	34-Se- 78	28	40-Zr- 96	48	50-Sn-126	68	58-Ce-142
9	34-Se- 80	29	41-Nb- 94	49	51-Sb-121	69	59-Pr-141
10	34-Se- 82	30	42-Mo- 96	50	51-Sb-123	70	60-Nd-142
11	35-Br- 79	31	42-Mo- 97	51	52-Te-122	71	60-Nd-144
12	35-Br- 81	32	44-Ru- 99	52	52-Te-123	72	60-Nd-146
13	36-Kr- 80	33	44-Ru-100	53	52-Te-124	73	60-Nd-148
14	36-Kr- 82	34	44-Ru-102	54	52-Te-125	74	60-Nd-150
15	36-Kr- 84	35	44-Ru-104	55	52-Te-126	75	62-Sm-154
16	36-Kr- 86	36	46-Pd-104	56	52-Te-128	76	64-Gd-152
17	37-Rb- 85	37	46-Pd-106	57	52-Te-130	77	64-Gd-160
18	37-Rb- 87	38	46-Pd-110	58	53-I –129	78	65-Tb-159
19	38-Sb- 86	39	48-Cd-111	59	54-Xe-128	79	65-Tb-160
20	38-Sb- 87	40	48-Cd-112	60	54-Xe-130	80	-

4.2. Lumped fission product averaging

Cross-section data for all pseudo fission product components were processed into multigroup constants with the NJOY code system [4.3]. This processing was carried out at 700K assuming infinite dilution. The free gas model was selected for the thermal scattering matrix. The flux calculator option was applied up to the upper end of the resolved resonance range or the WIMS-D library resonance range, whichever was lower. WLUP averaging spectrum was used to produce the multi-group cross section data.

Cross sections for the pseudo fission product were calculated by weighted averaging of the constituent nuclide cross sections. The weights can be chosen in several ways: for example, by adopting calculated relative nuclide number densities in which the weights depend on reactor type, fuel, operating history and cooling time, among others, and there is no guarantee that including a pseudo fission product in a decay chain will result in a correct burnup dependence of the concentration. Instead, the cumulative yields were used as weights in WLUP to obtain the pseudo fission product for a fissile nuclide, corrected for the explicitly

represented precursors (where applicable) to avoid double counting. Explicitly, the following expressions were used:

$$y^k = \sum_{l=1}^{79} y_l^k$$

$$\sigma_x^k = \frac{\sum_{l=1}^{79} y_l^k \cdot \sigma_{x,l}}{y^k}$$

where
y^k Cumulative fission product yield of the pseudo fission product for the fissile nuclide k,
y_l^k Cumulative fission product yield of the nuclide l for the fissile nuclide k,
σ_x^k Group cross section x of the pseudo fission product for the fissile nuclide k,
$\sigma_{x,l}$ Group cross section x of the constituent nuclide l,
x absorption, transport, scattering, etc.
k corresponds to U-235, U-238, Pu-239, etc.

All required yields were calculated by means of the AVRFPY code. Note that the overall sum of the explicitly represented fission product and the pseudo fission product yields is less than 2 because nuclides excluded by the selection criteria are not counted.

The yields depend on the parent fissile nuclide. Differences between the cross sections of the pseudo fission product from different fissile isotopes are shown in Figure 4.1, and were found to be smaller than anticipated. Therefore, a single pseudo fission product was defined for all fissile nuclides by taking the average of the pseudo fission product cross sections of ^{235}U, ^{238}U and ^{239}Pu in the ratio of w^k= 54%, 8% and 38% respectively:

$$y = \sum_{k=1}^{3} w^k \cdot y^k$$

$$\sigma_x = \sum_{k=1}^{3} w^k \cdot \sigma_x^k$$

where
y Cumulative fission product yield of the average pseudo fission product,
σ_x Group cross section x of the average pseudo fission product,
w^k Weight of the fissile nuclide k.

All other parameters have the same meaning as before.

The influence of the basic evaluated nuclear data is also quite small [4.4]. Cross sections based on the ENDF/B-VI and JEF-2.2 evaluated files are shown in Figure 4.2, along with the data from the original WIMS-D library. Although the WIMS-D 1986 data are not directly comparable because they have to be considered in combination with the associated yields, they illustrate the rather simple treatment in the original library of the pseudo fission product data (basically a *1/v* isotope, with a nearly constant resonant part and an adjusted fission yield to match the observed reactivity changes).

The pseudo fission product data in the WIMSD-IAEA-69 and 172 group libraries were calculated from the ENDF/B-VI rev. 8 files. Pseudo fission product cross-section data in both energy structures are shown in Figure 4.3.

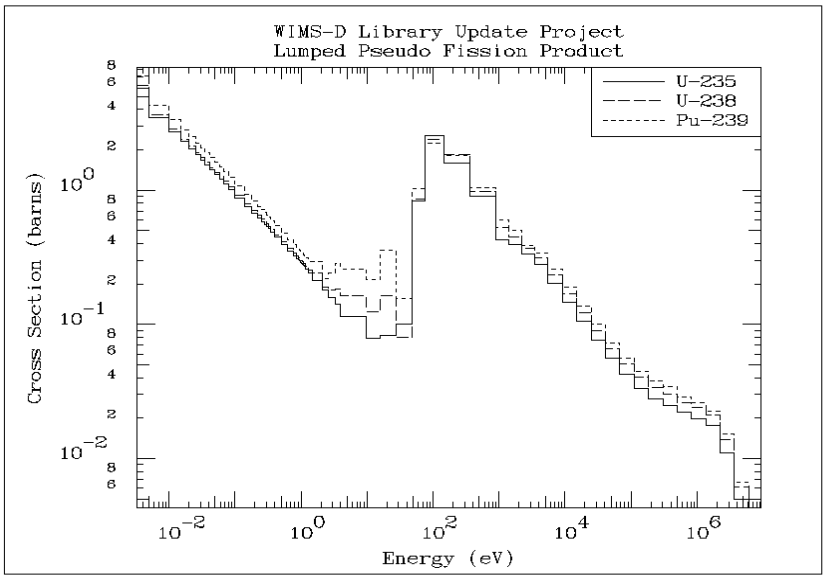

FiG. 4.1. Absorption cross section of the pseudo fission product for different fissile nuclides.

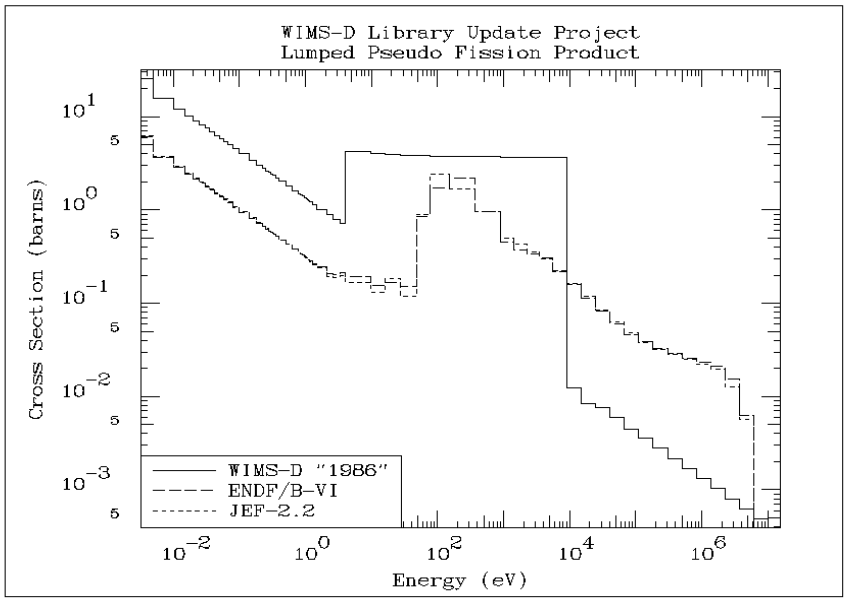

FIG. 4.2. Absorption cross section of the average pseudo fission product in different libraries.

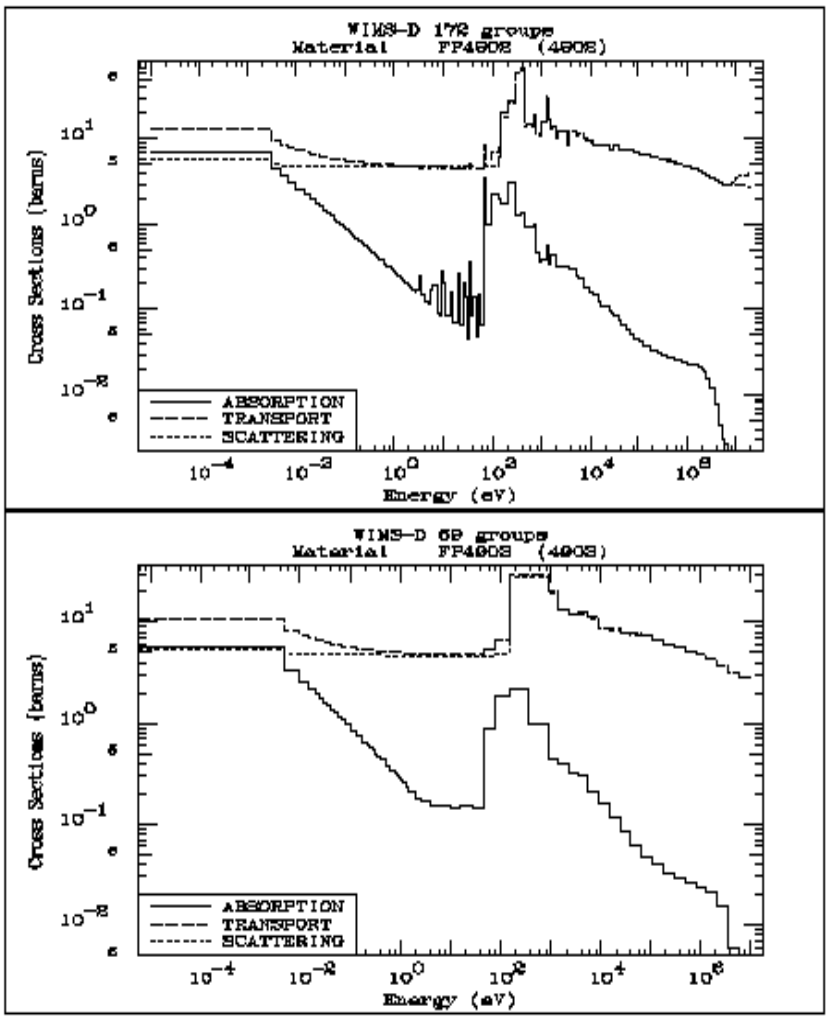

FIG. 4.3. Pseudo fission product cross section data.

REFERENCES

[4.1] TRKOV, A., Processing of the Fission Product Yield and Decay Data, Jožef Stefan Institute, Ljubljana, IJS-DP-8139, Rev. 1, October 1999.

[4.2] DUNFORD, C.L., ENDF Utility Codes Release 6.12 Manual, 5 April 2001.

[4.3] MACFARLANE, R.E., MUIR, D.W., The NJOY Nuclear Data Processing System, NJOY97.0 Code System for Producing Pointwise and Multigroup Neutron and Photon Cross Sections from ENDF/B Data, RSICC Code package PSR-368, May 1998.

[4.4] TRKOV, A., LOPEZ ALDAMA, D., Definition of the Pseudo Fission Product Data for Reactor Calculations, Proceeedings of Nuclear Energy in Central Europe ’99, Portoroz, Slovenia, 6-9 September 1999, pp. 57-62.

5. AVERAGE ENERGY RELEASE PER FISSION

The energy release per fission is required for burnup calculations, and is usually defined without the kinetic energy of the incident neutrons and the energy carried away by neutrinos. However, in the WIMS-D formatted libraries, the energy release per fission includes the contributions from the kinetic energy of incident neutrons and from the decay of the capture products:

$$W_{fiss}^{i} = E_{r}^{i} + Q_{c}^{i} + W_{n}^{i} \tag{5.1}$$

where W^{i}_{fiss} is the effective energy release in fission, E^{i}_{r} is the energy release in fission excluding the energy carried away by neutrinos and the kinetic energy of incident neutrons, Q^{i}_{r} is the contribution from the decay of the capture products, and W^{i}_{r} is the kinectic energy of the incident neutrons. Index *i* refers to a fissionable nuclide in all cases.

E^{i}_{r} values are extracted from the MF 1/MT 458 section of an evaluated nuclear data file, while the kinetic energy of the incident neutron is obtained by approximately averaging the energy with the fission reaction rate [5.1]. The averaging process involved the multigroup approximation and the cross sections from the updated WIMS-D library based on ENDF/B-VI data:

$$W_{n}^{i} = \frac{\sum_{g} E_{a}^{g} \cdot \sigma_{f,i}^{g} \Phi^{g}}{\sum_{g} \sigma_{f,i}^{g} \Phi^{g}} \tag{5.2}$$

where $\sigma^{g}_{f,i}$ is the microscopic fission cross section of the fissionable nuclide *i* in the energy group *g*, Φ^{g} is the neutron spectrum, and E_{a}^{g} is the average group energy. A typical PWR spectrum was used with 69 energy groups.

The average group energy was a simple mean of the group boundary values, except for the highest three groups for which more accurate values were adopted (7.2747, 4.5933, 2.8615 MeV, respectively), to give the average energy in a Maxwellian fission spectrum at a temperature corresponding to 1.4 MeV:

$$E_{a}^{g} = \frac{\int_{g} E\sqrt{E} \cdot \exp(-E/T)dE}{\int_{g} \sqrt{E} \cdot \exp(-E/T)dE} \tag{5.3}$$

The additional energy released due to gamma activation is calculated from

$$Q_{c} = \left(\bar{\nu} - 1\right) Q \tag{5.4}$$

where

$\left(\bar{\nu} - 1\right)$ represents the average number of neutrons that are captured, and

$Q = 6.1$ MeV.

The value of $\bar{\nu}$ was calculated from the constants in the updated WIMS-D library, and therefore was based on ENDF/B-VI data [5.1]. Condensation to one group assumed a typical

light water reactor spectrum used in NJOY to average the cross sections. *Q* was adopted from the old WIMS-D library because a rigorous calculation confirmed the adequacy of these data [5.2, 5.3].

A FORTRAN program ENFISS (included on WLUP CD-ROM) was written by Trkov to retrieve the energy per mole of fissioning material from an evaluated nuclear data file for the method presented above. The values included in the WIMSD-IAEA libraries are given in Table 5.1.

TABLE 5.1. ENERGY RELEASE PER FISSION FOR FISSIONABLE ACTINIDES

Nuclide	**MAT**	$\mathbf{W_{fiss}}$ [J/mole]
90-Th-232	2232	1.8670E-11
91-Pa-233(*)	1233	1.9600E-11
92-U –232	232	1.9270E-11
92-U –233	9233	1.9322E-11
92-U –234	234	1.9629E-11
92-U –235	2235	1.9551E-11
92-U –236	236	1.9321E-11
92-U –237	927	1.9830E-11
92-U –238	8238	2.0471E-11
93-Np-239(*)	1939	1.9600E-11
94-Pu-238	948	2.0250E-11
94-Pu-239	6239	2.0400E-11
94-Pu-240	1240	2.0655E-11
94-Pu-241	1241	2.0647E-11
94-Pu-242	242	2.0936E-11
95-Am-241	951	2.0944E-11
95-Am242m	952	2.0860E-11
95-Am-243	953	2.1442E-11
96-Cm-242	962	2.0532E-11
96-Cm-243	963	2.0573E-11
96-Cm-244	964	2.0578E-11

(*) : fission product data not available.
MAT: WIMS-D identification number.

REFERENCES

[5.1] PERŠIČ, A., TRKOV, A., The Energy Released by Neutron Capture in Thermal Reactors, International Conference on Nuclear Energy in Central Europe '99, Portorož, 6-9 September 1999.

[5.2] JAMES, M.F., Energy Released in Fission, J. Nucl. Energy, 23 (1969).

[5.3] JAMES, M.F., Energy Released in Fission of Th-232, U-233, U-234, U-236, Np-237, Pu-238, Pu-240 and Pu-242, J. Nucl. Energy, 25 (1971).

6. LIST OF MATERIALS

The essential information about materials included in the WIMSD-IAEA libraries are summarized in this chapter. General data for all materials are tabulated for the convenience of WIMS-D users and specifications for the resonance data of resonant nuclides are also presented. Additionally, a list of the main moderators with P1-scattering matrix has been prepared. Other kinds of data, such as detailed information about dosimetry materials and burnup chains, are given in Chapters 7 and 8.

6.1. General information

Table 6.1 presents materials information that has been included in the WIMSD-IAEA libraries. The following items are tabulated:

(1) **Material**: Material identification.
Atomic number (Z), chemical symbol, mass number (A) or other information that identifies the material.

(2) **ID**: WIMS-D identification number.
An integer number that usually consists of 1-4 digits. The numbers are the same as in the WIMS86 library for all materials included in both libraries.

(3) **At.Wt.**: Atomic weight (amu).

(4) **NF**: Resonance trigger (0-4)
Legend for the NF flag:
- 0 Material has no resonance tables.
- 1 Material is non-fissile with absorption resonance integral tables.
- 2 Material is fissile with absorption resonance integral tables.
- 3 Material is fissile with absorption and fission resonance integral tables.
- 4 Material is fissile without resonance integral tables.

(5) **T**: Temperatures at which thermal data are given (K).

(6) **Typ**: Type of material (M, S, D, FP, A, B)
Legend for material types:
- M Moderators.
- S Structural materials and other components.
- D Dosimetry reactions (to calculate reaction rates only).
- FP Fission products.
- A Actinides.
- B Burnable materials.

(7) **XS0**: Reference background cross section (barns). The value defines the dilution at which the cross section data are tabulated, and corresponds to the dilution commonly encountered in practical problems for this material. Note that one can not accommodate resonance integral tables of the scattering cross sections in a WIMS-D library due to format limitations. At present all cross sections (other than resonance integrals) entered in the WIMS-D library are self-shielded cross sections, but the reference Bondarenko background cross section is fixed. The reference dilution is taken to be infinite (labelled *inf.dil.* in the table) for some isotopes, in which case the elastic scattering cross section is taken to be fully-shielded, except for oxygen, where all cross sections are at infinite dilution (including elastic scattering cross sections) because dips in the spectrum due to the oxygen resonances are already included in the weighting function.

(8) **Description**: Brief description about the material, thermal scattering law (if not "free gas") and weighting spectrum (if not the standard PWR spectrum).

(9) **Data source**: Source of evaluated data for the final IAEA libraries.
Selection of the source of evaluated data for each material included in the 69 and 172 group WIMSD-IAEA libraries was performed by taking into account the evaluations included in the FOND-2 library and JEFF-3T starter file, as well as the results of analyses of more than 200 benchmark cases for different libraries. The specifications of the different evaluated nuclear data files processed for WLUP are given in Refs. [6.1-6.5].

TABLE 6.1. GENERAL INFORMATION ON MATERIALS

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
1-H –H2O	3001	1.00783	0	296 350 400 450 500 600	M	inf.dil.	Hydrogen bound in water	ENDF/B-VI.8
1-H –ZrH	5001	1.00783	0	296 400 500 600 700 800 1000 1200	M	10.0	Hydrogen bound in ZrH	ENDF/B-VI.8
1-D –D2O	3002	2.0141	0	296 350 400 450 500 600	M	inf.dil.	Deuterium bound in D2O. HWR spectrum	ENDF/B-VI.8
2-He- 3	3	3.01493	0	300	S	inf.dil.	Helium-3	JENDL-3.2
2-He- 4	4	4.03617	0	900	S	inf.dil.	Helium-4	JENDL-3.2
3-Li- 6	6	6.01507	0	300	S	inf.dil.	Lithium-6	ENDF/B-VI.8
3-Li- 7	7	7.01601	0	300	S	inf.dil.	Lithium-7	ENDF/B-VI.8
4-Be-nat	9	9.0122	0	296 400 500 600 700 800 1000 1200	S	inf.dil.	Berylium	ENDF/B-VI.8
5-B – 10	10	10.0129	0	300	B	1000.0	Boron-10 (burnable)	ENDF/B-VI.8
5-B – 10	1010	10.0129	0	300	S	1000.0	Boron-10 (unburnable)	ENDF/B-VI.8
5-B – 11	11	10.0129	0	300	B	300.0	Boron-11 (burnable)	ENDF/B-VI.8
5-B –nat	1011	10.811	0	300	S		Natural boron (unburnable)	ENDF/B-VI.8 From isotopes

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
6-C –nat	2012	12.0011	0	296 400 500 600 700 800 1000 1200	M	inf.dil.	Graphite	ENDF/B-VI.8
7-N –nat	14	14.0067	0	300	S	inf.dil.	Nitrogen	ENDF/B-VI.8
8-O –nat	6016	15.9905	0	293 450 600 900 1100	S	inf.dil. (included elastic scatt.)	Oxygen	ENDF/B-VI.8
9-F –nat	19	18.9982	0	300	S	inf.dil.	Fluorine	ENDF/B-VI.8
11-Na-nat	23	22.9895	0	300	S	inf.dil.	Sodium	JENDL-3.2
12-Mg-nat	24	24.3051	0	293 600 900	S		Magnesium	JENDL-3.2
13-Al-nat	27	26.9815	0	293	S	inf.dil.	Aluminium	ENDF/B-VI.8
14-Si-nat	29	28.0859	0	293 900	S		Silicon	ENDF/B-VI.8 From isotopes
15-P –nat	31	30.9741	0	293 900	S	2.0E5	Phosphorus	ENDF/B-VI.8
16-S –nat	32	32.0637	0	293 900	S	5.0E5	Sulphur	JENDL-3.2
17-Cl-nat	35	35.4526	0	300	S	inf.dil.	Chlorine	JENDL-3.2
20-Ca-nat	40	40.0803	0	300	S	inf.dil.	Calcium	ENDF/B-VI.8
22-Ti-nat	48	47.8789	0	293 900	S	3.5E4	Titanium	JENDL-3.2
23-V –nat	51	50.9416	0	293 900	S	4.5E5	Vanadium	ENDF/B-VI.8
24-Cr-nat	52	51.9959	0	293 600 900	S		Chromium	ENDF/B-VI.8 From isotopes
25-Mn-nat	55	54.9381	0	293 900	S	1.5E4	Manganese	ENDF/B-VI.8
26-Fe-nat	2056	55.8464	0	293 600 900	S		Iron	ENDF/B-VI.8 From isotopes
28-Ni-nat	58	58.6936	0	293 600 900	S		Nickel	ENDF/B-VI.8 From isotopes
27-Co- 59	1059	58.9332	0	293 900	S	2.5E5	Cobalt	ENDF/B-VI.8
29-Cu-nat	3063	63.5456	0	293 900	S		Copper	CENDL-3 From isotopes
40-Zr-nat	91	91.2196	0	293 600 900	S	300	Zirconium	JEF-2.2
41-Nb- 93	93	92.9032	0	293 900	S	3.0E4	Niobium	ENDF/B-VI.8

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
42-Mo-nat	96	95.9402	0	293 900	S	1.5E5	Molybdenum	JENDL-3.2
47-Ag-nat	3109	107.868	0	293 600 900	S		Silver (control rod material)	JENDL-3.2 From isotopes
48-Cd-nat	2113	112.411	0	300 600 900	S	2.0E3	Cadmium (control rod material)	JENDL-3.2
49-In-nat	2115	114.82	0	300 600 900	S	200	Indium (control rod material)	ENDF/B-VI.8
50-Sn-nat	118	117.241	0	293 600 900	S		Tin	JENDL-3.2 From isotopes
51-Sb-121	121	120.904	1	293 600 900	S	500	Antimony-121	JENDL-3.2
51-Sb-123	123	122.904	1	293 600 900	S	500	Antimony-123	JENDL-3.2
63-Eu-nat	152	151.965	0	700	S		Europium (control rod material)	ENDF/B-VI.8 From isotopes
64-Gd-154	2154	153.921	1	293 700 1100	B/FP	5.0E4	Gadolinium-154 (burnable absorber)	JENDL-3.2
64-Gd-155	2155	154.923	1	293 700 1100	B/FP	1.0E4	Gadolinium-155 (burnable absorber)	JENDL-3.2
64-Gd-156	2156	155.923	1	293 700 1100	B/FP	1.0E4	Gadolinium-156 (burnable absorber)	JENDL-3.2
64-Gd-157	2157	156.924	1	293 700 1100	B/FP	1.0E4	Gadolinium-157 (burnable absorber)	JENDL-3.2
64-Gd-158	2158	157.924	1	293 700 1100	B/FP	5.0E3	Gadolinium-158 (burnable absorber)	JENDL-3.2
66-Dy-160	160	159.925	0	293 700 1100	B/FP	2.0E5	Dysprosium-160	JEF-2.2
66-Dy-161	161	160.927	0	293 700 1100	B/FP	2.0E5	Dysprosium-161	JEF-2.2
66-Dy-162	162	161.927	0	293 700 1100	B/FP	2.0E5	Dysprosium-162	JEF-2.2
66-Dy-163	163	162.929	0	293 700 1100	B/FP	2.0E5	Dysprosium-163	JEF-2.2
66-Dy-164	164	163.928	0	293 700 1100	B/FP	2.0E5	Dysprosium-164	JEF-2.2

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
67-Ho-165	165	164.93	0	293 700 1100	B/FP	2.0E5	Holmium-165	ENDF/B-VI.8
68-Er-166	2166	165.93	1	293 700 1100	B	500	Erbium-166 (burnable absorber)	ENDF/B-VI.8
68-Er-167	2167	166.932	1	293 700 1100	B	500	Erbium-167 (burnable absorber)	ENDF/B-VI.8
72-Hf-176	2176	175.941	1	293 700 1100	B	1000	Hafnium-176 (burnable absorber)	CENDL-3
72-Hf-177	2177	176.943	1	293 700 1100	B	1000	Hafnium-177 (burnable absorber)	CENDL-3
72-Hf-178	2178	177.944	1	293 700 1100	B	500	Hafnium-178 (burnable absorber)	CENDL-3
72-Hf-179	2179	178.946	1	293 700 1100	B	1000	Hafnium-179 (burnable absorber)	CENDL-3
72-Hf-180	2180	179.947	1	293 700 1100	B	500	Hafnium-180 (burnable absorber)	CENDL-3
72-Hf-nat	178	178.487	0	293 600 900	S	500	Natural Hafnium (unburnable)	CENDL-3
73-Ta-nat	181	180.955	0	293 600 900	S	500	Tantalum	JENDL-3.2
74-W –nat	183	183.856	0	293 600 900	S	500	Tungsten	ENDF/B-VI.8
82-Pb-nat	207	207.262	0	300	S	I1	Lead-206, 207, 208	ENDF/B-VI.8 From isotopes
36-Kr- 83	4083	82.9141	0	700	FP	5.E5	Krypton-83	JENDL-3.2
42-Mo- 95	4095	94.9059	0	700	FP	3.E4	Molybdenum-95	JENDL-3.2
43-Tc- 99	4099	99.0005	1	293 700 1100	FP	3.E4	Technetium-99	JENDL-3.2
44-Ru-101	4101	100.906	0	700	FP	2.5E4	Ruthenium-101	JENDL-3.2
44-Ru-103	5103	102.906	0	700	FP	1.2E6	Ruthenium-103	JENDL-3.2
44-Ru-106	4106	105.908	0	700	FP	1.0E6	Ruthenium-106	JENDL-3.2
45-Rh-103	4103	102.905	0	700	FP	5.5E4	Rhodium-103	JENDL-3.2
45-Rh-105	4105	104.906	0	700	FP	4.5E7	Rhodium-105	JENDL-3.2
46-Pd-105	5105	104.905	0	700	FP	8.0E4	Palladium-105	ENDF/B-VI.8
46-Pd-107	4107	106.905	0	700	FP	2.0E5	Palladium-107	ENDF/B-VI.8
46-Pd-108	4108	107.904	0	700	FP	2.0E5	Palladium-108	ENDF/B-VI.8
47-Ag-109	4109	108.905	1	293 700 1100	FP	5.0E5	Silver-109	JENDL-3.2
48-Cd-113	4113	112.9	0	700	FP	2.0E8	Cadmium-113	ENDF/B-VI.8
49-In-115	4115	114.82	0	700	FP	3.0E7	Indium-115	JENDL-3.2

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
51-Sb-125	4125	124.905	0	700	FP	5.0E7	Antimony-125	JENDL-3.2
52-Te-127m	5127	126.905	0	700	FP	5.0E7	Tellurium-127m	JENDL-3.2
53-I –127	4127	126.905	0	700	FP	7.0E5	Iodine-127	ENDF/B-VI.8
54-Xe-131	4131	130.906	0	700	FP	7.0E5	Xenon-131	JENDL-3.2
55-Cs-133	4133	132.906	1	293 700 1100	FP	2.5E4	Cesium-133	ENDF/B-VI.8
55-Cs-134	4134	133.907	0	700	FP	5.0E5	Cesium-134	ENDF/B-VI.8
55-Cs-137	4137	136.907	0	700	FP	5.0E4	Cesium-137	JENDL-3.2
53-I –135	6135	134.91	0	700	FP	1.5E8	Iodine-135	JEF-2.2
54-Xe-134	5134	133.905	0	700	FP	1.0E5	Xenon-134	JENDL-3.2
54-Xe-135	4135	134.907	0	700	FP	2.5E8	Xenon-135	JENDL-3.2
55-Cs-135	5135	134.906	0	700	FP	5.0E4	Cesium-135	ENDF/B-VI.8
54-Xe-136	4136	135.908	0	700	FP	1.0E5	Xenon-136	JENDL-3.2
60-Nd-143	4143	142.91	0	700	FP	3.5E4	Neodymium-143	JENDL-3.2
60-Nd-145	4145	144.913	0	700	FP	4.5E4	Neodymium-145	JENDL-3.2
61-Pm-147	4147	146.915	0	700	FP	5.0E5	Promethium-147 (+n→Pm-148)	JENDL-3.2
61-Pm-147	5147	146.915	0	700	FP	5.0E5	Promethium-147 (+n→Pm-148m)	JENDL-3.2
62-Sm-147	6147	146.915	0	700	FP	4.5E5	Samarium-147	JENDL-3.2
61-Pm-148m	4148	147.918	0	700	FP	3.0E7	Promethium-148m	ENDF/B-VI.8
61-Pm-148	5148	147.918	0	700	FP	8.0E7	Promethium-148	JENDL-3.2
62-Sm-148	6148	147.915	0	700	FP	1.0E6	Samarium-148	JENDL-3.2
61-Pm-149	5149	148.918	0	700	FP	6.5E7	Promethium-149	JENDL-3.2
62-Sm-149	4149	148.917	0	700	FP	2.0E7	Samarium-149	ENDF/B-VI.8
62-Sm-150	4150	149.917	0	700	FP	1.0E5	Samarium-150	JENDL-3.2
62-Sm-151	4151	150.92	0	700	FP	5.0E6	Samarium-151	JENDL-3.2
62-Sm-152	4152	151.92	0	700	FP	1.0E6	Samarium-152	JENDL-3.2
63-Eu-151	5151	150.92	0	700	FP	I1	Europium-151	ENDF/B-VI.8
63-Eu-152	5152	151.925	0	700	FP	I1	Europium-152	JENDL-3.2
63-Eu-153	4153	152.922	0	700	FP	3.0E5	Europium-153	ENDF/B-VI.8
63-Eu-154	4154	153.922	0	700	FP	1.5E6	Europium-154	ENDF/B-VI.8
63-Eu-155	4155	154.923	0	700	FP	1.0E7	Europium-155	ENDF/B-VI.8
FP4902	4902	114.675	0	700	FP	N/A	Lumped fission product	ENDF/B-VI.8
90-Th-232	2232	232.033	2	293 600 900 1100	A	28.0	Thorium-232	JENDL-3.2
92-U –232	4232	232.033	0		FP		Pseudo fission product U-232(n,2n)U-231	N/A
92-U –232	232	232.033	4	293 700 1100	A	1.0E5	Uranium-232	JENDL-3.2
92-U –233	9233	233.045	3	293 600 900 1100	A	800.0	Uranium-233	JEF-2.2
91-Pa-231	1231	231.035	0	293 700 1100	FP	1.0E5	Protactinium-231 (non-fissile FP)	JENDL-3.2

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
91-Pa-233	1233	233.04	4	293 700 1100	A	5.5E5	Protactinium-233	JENDL-3.2
92-U –234	234	234.041	2	293 700 1100	A	1.0E5	Uranium-234	JENDL-3.2
92-U –235	2235	235.044	3	293 600 900 1100	A	800.0	Uranium-235	JEF-2.2
92-U –236	236	236.046	2	293 700 1100	A	1.0E4	Uranium-236	JENDL-3.2
92-U –237	4927	237.049	0		FP		Pseudo fission product U-238(n,2n)U-237	N/A
92-U –237	927	237.048	4	293 700 1100	A	1.5E7	Uranium-237	JENDL-3.2
92-U –238	8238	238.051	2	293 600 900 1100	A	28.0	Uranium-238	CENDL-2.1
93-Np-237	937	237.048	4	293 700 1100	A	1.0E5	Neptunium-237	ENDF/B-VI.8
93-Np-239	1939	239.053	4	293 700 1100	A	1.0E6	Neptunium-239	ENDF/B-VI.8
94-Pu-238	948	238.05	4	293 700 1100	A	3.0E4	Plutonium-238	FOND-2.2
94-Pu-239	6239	239.052	3	293 600 900 1100	A	700.0	Plutonium-239	FOND-2.2
94-Pu-240	1240	240.054	2	293 600 900 1100	A	2.0E3	Plutonium-240	FOND-2.2
94-Pu-241	1241	241.049	3	293 600 900 1100	A	1.0E4	Plutonium-241	FOND-2.2
94-Pu-242	242	242.058	2	293 700 1100	A	1.0E5	Plutonium-242 (high self-shielding)	FOND-2.2
94-Pu-242	1242	242.058	2	293 700 1100	A	1.0E3	Plutonium-242 (low self-shielding)	FOND-2.2
95-Am-241	951	241.057	4	293 700 1100	A	5.0E4	Americium-241	FOND-2.2

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
95-Am-242	1952	242.059	0	293 700 1100	FP	5.0E6	Americium-242 (non-fissile fp)	FOND-2.2
95-Am242m	952	242.059	4	293 700 1100	A	1.0E6	Americium-242m	FOND-2.2
95-Am-243	953	243.061	4	293 700 1100	A	5.0E5	Americium-243	FOND-2.2
96-Cm-242	962	242.058	4	293 700 1100	A	1.0E6	Curium-242	JENDL-3.2
96-Cm-243	963	243.061	4	293 700 1100	A	1.0E6	Curium-243	JENDL-3.2
96-Cm-244	964	244.063	4	293 700 1100	A	1.0E6	Curium-244	JENDL-3.2
v	1000	1	0	300	D		1/v absorber	N/A
Rv	1999	1	0	1	D		Resonance part of 1/v absorber	N/A
-v	2000	1	0	1	D		-1/v absorber	N/A
a	3000	1	0	1	D		Pure absorber	N/A
u	4000	1	0	1	D		Inverse lethargy intervals	N/A
6-C - 0	2212	12.0011	0	1	D		Graphite damage	ENDF/B-VI.7
40-Zr- 0	1091	91.2196	0	1	D		Zr damage	ENDF/B-VI.7
25-Mn- 55	1055	54.938	0	1	D		Mn-55(n,g)Mn-56	JENDL/D-99
26-Fe- 54	1054	53.9396	0	1	D		Fe-54(n,p)Mn-54	JENDL/D-99
26-Fe- 58	3058	57.9333	0	1	D		Fe-58(n,g)Fe-59	JENDL/D-99
27-Co- 59	2059	58.9332	0	1	D		Co-59(n,g)Co-60	JENDL/D-99
28-Ni- 58	1058	57.9354	0	1	D		Ni-58(n,p)Co-58	JENDL/D-99
29-Cu- 63	1063	62.9296	0	1	D		Cu-63(n,g)Cu-64	JENDL/D-99
36-Kr- 84	84	83.9114	0	1	D		Kr-84(n,g)Kr-85	ENDF/B-VI.7
45-Rh-103	2103	102.904	0	1	D		Rh-103(n,n')Rh-103m	JENDL/D-99
49-In-115	1115	114.904	0	1	D		In-115(n,n')In-115m	JENDL/D-99
49-In-115	3115	114.904	0	1	D		In-115(n,g)In-116m	JENDL/D-99
63-Eu-151	1151	150.92	0	1	D		Eu-151(n,g)Eu-152	JENDL/D-99
66-Dy-164	1164	163.928	0	1	D		Dy-164(n,g)Dy-165	ENDF/B-VI.7
71-Lu-176	176	175.941	0	1	D		Lu-176(n,g)Lu-177	ENDF/B-VI.7
79-Au-197	197	196.967	0	1	D		Au-197(n,g)Au-198	JENDL/D-99
90-Th-232	1232	232.038	0	1	D		Th-232(n,g)Th-233	JENDL/D-99
90-Th-232	3232	232.038	0	1	D		Th-232(n,f)	JENDL/D-99
92-U -235	1235	235.044	0	1	D		U-235(n,g)U-236	ENDF/B-VI.7
92-U -235	1003	235.044	0	1	D		U-235(n,f)	ENDF/B-VI.7
92-U -238	1238	238.051	0	1	D		U-238(n,g)U-239	JENDL/D-99
92-U -238	3238	238.051	0	1	D		U-238(n,f)	JENDL/D-99
93-Np-237	1237	237.048	0	1	D		Np-237(n,f)	JENDL/D-99
94-Pu-239	1239	239.053	0	1	D		Pu-239(n,f)	JENDL/D-99
90-Th-232	1632	232.033	0	1	D		Th-232(n,2n)	ENDF/B-VI.7
92-U –233	1633	233.045	0	1	D		U-233(n,2n)	ENDF/B-VI.7
92-U –235	1635	235.044	0	1	D		U-235(n,2n)	ENDF/B-VI.7
92-U –238	1638	238.051	0	1	D		U-238(n,2n)	ENDF/B-VI.7

Material	ID	At.Wt.	NF	T	Typ	XS0	Description	Data Source
94-Pu-239	1639	239.052	0	1	D		Pu-239(n,2n)	ENDF/B-VI.7
94-Pu-240	1640	240.054	0	1	D		Pu-240(n,2n)	ENDF/B-VI.7
94-Pu-241	1641	241.049	0	1	D		Pu-241(n,2n)	ENDF/B-VI.7
94-Pu-242	1642	242.058	0	1	D		Pu-242(n,2n)	ENDF/B-VI.7

6.2. Detailed information for resonance materials

Table 6.2 gives resonance data for all resonance isotopes. The following information is included:

(1) **Material**: Material identification.
Atomic number (Z), chemical symbol, mass number (A).
(2) **ID_r**: WIMS-D identification number for resonance data (real) .
(3) **NF**: Resonance trigger (1-3) Legend for the NF flag:
1 Material is non-fissile with absorption resonance integral tables.
2 Material is fissile with absorption resonance integral tables.
3 Material is fissile with absorption and fission resonance integral tables.
(4) **T_{res}**: List of temperatures in the resonance range (K).
(5) **PotXS**: Potential cross section (barns).
(6) **$XS0_{res}$**: List of background cross section values σ_o for resonance tabulation (barns).

TABLE 6.2. RESONANCE DATA

Material	ID_r	NF	T_{res}	PotXS	$XS0_{res}$
51-Sb-121	121.0	1	293 600 900	4.4760	1.0E10 5.0E5 5.0E4 1.0E4 1.0E3 5.0E2 1.0E2 10.
51-Sb-123	123.0	1	293 600 900	4.4879	1.0E10 5.0E5 5.0E4 1.0E4 1.0E3 5.0E2 1.0E2 10.
64-Gd-154	2154.0	1	293 700 1100	7.6744	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
64-Gd-155	2155.0	1	293 700 1100	5.7493	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
64-Gd-156	2156.0	1	293 700 1100	7.9722	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
64-Gd-157	2157.0	1	293 700 1100	4.1863	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
64-Gd-158	2158.0	1	293 700 1100	5.3521	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
68-Er-166	2166.0	1	293 700 1100	8.2448	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
68-Er-167	2167.0	1	293 700 1100	7.8427	1.E10 2.E4 3600. 1000. 260. 140. 64. 52. 28. 10.

Material	ID_r	NF	T_{res}	PotXS	$XS0_{res}$
72-Hf-176	2176.0	1	293 700 1100	8.2489	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
72-Hf-177	2177.0	1	293 700 1100	6.4331	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
72-Hf-178	2178.0	1	293 700 1100	7.5223	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
72-Hf-179	2179.0	1	293 700 1100	7.5855	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
72-Hf-180	2180.0	1	293 700 1100	8.2184	1.0E10 5.0E6 5.0E5 1.0E5 5.0E4 1.0E4 5.0E3 1.0E3 5.0E2 50.
43-Tc- 99	4099.0	1	293 700 1100	4.5564	1E10, 1E6, 5E5, 1E5, 3E4, 1E4, 1E3, 500
47-Ag-109	4109.0	1	293 700 1100	6.2198	1.0E10 1.0E6 5.0E5 1.0E5 5.0E4 1.0E4 1.0E3 5.0E2
55-Cs-133	4133.0	1	293 700 1100	3.5299	1.0E10 1.0E6 5.0E5 1.0E5 2.5E4 1.0E4 1.0E3 5.0E2
90-Th-232	2232.1	2	293 600 900 1100	13.1261	1.E10 2.E4 3600. 1000. 260. 140. 64. 52. 28. 10.
92-U -233	9233.0	3	293 600 900 1100	12.2989	1.E10 2.E4 3600. 1000. 260. 140. 64. 52. 28. 10.
92-U -234	234.0	2	293 700 1100	12.6113	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 5.E3 1.E3
92-U -235	2235.0	3	293 600 900 1100	11.6070	1.E10 3.E4 8000. 4500. 2800. 1800. 1200. 800. 500. 200.
92-U -236	236.0	2	293 700 1100	11.2615	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 5.E3 1.E3
92-U -238	8238.0	2	293 600 900 1100	11.8230	1E10, 2E4, 3.6E3, 1E3, 260, 140, 64, 52, 28, 10
94-Pu-239	6239.0	3	293 600 900 1100	10.7600	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 5.E3 1.E3

Material	ID_r	NF	T_{res}	PotXS	$XS0_{res}$
94-Pu-240	1240.0	2	293 600 900 1100	9.2474	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 5.E3 2.E3 1.E3 5.E2
94-Pu-241	1241.0	3	293 600 900 1100	12.0	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 5.E3 3.E3 1.E3 5.E2
94-Pu-242	242.0(1)	2	293 700 1100	10.5	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 8.E3 5.E3 1.E3 5.E2
94-Pu-242	1242.0(2)	2	293 700 1100	10.5	1.E10 5.E5 3.E5 1.E5 5.E4 1.E4 8.E3 5.E3 1.E3 5.E2

(1) High self-shielding (high concentration)
(2) Low self-shielding (low concentration)

6.3. Detailed information for materials with P1 scattering matrices

Table 6.3 shows the general information on materials with the P1-matrix data. These data are given in the same order that they are stored in the WIMSD-IAEA library. This information is very important for the preparation of WIMS-D input (DNB card). Note that due to WIMS-D code limitations, only four materials have P1-matrices and the data are given at only one temperature. The following information is presented:

Order Consecutive number of the P1-matrix in the library.
Material Material identification of the form:
atomic number (Z) – chemical symbol – associated compound.
ID WIMS-D identification number.
Tp1 Temperature for the P1-matrix (K).
Description Brief description of the material.
Data Source Source of evaluated data for the final WIMSD-IAEA libraries.

TABLE 6.3. MATERIALS WITH P1 MATRICES

Order	Material	ID	Tp1	Description	Data Source
1	1-H –H2O	3001	296	Hydrogen bound in water; PWR spectrum	ENDF/B-VI.8
2	1-D –D2O	3002	296	Deuterium bound in D_2O; HWR spectrum	ENDF/B-VI.8
3	6-C –nat	2012	296	Graphite; PWR spectrum	ENDF/B-VI.8
4	8-O –nat	6016	293	Oxygen; PWR spectrum	ENDF/B-VI.8

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7. DOSIMETRY DATA

Dosimetry data are included in the WIMS-D library as special materials to perform reaction rate calculations using the WIMS-D lattice code. A total of 15 dosimetry materials are contained in the '1986' WIMS library [7.1], including 8 dosimetry reactions, 2 damage cross-sections and 5 additional materials that are useful for special cases (such as a "1/v" absorber, a constant absorber and the inverse lethargy intervals).

All dosimetry files were updated from recently evaluated nuclear data files for the WIMS Library Update Project. Additionally, 22 new dosimetry reactions were included: 14 different dosimetry reactions, and eight (*n, 2n*) reactions for major actinides. Table 7.1 lists the relevant information for the dosimetry materials.

7.1. Source of data

The JENDL/D-99 [7.2] dosimetry library was selected as a source of evaluated nuclear data files. POINT2000 [7.3] library is the point-wise version of the ENDF/B-VI Rev. 7 evaluated nuclear data files, and was used for any missing data; POINT2000 was also the source of evaluated data for the (*n, 2n*) reactions. Furthermore, the corresponding files from the ENDF/B-VI Rev. 7 were processed with the NJOY code system [7.4] to generate a point-wise damage cross-section file at 300 K for natural carbon and zirconium. Table 7.1 shows the source of evaluated data for each dosimetry material.

7.2. Processing methods

The dosimetry materials of the WIMS-D library are special materials from the formatting point of view. They are non-burnable, and without resonance tables or scattering data. Hence, the WIMS-D formatted files for these materials contain the corresponding dosimetry reaction instead of absorption and transport cross sections.

These simplifying features and the fact that the dosimetry materials are reasonably independent of the rest of the library permits the use of the PREPRO-2000 code system [7.5] for nuclear data processing. WIMSIE code was developed to perform WIMS-D formatting and produce the special dosimetry files: positive and negative "1/v" materials, resonant part of the "1/v" absorber, constant absorber and inverse lethargy interval cross section.

The MERGER-LINEAR-SIGMA1-GROUPIE-DICTION-WIMSIE sequence was used to process the evaluated nuclear data. MERGER extracted the dosimetry reaction and general information section (MF = 1/MT = 451) from the source files of evaluated nuclear data. LINEAR was used because some point-wise dosimetry files from the JENDL/D-99 library were not linearly interpolable over the resonance range (reconstruction tolerance was set to 0.1% in all cases). RECENT was not required in this process because the resonance contribution (MF = 2) was always included in the point-wise cross-section data (MF = 3) of the evaluated source file. SIGMA1 Doppler broadened the cross section to 300K, and GROUPIE converted the multi-group data into 69 and 172 energy group structures. The averaging spectrum for most of the materials was converted to a linearly interpolable form, and was used to generate multi-group cross sections at infinite dilution. Finally, the index of the general information section was updated by DICTION, and WIMS-D formatting was performed by WIMSIE.

The processing can be done automatically using the WINDOWS/DOS procedures *wlupdosm.bat* and *dosmat1.bat*. Further details and instructions can be found in the comments of the procedures and the WIMSIE FORTRAN source. Alternatively, the dosimetry files can

be added to a WLUP library using the input option dosmat of the *runall.bat* procedure. All procedures and the FORTRAN source of WIMSIE are freely available from IAEA-NDS, and they are included on the WLUP CD-ROM.

TABLE 7.1. DOSIMETRY MATERIALS

Dosimetry reaction	Source of evaluated data	Filename	ZA number	MF	MT	WIMS ID	WLUP *.XSW file
Dosimetry reactions							
Mn-55(n,g)Mn-56	JENDL/D-99	Mn55	25055	3	102	1055	Mn55ng"L"
Fe-54(n,p)Mn-54	JENDL/D-99	Fe54	26054	3	103	1054	Fe54np"L"
Fe-58(n,g)Fe-59	JENDL/D-99	Fe58	26058	3	102	3058	Fe58ng"L"
Co-59(n,g)Co-60	JENDL/D-99	Co59	27059	3	102	2059	Co59ng"L"
Ni-58(n,p)Co-58	JENDL/D-99	Ni58	28058	3	103	1058	Ni58np"L"
Cu-63(n,g)Cu-64	JENDL/D-99	Cu63	29063	3	102	1063	Cu63ng"L"
Kr-84(n,g)Kr-85	POINT2000	Za036084	36084	3	102	84	Kr84ng"L"
Rh-103(n,n')Rh-103m	JENDL/D-99	Rh103	45103	3	51	2103	Rh103ni"L"
In-115(n,n')In-115m	JENDL/D-99	In115	49115	3	51	1115	In115ni"L"
In-115(n,g)In-116m	JENDL/D-99	In115	49115	3	102	3115	In115ng"L"
Eu-151(n,g)Eu-152	JENDL/D-99	Eu151	63151	3	102	1151	Eu151ng"L"
Dy-164(n,g)Dy-165	POINT2000	Za066164	66164	3	102	1164	Dy164ng"L"
Lu-176(n,g)Lu-177	POINT2000	Za071176	71176	3	102	176	Lu176ng"L"
Au-197(n,g)Au-198	JENDL/D-99	Au197	79197	3	102	197	Au197ng"L"
Th-232(n,g)Th-233	JENDL/D-99	Th232	90232	3	102	1232	Th232ng"L"
Th-232(n,f)	JENDL/D-99	Th232	90232	3	18	3232	Th232nf"L"
U-235(n,g)U-236	POINT2000	Za092235	92235	3	102	1235	U235ng"L"
U-235(n,f)	POINT2000	Za092235	92235	3	18	1003	U235nf"L"
U-238(n,g)U-239	JENDL/D-99	U238	92238	3	102	1238	U238ng"L"
U-238(n,f)	JENDL/D-99	U238	92238	3	18	3238	U238nf"L"
Np-237(n,f)	JENDL/D-99	Np237	93237	3	18	1237	Np237nf"L"
Pu-239(n,f)	JENDL/D-99	Pu239	94239	3	18	1239	Pu239nf"L"
(n,2n) reaction for major actinides							
Th-232(n,2n)	POINT2000	Za090232	90232	3	16	1632	Th232n2"L"
U-233(n,2n)	POINT2000	Za092233	92233	3	16	1633	U233n2"L"
U-235(n,2n)	POINT2000	Za092235	92235	3	16	1635	U235n2"L"
U-238(n,2n)	POINT2000	Za092238	92238	3	16	1638	U238n2"L"
Pu-239(n,2n)	POINT2000	Za094239	94239	3	16	1639	Pu239n2"L"
Pu-240(n,2n)	POINT2000	Za094240	94240	3	16	1640	Pu240n2"L"
Pu-241(n,2n)	POINT2000	Za094241	94241	3	16	1641	Pu241n2"L"
Pu-242(n,2n)	POINT2000	Za094242	94242	3	16	1642	Pu242n2"L"
Damage cross sections							
C-damage	ENDF/B-VI	Cdam	6000	3	444	2212	Cdam"L"
Zr-damage	ENDF/B-VI	Zrdam	40000	3	444	1091	Zrdam"L"
Special dosimetry materials							
1/v absorber	WLUP	Wlup1v	99	3	102	1000	Wlup1v"L"
Res. Part of 1/v						1999	Wlupr1v"L"
-1/v absorber						2000	Wlup_1v"L"
Inv. Leth. interv.						4000	Wlup1u"L"
Const.=1 absorber						3000	Wlup1a"L"

Suffix “L” denotes 172 energy group structure, otherwise 69 energy group structure is implied.

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8. BURNUP DATA

8.1.Actinide chain

Fig. 8.1 depicits the actinide burnup and decay transitions implemented in the WIMSD-IAEA libraries.

Numbered items in Fig. 8.1:

(1) Direct capture in ^{243}Cm yields ^{244}Cm.
(2) Direct capture in ^{242}Cm yields ^{243}Cm.
(3) Beta decay of ^{242}Am yields ^{242}Cm. Branching ratio (B_{Cm2} = 82.7%) is accounted for by an effective (reduced) yield for production of ^{242}Am, which is treated as a fission product (i.e. has no fission cross section). The positron emission branch that produces ^{242}Pu is ignored.
(4) ^{242m}Am decays by isomeric transition to ^{242}Am. Unfortunately, the concept of a *reduced* ^{242}Am concentration cannot be implemented for production by IT decay of ^{242m}Am because such a yield by decay cannot be specified in the WIMS-D library. See the discussion on ^{242}Am production by capture in ^{241}Am.
(5) Capture in ^{241}Am results in ^{242m}Am with a branching ratio B_{Am2} and is spectrum-dependent. Calculations based on ENDF/B-VI Rev.5 data produce values ranging from 0.132 for the plutonium recycling benchmark to 0.109 for the BAPL-2 benchmark. A value for $B_{Am2} = 0.12$ is retained (as in the "1986" WIMS-D library), and approximates to the DIMPLE-S01 benchmark.
(6) Reduced ^{242}Am is produced from capture in ^{241}Am. Since only one nuclide can be specified as the capture product (^{242m}Am under the previous item), ^{242}Am is treated as a fission product with a yield proportional to the capture to fission (*c/f*) ratio. Unfortunately, the ratio depends strongly on the neutron spectrum. Calculations based on ENDF/B-VI Rev.5 data produce *c/f* ratios ranging from 42 for the plutonium recycling benchmark to 124 for the BAPL-2 benchmark. A value of *c/f* = 92 has been adopted, which corresponds approximately to the DIMPLE-S01 benchmark. The expression for the reduced yield of ^{242}Am is given by:

$$(c/f)*(1-B_{Am2})*B_{Cm2}$$

Fission in ^{241}Am is predominantly a threshold reaction with a small sub-threshold contribution, and ^{241}Am fission is not an important contributor to reactivity. The fission cross section of ^{241}Am in the WIMS-D library is forced to be proportional to the absorption cross section (normalised to conserve the selected *c/f* ratio) in order to make the yield of ^{242g}Am exact. Thus, the effective reduced ^{242}Am yield is 67 atoms per fission, based on the same data for B_{Cm2} and B_{Am2} as for items (3) and (5), respectively.
(7) ^{241}Am decays by alpha emission to ^{237}Np.
(8) ^{244}Cm decays by alpha emission to ^{240}Pu.
(9) ^{243}Cm decays by alpha emission to ^{239}Pu.
(10) ^{242}Cm decays by alpha emission to ^{238}Pu.
(11) ^{241}Pu decays by beta emission to ^{241}Am.
(12) Capture in ^{239}Np: resulting ^{240}Np is assumed to decay instantly by beta emission to ^{240}Pu.
(13) ^{239}Np decays by beta emission to ^{239}Pu.
(14) Capture in ^{237}Np: resulting ^{238}Np is assumed to decay instantly by beta emission to ^{238}Pu.
(15) ^{238}Pu decays by alpha emission to ^{234}U.
(16) Capture in ^{238}U: resulting ^{239}U is assumed to decay instantly by beta emission to ^{239}Np.

(17) Production of ^{237}U from the ($n,2n$) reaction of ^{238}U: a pseudo fission product (ID=4927) is defined, which decays instantly into ^{237}U. The yield is equal to the ratio of ($n,2n$)/(n,f) reactions of ^{238}U, and is sensitive to the detailed shape of the spectrum and therefore difficult to determine. The reaction contribution above 10 *MeV* is significant. Yield per fission ($n,2n$)/(n,f) =0.06 has been adopted. The pseudo fission product decays instantly into ^{237}U.
(18) Capture product of ^{233}Pa is assumed to decay instantly to ^{234}U.
(19) ^{237}U decays by beta emission to ^{237}Np.
(20) Capture chain from ^{232}U to ^{238}U is represented explicitly.
(21) Production of ^{232}U from the ($n,2n$) reaction in ^{233}U is represented by a pseudo fission product (ID=4927), which decays instantly to ^{232}U. The yield is equal to the ratio of ($n,2n$)/(n,f) reactions.
(22) Production of ^{232}U, involves the introduction of fission product ^{231}Pa (i.e., fission cross section is deleted from the cross section set). Fission Yield is equal to the ratio of ($n,2n$)/(n,f) reactions of ^{232}Th, and the capture product of ^{231}Pa is assumed to decay instantly to ^{232}U.
(23) Capture product of ^{232}Th is assumed to decay instantly to ^{233}Pa.

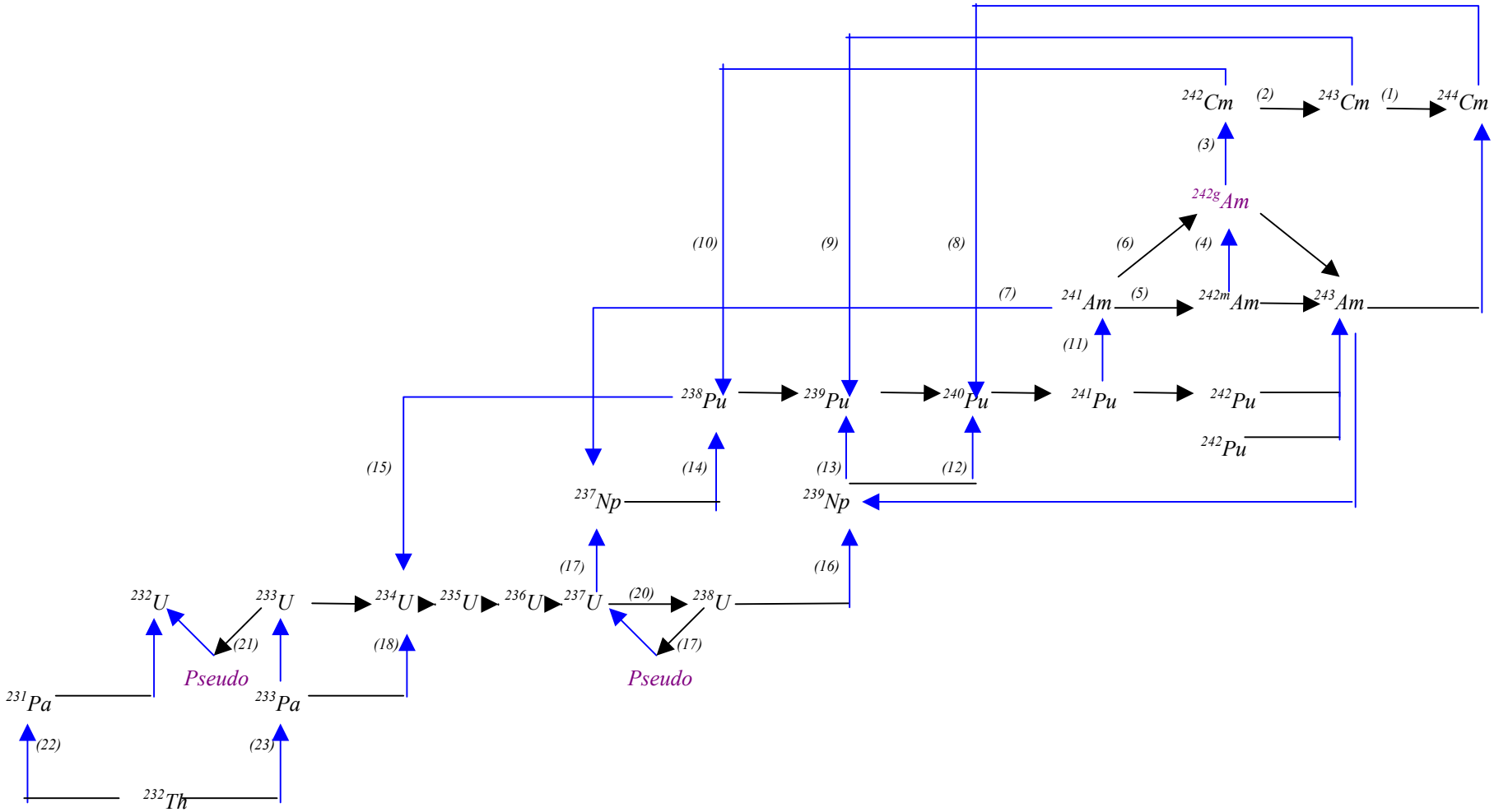

FIG .8.1. Actinide chain.

8.2. Fission product yields and decay data

Within the scope of WLUP, the fission product yields and decay data were updated for the materials containing burnup data. AVRFPY [8.1] was developed to retrieve the corresponding information from the evaluated data files and to produce a consistent set of cumulative fission yields. Relevant features of the fission product yields and decay data formats and processing are considered in the following sub-sections.

The energy release per fission is also given in the same data block for fissile actinides, and was discussed in Chapter 5 (see also Table 5.1).

8.2.1. Format considerations

ENDF-6 format [8.2] for fission product yields contains the parameter FPS as "state" designator (FPS = 0.0 is the ground state, FPS = 1.0 is the first excited state, etc.). The ZA number and the parameters LIS and LISO identify the decaying nucleus in the decay-data format: LIS is the excited state number, and LISO is the isomeric state number. Thus, the FPS designator in the fission product yield data corresponds to the LISO parameter, but a more precise description of the parameters in the ENDF-6 formats manual would be desirable.

Another point worth mentioning is the definition of a "nearly-stable" nuclide, with respect to the cumulative fission product yields and possible inconsistencies or misinterpretations of the data. Nearly-stable nuclides with very long (but finite) half-lives need not be included in the cumulative yield of their daughter product, but unfortunately the definition of a "nearly-stable" nuclide is lacking. Ambiguities were avoided by using an option in AVRFPY code to define cumulative yields by summing the independent yields for precursors that were not treated explicitly.

Deviations from the recommended format were observed during the processing of some fission product yield data, namely the yields of the higher excited states precede those for the lower states. AVRFPY is tolerant to this kind of formatting inconsistencies.

8.2.2. Fission product yields interpolation

Fission product yields may be given at more than one neutron energy by integrating and averaging the data in the normal manner. Interpolation procedures are described in recent versions of the ENDF-6 manual. Considering the nature of the measurements, a histogram interpolation seems reasonable, and the procedures are more or less unambiguous when the yields for a particular fission product are specified at all energies. However, if the yield for a particular isotope is given at 100 keV but omitted at 0.025 eV (for example), it is unclear what value one should assume at the lower energy. While the threshold energy is mandatory for cross sections, some formal recommendation is required for the fission yields (for example, assume zero where the yield is not specified). Examples where the yields were not specified at all energies are listed in Ref. [8.1].

Ambiguities were avoided (regardless of the prescribed interpolation law specified in the ENDF files) by assuming histogram interpolation for the fission product yields in all cases.

8.2.3. Averaging of fission product yields

The fission product yields are usually given on a very coarse energy grid (no more than three points), therefore there is no need to use an elaborate weighting function for averaging. A

four-points averaging function was defined in AVRFPY according to the following conditions:

- Lower boundary of the thermal group is at 10^{-5} eV or at the first energy point at which the yields are given (whichever is higher). Upper boundary of the thermal group is at 0.55 eV, which is approximately the cadmium cutoff energy; upper boundary of the epithermal group is at 1 keV; upper boundary of the fast group is 10 MeV.
- The integral of the thermal spectrum is defined such that the spectral ratio (i.e., ratio of the thermal flux to the sum of the epithermal and fast flux) is 5.785, while the integral of the fast spectrum is defined such that the ratio of the fast to epithermal flux is 0.9279.
- The fission cross section of the fissile parent nuclide is defined in the same group structure from the average thermal cross section, the resonance integral and the fission spectrum averaged cross section. The three-group fission reaction rate is calculated on the basis of the weighting function.
- The spectrum at 0.55 eV assumes $1/E$ shape in the epithermal range, and the fission cross section at this energy is assigned *1/v* cross section behaviour in the thermal group (where v is the neutron speed). The reaction rate weighting function is the product of the spectrum and the fission cross section. At other energies, the reaction rate weighting function is defined to conserve the integrals and assuming log-log interpolation.

The three-group averaging flux is typical of light water reactors, and corresponds to the EPRI-CELL LWR spectrum available for cross section averaging as option IWT = 5 in NJOY [8.3].

Perhaps the fission reaction rate weighting function seems unnecessarily complicated, but this parameter provides a unique and consistent way of averaging the fission product yields. For common fissile nuclides, the contribution to the yields from the fast neutrons is only about 1 to 2%, which hardly affects the interpolated yields. For fertile nuclides with a fission threshold, the yields come almost entirely from the fast contribution.

Table 8.1 lists the fission product yields included in the WLUP library for fissile actinides. The first column is the MAT number of each fission product material that can also be found in Table 6.1. Fission product yield data have been taken from the ENDF/B-VI library.

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES

FP	Th-232	U-232	U-233	U-234	U-235	U-236
4083	2.1568E-02	1.4994E-02	1.0137E-02	1.2064E-02	5.3558E-03	5.6357E-03
4095	5.7526E-02	6.2084E-02	6.3633E-02	6.3566E-02	6.5398E-02	6.4159E-02
4099	2.9831E-02	4.2147E-02	4.9240E-02	5.0940E-02	6.1426E-02	5.8624E-02
4101	7.1353E-03	1.9994E-02	3.1732E-02	3.3941E-02	5.1716E-02	5.2293E-02
5103	1.5533E-03	1.0612E-02	1.5735E-02	2.4172E-02	3.0351E-02	4.1560E-02
4106	4.8919E-04	9.9948E-04	2.4647E-03	4.2917E-03	4.0432E-03	1.0130E-02
4103	6.1460E-11	0.0000E+00	1.3850E-09	2.8328E-09	1.5506E-09	0.0000E+00
4105	5.2542E-04	2.4342E-03	4.9826E-03	1.2396E-02	9.7556E-03	2.4772E-02
5105	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4107	5.1073E-04	2.5986E-04	1.1462E-03	2.6844E-03	1.4932E-03	6.1605E-03
4108	6.1235E-04	8.1930E-05	7.5793E-04	1.8573E-03	5.5612E-04	3.8379E-03
4109	6.5951E-04	8.9965E-05	3.9500E-04	1.2266E-03	3.2178E-04	1.5383E-03
4113	7.6790E-04	1.3763E-04	1.3474E-04	5.8765E-04	1.4335E-04	4.0398E-04
4115	7.3315E-04	1.7891E-04	1.4368E-04	6.5234E-04	1.2384E-04	3.6606E-04
4125	3.2954E-04	1.5832E-03	1.1704E-03	1.5650E-03	3.4699E-04	1.6429E-03
5127	1.7758E-04	6.7030E-04	9.7322E-04	6.8052E-04	2.8043E-04	6.1887E-04
4127	8.3719E-04	3.1595E-03	4.5880E-03	3.2081E-03	1.3220E-03	2.9175E-03
6135	5.5944E-02	3.5214E-02	5.0304E-02	4.8982E-02	6.2900E-02	5.9862E-02
4131	1.6208E-02	3.7488E-02	3.6046E-02	3.7359E-02	2.8973E-02	2.9503E-02
5134	5.2041E-02	5.2266E-02	6.3002E-02	5.7405E-02	7.8448E-02	7.6933E-02
4135	1.0204E-04	1.7299E-02	1.2268E-02	6.7636E-03	2.5761E-03	1.0491E-03
4136	5.5447E-02	6.7405E-02	6.6676E-02	6.3065E-02	6.0911E-02	6.3242E-02
4133	4.0206E-02	5.8046E-02	5.9502E-02	6.4635E-02	6.6967E-02	6.8852E-02
4134	3.0400E-10	8.2302E-05	2.6880E-06	1.7200E-06	7.6560E-08	4.4602E-08
5135	3.7180E-08	6.7460E-04	5.9402E-05	4.3787E-05	4.9265E-06	1.6545E-06
4137	5.7296E-02	7.8080E-02	6.8360E-02	5.9723E-02	6.3429E-02	6.1850E-02
4143	6.6343E-02	5.0881E-02	5.9679E-02	6.1510E-02	5.9626E-02	5.7802E-02
4145	5.4486E-02	3.1161E-02	3.4464E-02	3.9922E-02	3.9396E-02	4.1710E-02
4147	1.3998E-02	5.6663E-03	8.1695E-03	9.4832E-03	1.0549E-02	1.0788E-02
5147	1.5786E-02	6.3897E-03	9.2125E-03	1.0694E-02	1.1896E-02	1.2165E-02
5148	1.9600E-13	2.1403E-06	3.1768E-09	1.7000E-08	4.6130E-11	3.0601E-10
4148	5.2999E-13	4.9907E-06	1.0024E-08	4.5900E-08	8.6204E-11	8.2804E-10
5149	1.0885E-02	6.6702E-03	7.7824E-03	1.0361E-02	1.0816E-02	1.3400E-02
6147	0.0000E+00	9.3132E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4149	0.0000E+00	1.4016E-07	0.0000E+00	9.3132E-10	0.0000E+00	0.0000E+00
4150	1.4500E-09	1.5721E-04	4.3939E-06	8.3398E-06	2.9912E-07	4.5012E-07
4151	3.6366E-03	3.4303E-03	3.1569E-03	3.1812E-03	4.1863E-03	4.1489E-03
4152	7.5544E-04	2.6680E-03	2.1358E-03	2.4863E-03	2.6699E-03	3.1520E-03
5151	0.0000E+00	9.3132E-09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5152	0.0000E+00	7.9344E-08	7.7020E-11	1.9600E-10	1.7894E-12	1.2761E-12
4153	3.1008E-04	1.9057E-03	1.0368E-03	1.4876E-03	1.5845E-03	2.5288E-03
4154	2.2000E-13	6.3108E-06	2.0964E-08	5.9700E-08	1.9134E-09	1.5201E-09
4155	3.6170E-05	1.0479E-03	2.1433E-04	5.0722E-04	3.2283E-04	9.3659E-04
2154	2.6857E-21	2.0003E-08	6.1676E-12	1.8305E-11	1.1041E-13	7.1384E-14
2155	0.0000E+00	2.0303E-07	1.4552E-10	4.6566E-10	2.9104E-11	0.0000E+00
2156	2.6909E-05	7.6227E-04	1.2808E-04	2.0886E-04	1.4961E-04	3.3730E-04
2157	9.3226E-06	5.2407E-04	6.3136E-05	1.0939E-04	6.2396E-05	2.3414E-04
2158	4.6418E-06	3.3349E-04	2.0584E-05	6.3639E-05	3.3495E-05	1.1239E-04
160	4.8699E-14	2.5586E-06	1.3980E-09	5.6542E-09	2.8055E-10	2.2804E-10
161	1.4488E-07	8.5758E-05	1.2150E-06	4.3809E-06	9.0263E-07	4.9268E-06
162	7.9760E-08	5.2248E-05	1.2610E-07	1.5718E-06	1.6701E-07	2.0604E-06
163	4.6346E-08	3.5249E-05	5.9395E-08	4.9766E-07	6.1723E-08	1.1237E-06
164	2.0310E-08	2.3791E-05	1.9559E-08	2.8885E-07	1.9597E-08	4.4972E-07
165	3.5366E-09	1.7153E-05	6.3360E-09	9.4573E-08	9.7865E-09	1.7198E-07
2166	3.5499E-12	7.8014E-06	9.3910E-10	6.6517E-09	4.0071E-10	4.3493E-09
2167	0.0000E+00	4.6787E-08	3.1161E-14	5.2270E-13	1.0779E-14	4.0002E-14
4902	1.2897E+00	1.2193E+00	1.1567E+00	1.1318E+00	1.0693E+00	1.0279E+00

FP	U-237	U-238	Pu-238	Pu-239	Pu-240	Pu-241
4083	4.7494E-03	3.9366E-03	3.7834E-03	2.9713E-03	2.3321E-03	2.0129E-03
4095	5.6749E-02	5.1293E-02	4.4398E-02	4.8452E-02	4.5430E-02	3.9493E-02
4099	6.2600E-02	6.2380E-02	6.1360E-02	6.2329E-02	5.9725E-02	6.0014E-02
4101	5.8041E-02	6.2091E-02	6.0481E-02	6.0355E-02	6.3003E-02	6.2319E-02
5103	4.9475E-02	6.2730E-02	5.8968E-02	6.9905E-02	6.4032E-02	6.7759E-02
4106	2.0629E-02	2.4953E-02	4.2394E-02	4.3504E-02	5.1508E-02	6.1080E-02
4103	0.0000E+00	0.0000E+00	4.7233E-09	0.0000E+00	0.0000E+00	0.0000E+00
4105	2.7092E-02	4.0929E-02	4.7705E-02	5.6475E-02	5.6237E-02	6.1004E-02
5105	0.0000E+00	3.7253E-09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4107	1.1229E-02	1.4459E-02	3.0108E-02	3.3272E-02	4.0149E-02	4.8863E-02
4108	4.9531E-03	6.0098E-03	2.1403E-02	2.1595E-02	2.9479E-02	3.7683E-02
4109	1.7857E-03	2.5171E-03	1.2165E-02	1.4669E-02	1.8764E-02	2.5873E-02
4113	4.2998E-04	4.5358E-04	8.1058E-04	8.1467E-04	1.3448E-03	1.4944E-03
4115	3.9589E-04	3.5749E-04	7.9462E-04	4.1488E-04	6.0995E-04	3.6264E-04
4125	1.1912E-03	4.8524E-04	1.4977E-03	1.1332E-03	8.0031E-04	4.6902E-04
5127	4.3463E-04	2.3883E-04	6.4669E-04	8.8600E-04	6.9736E-04	4.0693E-04
4127	2.0490E-03	1.1259E-03	3.0487E-03	4.1768E-03	3.2876E-03	1.9184E-03
6135	6.6245E-02	7.0147E-02	5.7400E-02	6.5354E-02	6.8468E-02	6.9543E-02
4131	3.2142E-02	3.2878E-02	3.9158E-02	3.8568E-02	3.4617E-02	3.1010E-02
5134	6.7222E-02	7.4571E-02	6.5956E-02	7.6577E-02	7.5124E-02	7.8816E-02
4135	3.8408E-04	2.6864E-04	9.9351E-03	1.0763E-02	5.3067E-03	2.2690E-03
4136	6.3711E-02	6.6835E-02	7.2144E-02	6.8781E-02	6.5620E-02	6.8242E-02
4133	5.4541E-02	6.7293E-02	5.8731E-02	7.0145E-02	6.8519E-02	6.7260E-02
4134	4.3100E-09	6.4600E-09	5.5000E-06	6.6982E-06	1.0957E-06	2.3200E-07
5135	2.5492E-07	3.7107E-07	1.1586E-04	1.2632E-04	3.0861E-05	7.3710E-06
4137	6.6976E-02	6.2259E-02	6.5790E-02	6.7092E-02	6.6973E-02	6.8184E-02
4143	4.8311E-02	4.6168E-02	4.5399E-02	4.4179E-02	4.4612E-02	4.5871E-02
4145	3.6631E-02	3.8706E-02	3.2378E-02	2.9902E-02	3.0794E-02	3.2792E-02
4147	1.2297E-02	1.2185E-02	1.0512E-02	9.4122E-03	1.0232E-02	1.0739E-02
5147	1.3867E-02	1.3741E-02	1.1853E-02	1.0614E-02	1.1539E-02	1.2110E-02
5148	1.4400E-11	6.1300E-12	1.5400E-07	1.3322E-08	4.2358E-09	1.9700E-10
4148	3.9000E-11	1.6600E-11	4.1600E-07	4.6685E-08	1.1007E-08	4.6000E-10
5149	1.4457E-02	1.6316E-02	1.5978E-02	1.2175E-02	1.3552E-02	1.4765E-02
6147	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4149	0.0000E+00	0.0000E+00	5.5879E-09	0.0000E+00	0.0000E+00	0.0000E+00
4150	6.6106E-08	3.2902E-08	4.5368E-05	1.1796E-05	4.1213E-06	5.0806E-07
4151	7.7194E-03	7.9940E-03	9.0801E-03	7.3959E-03	8.5185E-03	9.1302E-03
4152	5.2453E-03	5.3023E-03	6.7851E-03	5.7758E-03	6.5267E-03	7.1763E-03
5151	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5152	7.5468E-14	2.9200E-14	4.3734E-09	9.1910E-10	6.8450E-11	1.5467E-12
4153	3.4638E-03	4.1479E-03	4.6898E-03	3.6288E-03	4.9598E-03	5.4059E-03
4154	1.6100E-10	8.2500E-11	9.7200E-07	2.8482E-07	4.9604E-08	3.0700E-09
4155	1.1876E-03	1.4152E-03	2.3947E-03	1.6681E-03	2.4293E-03	2.4141E-03
2154	0.0000E+00	0.0000E+00	5.8296E-10	9.5354E-11	6.8109E-12	7.9013E-14
2155	0.0000E+00	0.0000E+00	1.2573E-08	1.6298E-09	2.3283E-10	0.0000E+00
2156	5.7400E-04	7.6033E-04	1.5965E-03	1.2479E-03	1.6266E-03	1.7212E-03
2157	4.2555E-04	4.1375E-04	9.9782E-04	7.4955E-04	1.2026E-03	1.3537E-03
2158	1.4845E-04	1.8487E-04	7.9722E-04	4.2047E-04	7.6087E-04	9.2245E-04
160	2.7200E-11	1.8900E-11	3.7554E-07	6.5823E-08	3.9059E-08	1.2501E-09
161	1.0424E-05	1.2154E-05	1.0235E-04	4.9367E-05	1.0920E-04	8.4690E-05
162	2.9607E-06	3.4052E-06	3.6491E-05	2.2962E-05	4.9895E-05	1.2725E-07
163	5.1469E-07	2.0314E-06	1.7956E-05	9.7278E-06	1.7608E-05	5.9028E-08
164	2.7678E-07	1.2469E-06	6.9782E-06	3.6640E-06	8.8938E-06	1.9668E-08
165	9.9237E-08	7.6671E-07	2.9935E-06	1.5351E-06	4.2080E-06	6.1574E-09
2166	6.8454E-10	2.6124E-09	4.6166E-07	1.9353E-07	3.3731E-07	7.6238E-11
2167	0.0000E+00	0.0000E+00	1.6820E-10	2.4487E-11	3.3244E-11	0.0000E+00
4902	1.0159E+00	9.5590E-01	9.1677E-01	8.6658E-01	8.5210E-01	8.2046E-01

FP	Pu-242	Am-241	Am-242m	Am-243	Cm-242	Cm-243
4083	1.7261E-03	2.0704E-03	2.4780E-03	1.6960E-03	1.9123E-03	3.5552E-03
4095	3.6769E-02	3.8736E-02	3.3118E-02	3.7567E-02	4.0193E-02	2.9071E-02
4099	5.5596E-02	6.0204E-02	5.3773E-02	5.4254E-02	5.4339E-02	5.0401E-02
4101	6.0042E-02	6.0520E-02	5.8706E-02	5.9247E-02	5.9534E-02	5.9465E-02
5103	6.5013E-02	6.3420E-02	7.0727E-02	5.9047E-02	5.9433E-02	6.4216E-02
4106	5.7887E-02	5.3721E-02	6.1625E-02	5.6247E-02	5.4148E-02	5.8831E-02
4103	0.0000E+00	1.2995E-08	1.0101E-08	6.9508E-10	1.0894E-06	8.3197E-08
4105	6.8785E-02	5.9877E-02	6.9685E-02	5.8831E-02	5.7879E-02	6.3884E-02
5105	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0117E-07	2.2352E-08
4107	5.0893E-02	5.1974E-02	5.3814E-02	5.2454E-02	5.1343E-02	5.6669E-02
4108	4.4023E-02	4.1846E-02	4.1088E-02	4.9349E-02	4.4848E-02	4.3060E-02
4109	3.2349E-02	2.4135E-02	3.7488E-02	3.7772E-02	3.4062E-02	4.1053E-02
4113	3.0500E-03	2.3773E-03	2.4775E-03	4.1452E-03	3.4570E-03	4.5936E-03
4115	1.0527E-03	1.0104E-03	7.0211E-04	9.7105E-04	1.0526E-03	1.5493E-03
4125	1.1898E-03	1.3820E-03	1.0366E-03	1.2983E-03	1.5593E-03	1.0230E-03
5127	4.6932E-04	8.4306E-04	4.6682E-04	6.1131E-04	6.5328E-04	1.1471E-03
4127	2.2125E-03	3.9743E-03	2.2007E-03	2.8819E-03	3.0787E-03	5.4075E-03
6135	6.9520E-02	5.1243E-02	5.6051E-02	6.0422E-02	3.8947E-02	4.0149E-02
4131	3.0408E-02	3.8700E-02	3.4837E-02	3.1949E-02	3.4554E-02	3.1935E-02
5134	7.3659E-02	7.5312E-02	6.9900E-02	6.2173E-02	6.2682E-02	7.5197E-02
4135	1.4391E-03	1.6112E-02	1.0444E-02	7.2507E-03	2.6554E-02	1.8515E-02
4136	6.6998E-02	7.3761E-02	6.3303E-02	7.1469E-02	7.1501E-02	4.2207E-02
4133	6.5326E-02	5.6648E-02	5.9815E-02	5.6193E-02	5.6472E-02	5.7421E-02
4134	9.5048E-08	1.4857E-05	4.6100E-06	7.3900E-06	2.6920E-04	4.5320E-05
5135	3.6464E-06	1.9652E-04	8.0383E-05	1.2420E-04	2.1296E-03	4.3690E-04
4137	6.5203E-02	6.2113E-02	6.2654E-02	7.2893E-02	6.8501E-02	6.3798E-02
4143	4.5558E-02	3.7852E-02	4.6437E-02	5.2106E-02	4.9674E-02	4.2898E-02
4145	3.4032E-02	3.3833E-02	3.3555E-02	3.4182E-02	3.2976E-02	3.2752E-02
4147	1.1152E-02	9.8305E-03	1.1593E-02	1.0980E-02	1.0246E-02	9.8333E-03
5147	1.2576E-02	1.1085E-02	1.3074E-02	1.2381E-02	1.1554E-02	1.1089E-02
5148	3.4425E-10	9.7668E-08	3.6200E-08	2.0200E-07	1.4820E-05	4.2600E-07
4148	9.2978E-10	2.5696E-07	8.4500E-08	5.4700E-07	4.0060E-05	9.9400E-07
5149	1.5796E-02	1.5030E-02	1.7205E-02	1.5570E-02	1.4925E-02	1.9853E-02
6147	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	7.4506E-09	0.0000E+00
6148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4149	0.0000E+00	9.3132E-10	0.0000E+00	7.4506E-09	1.7704E-06	1.4901E-08
4150	7.0891E-07	3.5389E-05	2.3567E-05	5.9485E-05	1.0083E-03	1.1072E-04
4151	9.9264E-03	8.9367E-03	1.2181E-02	9.6680E-03	9.3288E-03	1.2449E-02
4152	7.9192E-03	7.6755E-03	1.0240E-02	7.9735E-03	7.5008E-03	1.2379E-02
5151	0.0000E+00	0.0000E+00	0.0000E+00	1.8626E-09	3.1851E-07	9.3132E-10
5152	5.1534E-12	2.7798E-09	1.1693E-09	1.2427E-08	2.1466E-06	2.4134E-08
4153	6.2335E-03	6.1598E-03	8.2910E-03	5.8805E-03	5.4576E-03	1.3095E-02
4154	8.4626E-09	8.9188E-07	5.9000E-07	2.2200E-06	8.3310E-05	7.7400E-06
4155	3.2663E-03	3.5373E-03	3.6112E-03	3.0897E-03	2.9203E-03	7.0835E-03
2154	4.9770E-13	2.8692E-10	1.2299E-10	1.5801E-09	5.2700E-07	7.7997E-09
2155	0.0000E+00	8.3819E-09	2.7940E-09	2.7008E-08	3.4801E-06	1.4901E-07
2156	2.3708E-03	2.2731E-03	3.2755E-03	2.1927E-03	2.0465E-03	4.4506E-03
2157	1.6465E-03	1.5481E-03	1.5505E-03	1.4950E-03	1.3644E-03	4.5538E-03
2158	1.1066E-03	9.1379E-04	8.7542E-04	9.5681E-04	8.8679E-04	3.4490E-03
160	7.7930E-09	5.5216E-06	3.1216E-07	8.7831E-07	2.0397E-05	1.5250E-05
161	2.3842E-04	2.9994E-04	2.0151E-04	1.9933E-04	1.8518E-04	1.2185E-03
162	1.2223E-04	9.2629E-05	1.2900E-04	8.2178E-05	6.0854E-05	7.5840E-04
163	5.2622E-05	2.6977E-05	6.5656E-05	3.2420E-05	2.4512E-05	5.5757E-04
164	1.3828E-05	6.8755E-06	2.1884E-05	1.3948E-05	1.0676E-05	2.5393E-04
165	8.5095E-06	3.6245E-06	1.0669E-05	5.9795E-06	5.2570E-06	1.1049E-04
2166	1.5995E-07	5.0240E-07	1.0317E-06	7.4075E-07	1.5726E-06	2.1053E-05
2167	2.0941E-12	3.0316E-10	1.9090E-10	3.4660E-10	1.6140E-08	4.4480E-08
4902	8.1883E-01	8.3140E-01	8.2861E-01	8.3416E-01	8.4899E-01	8.3552E-01

FP	Cm-244
4083	1.5996E-03
4095	3.0264E-02
4099	5.1176E-02
4101	6.2015E-02
5103	6.7017E-02
4106	5.8890E-02
4103	3.5144E-08
4105	6.4092E-02
5105	0.0000E+00
4107	5.2012E-02
4108	4.3007E-02
4109	3.4011E-02
4113	8.3642E-03
4115	3.2379E-03
4125	1.7943E-03
5127	8.1743E-04
4127	3.8534E-03
6135	4.4201E-02
4131	2.3891E-02
5134	4.8740E-02
4135	1.2202E-02
4136	6.2433E-02
4133	3.9817E-02
4134	2.7930E-05
5135	3.4881E-04
4137	6.7576E-02
4143	4.7835E-02
4145	3.7848E-02
4147	1.3543E-02
5147	1.5271E-02
5148	5.9100E-07
4148	1.3800E-06
5149	2.0910E-02
6147	0.0000E+00
6148	0.0000E+00
4149	2.2352E-08
4150	1.5129E-04
4151	1.4904E-02
4152	1.1923E-02
5151	3.7253E-09
5152	4.2934E-08
4153	9.0419E-03
4154	8.3300E-06
4155	5.2683E-03
2154	9.2892E-09
2155	1.6158E-07
2156	3.6666E-03
2157	2.5765E-03
2158	1.7837E-03
160	5.4656E-06
161	4.6575E-04
162	2.7072E-04
163	1.6845E-04
164	9.9071E-05
165	5.6641E-05
2166	1.3112E-05
2167	2.4940E-08
4902	8.5929E-01

8.3. Fission product chains

Burnup and decay data are given in Table 8.2. Decay data were taken from ENDF/B-VI files. Fission product burnup and decay transitions implemented in the WIMSD-IAEA libraries are also shown in Fig. 8.2.

Data in Table 8.2 include:

Isotope Material identification of the form:
Atomic number (Z) – chemical symbol - mass number (A).
MAT WIMS-D identification number.
HL Decay constant (sec^{-1}).
DP Decay product (MAT number).
CP Capture product and WIMS-D identification number.
BR Branching ratio for the capture product formation.

TABLE 8.2. BURNUP AND DECAY DATA

Isotope	MAT	HL	DP	CP	BR
5-B – 10	10	-	Stable	B-11 (11)	1.0
5-B – 11	11	-	Stable	-	
64-Gd-154	2154	-	Stable	Gd-155 (2155)	1.0
64-Gd-155	2155	-	Stable	Gd-156 (2156)	1.0
64-Gd-156	2156	-	Stable	Gd-157 (2157)	1.0
64-Gd-157	2157	-	Stable	Gd-158 (2158)	1.0
64-Gd-158	2158	-	Stable	-	
66-Dy-160	160	-		Dy-161 (161)	1.0
66-Dy-161	161	-		Dy-162 (162)	1.0
66-Dy-162	162	-		Dy-163 (163)	1.0
66-Dy-163	163	-		Dy-164 (164)	1.0
66-Dy-164	164	-		Ho-165 (165)	1.0
67-Ho-165	165	-		-	
68-Er-166	2166	-	Stable	Er-167 (2167)	1.0
68-Er-167	2167	-	Stable	-	
72-Hf-176	2176	-	Stable	Hf-177 (2177)	1.0
72-Hf-177	2177	-	Stable	Hf-178 (2178)	1.0
72-Hf-178	2178	-	Stable	Hf-179 (2179)	1.0
72-Hf-179	2179	-	Stable	Hf-180 (2180)	1.0
72-Hf-180	2180	-	Stable	-	
36-Kr- 83	4083	-		-	
42-Mo- 95	4095	-	Stable	-	
43-Tc- 99	4099	-	Stable	-	
44-Ru-101	4101	-	Stable	-	
44-Ru-103	5103	2.043E-07	Rh-103 (4103)	-	
44-Ru-106	4106	2.179E-08	-	-	
45-Rh-103	4103	-	Stable	-	
45-Rh-105	4105	5.445E-06	Pd-105 (5105)	-	
46-Pd-105	5105	-	Stable	-	
46-Pd-107	4107	-	Stable	Pd-108 (4108)	1.0

46-Pd-108	4108	-	Stable	Ag-109 (4109)	1.0
47-Ag-109	4109	-	Stable	-	
48-Cd-113	4113	-	Stable	-	
49-In-115	4115	-	Stable	-	
51-Sb-125	4125	8.051E-09	-	-	
52-Te-127m	5127	7.360E-08	I-127 (4127)	-	
53-I –127	4127	-	Stable	-	
54-Xe-131	4131	-	Stable	-	
55-Cs-133	4133	-	Stable	Cs-134 (4134)	1.0
55-Cs-134	4134	1.065E-08	-	Cs-135 (5135)	1.0
55-Cs-137	4137	7.322E-10	-	-	
53-I –135	6135	2.913E-5	Xe-135 (4135)	-	
54-Xe-134	5134	-	Stable	Xe-135 (4135)	1.0
54-Xe-135	4135	2.107E-05	Cs-135 (5135)	Xe-136 (4136)	1.0
55-Cs-135	5135	-	Stable	-	
54-Xe-136	4136	-	Stable	-	
60-Nd-143	4143	-	Stable	-	
60-Nd-145	4145	-	Stable	-	
61-Pm-147	4147	8.373E-09	Sm-147 (6147)	Pm-148m (4148)	1.0 (1)
61-Pm-147	5147	8.373E-09	Sm-147 (6147)	Pm-148 (5148)	1.0 (1)
62-Sm-147	6147	-	Stable	Sm-148 (6148)	1.0
61-Pm-148m	4148	1.943E-07	Sm-148 (6148)	Pm-149 (5149)	1.0
61-Pm-148	5148	1.494E-06	Sm-148 (6148)	Pm-149 (5149)	1.0
62-Sm-148	6148	-	Stable	Sm-149 (4149)	1.0
61-Pm-149	5149	3.627E-06	Sm-149 (4149)	Sm-150 (1450)	1.0
62-Sm-149	4149	-	Stable	Sm-150 (4150)	1.0
62-Sm-150	4150	-	Stable	Sm-151 (4151)	1.0
62-Sm-151	4151	2.441E-10	Eu-151 (5151)	Sm-152 (4152)	1.0
62-Sm-152	4152	-	Stable	Eu-153 (4153)	1.0 (2)
63-Eu-151	5151	-	Stable	Eu-152 (5152)	1.0
63-Eu-152	5152	1.648E-09	(3)	Eu-153 (4153)	1.0
63-Eu-153	4153	-	Stable	Eu-154 (4154)	1.0
63-Eu-154	4154	2.557E-09	Gd-154 (2154)	Eu-155 (4155)	1.0
63-Eu-155	4155	4.693E-09	Gd-155 (2155)	-	
FP4902	4902	-		-	
90-Th-232	2232	-		Pa-233 (1233)	1.0
92-U-232	232	3.1894E-10	-	U-233 (9233)	1.0
92-U -233	9233	-		U-234 (234)	1.0
91-Pa-231	1231	6.70784E-13	-	U-232 (232)	1.0
91-Pa-233	1233	2.971E-07	U-233 (9233)	U-234 (234)	1.0
92-U -234	234				
92-U -235	2235	3.1223E-17	-	U-236 (236)	1.0
92-U -236	236	-		U-237 (927)	1.0
92-U -237	927	1.189E-06	Np-237 (937)	U-238 (8238)	1.0
92-U -238	8238	-		Np-239 (1939)	1.0
93-Np-237	937	-		Np-239	1.0
93-Np-239	1939	3.407E-06	Pu-239 (6239)	Pu-240 (1240)	1.0
94-Pu-238	948	2.505E-10	U-234 (234)	Pu-239 (6239)	1.0
94-Pu-239	6239	-		Pu-240 (1240)	1.0
94-Pu-240	1240	-		Pu-241 (1241)	1.0
94-Pu-241	1241	1.531E-09	Am-241 (951)	Pu-242 (1242)	1.0

94-Pu-242	242	-		Am-243 (953)	1.0
94-Pu-242	1242 (8)	-		Am-243 (953)	1.0
95-Am-241	951	5.076E-11	Np-237 (937)	Am-242m (952)	0.12
95-Am-242	1952	1.202E-05	Cm-242 (962)	Am-242 (953)	0.80
95-Am-242m	952	1.558E-10	Am-244 (1952)	Am-243 (953)	1.0
95-Am-243	953	-		Cm-244 (964)	1.0
96-Cm-242	962	4.924E-08	Pu-238 (948)	Cm-243 (963)	1.0
96-Cm-243	963	7.707E-10	Pu-239 (6239)	Cm-244 (964)	1.0
96-Cm-244	964	1.214E-09	Pu-240 (1240)	-	

(1) Pm-147 + n → Pm-148m Mat 4147
→Pm-148 Mat 5147

(2) Sm-152 +n → [Sm-153] → Eu-153

(3) Eu-152 decays into void (ignore 72.08% Sm-152 and 27.92 % Gd-152)

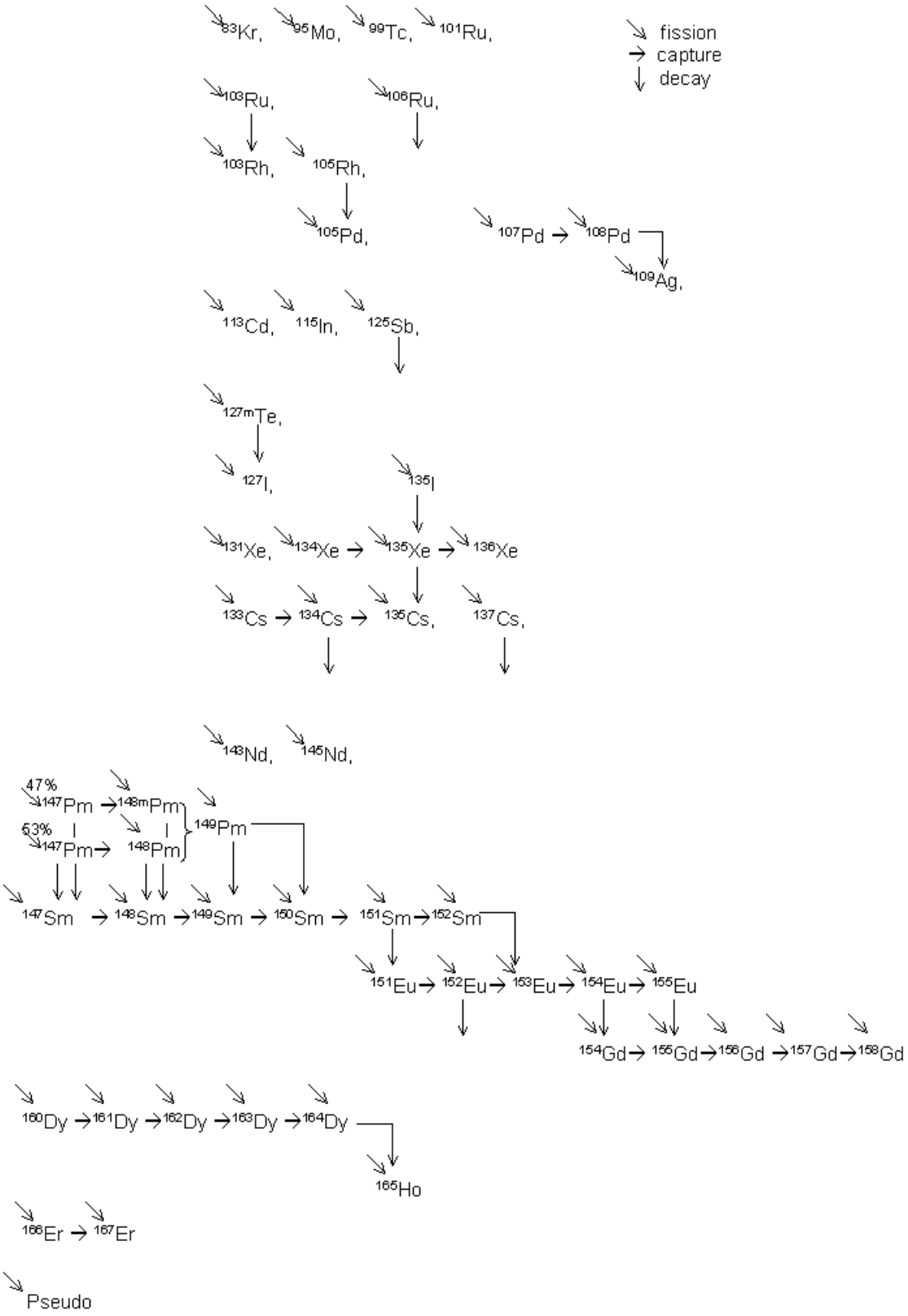

FIG. 8.2. Fission product chains.

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9. FISSION SPECTRUM IN THE LIBRARY

The XSPMIX code has been developed to produce an averaged fission spectrum from several individual isotope spectra, given the weights for each isotope as input. Isotopes and weights adopted for the WLUP libraries are: ^{235}U, ^{238}U and ^{239}Pu in the ratio of 54%, 8% and 38%, respectively.

Tables 9.1 and 9.2 list the average integral spectra of the 69 and 172 group libraries, respectively. Both spectra (per unit energy) are shown in Fig. 10.1.

TABLE 9.1. AVERAGE FISSION SPECTRUM FOR 69 GROUP LIBRARY

Neutron Energy (eV)	Fission Spectrum
1.00000E+07	2.76618619E-02
6.06550E+06	1.16180994E-01
3.67900E+06	2.18477324E-01
2.23100E+06	2.32844964E-01
1.35300E+06	1.74191684E-01
8.21000E+05	1.08170442E-01
5.00000E+05	6.10514991E-02
3.02500E+05	3.14032026E-02
1.83000E+05	1.55065255E-02
1.11000E+05	7.54445791E-03
6.73400E+04	3.62444320E-03
4.08500E+04	1.73872744E-03
2.47800E+04	8.40678287E-04
1.50300E+04	4.03833983E-04
9.11800E+03	1.86793957E-04
5.53000E+03	8.33578233E-05
3.51910E+03	4.29143147E-05
2.23945E+03	2.21586834E-05
1.42510E+03	1.14833065E-05
9.06899E+02	9.10655854E-06
3.67263E+02	2.52294785E-06
1.48729E+02	6.13992597E-07
7.55014E+01	1.86799028E-07
4.80520E+01	1.18147128E-07
2.77000E+01	5.79575818E-08
1.59680E+01	2.61382667E-08
9.87700E+00	1.37659502E-08

TABLE 9.2. AVERAGE FISSION SPECTRUM FOR 172 GROUP LIBRARY

Neutron Energy (eV)	Fission Spectrum	Neutron Energy (eV)	Fission Spectrum
1.96403E+07	4.50643984E-06	7.46586E+03	9.69083048E-05
1.73325E+07	2.63274960E-05	5.53085E+03	2.43018967E-05
1.49182E+07	4.15696195E-05	5.00450E+03	6.22363877E-05
1.38403E+07	3.40640079E-04	3.52662E+03	6.34691742E-06
1.16183E+07	1.02384132E-03	3.35463E+03	3.83770457E-05
1.00000E+07	4.14727954E-03	2.24867E+03	6.89237095E-06
8.18731E+06	1.11972867E-02	2.03468E+03	1.45131244E-05
6.70320E+06	9.93372593E-03	1.50733E+03	1.90397725E-06
6.06531E+06	1.37103824E-02	1.43382E+03	5.03406272E-06
5.48812E+06	4.07796465E-02	1.23410E+03	5.38154154E-06
4.49329E+06	6.00652881E-02	1.01039E+03	2.05559218E-06
3.67879E+06	7.79801980E-02	9.14242E+02	3.36999256E-06
3.01194E+06	9.10528079E-02	7.48518E+02	1.36404537E-06
2.46597E+06	4.82219942E-02	6.77287E+02	3.84475379E-06
2.23130E+06	4.87308837E-02	4.53999E+02	1.27373232E-06
2.01897E+06	9.54958349E-02	3.71703E+02	9.37115260E-07
1.65299E+06	8.85258690E-02	3.04325E+02	1.30166814E-06
1.35335E+06	4.05771099E-02	2.03995E+02	6.08810296E-07
1.22456E+06	3.78627107E-02	1.48625E+02	1.23800902E-07
1.10803E+06	3.50320116E-02	1.36742E+02	4.42681028E-07
1.00259E+06	3.22486013E-02	9.16609E+01	1.39690044E-07
9.07180E+05	2.94619855E-02	7.56736E+01	6.51219665E-08
8.20850E+05	7.28234425E-02	6.79040E+01	9.69046781E-08
6.08101E+05	1.95698049E-02	5.55951E+01	3.08095025E-08
5.50232E+05	1.74587257E-02	5.15780E+01	2.51899426E-08
4.97871E+05	1.55243613E-02	4.82516E+01	2.04793853E-08
4.50492E+05	1.36997513E-02	4.55174E+01	3.94456414E-08
4.07622E+05	3.21204551E-02	4.01690E+01	1.99502583E-08
3.01974E+05	8.14305712E-03	3.72665E+01	2.39361810E-08
2.73237E+05	7.17982790E-03	3.37201E+01	2.13036788E-08
2.47235E+05	1.63376555E-02	3.05113E+01	1.05909832E-08
1.83156E+05	1.34486463E-02	2.76077E+01	9.54601020E-09
1.22773E+05	2.34976108E-03	2.49805E+01	8.60641336E-09
1.11090E+05	5.31888800E-03	2.26033E+01	1.13493481E-08
8.22975E+04	2.43065669E-03	1.94548E+01	1.26354998E-08
6.73795E+04	1.80617836E-03	1.59283E+01	7.90818522E-09
5.51656E+04	1.89245259E-03	1.37096E+01	8.81607232E-09
4.08677E+04	4.62097669E-04	1.12245E+01	4.65834082E-09
3.69786E+04	8.58279178E-04	9.90555E+00	2.51249599E-09
2.92830E+04	1.92569350E-04	9.18981E+00	3.06431214E-09
2.73944E+04	2.59205204E-04	8.31529E+00	2.76722867E-09
2.47875E+04	7.37316965E-04	7.52398E+00	4.75571360E-09
1.66156E+04	1.26406419E-04	6.16012E+00	2.82854784E-09
1.50344E+04	2.94676080E-04	5.34643E+00	1.05136533E-09
1.11378E+04	1.33474052E-04	5.04348E+00	3.16667803E-09
9.11882E+03	9.40028622E-05	4.12925E+00	4.46896714E-10

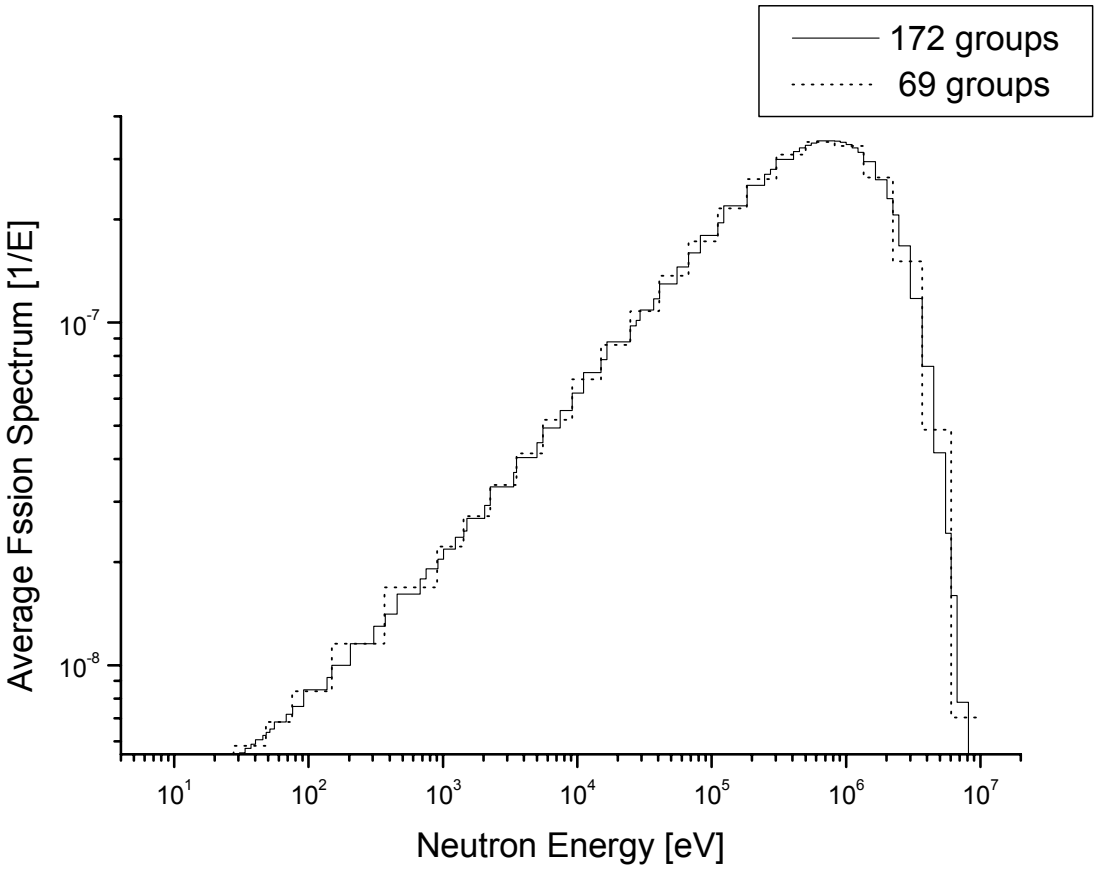

FIG. 9.1. Average fission spectrum for 69 and 172 group library.

10. AVERAGING FLUX AND CURRENT SPECTRA

The flux and current spectra used in the preparation of WIMS-D libraries for weighting pointwise cross sections are briefly described below. Essentially, the adopted neutron spectrum in WLUP is the standard PWR spectrum included in the GROUPR module of NJOY, modified to smooth the form to a pure 1/E shape in the resonance energy region where special treatment is needed for the main resonance materials. A special spectrum has been generated with the MCNP code for heavy water reactors, and was used for deuterium data only.

Another special spectrum has been generated for the thorium fuel cycle which is used to average thorium-232, protoactinium-231 and uranium-233 data only. These spectra are discussed in Section 10.1.

In the formalism of multi-group libraries, a neutron current spectrum is necessary in order to obtain the 'transport correction' from P1 cross section data. The correction is made by weighting P1 cross-sections with a 'typical' neutron current spectrum. The selection of the weight spectrum for this process is simplified by choosing the "British current spectrum", a reference spectrum used to generate the old WIMS library [10.1]. This approach was adopted in the preparation of the WLUP-69 group libraries, with the exception of the deuterium data. The necessary multi-group neutron current spectrum for deuterium and 172 group libraries were generated by solving the B1 equations for typical LWR and HWR systems. These spectra are shown in Section 10.2.

10.1. Neutron flux spectra

Standard WIMS libraries would appear to be oriented to Light Water Reactors (LWR), since their P0 and P1 neutron spectra are typical of LWR. There are differences in the shapes of LWR and HWR spectra as a function of energy, and these variations have some impact for the main moderators (hydrogen in H_2O, and deuterium in D_2O). Furthermore, for fuels other than typical U systems, such effects can be significant, depending on the type of cells analysed, temperature of different component materials, and the number of energy groups of the WIMS library.

Some selected experimental and calculational benchmarks have been modelled with the MCNP code [10.1] (axially infinite cylindrical cells, KCODE option) to generate neutron spectra for heavy water reactors and Th-^{233}U fuels. Run tallies of average neutron fluxes over the main component of the cells (fuel, can, coolant, pressure tube calandria tube and moderator) were obtained in each calculation, as a function of energy and over an appropriate energy mesh. An averaged spectrum was subsequently obtained from these results. Figure 10.1 shows the neutron flux spectra used for all materials.

The energy grid (eV) used to generate mean flux tallies over a cell (defined for MCNP as equivalent to a component of the reactor cell - fuel, can, coolant, etc.) is specified in Table 10.1.

TABLE 10.1. ENERGY GRID (eV) USED TO GENERATE MEAN FLUX TALLIES

1.000E-05	4.900E-01	5.400E+05	6.000E+06	1.400E+07
9.000E-03	5.700E-01	6.500E+05	8.000E+06	1.420E+07
1.600E-02	6.000E-01	7.700E+05	1.000E+07	1.430E+07
2.400E-02	1.000E+00	9.000E+05	1.250E+07	1.440E+07
2.900E-02	4.000E+00	9.410E+05	1.260E+07	1.450E+07
3.300E-02	9.118E+03	1.000E+06	1.270E+07	1.460E+07
4.300E-02	2.000E+04	1.050E+06	1.280E+07	1.470E+07
5.000E-02	3.070E+04	1.120E+06	1.290E+07	1.480E+07
5.400E-02	6.070E+04	1.190E+06	1.300E+07	1.490E+07
5.900E-02	1.200E+05	1.210E+06	1.310E+07	1.500E+07
7.000E-02	2.010E+05	1.310E+06	1.320E+07	1.510E+07
9.000E-02	2.830E+05	1.400E+06	1.330E+07	1.520E+07
1.120E-01	3.560E+05	2.220E+06	1.340E+07	1.530E+07
1.400E-01	3.770E+05	2.350E+06	1.350E+07	1.540E+07
1.700E-01	3.990E+05	2.630E+06	1.360E+07	1.550E+07
2.100E-01	4.420E+05	3.000E+06	1.370E+07	1.568E+07
3.000E-01	4.740E+05	4.000E+06	1.380E+07	2.000E+07
4.000E-01	5.020E+05	5.000E+06	1.390E+07	

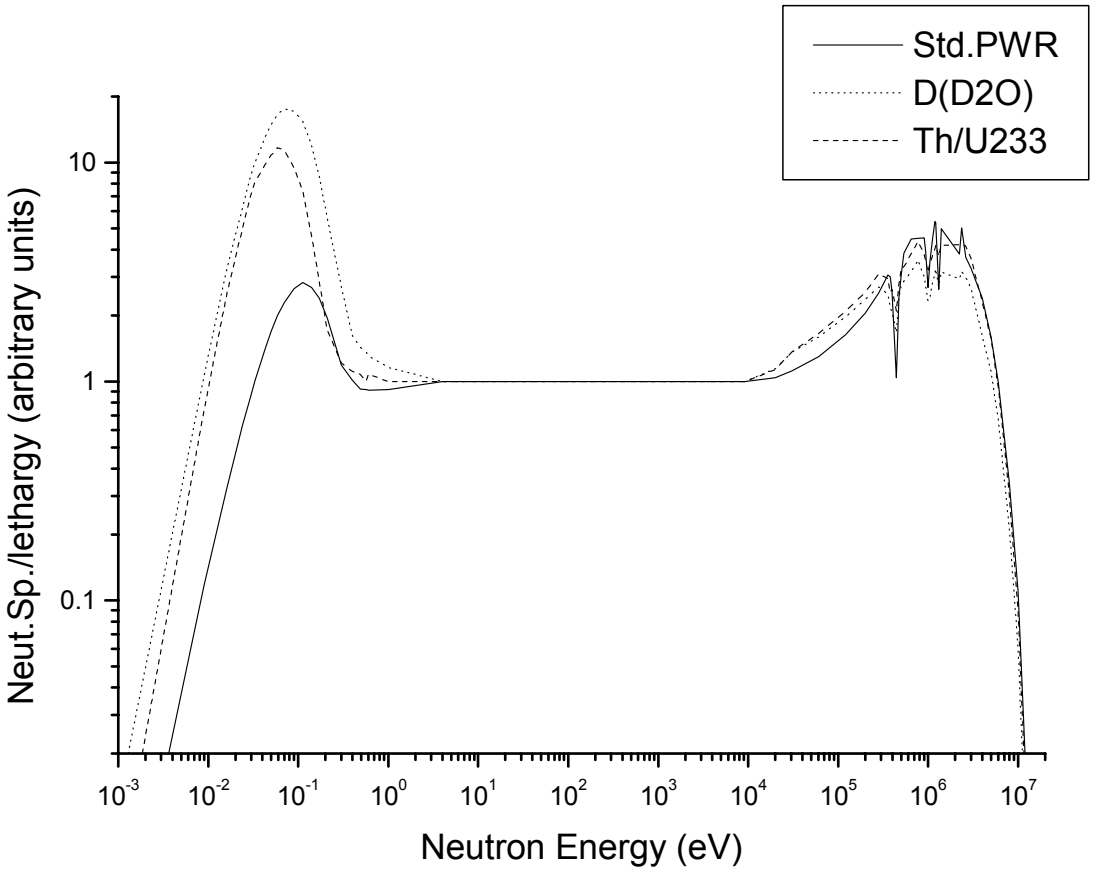

FIG. 10.1. Neutron flux spectra.

10.2. Neutron current spectra

The multi-group WIMS-D libraries include transport-corrected total cross sections, as is generated from P1-multi-group scattering cross sections weighted with a typical neutron current spectrum. The choice of the weighting spectrum for this process is normally simplified by choosing the "British current spectrum" [10.2]. For 172 group libraries and deuterium in D_2O, the B1-equations are solved to generate current spectra for typical systems using the neutron multi-group transport calculation program CONDOR [10.3]. The shapes of the current spectra for HWR differ significantly from the LWR spectra. These differences are reflected in the calculated parameters for HWR lattices when the HWR spectrum is used to generate the cross section library.

10.2.1. Neutron current spectra generation

A cell transport code such as WIMS-D or CONDOR must be able to calculate the criticality spectrum for at least the homogenised assembly. This "leakage" spectrum is used to take into account the energy differences between criticality and infinite-medium flux for subsequent determination of the diffusion coefficients and burnup. The B1-method is normally used in multi-group form to obtain the "leakage" spectrum and define the flux and current spectrum [10.4]. The current spectrum calculated by means of the B1-method can be used to obtain the transport correction for the multi-group cross-section library so long as:

1) the number of groups adopted for the B1-calculation is large enough compared with the number of groups of the final library to give sufficient energy resolution, and
2) the P1-cross sections for all the important isotopes are used to solve the B1 equations for a particular lattice.

Hence, the WIMS-D code is unsuitable for this purpose, because of the restriction to 69 energy groups and the P1-cross sections are only available for H, D, C and O. CONDOR can be used with greater confidence to determine the neutron current spectrum for transport corrections prior to the generation of WIMS-D libraries: this code can use a cross section library with any number of groups and can accommodate all materials with P1-cross sections. This code has been used with a 190 group library to obtain the B1-current spectra for two typical lattices.

10.2.2. Calculations

The two referenced lattices modelled with CONDOR to give B1-option leakage spectrum were:

- LWR-Rowlands [10.5]
- typical CANDU-HWR lattice,
- CADNU-ZED2 lattice [10.6].

Calculations were performed with 190-energy group library.

10.2.3. Results

A program has been written to process the B1-current spectra output from CONDOR (normalisation and group averaging over the WIMS-D 69 standard groups and 172 groups, and format of the tables for plotting). Figures 10.2 and 10.3 show the different current spectra used to prepare the 69 and 172 group WLUP libraries.

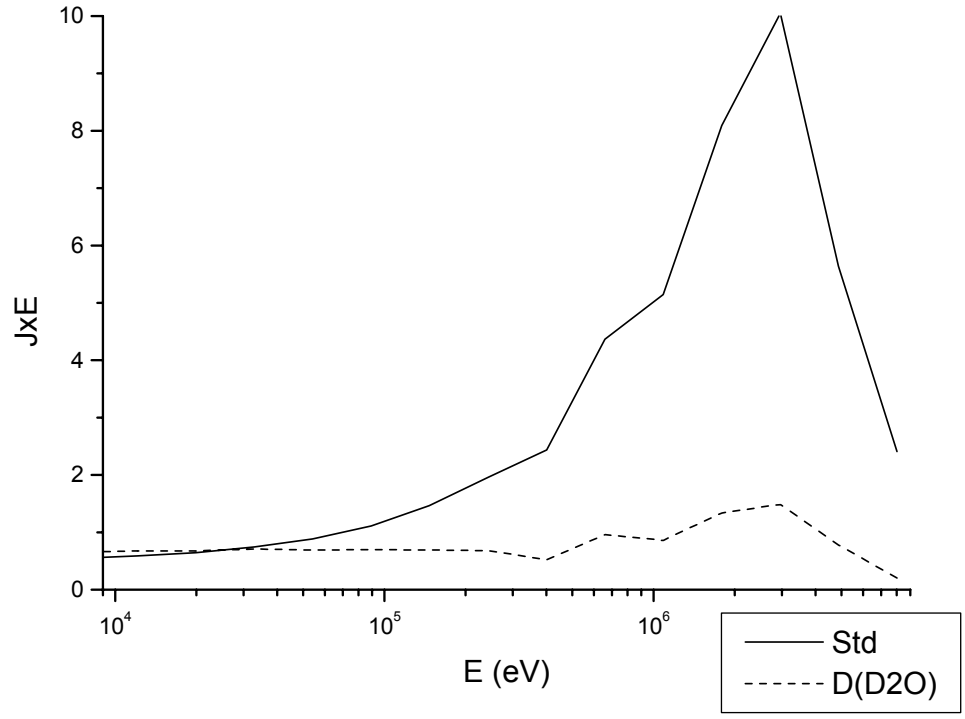

*FIG. 10.2. J*E for 69 group libraries.*

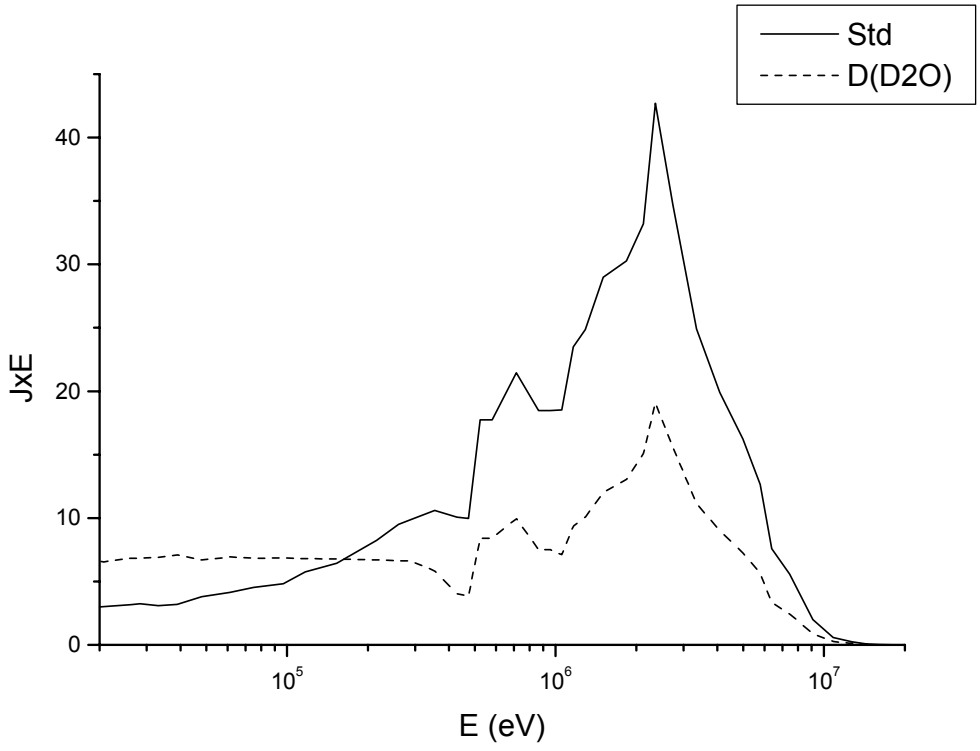

*FIG. 10.3. J*E – 172 group libraries.*

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11. ENERGY STRUCTURE

69 group library
The original WIMS-D structure is used, with 14 fast groups between 9.118 keV and 10 MeV, 13 resonance groups between 4 eV and 9.118 keV, and 42 thermal groups from 0 and 4 eV. Table 11.1 lists the energy limits of the groups.

172 group library
The structure of new commercial WIMS libraries has been adopted, with 45 fast groups between 9.119 keV and 19.64 MeV, 47 resonance groups between 4 eV and 9.119 keV, and 80 thermal groups from 10^{-5} to 4eV. Table 11.2 lists the energy limits of the groups.

Table 11.3 lists the correspondence between 172 and 69 energy groups.

Table 11.1. 69 ENERGY GROUP STRUCTURE

Fast groups		Resonant groups		Thermal groups	
Group	**Emax (eV)**	**Group**	**Emax (eV)**	**Group**	**Emax (eV)**
1	1.00000E+07	15	9.11800E+03	28	4.00000E+00
2	6.06550E+06	16	5.53000E+03	29	3.30000E+00
3	3.67900E+06	17	3.51910E+03	30	2.60000E+00
4	2.23100E+06	18	2.23945E+03	31	2.10000E+00
5	1.35300E+06	19	1.42510E+03	32	1.50000E+00
6	8.21000E+05	20	9.06899E+02	33	1.30000E+00
7	5.00000E+05	21	3.67263E+02	34	1.15000E+00
8	3.02500E+05	22	1.48729E+02	35	1.12300E+00
9	1.83000E+05	23	7.55014E+01	36	1.09700E+00
10	1.11000E+05	24	4.80520E+01	37	1.07100E+00
11	6.73400E+04	25	2.77000E+01	38	1.04500E+00
12	4.08500E+04	26	1.59680E+01	39	1.02000E+00
13	2.47800E+04	27	9.87700E+00	40	9.96000E-01
14	1.50300E+04			41	9.72000E-01
				42	9.50000E-01
				43	9.10000E-01
				44	8.50000E-01
				45	7.80000E-01
				46	6.25000E-01
				47	5.00000E-01
				48	4.00000E-01
				49	3.50000E-01
				50	3.20000E-01
				51	3.00000E-01
				52	2.80000E-01
				53	2.50000E-01
				54	2.20000E-01
				55	1.80000E-01
				56	1.40000E-01
				57	1.00000E-01
				58	8.00000E-02
				59	6.70000E-02
				60	5.80000E-02
				61	5.00000E-02
				62	4.20000E-02
				63	3.50000E-02
				64	3.00000E-02
				65	2.50000E-02
				66	2.00000E-02
				67	1.50000E-02
				68	1.00000E-02
				69	5.00000E-03

TABLE 11.2. 172 ENERGY GROUP STRUCTURE

Fast groups		Resonant groups		Thermal groups			
g	**Emax (eV)**	**g**	**Emax (eV)**	**g**	**Emax (eV)**	**g**	**Emax (eV)**
1	1.96403E+07	46	9.11882E+03	93	4.00000E+00	140	4.33000E-01
2	1.73325E+07	47	7.46586E+03	94	3.38075E+00	141	4.00000E-01
3	1.49182E+07	48	5.53085E+03	95	3.30000E+00	142	3.91000E-01
4	1.38403E+07	49	5.00450E+03	96	2.76792E+00	143	3.50000E-01
5	1.16183E+07	50	3.52662E+03	97	2.72000E+00	144	3.20000E-01
6	1.00000E+07	51	3.35463E+03	98	2.60000E+00	145	3.14500E-01
7	8.18731E+06	52	2.24867E+03	99	2.55000E+00	146	3.00000E-01
8	6.70320E+06	53	2.03468E+03	100	2.36000E+00	147	2.80000E-01
9	6.06531E+06	54	1.50733E+03	101	2.13000E+00	148	2.48000E-01
10	5.48812E+06	55	1.43382E+03	102	2.10000E+00	149	2.20000E-01
11	4.49329E+06	56	1.23410E+03	103	2.02000E+00	150	1.89000E-01
12	3.67879E+06	57	1.01039E+03	104	1.93000E+00	151	1.80000E-01
13	3.01194E+06	58	9.14242E+02	105	1.84000E+00	152	1.60000E-01
14	2.46597E+06	59	7.48518E+02	106	1.75500E+00	153	1.40000E-01
15	2.23130E+06	60	6.77287E+02	107	1.67000E+00	154	1.34000E-01
16	2.01897E+06	61	4.53999E+02	108	1.59000E+00	155	1.15000E-01
17	1.65299E+06	62	3.71703E+02	109	1.50000E+00	156	1.00000E-01
18	1.35335E+06	63	3.04325E+02	110	1.47500E+00	157	9.50000E-02
19	1.22456E+06	64	2.03995E+02	111	1.44498E+00	158	8.00000E-02
20	1.10803E+06	65	1.48625E+02	112	1.37000E+00	159	7.70000E-02
21	1.00259E+06	66	1.36742E+02	113	1.33750E+00	160	6.70000E-02
22	9.07180E+05	67	9.16609E+01	114	1.30000E+00	161	5.80000E-02
23	8.20850E+05	68	7.56736E+01	115	1.23500E+00	162	5.00000E-02
24	6.08101E+05	69	6.79040E+01	116	1.17000E+00	163	4.20000E-02
25	5.50232E+05	70	5.55951E+01	117	1.15000E+00	164	3.50000E-02
26	4.97871E+05	71	5.15780E+01	118	1.12535E+00	165	3.00000E-02
27	4.50492E+05	72	4.82516E+01	119	1.11000E+00	166	2.50000E-02
28	4.07622E+05	73	4.55174E+01	120	1.09700E+00	167	2.00000E-02
29	3.01974E+05	74	4.01690E+01	121	1.07100E+00	168	1.50000E-02
30	2.73237E+05	75	3.72665E+01	122	1.04500E+00	169	1.00000E-02
31	2.47235E+05	76	3.37201E+01	123	1.03500E+00	170	6.90000E-03
32	1.83156E+05	77	3.05113E+01	124	1.02000E+00	171	5.00000E-03
33	1.22773E+05	78	2.76077E+01	125	9.96000E-01	172	3.00000E-03
34	1.11090E+05	79	2.49805E+01	126	9.86000E-01		1.00000E-05
35	8.22975E+04	80	2.26033E+01	127	9.72000E-01		
36	6.73795E+04	81	1.94548E+01	128	9.50000E-01		
37	5.51656E+04	82	1.59283E+01	129	9.30000E-01		
38	4.08677E+04	83	1.37096E+01	130	9.10000E-01		
39	3.69786E+04	84	1.12245E+01	131	8.60000E-01		
40	2.92830E+04	85	9.90555E+00	132	8.50000E-01		
41	2.73944E+04	86	9.18981E+00	133	7.90000E-01		
42	2.47875E+04	87	8.31529E+00	134	7.80000E-01		
43	1.66156E+04	88	7.52398E+00	135	7.05000E-01		
44	1.50344E+04	89	6.16012E+00	136	6.25000E-01		
45	1.11378E+04	90	5.34643E+00	137	5.40000E-01		
		91	5.04348E+00	138	5.00000E-01		
		92	4.12925E+00	139	4.85000E-01		

TABLE 11.3. CORRESPONDENCE BETWEEN 172 AND 69 ENERGY GROUPS

172-group	69-group	172-group	69-group	172-group	69-group
8	1	77	24	140	47
11	2	81	25	142	48
14	3	84	26	143	49
17	4	92	27	145	50
22	5	94	28	146	51
25	6	97	29	147	52
28	7	101	30	148	53
31	8	108	31	150	54
33	9	113	32	152	55
35	10	116	33	155	56
37	11	117	34	157	57
41	12	119	35	159	58
43	13	120	36	160	59
45	14	121	37	161	60
47	15	123	38	162	61
49	16	124	39	163	62
51	17	126	40	164	63
54	18	127	41	165	64
57	19	129	42	166	65
61	20	131	43	167	66
64	21	133	44	168	67
67	22	135	45	170	68
71	23	137	46	172	69

12. WIMSD-5B EXTENSIONS

The major modifications and extensions are:

(1) Upper limit extended from 69 to 200 energy groups
(2) Upper energy of the first fast group extended from 10 to 20 MeV
(3) Number of allowed resonance groups extended from 13 to 55
(4) Number of allowed resonant isotopes increased to 30
(5) Maximum number of nuclides in the library increased to 300
(6) Maximum number of burnable nuclides in WIMS-D input increased to 60
(7) Modification to handle WIMS-D libraries with an extended format that includes multiple product-nuclei reactions

12.1. Purpose of extensions

The newly developed library has an increased number of isotopes and exists in two versions; with 69 and 172 library groups. All versions of the standard WIMS-D code [12.1], including WIMSD-5B [12.2], have been developed for a library with a maximum of 69 groups. Although the number of library groups used in WIMS-D calculations is read from that library, there exists a set of auxiliary arrays in the code with dimensions assuming the use of a 69-group library. Those arrays had to be identified and modified if the extended 172-group library was to be used. Furthermore, arrays also exist with dimensions depending on the number of fast, resonance and thermal groups, which had to be revised. A similar situation existed with the number of isotopes in the library, i.e., the total number of isotopes, the number of fissionable isotopes and the number of fission products, which are read from the library. Although formally taking library values, all of these arrays are used in particular subroutines in an indirect way.

Thus, the main goal of the WIMSD-5B code modifications has been to enable the code to deal with the 172-group cross section library. Some minor changes had to be introduced to make all the code options work with an increased number of isotopes. Finally, the arrays with fixed dimensions have been included in the general scheme of dynamic memory organization adopted in the WIMS-D code

A new option proposed by Jerdev has been added, that offers the option of multiple product nuclei in the burnup chains. Standard WIMS-D is limited to single capture and decay products. Modifications were needed in both the code and the library to introduce the possibility of branching in WIMSD-5B when a library with above mentioned extensions is applied (currently released WIMS-D libraries do not use this feature). These extensions comprise 'virtual' isotopes that contain excitation cross sections corresponding to the additional burnup channels. The convention has been adopted that an isotope with ID $\geq$ 100000 is defined as virtual, and represents a copy of the isotope with ID $- N \times 100000$ (N = 1...9) labelled 'base'. This approach is illustrated in Fig.12.1 with one base (^{241}Am) and two virtual isotopes (IDs 109241 and 209241). The base isotope in Fig.12.1 leads to plutonium, while the virtual isotopes allow for build-up of Am and Cm.

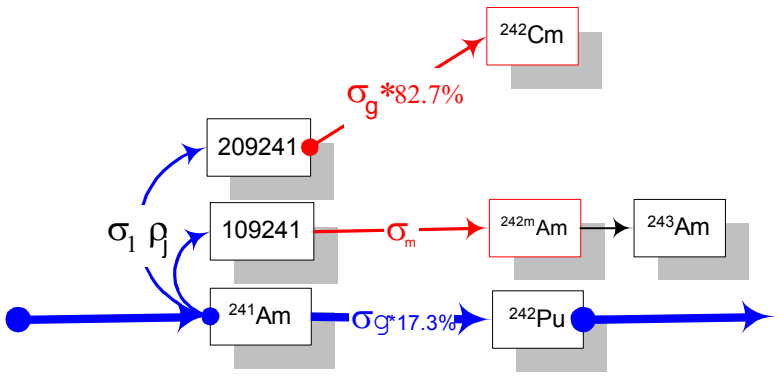

FIG. 12.1. Base isotope Am-241, virtual 109241 and 209241.

During the burnup chain execution, the isotope with ID ≥ 100000 may be identified, and then the relevant base isotope is searched and the number density taken as the number density of a respective virtual isotope. A convention has been assumed to allow for using library cross sections of the base isotopes for the virtual isotope(s) if the data for the latter are missing in the library: if the library capture cross sections of the virtual isotope are less or equal to zero, the capture cross sections for the virtual isotope are copied from the respective base isotope, otherwise they are taken from the library. Virtual isotopes then enter the regular procedure for reaction rates calculation and burnup equation integration, giving the respective contributions to the daughter isotopes not accounted for in the standard WIMS approach. This group of code modifications does not influence results obtained with the standard libraries.

Note that the FOND22 library prepared by Jerdev is not equivalent to the WIMS/ABBN library - latter has two additional features improving the results for reactor systems with plutonium:

- resonance self-shielding of ^{242}Pu in the thermal energy region is treated more accurately by redefineng a number of thermal groups as resonance groups,
- fission spectrum of ^{239}Pu is given more weight.

Finally, three modifications proposed by Fink [12.3] have been added:

(1) updated values of Avogadro's number to 0.6022142E24 and electron charge to 1.6021765E-19 C (1998 values) [12.4], avoiding some discrepancies when weight fractions are adopted in benchmark problems;
(2) small correction in HFS routine to avoid precision problems with thin annuli (i.e., all local variables expressed in double precision);
(3) change of the default value of TOLERANCE card from 1.e-4 to 1.e-5.

The extended code has been tested on 16 standard WIMSD-5B test cases, and the set of WLUP-CRP benchmarks has also been calculated. These results are discussed in detail below because some of them imply limitations, of which code users should be aware.

12.2. Programming details of code extension

The basic assumption underlying the work on the WIMSD-5B code extension has been to leave untouched the original version distributed by NEA DATA BANK [12.2]. For that reason the modifications have been prepared in the form of an UPDATE deck, composed of three files. The source deck is distributed with file identification **src** and comprises the program divided into decks, each of them preceded by the card ***ident namedeck** and with all cards in the deck named and numbered in columns 73 through 80. This division of the WIMSD-5B follows the original code modules, and hence the **namedeck**s have the respective

names of those modules. Besides the source deck, the code package includes file **upn**, with modifications that refer to the address in **src** given as **namedeck.xxxx**, and **xxxx** denoting the card number in the **namedeck**. The third member of the code package is the auxiliary Fortran program **upd**, that has to be compiled and run. This program takes the **upn** deck and introduces the modifications into the program deck **src**, resulting in a set of Fortran programs divided into modules corresponding to **namedeck**s that create the modified WIMSD-5B code and have to be compiled in a standard way. The modifications introduced by the above procedure can be easily traced in the updated modules as they are identified in columns 73 through 80.

The above procedure has been made available by the author of the **upd** code (MacFarlane, Los Alamos National Laboratory). He has also agreed that the **upd** code be included with the WIMSD-5B package as distributed by the NEA Data Bank.

The first group of modifications to WIMSD-5B with the identifier **upsrcl**, **l** = 1,2,3 is connected with the field-length definition (**l** = 1), timing procedures (**l** = 2,3), and avoids an error in subroutine **readda** that is experienced with some compilers (**l** = 4).

Another set of changes extends the code capabilities, and is denoted by the identification labels **upl,** with **l** = 1, 2, ... to distinguish different types of modification.

– **up1** - corrections refer to the increase in the allowed number of resonance isotopes. The change has been introduced through the use of the statement **parameter (nrmax = 30)**. Thus, the main routines in the relevant modules have this command in their headings, while numerous subroutines, which previously had fixed numbers for array dimensions, now make use of the variable **nrmax**. This approach permits easy further changes in the limitation of a variable, necessitating only the substitution of the present number 30 in the parameter statement. The re-allocation of variables has been defined in the module (deck) prelud. Changes are also required in a set of other modules, and they have been introduced with the identifiers shown in Table 12.1.

TABLE 12.1. CHANGES INTRODUCED TO MODIFY THE MAXIMUM NUMBER OF RESONANT ELEMENTS

Module / deck	ident	subroutines
prelud	up1	prelude, nuprel
chain1	up1a	Datag
chain2	up1b	Two
chain3	up1c	chn03, resalt, resint, three
chain4	up1d	Four
chain5	up1e	ichn05
chai12	up1f	ingres, wimsbx
chai15	up1g	datorg, react
chai16	up1h	chn16, intsig

TABLE 12.2. CHANGES INTRODUCED IN ARRAY DIMENSIONS FOR CONSISTENCY AND IN THE PRINTOUT

Module / deck	ident	Module / deck	ident
Prelud	up2	chain12	up2d
Chain2	up2a	Wimsdl	up3
Chain5	up2b	Prelud	up4
Chain8	up2c		

-**up2** - update some array dimensions for consistency. The identifiers and subroutines in which these changes have been introduced are shown in Table 12.2.

−**up3** - creates printout 'WIMSD-5B' at the start of the job.

−**up4** - restores chain4 printout under the option CELL 6, and deactivates the printout with the option CELL 5.

−**up5** - corrects an error in the original version of the code, and implements Fink modifications.

−**up6** - comprises all changes necessary to extend the number of energy groups and unify the treatment of variables in the common block (cf. Table 12.3). The extended library may have up to 200 groups and 55 resonance groups, introduced within **prelud** through the instruction **parameter (ng=200**) and **parameter (ng2=55).** A check is made of the numbers read from the library at each run; if this number exceeds the limiting values, a suitable message is printed and the code execution is terminated. This approach allows for an easy further extension of the number of energy groups, and is consistent with the increase in the number of resonance elements.

The following additional changes were found to be necessary in the variables that adopted implicitly the specified size of energy groups:

- chain1: increase the size of a local array needed to read group dependent bucklings;
- chain1: pseudo tape option (input card STORE);
- an additional check for the number of library groups; if > ng, the code stops with informative printout;
- an additional check: if the first entry on the STORE card exceeds the available memory, the code stops with informative printout;
- chain4: extension of dimensions of local arrays using the parameter statement in subroutine DIFENR – a local variable nng=ng has been introduced;
- chain5: the auxiliary array WL has been made local with the usage of parameter (ll=500) to define size;
- chain14: a minor correction has been made to the format of the printout of the final k-infinity where only two digits had been foreseen for the number of library groups.

TABLE 12.3. CHANGES INTRODUCED TO MODIFY THE MAXIMUM NUMBER OF LIBRARY GROUPS, IDENT UP6

Module / deck	Subroutines	Total no. groups	No. res. groups	Dynamic dimen.
Prelud	nuprel, prelud	+	+	+
Chain1	Datag	+		
Chain2	Ichn02, two			+
Chain3	ichn03, three, resalt, dasqhe		+	+
Chain4	Difenr	+		
Chain5	ichn05, five	+		+

Increases in the number of resonance groups necessitated the following modifications in chain3:

- introduction of a local variable nng2=ng2 through the **parameter** statement in several subroutines.
- increase of local array GARBIJ with respective comment in the code, which was achieved through the parameter (ll=330) statement to facilitate possible extensions;
- modification of treatment of arrays in the secondary condensation under ICAR option.

The last modification consisted of the allocation of 3 new arrays in the memory: **xxfs**, **idno** and **rnuf**. While these arrays had not been included previously in the general WIMS treatment of COMMON block, they had originally been introduced into the labelled COMMON block with fixed dimensions that were determined by the number of resonance isotopes and resonance groups adjusted to the '86' British library by the authors of the ICAR option. They are now included in the general approach of dynamic array allocation, invoking a whole set of coding modifications in PRELUD as well as in the DIMENSION and COMMON statements.

–**up7** - The extension in the number of fuel materials required only minor changes to chain12, as the limitations were caused by the printout of burnup results. Two modifications were made in subroutines PPEAK and INGRES:

- number of fuel materials has been extended up to 100 in PPEAK;
- extensions have been applied in INGRES to the number of materials undergoing burnup and to the isotopes taking part in the burnup process. (new limits are 60 and 300, respectively).

These extensions required the introduction of **parameter** statements to avoid the fixed dimensioning of arrays.

–**up8** - The expanded burnup calculations required changes only in subroutine WIMSB4 of chain12. Two sets of statements have been introduced:

- at the beginning of WIMSB4, a search for a nuclide with ID ≥ 100000 is carried out,followed by a search for a base isotope - a warning is printed if the latter is not found. Density updates for each virtual isotope are made and, if none of the capture cross sections for the virtual isotope exceed zero, their values are taken from the respective data for the base isotope.
- number densities of virtual isotopes are cleared after solution of the burnup equation to ensure the usage of self-shielded few-group cross sections averaged over the correct neutron spectrum in each burnup step.

–**up9** - The code user is given the option to avoid two formal requirements in the code input for burnup calculations:

- mandatory specification of the resonance table number for resonant isotopes with several such tables; by default the first resonance table will be used and the printout will denote the isotope ID with ".0" suffix.
- mandatory specification of small but non-zero concentration for resonance isotopes, with the suffix differing from ".0" and taking part in the burnup process (i.e., with zero concentration at the start of burnup calculations).

12.3. Testing the extended version of the code

The modification version of WIMSD-5B as described above has been tested on 16 standard test cases distributed with the code. Different libraries have been used:

- British '86' library delivered to NEA Data Bank, together with the code to show what differences can be expected for the test cases if calculated on different computers and operating systems.
- 69-group library based on ENDFB-VI, and developed through IAEA CRP.
- 172-group library based on ENDFB-VI, and developed through IAEA CRP.
- 69-group library based on ENDFB-VI, with additional isotopes according to the extended convention of Jerdev.
- 69-group library based on FOND22.
- 69-group library based on FOND22, with additional isotopes according to the extended convention of Jerdev.

Switching between 69 to 172-group libraries requires modifications to the input. Thus, modifications have to be made to the NGROUPS, FEWGROUP, THERMAL, ALPHA and PARTITION cards (if these cards are included in the input). The correspondence between the 172-group and 69-group schemes are based on their respective group boundaries, as given in Table 11.3.

WLUP-CRP benchmarks have been calculated for the same libraries as used in standard test cases. These calculations have been carried out with the first three of the libraries listed above, while using the same number of energy groups in the transport calculations as library groups. Additionally, calculations were performed using the 172-group library in 69 transport groups.

The above tests demonstrated that the code is functional. However, these studies also revealed several drawbacks to the test cases, which necessitated modifications to be run with extended libraries. Changes to the test cases are listed in Table 12.4, although the value of the 'nisotopes' input card depends on the library (value of 92 should be satisfactory for presently developed libraries). Besides, the pseudo-tape option cannot be used with a 172-group library unless the size of the memory required for the calculations is substantially increased (currently set to 1000000). A suitable informative message has been coded into the program.

TABLE 12.4. CHANGES TO BE INTRODUCED TO THE STANDARD WIMSD-5B TEST CASES

Test case	original text	correction for CRP library
test04	nisotopes 60	nisotopes 86
test06	store 200000	store 600000
test12	4157 (Gd-157)	2157
test13	9056 (SS)	follow composition of SS

A very important modification is needed in test06, which verifies the **pseudo tape** option and the **library** option accompanied by **replace**, **increase**, **multiply**. The first option necessitates the first entry on the STORE input card to be adjusted to the library size. However, the second option is much more troublesome, with the inclusion of the library modifications (as well as the library printout) through specification of direct addresses index of respective cross sections. These specifications have to be taken from the library map; each library has a

different map of addresses, and therefore test06 data are restricted only to the '86' library. The simplest way to run test06 for other libraries is to remove the options **replace**, **increase**, **multiply** and treat as a test for **pseudo tape** and **library** options only. An even better solution is to make one run with the **library** option, note the relevant addresses, and substitute them into **replace**, **increase**, **multiply** options for the next run.

When applying the 172-group library, difficulties with convergence of numerical solutions to the transport equation have been observed that are not encountered with the 69-group libraries. These problems appeared on the second level of WIMS-D calculations, (i.e., main transport routine using DSN or PERSEUS) and/or the third level (i.e., solution accounting for the leakage). However, an important point of note is that the first level was successfully achieved in all cases (i.e., cell) multi-group solution for the pin cell.

Convergence fails for fuel regions composed entirely of uranium. A few-group structure is recommended in such cases, with the resonance region averaged to the 13 groups as specified in the 69-group library. The detailed resonance structure of the 172-group library is then still used for the evaluation of resonance parameters in the pin cell calculation (i.e., in the first step of WIMS calculations). Their averaging to fewer groups in subsequent modules of the code can help to avoid the lack of convergence.

Difficulties with numerical convergence often occur if a material region is represented in the input by several regions with the same material composition. Hence, the specification of adjacent regions with the same material should be avoided.

REFERENCES

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[12.2] WIMSD5, NEA Data Bank Documentation, No. 1507/02, 1996.

[12.3] FINK, J., Modifications made to WIMSD5B source, Nucleoelectrica Argentina S.A., NT/FN/01/003, April 2001.

[12.4] Journal of Physical and Chemical Reference Data, Vol.28, No. 6, pp. 1713-1852, 1999.

13. PROCESSING OPTIONS FOR EVALUATED NUCLEAR DATA

A brief history of the codes and methods development can be found in Chapter 1. The main codes for data processing are:

- NJOY Nuclear Data Processing System (Version 99.65) to generate multigroup constants for WIMS-D from the evaluated nuclear data files,
- AVRFPY code to process fission product yield and decay data,
- WILLIE code to manage the WIMS-D library,
- NRSC system of codes to calculate the Goldstein-Cohen parameters,
- ENDF pre-processing codes for dosimetry cross sections,
- WIMSIE to convert PrePro output for dosimetry reactions into WIMS-D format,
- XnWlup for interactive visualisation of the cross sections in WIMS-D libraries.

There also exist a number of additional utility codes for performing minor data manipulation, post-processing of WIMS-D code outputs, and sorting and comparing results.

13.1. NJOY data processing sequence

The following modules of the NJOY code system are invoked in sequence for WIMS-D library generation: MODER-RECONR-BROADR-UNRESR/PURR-THERMR-GROUPR-WIMSR. Both the main function and input parameters are briefly described below (for details, see the NJOY-Manual [13.1]).

MODER: a file format conversion utility that requires no additional explanation.

RECONR: cross section reconstruction.
ERR: resonance reconstruction tolerance criterion of 0.1% was chosen for all isotopes; all other options took the default values.

BROADR: Doppler broadening.
ERRTHN Tolerance for thinning of 0.1% was used for all isotopes.
The temperatures were selected to cover the range of typical spatial regions where the isotope is likely to be used. More details were given in the temperature mesh for moderators (where the temperature list is governed by the available temperatures in the scattering law library) and resonance absorbers. The same temperature input list is also required by UNRESR, THERMR and GROUPR.

PURR: unresolved resonance data processing for the main resonant isotopes.
Although much slower to run than UNRESR, (which serves a similar purpose), PURR was selected because of superior underlying physics. Furthermore, UNRESR produced non-monotonic self-shielding factors at moderately high dilutions, and therefore the use of this module was restricted to less important nuclides. Principal input parameters for PURR are the temperature list and the Bondarenko background cross section mesh. The same values of these parameters are also used in GROUPR.

UNRESR: unresolved resonance data processing.
This module is used in place of PURR for some fission products and other less important isotopes.

THERMR: thermal scattering law.
Free gas model is used for all materials except the main moderators: H in H_2O, H in ZrH, D in D_2O, Be and C - thermal-scattering law data are taken from the corresponding evaluated data file for these materials.
TOL: angular distribution tolerance criterion of 0.1% is used for all materials.
NBIN: number of equi-probable angles is 12 for all materials.
EMAX: maximum energy for thermal treatment is set to 4.0 eV, which is the boundary condition for the thermal range in the WIMS-D library.

GROUPR: group-averaged data preparation.
IGN: group structure parameter is set to 16 (x-mas scheme) for 172 group libraries and to 9 (epri-cpm) for 69 group libraries. Tables with group structure for both the 69 and 172 group libraries are included in Chapter 11.
IWT: weighting spectrum parameter is 1 for all cases read in pointwise form from input (spectra are shown in Chapter 10), and have 1/E form in the epithermal range. IWT is set to negative for resonant isotopes in order to activate the flux calculator for homogeneous mixtures of the resonant isotope with hydrogen from 0.1 eV up to the upper limit of the resolved resonance range (see Chapter 3); the narrow resonance approximation is used above this energy. NJOY input instructions for the flux calculator require the following parameters:
EHI: upper energy limit to which the flux calculation is applied [eV],
SIGPOT: potential cross section of the resonant absorber [barns],
NFLMAX: maximum number of points at which the neutron spectrum is generated with the flux calculator,
LORD: Legendre order is 1 for all cases.

The Bondarenko background cross sections were chosen according to the dimensions and compositions at which the materials are likely to be used. Values used for WIMSD-IAEA libraries are included in Tables 6.1. and 6.2. of Chapter 6.

Table 13.1. lists the flux calculator parameters for materials in the WIMSD-IAEA libraries.

WIMSR: formatting multigroup cross sections for WIMS.
The relevant input options for this module are:

SGREF:reference background cross section,
SIGP:potential cross section,
LAMBDA: values of Goldstein-Cohen λ parameter,
JPI: current weighting spectrum flag,
ISOF: fission spectrum flag,
IBURN: burnup data flag.

While all these parameters are described and the adopted values tabulated in previous chapters, remarks are also given here.

Reference background cross section (SGREF): WIMS-D library format only allows self-shielding in the resonance energy range for the resonance isotopes, which appear in the fuel, and even here the self-shielding effects are only considered for absorption and fission. If important for other data types, shelf-shielding should be incorporated by defining a reference value of the background cross section, so that appropriate cross sections can be picked when assembling the data for the WIMS-D library. Clearly, only one set of cross sections can be entered, therefore the selection of reference SGREF must be exercised according to the conditions for which the isotope in question is most likely to be used. Selected reference values for each isotope are included.

Potential cross section (SIGP): potential cross section is calculated from the atomic radius in ENDF file MF = 2 and is constant for isotopes with tabulated resonance integrals; potential cross section for other materials is equal to the energy-dependent scattering cross section, flagged by input (SIGP = 0). This convention is consistent with the WIMS approach, and the adopted values are included in Table 6.2. of Chapter 6.

The rest of the parameters are discussed in other chapters.

TABLE 13.1. FLUX CALCULATOR PARAMETERS

Isotope	EHI [eV]	SIGPOT [barns]	Isotope	EHI [eV]	SIGPOT [barns]	Isotope	EHI [eV]	SIGPOT [barns]
36-Kr-83	1.4873e2	6.2126	54-Xe-134	9.1180e3	3.5099	72-Hf-nat	1.48728e2	7.5867
42-Mo-95	1.4251e3	6.0477	54-Xe-135	1.4873e2	3.5491	72-Hf-176	3.6726e2	8.2489
43-Tc-99	3.5191e3	4.5564	54-Xe-136	9.1180e3	4.5239	72-Hf-177	1.4873e2	6.4331
44-Ru-101	9.0690e2	4.2436	55-Cs-133	9.06898e2	3.5299	72-Hf-178	1.4251e3	7.5223
44-Ru-103	9.1880e3	3.9268	55-Cs-134	1.48728e2	3.5299	72-Hf-179	1.4873e2	7.5855
44-Ru-106	7.5501e1	3.3415	55-Cs-135	1.48728e2	3.5299	72-Hf-180	2.2395e3	8.2184
45-Rh-103	3.5191e3	4.8911	55-Cs-137	7.5501e1	3.2701	73-Ta-181	2.2395e3	7.6454
45-Rh-105	4.0	4.8413	60-Nd-143	3.5191e3	3.7831	74-W-nat	3.6726e2	9.0780
46-Pd-105	9.06898e2	5.4739	60-Nd-145	3.5191e3	4.7165	90-Th-232	2.2395e3	13.1261
46-Pd-107	9.06898e2	4.1206	61-Pm-147	7.5501e1	4.0979	91-Pa-231	7.5501e1	11.2522
46-Pd-108	1.48728e3	4.1462	62-Sm-147	9.069e2	7.7726	91-Pa-233	1.5968e1	13.1299
47-Ag-107	5.5300e3	5.7575	62-Sm-148	3.5191e3	6.7820	92-U-232	7.5501e1	12.0687
47-Ag-109	5.5300e3	6.2198	62-Sm-149	7.551e1	8.657	92-U-233	4.8052e1	12.2989
48-Cd-nat	3.6726e2	4.8103	62-Sm-150	1.4251e3	7.2236	92-U-234	1.4251e3	12.0113
48-Cd-113	9.06898e3	5.7039	62-Sm-151	1.4873e2	5.9970	92-U-235	4.4713e2	11.6070
49-In-nat	9.06898e2	5.5572	62-Sm-152	3.5191e3	8.3478	92-U-236	1.4251e3	11.2615
49-In-115	1.4251e3	5.0695	63-Eu-151	7.55e1	9.7314	92-U-237	1.4873e2	11.3949
50-Sn-112	1.4251e3	4.8394	63-Eu-152	4.8052e1	9.7314	92-U-238	1.785e3	11.8237
50-Sn-114	2.23945e3	4.8962	63-Eu-153	7.55e1	8.4496	93-Np-237	1.4873e2	11.4369
50-Sn-115	9.06898e2	4.7917	63-Eu-154	4.8052e1	9.7314	93-Np-239	3.67262e2	10.4979
50-Sn-116	1.4251e3	4.6389	63-Eu-155	2.77e1	6.8813	94-Pu-238	1.4873e2	10.9999
50-Sn-117	2.23945e3	4.5377	64-Gd-154	2.2395e3	7.6744	94-Pu-239	6.222e2	10.7600
50-Sn-118	3.5191e3	4.4993	64-Gd-155	1.4873e2	5.7493	94-Pu-240	9.06898e2	9.2474
50-Sn-119	9.06898e2	4.1410	64-Gd-156	1.4251e3	7.9722	94-Pu-241	7.5501e1	12.0000
50-Sn-120	5.5300e3	4.5239	64-Gd-157	1.4873e2	4.1863	94-Pu-242	9.06898e2	10.5000
50-Sn-122	5.5300e3	4.0828	64-Gd-158	5.5300e3	5.3521	94-Pu-242	9.06898e2	10.5000
50-Sn-124	9.1180e3	4.3744	66-Dy-160	1.5968e1	5.3896	95-Am-241	1.4873e2	11.0329
51-Sb-121	1.4251e3	4.4760	66-Dy-161	4.8052e1	5.4120	95-Am-242	1.000e2	11.4369
51-Sb-123	2.2395e3	4.4879	66-Dy-162	3.6726e2	5.4347	95-Am-242m	3.30	11.7694
51-Sb-125	9.877	4.3855	66-Dy-163	3.6726e2	5.4570	95-Am-243	1.4873e2	11.6144
52-Te-127m	9.118e3	3.6	66-Dy-164	1.4873e2	7.2936	96-Cm-242	1.4873e2	10.7518
53-I-127	9.06898e2	4.9577	67-Ho-165	1.4873e2	5.5015	96-Cm-243	4.8052e1	12.2668
53-I-135	9.06898e2	4.812	68-Er-166	3.67262e2	8.2448	96-Cm-244	9.0690e2	14.2109
54-Xe-131	2.2395e3	3.6216	68-Er-167	3.67262e2	7.8427			

13.2. Data processing procedures

Batch data processing procedures were designed with the objective of simplifying the data processing task and input file maintenance:

- A single NJOY master input file contains inputs for all materials to be processed that are separated by special delimiter strings.
- Inputs for individual materials are extracted from the master file with the NJISPL code, which recognises the special input-delimiter strings.
- Multi-group constants for updating the WIMS-D library are generated by running NJOY for all materials in sequence. Although also used for other functions, a special batch procedure (RUNALL) is available for this purpose. See explanations and comments in the RUNALL.BAT source.
- A single set of input instructions is provided for the WILLIE program, which inserts or replaces the multi-group constants in the WIMS-D library.
- A batch procedure (BNCHALL) is available to execute all benchmark test cases.
- Programs, inputs, batch procedures and script files are included on the WLUP CD-ROM, with descriptive comments wherever possible. A brief description of the code and operating instructions for most programs can be retrieved quickly from the source by using a system search utility to list the records beginning with "C-".

13.3. Special issues

Fission cross section of ^{241}Am

The fission channel in ^{241}Am has a threshold, and therefore the capture to fission ratio is strongly spectrum dependent. This ratio may reach a value 124 for well-thermalized lattices and may be as low as 42 for lattices with a high content of degraded plutonium. A typical PWR lattice has a ratio of about 92.

Burnup of ^{241}Am in the WIMS-D library with branching to ^{242g}Am and ^{242m}Am cannot be represented accurately because the WIMS-D library allows only a single capture product to be specified. ^{242m}Am is considered more important from the reactivity point of view, and therefore this branch is treated explicitly. However, ^{242g}Am is important in the formation of ^{242}Cm by decay, leading on to ^{238}Pu. ^{242g}Am production can only be dealt with in WIMS-D by treating this nuclide as a fission product of ^{241}Am with a yield equal to the capture to fission ratio.

Spectrum dependence of the effective ^{242g}Am production is avoided by forcing the shape of the fission cross section to be proportional to the absorption cross section, such that the capture to fission ratio of 92 is approximately conserved for an average lattice. This crude adjustment of the fission cross section is tolerable because ^{241}Am is not an important contributor to reactivity. With the fission cross section forced to be proportional to capture, ^{242g}Am production via an artificial fission product is exact.

FIDLAM has been written by Trkov (and included on WLUP CD-ROM), to adjust the ^{241}Am fission cross section. This program redefines the fission cross section to be proportional to the absorption cross section such that the capture to fission ratio is equal to CFR, a value defined in the DATA statement of the program.

Pseudo fission products to simulate (n, 2n) reaction for ^{238}U, ^{233}U, ^{242}Am and ^{231}Pa

The approach used in the WIMKAL-88 library was adopted to model (n, 2n) production from ^{238}U, ^{233}U and ^{242}Am [13.2]. This model consists of introducing a pseudo fission product with an effective fission yield that represents the ratio of the (n, 2n) to fission reaction rate of the precursor nuclide and zero absorption cross section. A decay constant of unity is assigned to this pseudo fission product, so that in normal burnup calculations this entity goes immediately to an equilibrium concentration and appears as an effective (n, 2n) source in the corresponding burnup equation. The diagram of the actinide chain represents this approach (see Fig. 8.1 of Chapter 8).

REFERENCE

[13.1] MACFARLANE, R.E., MUIR, D.W., The NJOY Nuclear Data Processing System Version 91, LA-12740-M (October 1994). RSICC Package PSR-480. Version 99.56.

[13.2] KIM, J.D., WIMKAL-88. The 1988 Version of the WIMS-KAERI Library, Summary Report, IAEA-NDS-92, Rev. 0., August 1990.

14. BENCHMARKS

Descriptions of the organization, name conventions, contents and documentation of WLUP benchmarks are given in this chapter. Benchmarks objectives and types are discussed, followed by specifications on how to run and compare the results of different WIMS-D libraries, and a brief description of benchmarks and references. Finally, benchmark results for the final WLUP libraries (69 and 172 groups) are presented. Annex I describes the QVALUE program for the calculation of the lattice slowing-down density. Annex II lists the main parameters of the criticality benchmarks, while Annex III contains a list of WLUP-library materials included in the inputs of benchmarks, ordered by temperature, component and material. Annex IV and V provide specifications of the standard and supplementary benchmarks.

14.1. Objectives of WLUP benchmarks

A set of well documented benchmarks has been selected with the following objectives:

(1) test the performance of new WIMS-D libraries generated by WLUP,
(2) comparison of results obtained with libraries generated from different basic nuclear data,
(3) detection of discrepant trends in the results for the main materials.

Discrepancies between measured and calculated integral parameters do not only occur as a result of uncertainties in the basic nuclear data from which the library is generated, but also from format limitations in the library that prevent accurate representation of the data and approximations in the calculational models. Furthermore, errors are associated with the measured parameters due to uncertainties in geometry, material composition, statistical uncertainties in the measurements and other simplifying assumptions.

Special care is required when interpreting the comparisons between measurements and calculations, particularly since most of the benchmark test cases involve lattice pin-cell calculations with input bucklings. Under no circumstances should the performance of a library be judged on the basis of the absolute criticality prediction alone, while relative comparisons between different libraries and general trends are valid estimators.

14.2. How to run the benchmarks

All the benchmarks can be run using the batch file **bnchall.bat**, that calls the WIMS-D program with the appropriate WIMS-D input files and WIMS-D library, analyzes the result with special auxiliary programs and reference experimental results files, and writes a summary file of results with percent differences assigned to the calculated and measured parameters.

The user can run all or a group of benchmarks, with the keyword for the desired benchmark group being entered after the library name if necessary (see comments on bnchall.bat file and the readme file included on the “programs” subdirectory for different options and batch files included for running with 69 or 172 group libraries).

14.3. How to compare results of different WIMS-D libraries

The results of benchmarks obtained with different libraries can be compared using the program **smrlib**, which reads the summary files produced by bnchall.bat and writes a file summarizing the results obtained using several different WIMS-D libraries.

Program **qvalue** has been developed to process SMRLIB output in order to plot the difference in the calculated multiplication factor from reference Δk_{eff} as a function of q-value. More information can be found in Appendix I.

14.4. Benchmark types

There are two sequences of benchmarks: **standard** and **supplementary.** The standard sequence of tests includes a set of benchmarks that can be analysed using just the WIMS-D code. A supplementary sequence of benchmarks may require additional processing such as cross section homogenization, whole core calculations, etc.

The standard sequence of benchmarks is classified in two categories:
(1) **criticality experimental benchmarks** (main parameter compared: k_{eff}),
(2) **burnup benchmarks** (main parameters compared: isotopic concentrations of actinides and fission products as a function of burnup).

The supplementary sequence of benchmarks involves two new categories:
(3) **temperature coefficient benchmarks**,
(4) **whole-core calculation benchmarks**.

14.5. Organization of standard criticality experimental benchmarks

Standard criticality experimental benchmarks are organized by **groups**, **benchmarks** and **cases**.

A **group** is characterized by a well-defined type of fuel and coolant materials; more than one benchmark may be found within a group.

A **benchmark** corresponds to one or more experiments carried out in a certain laboratory or experimental facility, and can include a whole series of measurements (cases) with a similar configuration and change of one or more parameters at a time.

A **case** is a unique well-documented configuration of materials, lattice pitch, geometry and temperature, giving at least the experimentally-measured material buckling and estimated error for the critical case.

Benchmark groups

Group	**Keyword (in benchall.bat)**
1) H_2O-moderated uranium metal lattices	critume
2) H_2O-moderated uranium oxide critical lattices	crituo2
3) WWER-type UO_2-H_2O critical lattices	wwercr
4) H_2O-moderated UO_2-PuO_2 (MOX) critical lattices	critmox
5) Uranium and plutonium intermediate spectrum critical homogeneous systems	critisp

6) H_2O-moderated $^{233}UO_2$-ThO_2 lattices crithth
7) D_2O-moderated $^{233}UO_2$-ThO_2 lattices critdth
8) D_2O-moderated uranium oxide critical lattices d2ocrit
9) D_2O-moderated $^{235}UO_2$-ThO_2 critical lattices d2ocrit

Identification of each benchmark group

FUE :	Fuel	UME	: Uranium metal;
		UO2	: UO_2
		MOX	: PuO_2-UO_2
		U	: Highly enriched uranium
		Pu	: Plutonium
		Th3	: ThO_2-$^{233}UO_2$ mixture
		Th5	: ThO_2-$^{235}UO_2$ mixture
CO :	Coolant	LW	: Light water
		LB	: Light water with boron
		MI	: Homogeneous mixture with fuel
		HW	: Heavy water

Summary of Benchmark groups according to classification by fuel and coolant

	FUE-CO (keyword)		**#benchmarks**	**#cases**
1)	UME-LW	(critume)	6	64
2)	UO2-LW	(crituo2)	14	57
3)	UO2-LB	(wwercr)	1	25
4)	MOX-LW	(critmox)	4	40
5)	U-MI	(critisp)	1	1
	Pu-MI	(critisp)	1	1
6)	Th3-LW	(crithth)	1	8
7)	Th3-HW	(critdth)	1	8
8)	UO2-HW	(d2ocrit)	4	11
9)	Th5-HW	(d2ocrit)	1	4
		total:	24	219

Details of each benchmark group are included in Annex IV.

Main sources of experimental results and references

The bulk of information on UME-LW, UO2-LW and MOX-LW benchmarks has been retrieved from the compilation edited by Bernocchi and Martinelli [14.1], and from original publications referenced in this work.

Experimental results for UO2-LB (WWER lattices) have been extracted from the Final Reports of TIC [14.2].

U-MI and Pu-MI benchmarks (uranium and plutonium intermediate spectrum for critical homogeneous systems): original report of Fox, King, Pitcher and Sander is the main reference [14.3].

The main data source for Th3-LW and Th3-HW benchmarks is Windsor, Tunney and Price [14.4].

Other HW benchmarks (UO2-HW and Th5-HW) are related mainly to CANDU type fuel clusters, and the main reference is IAEA-TECDOC-887 [14.5], supplemented by original publications.

Some of the benchmark groups have been collected together and published as the NEA International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition [14.6].

A more detailed list of references of WLUP benchmarks is included in Annex IV, with a description of each benchmark.

Identification of benchmarks by origin

Each benchmark that includes one or more individual cases has two natural identification tags: Laboratory (LAB) and Experimental Facility (FAC). Tags considered in the WLUP benchmark sequence are listed below.

LAB	**Laboratory**
AECL	Atomic Energy of Canada Limited - Canada
AEEW	Atomic Energy Establishment, Winfrith - UK
AERE	Atomic Energy Research Establishment [Harwell] - UK
AERL	Atomic Energy Research Laboratory [Ozeny] - Japan
ANL	Argonne National Laboratory - USA
BAPL	Bettis atomic Power Laboratory [Westinghouse] - USA
BAW	Babcock and Wilcox [B&W Company] - USA
BNL	Brookhaven National Laboratory - USA
BNW	Battelle NorthWest [Laboratory] - USA
CRIP	Central Research Institute for Physics of the Hungarian Academy of Sciences, Budapest - Hungary
CURL	Cornell University [Nuclear] Reactor Laboratory - USA
GE	General Electric [Company] - USA
HW	Hanford Works [Richland] - USA
JAERI	Japan Atomic Energy Research Institute - Japan
JNCDI	Japan Nuclear Cycle Development Institute - Japan
NAIG	Nippon Atomic Industries Group - Japan
NPY	Norway-Poland-Yugoslavia [Association, Kjeller] - Norway
SCKBN	Studie Centrum voor Kernenenergie-BelgoNucleaire [Association]-Belgium
SRL	Savannah River Laboratory - USA
WAPD	Westinghouse Atomic Power Department – USA.

FAC (Facility name)	**LAB**
BAY2	BAW
CRX	WAPD
CX10	BAW
DCA (Deuterium Critical Assembly)	JNCDI
DIMPLE	AEEW
HECTOR	AEEW
JUNO	AEEW
NCA	NAIG
NORA	NPY

OCF	AERL
TCA (Tank type Critical Assembly)	JAERI
TRX	BAPL
VENUS	SCKBN
ZED2	AECL
ZPR	CURL
ZPR7	ANL
ZR6	CRIP

There are some benchmarks that were carried out using experimental facilities without a specified name. These facilities are identified with the laboratory name where the facility is (or was) installed, followed by the letters ea (experimental assembly):

AECLea
AEREa
BNLea
BNWea
GEea
HWea
SRLea

Subdivision of each benchmark according to fissile material content in the fuel

Taking into account the results of the standard sequence of benchmarks, a reasonable approach would be to subdivide them according to "enrichment" expressed as percent of fissile material (^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu) in heavy metal (Th and all heavier elements). Four categories were established:

A. Below 2.0%
B. Between 2.0% and 4.0%
C. Between 4.0% and 6.0%
D. Over 6.0%

The final results and plots for each group of benchmark are presented within this subdivision, and the order of WIMS calculations in bnchall.bat has been adapted to this classification.

Cases

A 10-characters name is assigned to each benchmark case, in order to facilitate a fast identification of each case in the list of results. WIMS-D input file names are the same short names (without the case number). Each WIMS input includes all cases of a benchmark, or one sub-set of cases corresponding to one of the four subgroups with fissile material content in the fuel.

A numerical identifier is used to identify each case.

Lists of all cases by group and benchmark are included in Appendix II.

14.6. Index of criticality benchmarks

Benchmarks by groups are listed, ordered by name, enrichment, number of cases, WIMS input name (.WIN) and short names. The first number in the list is the chapter and section of the Benchmark description document (Appendix IV). A line represents a separator between two different enrichments.

1) UME-LW (CRITUME)

Benchmark identification	W%u235	#cases	.win	Short name
1.02) UME-LW-AECL-AECLea	0.714	1	aecl_um	aecl_um
1.03) UME-LW-AERE-AEREea	a) 0.928	5	aere_uma	aere_uma1-5
1.05) UME-LW-HW-HWea	a) 0.95	4	hw_uma	hw_uma1-4
	b) 1.007	6	hw_umb	hw_umb1-6
1.04) UME-LW-BNL-BNLea	a) 1.016	7	bnl_uma	bnl_uma1-7
	b) 1.027	16	bnl_umb	bnl_umb1-16
1.03) UME-LW-AERE-AEREea	b) 1.142	2	aere_umb	aere_umb1-2
1.04) UME-LW-BNL-BNLea	c) 1.143	2	bnl_umc	bnl_umc1-2
	d) 1.299	7	bnl_umd	bnl_umd1-7
1.01) UME-LW-BAPL-TRX	1.3	2	trx_um	trx_um1-2
1.05) UME-LW-HW-HWea	c) 1.44	5	hw_umc	hw_umc1-5
1.06) UME-LW-SRL-SRLea	3.0	7	srl_um	srl_um1-7

2) UO2-LW (CRITUO2)

Benchmark identification	W%u235	#cases	.win	Short name
2.01) UO2-LW-BAPL-TRX	1.31	6	bapl1_3, bapl_trx	bapl1-6
2.03) UO2-LW-NAIG-NCA	2.02	1	naig_nca	naig_nca
2.04) UO2-LW-CURL-ZPR	2.07	4	curl_zpr	curl_zpr1-4
2.05) UO2-LW-BAW-BAY2	a) 2.46	1	bawbay2a	baw_bay2a
2.06) UO2-LW-BAW-CX10	2.46	1	baw_cx10	baw_cx10
2.07) UO2-LW-AERL-OCF	2.49	2	aerl_ocf	aerl_ocf1-2
2.08) UO2-LW-JAERI-TCA	2.6	7	jaeritca	jaeritca1-7
2.09) UO2-LW-WAPD-CRX	a) 2.7	6	wapdcrxa	wapd_crxa1-6
2.10) UO2-LW-AEEW-JUNO	3.0	1	aeewjuno	aeewjuno
2.02) UO2-LW-AEEW-DIMPLE	3.0	3	rn100h	r1-3100h
2.11) UO2-LW-BNL-BNLea	3.04	5	bnluo2	bnluo2_1-5
2.12) UO2-LW-ANL-ZPR7	a) 3.04	5	anlzpr7a	anl_zpr7a1-5
2.13) UO2-LW-NPY-NORA	3.41	3	npy_nora	npy_nora1-3
2.09) UO2-LW-WAPD-CRX	b) 3.7	2	wapdcrxb	wapd_crxb1-2
2.14) UO2-LW-SCKBN-VENUS	4.01	2	sckvenus	sckvenus1-2
2.05) UO2-LW-BAW-BAY2	b) 4.02	2	bawbay2b	baw_bay2b1-2
2.09) UO2-LW-WAPD-CRX	c) 4.43	1	wapdcrxc	wapd_crxc
2.12) UO2-LW-ANL-ZPR7	b) 4.95	2	anlzpr7b	anl_zpr7b1-2
2.09) UO2-LW-WAPD-CRX	d) 5.74	3	wapdcrxd	wapd_crxd1-3

3) UO2-LB (WWER)

Benchmark identification	W%u235	#cases	.win	Short name
3.01) UO2-LB-CRIP-ZR6	a) 1.6	3	wwercra	wwercra1-3
3.01) UO2-LB-CRIP-ZR6	b) 3.6	18	wwercrb	Wwercrb4-21
3.01) UO2-LB-CRIP-ZR6	c) 4.4	4	wwercrb	wwercrc22-25

4) MOX-LW (CRITMOX)

Benchmark identification	W%u235	#cases	.win	Short name
4.03) MOX-LW-GE-GEea	0.22	6	ge_pu	ge_pu1-6
4.01) MOX-LW-WAPD-CRX	0.72	6	wcrx_pu	wcrx_pu1-6
4.02) MOX-LW-JAERI-TCA	0.72	4	jtca_pu	jtca_pu1-4
4.04) MOX-LW-BNW-BNWea	0.72	24	bnw_pua	bnw_pua1-8
			bnw_pub	nw_pub1-5
			bnw_puc	bnw_puc1-6
			bnw_pud	nw_pud1-5

5.1) U-MI (CRITISP)

Benchmark identification	W%u235	#cases	.win	Short name
5.01) U-MI-AEEW-HECTOR	92.3	1	hiss	hiss1

5.2) Pu -MI (CRITISP)

Benchmark identification	W%u235	#cases	.win	Short name
5.02) Pu-MI-AEEW-HECTOR	0.0	1	hiss	hiss2

6) Th3-LW (BNLTH2O)

Benchmark identification	W%u235	#cases	.win	Short name
6.01) Th3-LW-BNL-BNLea	97.0	8	bnlth2o	bnl_thh2o1-8

7) Th3-HW (BNLTD2O)

Benchmark identification	W%u235	#cases	.win	Short name
6.01) Th3-HW-BNL-BNLea	97.0	8	bnltd2o	bnl_thd2o1-8

8) UO2-HW (CRITD2O)

Benchmark identification	W%u235	#cases	.win	Short name
8.01) UO2-HW-AECL-ZED2	0.72			
a)37 rods-square		2	e1t1d2o	zed2t1d2o
			e1t1air	zed2t1air
b)28 rods-hexag.		2	e1t2	zed2t2p24
				zed2t2p40
c)28 rods-square		1	e1t3	zed2t3p24
8.02) UO2-HW-JNCDI-DCA		6	e2t1	dcat1d22
				dcat1a22
				dcat1h22
				dcat1d25
				dcat1a25
				dcat1h25

9) Th5-HW (CRITD2O)

Benchmark identification	W%u235	#cases	.win	Short name
9.01) Th5-HW-AECL-ZED2	93.0	4	e1t4	zed2t4a22
				zed2t4d22
				zed2t4a28
				zed2t4d28

14.7. Standard burnup benchmarks

Three burnup benchmarks were selected for the standard sequence of tests.

(1) NPD. 19-rod Fuel Clusters [14.7]
D_2O-moderated uranium oxide lattices. Analysis of isotopic composition as a function of Burnup (key in benchall.bat: d2oe3)

(2) NEA Burnup Credit Criticality Benchmark [14.8]
H_2O-moderated uranium oxide lattices. Analysis of isotopic composition as a function of burnup (key in benchall.bat: bucr1a, bucr1b)

(3) LWR-Pu Recycling Benchmarks [14.9]
H_2O-moderated mixed oxide lattices. Analysis of isotopic composition as a function of burnup (key in benchall.bat: purecy)

Details of each standard burnup benchmark are included in Appendix IV.

14.8. Supplementary benchmarks

A) Criticality benchmarks (main parameter compared: k_{eff})

1. MARIA tubular fuel -with berylium moderator benchmark.
   Be-moderated 80% enriched uranium-aluminium tubular fuel.
   Multiplication factor (K) comparison with results obtained with MCNP code using standard library based on ENDF/B-VI; for heterogeneous and homogenized cases (BE)

B) Burnup benchmarks (main parameters compared: isotopic concentrations of actinides and fission products as a function of burnup).

2. OWR-MTR experimental and numerical burnup benchmark.
   H_2O-moderated 94% enriched uranium-aluminium fuel plates.
   Analysis of spent ^{235}U isotope as a function of burnup, and numerical comparison of isotopic concentration of actinides at end of cycle (MTRBURN)

3. PWR Thorium pin cell numerical burnup benchmark.
   H_2O-moderated ThO_2(75 w/o)-UO_2(25 w/o - 19.5 w/o ^{235}U) mixed oxide fuel rods.
   Numerical comparison of k_∞ eigenvalue and isotopic concentrations of actinides and fission products as a function of burnup,

C) Temperature coefficient benchmarks (parameter compared reactivity temperature coefficient)

4. DOPPLER numerical benchmark.
   H_2O-moderated uranium oxide lattices.
   Reactivity temperature coefficient compared with results obtained with MCNP code and standard library based on ENDF/B-VI (DOPPLER).

5. RTC experimental benchmarks.
   H_2O-moderated mixed oxide lattices.
   Reactivity temperature coefficient differences between calculated and experimental values obtained from measured buckling of 4 experimental facilities: KRITZ, NORA, R1100H and VVER (RTC)
   5.1 KRITZ
   5.2 NORA
   5.3 R1100H
   5.4 VVER

D) Others (parameter compared: neutron flux distributions)

6. DCA experimental benchmark with Gd-poisoned rods.
   D_2O-moderated cluster with 54 uranium oxide rods.
   Analysis of critical experiments on gadolinium-poisoned cluster-type fuel assemblies of 54 Rods in Heavy Water Lattices of DCA Facility.
   Comparison of measured and calculated thermal flux spatial distribution (D2OGD)

E) Whole-core benchmarks (parameters compared: several full core parameters)

7. TRIGA-IJS benchmark.

Details of each supplementary benchmark can be found in Appendix V. Results of supplementary benchmarks with all WIMSD-IAEA libraries are included in Appendix VI.

14.9. Benchmark results for final WLUP libraries

Benchmark summary results for the final WIMSD-IAEA libraries (69 and 172 groups) are included in this document. WIMS-D inputs, reference solution, post-processing codes and batch files for running WLUP benchmarks and graphs of leakage spectrum for each benchmark are included on WLUP CD-ROM.

Sections 14.9.1 to 14.9.10 contain standard benchmark results for WIMSD-IAEA libraries as tables and graphs. The WIMS86 library results are also included for comparison with the new, non-adjusted libraries.

The tables of criticality benchmarks give k_{eff} vs. q-value for the IAEA and WIMS86 libraries, and the names of the individual benchmarks. Tables with spectral index results are also included for the benchmark groups.

Graphs have also been produced of k_{eff} vs. q-value for the standard criticality benchmarks, different groups indexed in Section 14.5 and for different groups of enrichments. These data show the differences between calculated and experimental or reference values of the atomic densities of isotopes for the burnup benchmarks.

Comments are given after the tables and graphs of each group.

Tables of results for all benchmarks and libraries are included in Appendix VI. These tables were obtained by means of the SMRLIB program. Results of the full sequence of benchmarks with WIMS-D libraries are also included on WLUP CD-ROM.

14.9.1. H_2O-moderated uranium metal lattices

(a) Enrichment A (< 2% wt ^{235}U)

TABLE 14.1. k_{eff} vs. q-VALUE FOR H_2O MODERATED URANIUM METAL CRITICAL LATTICES - ENRICHMENT A (< 2% wt ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.821	1.00492	1.00259	1.01356	1.00000	0.00240	aecl_um
0.534	1.01481	1.01105	1.01994	1.00000	0.00800	aere_uma1
0.570	1.01313	1.00760	1.01515	1.00000	0.00600	aere_uma2
0.637	0.99957	0.99668	0.99945	1.00000	0.00330	aere_uma3
0.703	0.99910	0.99726	1.00127	1.00000	0.00270	aere_uma4
0.719	1.01215	1.00963	1.01540	1.00000	0.00280	aere_uma5
0.609	1.00218	0.99773	1.00031	1.00000	0.00100	hw_uma1
0.646	0.99978	0.99625	0.99877	1.00000	0.00100	hw_uma2
0.679	1.00240	0.99952	1.00285	1.00000	0.00100	hw_uma3
0.744	0.99757	0.99561	1.00102	1.00000	0.00100	hw_uma4
0.604	0.99973	0.99614	0.99726	1.00000	0.00100	hw_umb1
0.667	0.99891	0.99674	0.99813	1.00000	0.00100	hw_umb2
0.686	1.00577	1.00393	1.00605	1.00000	0.00100	hw_umb3
0.545	1.00475	0.99963	1.00259	1.00000	0.00100	hw_umb4
0.629	1.00115	0.99812	1.00044	1.00000	0.00100	hw_umb5
0.704	0.99578	0.99391	0.99877	1.00000	0.00100	hw_umb6
0.643	0.99269	0.99269	0.99463	1.00000	0.00160	bnl_uma1
0.709	0.99401	0.99472	0.99618	1.00000	0.00100	bnl_uma2
0.761	0.99563	0.99665	0.99850	1.00000	0.00120	bnl_uma3
0.599	0.99640	0.99519	0.99729	1.00000	0.00100	bnl_uma4
0.714	0.99243	0.99274	0.99383	1.00000	0.00100	bnl_uma5
0.540	0.99856	0.99495	0.99912	1.00000	0.00170	bnl_uma6
0.793	0.99081	0.99087	0.99418	1.00000	0.00100	bnl_uma7
0.597	0.99304	0.99257	0.99560	1.00000	0.00490	bnl_umb1
0.641	0.99614	0.99613	0.99805	1.00000	0.00170	bnl_umb2
0.706	0.99526	0.99598	0.99735	1.00000	0.00100	bnl_umb3
0.758	0.99433	0.99537	0.99708	1.00000	0.00100	bnl_umb4
0.597	0.99962	0.99839	1.00047	1.00000	0.00100	bnl_umb5
0.642	0.99643	0.99591	0.99687	1.00000	0.00100	bnl_umb6
0.711	0.99616	0.99647	0.99755	1.00000	0.00100	bnl_umb7
0.767	0.99321	0.99387	0.99572	1.00000	0.00100	bnl_umb8
0.538	1.00154	0.99790	1.00205	1.00000	0.00170	bnl_umb9
0.651	0.99530	0.99394	0.99440	1.00000	0.00100	bnl_umb10
0.726	0.99464	0.99433	0.99590	1.00000	0.00100	bnl_umb11
0.790	0.99475	0.99481	0.99812	1.00000	0.00100	bnl_umb12
0.590	0.99750	0.99426	0.99523	1.00000	0.00120	bnl_umb13
0.688	0.99621	0.99500	0.99616	1.00000	0.00100	bnl_umb14
0.727	0.99270	0.99201	0.99406	1.00000	0.00290	bnl_umb15
0.799	0.99081	0.99054	0.99493	1.00000	0.00160	bnl_umb16
0.595	1.00249	0.99972	0.99896	1.00000	0.00700	aere_umb1
0.657	1.00315	1.00152	1.00252	1.00000	0.00250	aere_umb2
0.730	0.99097	0.99220	0.99269	1.00000	0.00100	bnl_umc1
0.582	0.99890	0.99655	0.99580	1.00000	0.00210	bnl_umc2
0.553	0.99841	0.99712	0.99553	1.00000	0.00100	bnl_umd1
0.595	0.99603	0.99553	0.99342	1.00000	0.00100	bnl_umd2
0.658	0.99255	0.99308	0.99154	1.00000	0.00100	bnl_umd3
0.659	0.99543	0.99597	0.99451	1.00000	0.00230	bnl_umd4
0.708	0.99264	0.99368	0.99316	1.00000	0.00100	bnl_umd5
0.673	0.99335	0.99331	0.99221	1.00000	0.00100	bnl_umd6
0.731	0.99321	0.99367	0.99442	1.00000	0.00100	bnl_umd7
0.619	0.99523	0.99515	0.99309	1.00000	0.00300	trx_um1
0.708	0.99429	0.99531	0.99482	1.00000	0.00100	trx_um2
0.535	1.00434	1.00017	0.99553	1.00000	0.00100	hw_umc1
0.567	1.00680	1.00353	0.99971	1.00000	0.00100	hw_umc2
0.598	1.00724	1.00473	1.00208	1.00000	0.00100	hw_umc3
0.657	1.00919	1.00772	1.00802	1.00000	0.00100	hw_umc4
0.716	1.00828	1.00739	1.01092	1.00000	0.00100	hw_umc5

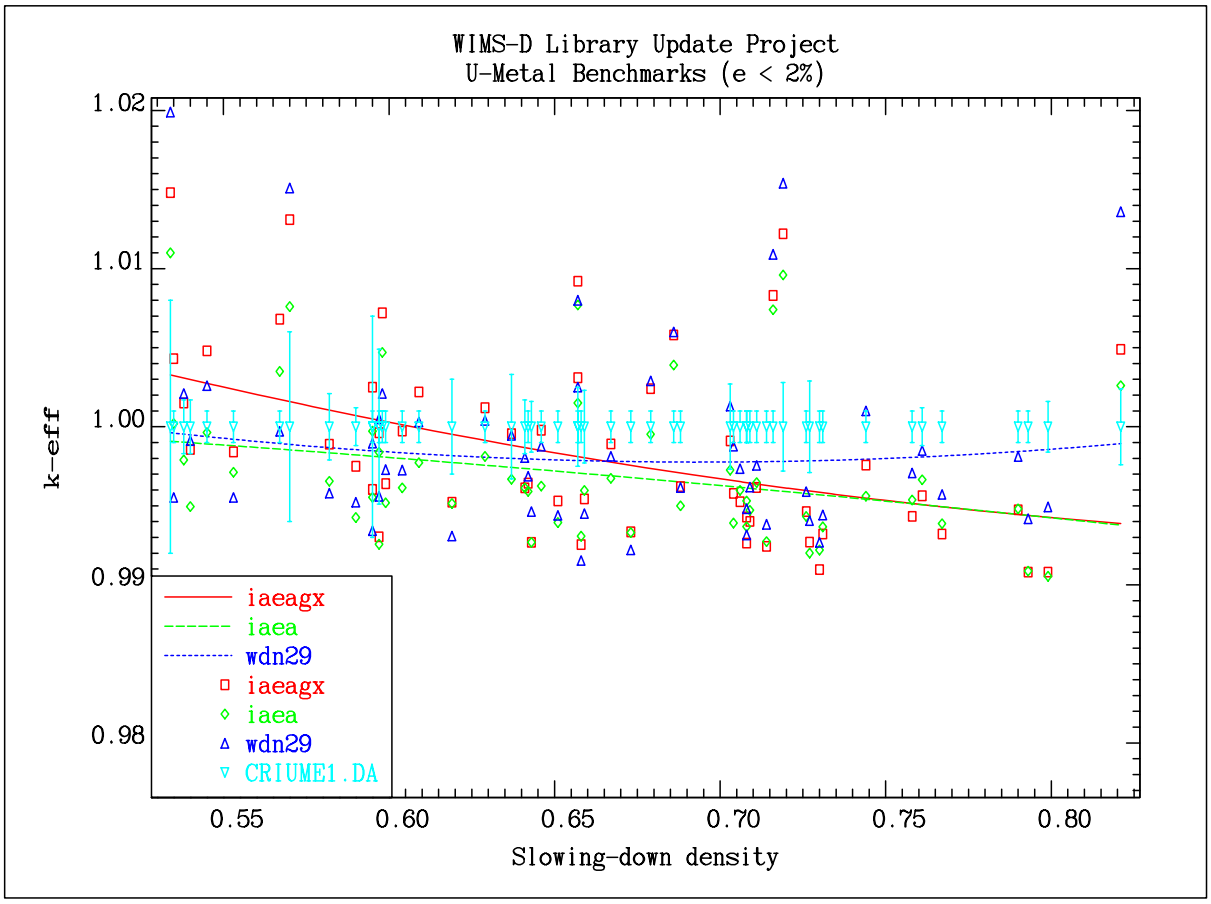

Fig. 14.1. H_2O-moderated uranium metal lattices\k_{eff} vs q. Enrichment A (< 2% wt ^{235}U) standard criticality benchmarks.

Uranium metal lattices with enrichment < 2% represent the largest set of cases, including 57 individual lattices with *q*-values ranging from 0.53 to 0.82. The criticality condition is predicted to within 1% for most cases.

(b) Enrichment B (> 2% and < 4% wt ^{235}U)

TABLE 14.2. k_{eff} vs.q-VALUE FOR H_2O MODERATED URANIUM METAL CRITICAL LATTICES - ENRICHMENT B (> 2% and < 4% wt ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.423	1.02730	1.02479	1.01268	1.00000	0.00290	srl_um1
0.494	1.01502	1.01399	1.00616	1.00000	0.00280	srl_um2
0.556	1.00134	1.00113	0.99782	1.00000	0.00280	srl_um3
0.324	1.00436	1.00236	0.98871	1.00000	0.00330	srl_um4
0.399	1.01849	1.01748	1.00520	1.00000	0.00310	srl_um5
0.460	1.00579	1.00566	0.99678	1.00000	0.00300	srl_um6
0.521	0.99696	0.99734	0.99323	1.00000	0.00300	srl_um7

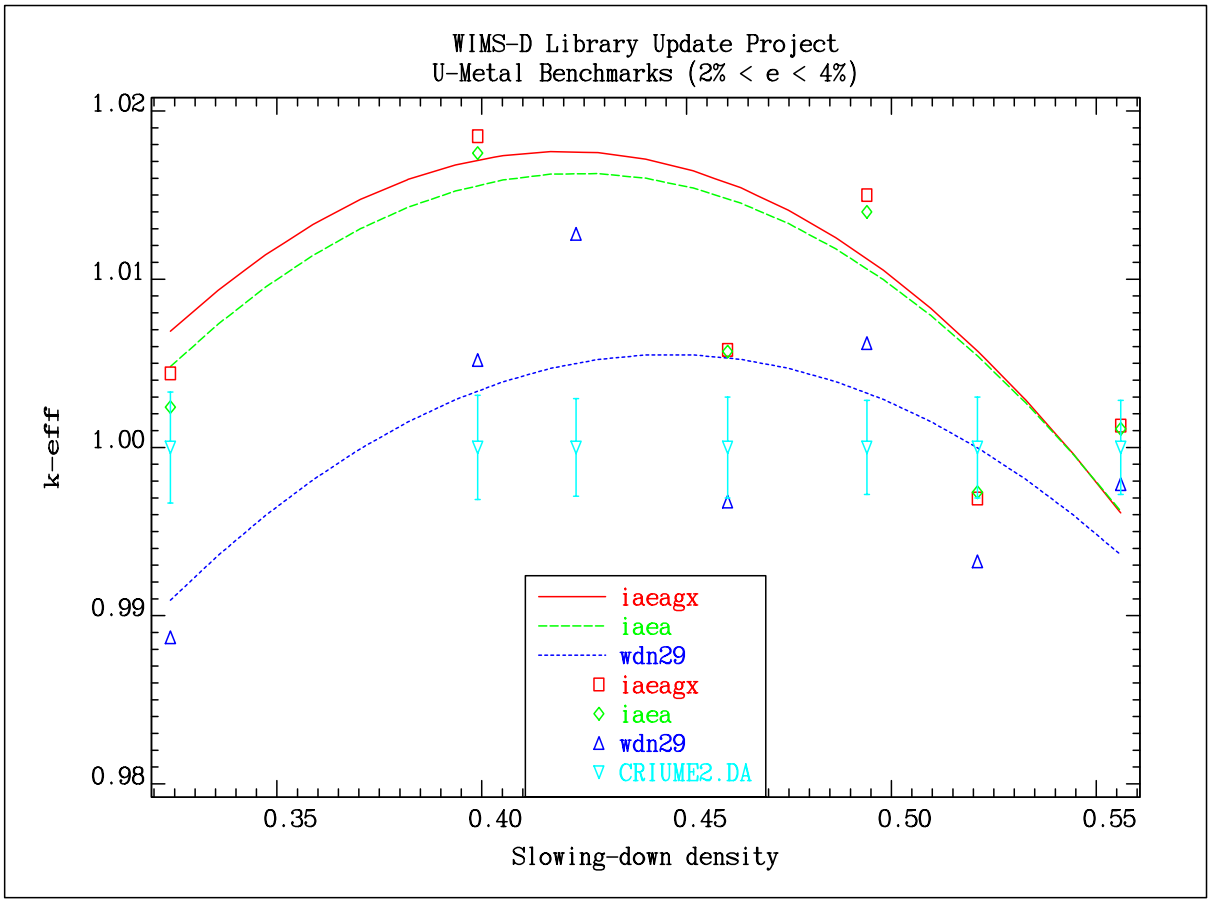

Fig. 14.2. H_2O-moderated uranium metal lattices k_{eff} vs q. Enrichment B (> 2% and < 4% wt ^{235}U) standard criticality benchmarks.

There are only seven cases of uranium metal lattices with enrichment between 2 and 4%, and they are all SRL assemblies. q-values range from 0.32 to 0.56, implying harder spectra than the low-enrichment cases A. Fairly large discrepancies are observed in the predicted criticality for all libraries, although these differences are judged to be unreliable because of the small number of cases.

(c) Spectral Index

Only two cases are included with spectral index calculations for U-metal lattices: trx_um1 and trx_um2. Definitions of the parameters are given in the description of the benchmarks (Appendix IV). Table 14.3 lists the results for the IAEA libraries and WIMS86: calculated Del28 and ConvR are within the experimental values for IAEA libraries, while calculated Rho28 are larger than experimental values by 2 - 4% and calculated Del25 are smaller than experimental values by 0.7 – 1.9 %.

TABLE 14.3. SPECTRAL INDEX RESULTS FOR H_2O MODERATED URANIUM METAL CRITICAL LATTICES*

lattice	Rho28	Del25	Del28	ConvR
trx_um1 exp	1.320(~1.6)	0.0987(~1.0)	0.0946(~4.3)	0.797(~1.0)
iaea172	1.364(3.36)	0.0980(-.70)	0.0991(4.80)	0.797(0.00)
iaea69	1.373(4.04)	0.0980(-.74)	0.0981(3.67)	0.800(0.41)
wims86	1.355(2.67)	0.0979(-.82)	0.1009(6.68)	0.794(-.41)
trx_um2 exp	0.837(~1.9)	0.0614(~1.3)	0.0693(~5.1)	0.647(~.93)
iaea172	0.860(2.74)	0.0602(-1.9)	0.0710(2.42)	0.644(-.42)
iaea69	0.862(3.01)	0.0602(-1.9)	0.0700(1.05)	0.645(-.26)
wims86	0.850(1.55)	0.0602(-1.9)	0.0721(3.98)	0.641(-.90)

(*) values within brackets are experimental errors (first line) and percent difference from experimental values for calculations with different libraries.

14.9.2. H_2O-moderated uranium oxide critical lattices

(a) Enrichment A (< 2% wt ^{235}U)

TABLE 14.4. k_{eff} vs. q-VALUE FOR H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICHMENT A (< 2% wt ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.644	0.99910	0.99964	0.99887	1.00000	0.00100	bapl1
0.677	0.99802	0.99899	0.99820	1.00000	0.00100	bapl2
0.727	0.99766	0.99900	0.99868	1.00000	0.00100	bapl3
0.654	0.99136	0.99203	0.99110	1.00000	0.00500	bapl4
0.697	0.99301	0.99419	0.99350	1.00000	0.00500	bapl5
0.736	0.99174	0.99320	0.99297	1.00000	0.00500	bapl6

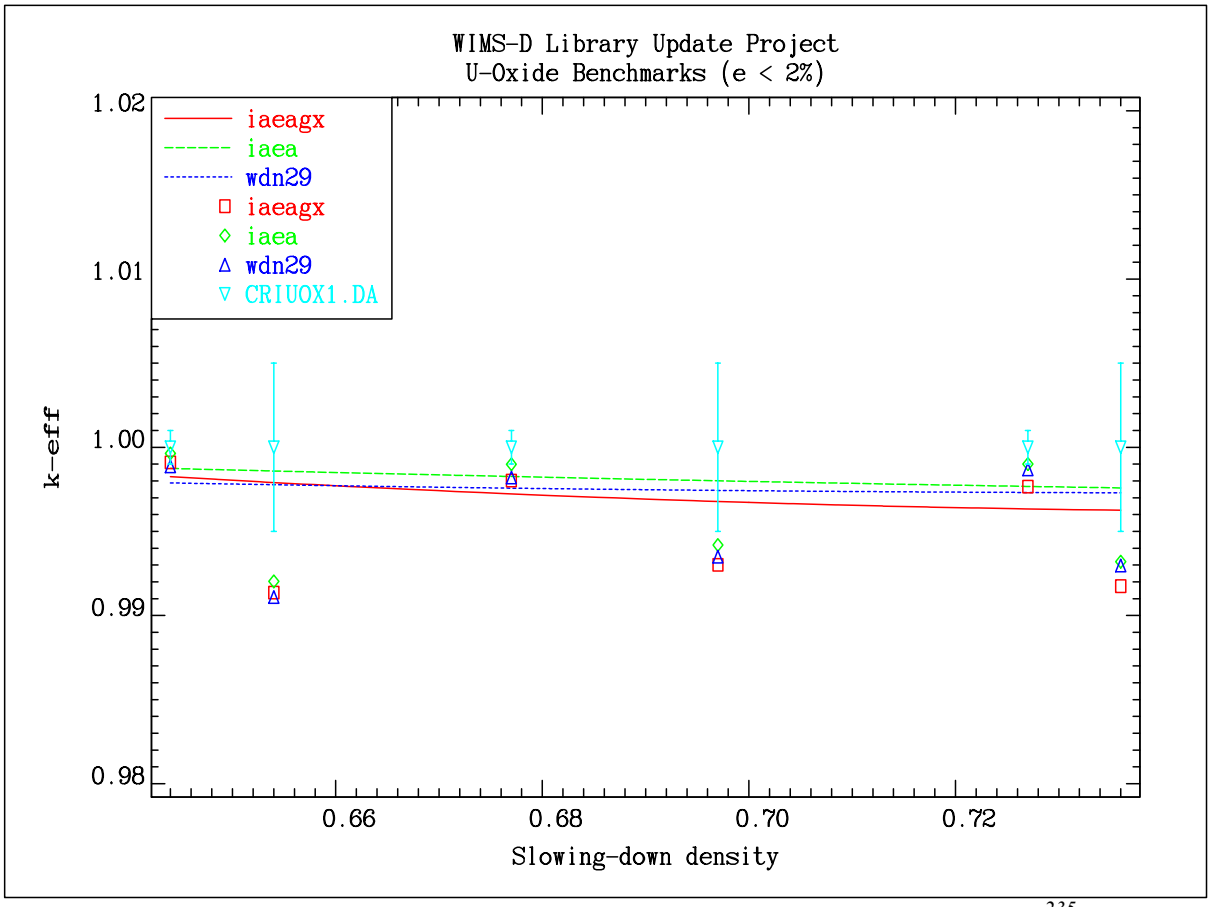

Fig. 14.3. H_2O-moderated UO_2 lattices k_{eff} vs q. Enrichment A (< 2% wt ^{235}U) standard criticality benchmarks.

Six cases are included for uranium oxide lattices with enrichment < 2%. All lattices are BAPL with q-values ranging from 0.64 to 0.74. Criticality condition is slightly underpredicted for cases BAPL 1-3, while the uncertainties in cases BAPL 4-6 are much larger and the discrepancies between measurements and calculations are comparatively high (which may indicate possible problems with the last three integral measurements).

(6) Enrichment B (> 2% and < 4% wt ^{235}U)

TABLE 14.5. k_{eff} vs. q-VALUE FOR H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICHMENT B (> 2% AND < 4% WT ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.672	1.00173	1.00386	1.00142	1.00000	0.00400	naig_nca
0.526	1.00499	1.00410	0.99891	1.00000	0.00500	curl_zpr1
0.621	0.98506	0.98628	0.98229	1.00000	0.00500	curl_zpr2
0.686	0.99358	0.99539	0.99327	1.00000	0.00500	curl_zpr3
0.745	0.99260	0.99449	0.99402	1.00000	0.00500	curl_zpr4
0.540	1.01091	1.01175	1.00640	1.00000	0.00250	baw_bay2a
0.577	0.99088	0.99242	0.98754	1.00000	0.00130	baw_cx10
0.613	0.99907	1.00107	0.99718	1.00000	0.00220	aerl_ocf1
0.663	0.99944	1.00184	0.99910	1.00000	0.00400	aerl_ocf2
0.561	0.99093	0.99237	0.98688	1.00000	0.00050	jaeritca1
0.578	0.98892	0.99064	0.98557	1.00000	0.00050	jaeritca2
0.601	0.98488	0.98697	0.98243	1.00000	0.00050	jaeritca3
0.542	1.00870	1.00950	1.00366	1.00000	0.00330	jaeritca4
0.568	0.99402	0.99534	0.99001	1.00000	0.00190	jaeritca5
0.608	0.99539	0.99738	0.99320	1.00000	0.00230	jaeritca6
0.636	1.00025	1.00251	0.99916	1.00000	0.00400	jaeritca7
0.537	1.00542	1.00431	0.99961	1.00000	0.00140	wapd_crxa1
0.555	1.00198	1.00143	0.99662	1.00000	0.00140	wapd_crxa2
0.576	1.00363	1.00366	0.99901	1.00000	0.00130	wapd_crxa3
0.612	0.99920	1.00008	0.99577	1.00000	0.00120	wapd_crxa4
0.632	0.99253	0.99382	0.98975	1.00000	0.00150	wapd_crxa5
0.760	1.00665	1.00868	1.00762	1.00000	0.00140	wapd_crxa6
0.611	0.99157	0.99358	0.98878	1.00000	0.00240	aeewjuno
0.486	1.00515	1.00185	0.99442	1.00000	0.00100	r1100h
0.635	1.00331	1.00146	0.99807	1.00000	0.00100	r2100h
0.452	1.00526	1.00161	0.99416	1.00000	0.00100	r3100h
0.579	0.99525	0.99428	0.98872	1.00000	0.00050	bnluo2_1
0.607	0.98710	0.98698	0.98180	1.00000	0.00160	bnluo2_2
0.640	0.98782	0.98845	0.98407	1.00000	0.00170	bnluo2_3
0.686	0.98897	0.99025	0.98706	1.00000	0.00160	bnluo2_4
0.746	0.98495	0.98657	0.98489	1.00000	0.00140	bnluo2_5
0.353	1.00430	1.00112	0.99498	1.00000	0.00050	anl_zpr7a1
0.434	0.99746	0.99628	0.98820	1.00000	0.00100	anl_zpr7a2
0.465	0.99228	0.99245	0.98443	1.00000	0.00260	anl_zpr7a3
0.508	1.00044	0.99873	0.99224	1.00000	0.00100	anl_zpr7a4
0.509	0.98654	0.98768	0.98048	1.00000	0.00260	anl_zpr7a5
0.549	1.00400	1.00419	0.99714	1.00000	0.00490	npy_nora1
0.631	1.00364	1.00533	1.00111	1.00000	0.00320	npy_nora2
0.698	0.99850	1.00055	0.99846	1.00000	0.00260	npy_nora3
0.503	1.00508	1.00442	0.99639	1.00000	0.00100	wapd_crxb1
0.577	0.99726	0.99864	0.99251	1.00000	0.00120	wapd_crxb2

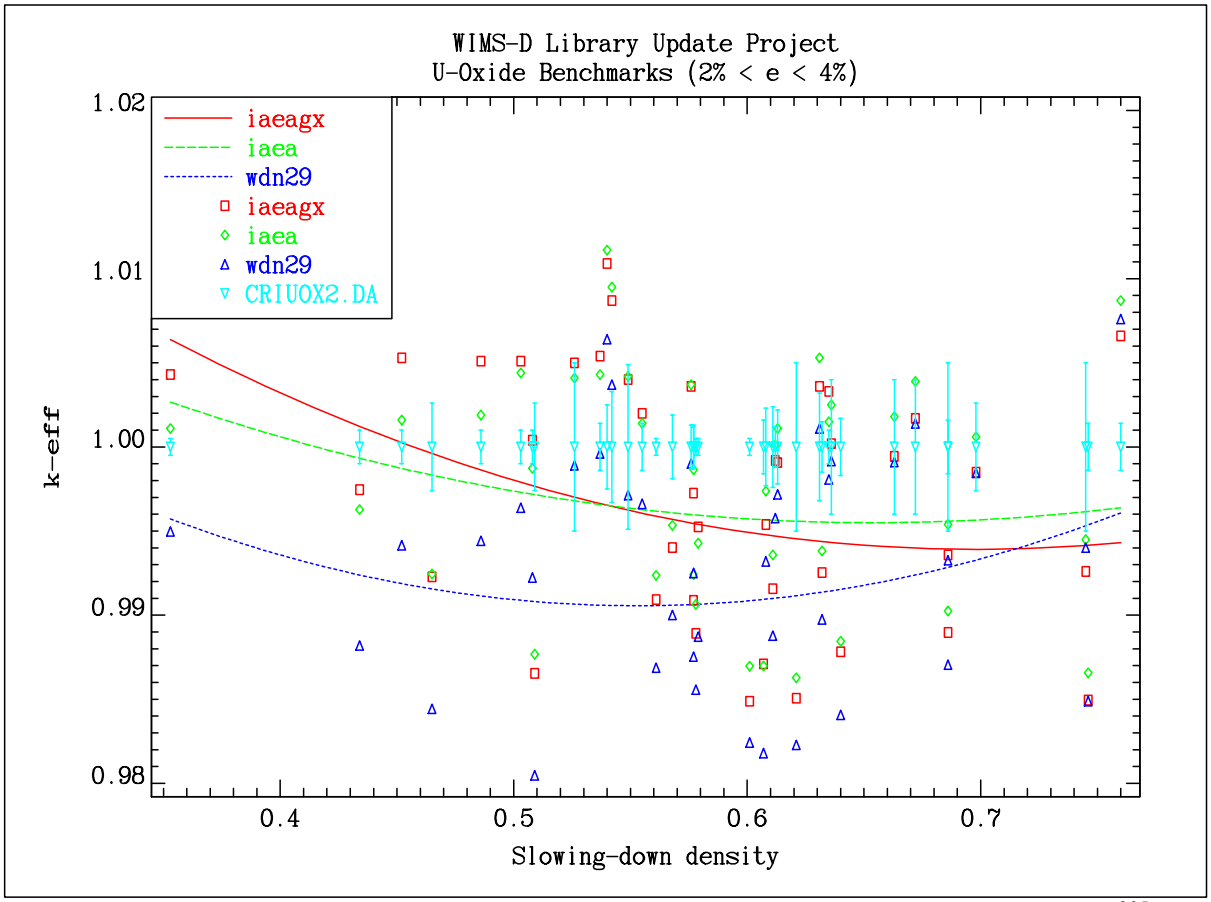

Fig. 14.4. H_2O-moderated UO_2 lattices k_{eff} vs q. Enrichment B (> 2% and < 4% wt ^{235}U) standard criticality benchmarks.

Uranium oxide lattices with enrichment between 2 and 4% constitute a large set of cases (42), with *q*-values ranging from 0.35 to 0.76. Criticality condition is predicted within 1% for more than 50% of the cases. Underpredictions of the multiplication factor of more than 1% occur for some lattices (different experiments) with a similar trend for all libraries. The IAEA libraries seem to perform slightly better on average.

(c) Enrichment C (> 4% and < 6% wt ^{235}U)

TABLE 14.6. k_{eff} vs. q-VALUE FOR H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICHMENT C (> 4% AND < 6% WT ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.513	0.99155	0.99201	0.98355	1.00000	0.00480	sckvenus1
0.646	0.99049	0.99312	0.98943	1.00000	0.00100	sckvenus2
0.463	0.98931	0.98839	0.97834	1.00000	0.00330	baw_bay2b1
0.486	0.99274	0.99246	0.98303	1.00000	0.00120	baw_bay2b2
0.503	0.99764	0.99686	0.98774	1.00000	0.00240	wapd_crxc
0.448	1.00286	1.00183	0.99071	1.00000	0.00200	anl_zpr7b1
0.484	1.00214	1.00250	0.99277	1.00000	0.00530	anl_zpr7b2
0.464	1.00069	1.00087	0.99010	1.00000	0.00490	wapd_crxd1
0.495	1.00970	1.01075	1.00159	1.00000	0.00360	wapd_crxd2
0.617	1.00197	1.00493	1.00112	1.00000	0.00210	wapd_crxd3

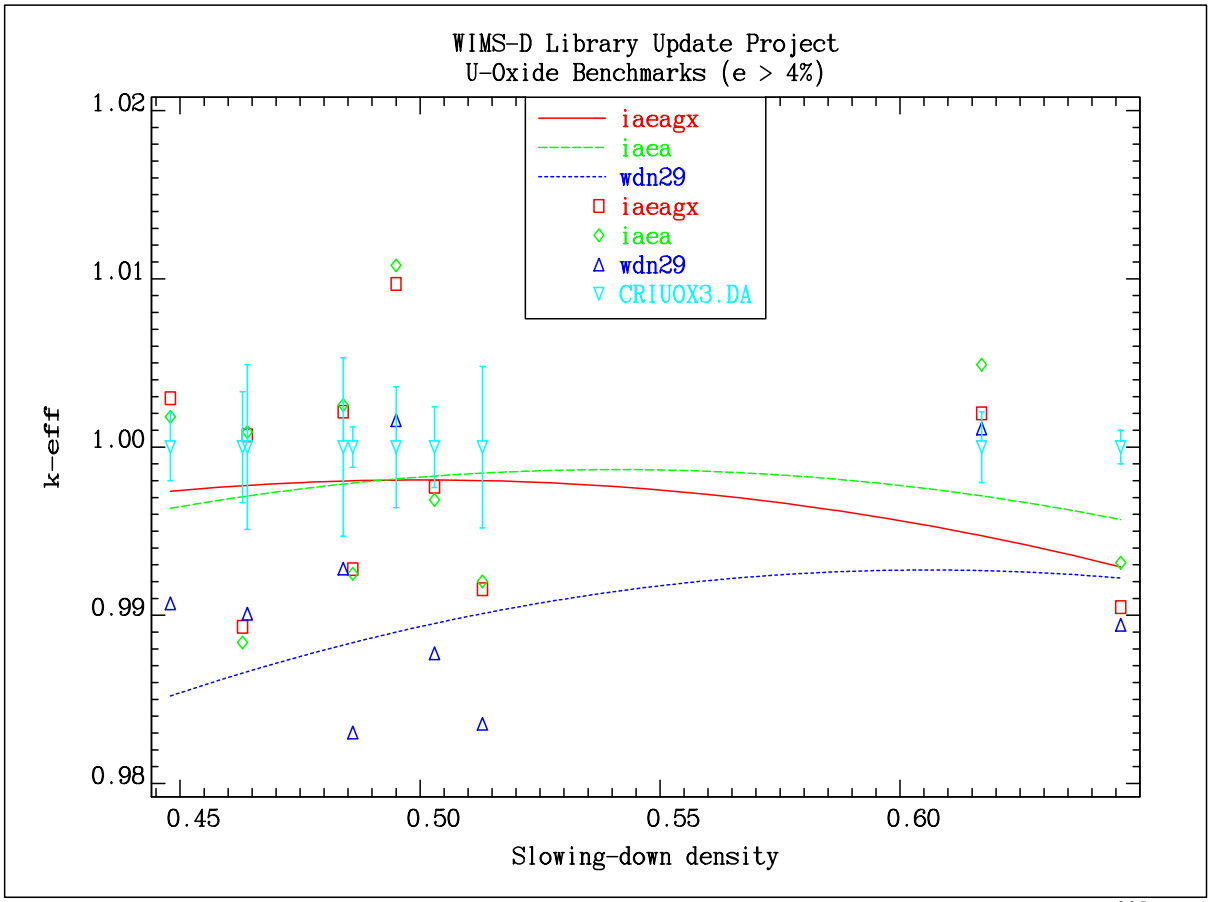

Fig. 14.5. H_2O-moderated UO_2 lattices k_{eff} vs q. Enrichment C (> 4% and < 6% wt ^{235}U) standard criticality benchmarks.

Uranium oxide lattices with enrichment > 4% include ten cases with q-values ranging from 0.45 to 0.65. Criticality condition is predicted to within 1% for practically all cases with the IAEA libraries, while the WIMS86 library shows somewhat larger errors for low q-values.

(d) Spectral Index

Definitions of the parameters are given in the description of the benchmarks (Appendix IV). Table 14.7 lists average differences from experimental values for the IAEA libraries and WIMS86. Calculated Del25, Del28 and ConvR are within the uncertainties of the experimental values for all libraries, while calculated Rho28 are slightly larger than the experimental values and close to the experimental uncertainty of 3%.

TABLE 14.7. SPECTRAL INDEX RESULTS FOR H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES. AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES*

	Rho28		Del25		Del28		ConvR	
	E(%)	Std.D	E(%)	Std.D	E(%)	Std.D	E(%)	Std.D
exp	3.05		9.24		7.00		2.75	
iaea172	3.20	2.50	-0.77	1.05	0.40	6.41	1.83	1.76
iaea69	3.63	2.41	-1.04	1.02	-0.61	6.16	2.33	2.00
wims86	3.00	2.35	-1.07	1.17	2.53	6.32	1.93	1.94

(*) E(%) are experimental errors in the first line of data, while percent difference of the calculated values from the experimental data are given on the other lines; Std.D are % standard deviations of these differences, and measure the spread of results.

14.9.3. WWER-type UO_2-H_2O critical lattices

(a) Enrichment A (< 2% wt ^{235}U)

TABLE 14.8 k_{eff} vs. q-VALUE FOR WWER H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICMENT A (< 2% WT ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.630	0.98804	0.98949	0.98587	1.00000	0.00500	p2w1b0t1
0.667	0.98644	0.98746	0.98575	1.00000	0.00600	p2w1b4t1
0.714	0.99639	0.99849	0.99652	1.00000	0.00500	p3w1b0t1

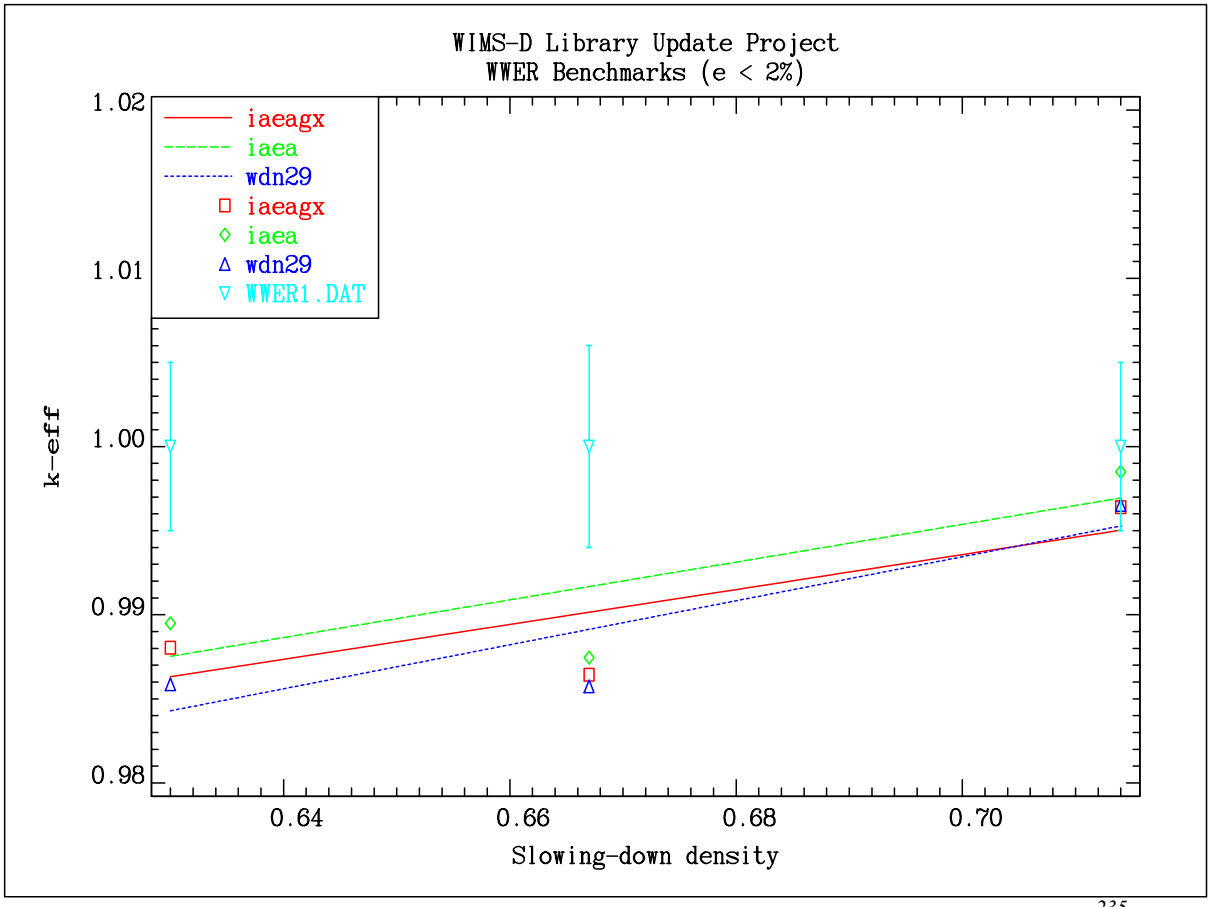

Fig. 14.6. H_2O-moderated WWER UO_2 lattices k_{eff} vs q. Enrichment A (< 2% wt ^{235}U) standard criticality benchmarks.

Only three WWER lattices with enrichment < 2% are included, and their q-values are 0.63, 0.67 and 0.71. Criticality is significantly underpredicted with all libraries, which is not consistent with the observations for the previously described low-enriched uranium oxide lattices. These observations imply possible problems with the measurements or inadequate "buckling correction" for leakage.

(b) Enrichment B (> 2% and < 4% wt ^{235}U)

TABLE 14.9. k_{eff} vs. q-VALUE FOR WWER H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICHMENT B (> 2%,< 4% WT ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.509	0.99918	1.00110	0.99342	1.00000	0.00500	p2w2b0t1
0.507	0.99474	0.99656	0.98910	1.00000	0.00600	p2w2b0t2
0.503	0.99335	0.99506	0.98759	1.00000	0.00600	p2w2b0t3
0.545	1.00477	1.00621	1.00034	1.00000	0.00500	p2w2b5t1
0.541	1.00018	1.00155	0.99587	1.00000	0.00500	p2w2b5t2
0.535	1.00026	1.00150	0.99581	1.00000	0.00500	p2w2b5t3
0.562	1.00213	1.00338	0.99827	1.00000	0.00500	p2w2b6t1
0.557	1.00373	1.00487	1.00000	1.00000	0.00500	p2w2b6t2
0.550	1.00066	1.00171	0.99677	1.00000	0.00500	p2w2b6t3
0.574	1.00556	1.00663	1.00215	1.00000	0.00600	p2w2b7t1
0.434	0.99137	0.99104	0.97999	1.00000	0.00500	p1w2b0t1
0.431	0.98365	0.98321	0.97213	1.00000	0.00500	p1w2b0t2
0.426	0.98075	0.98013	0.96889	1.00000	0.00500	p1w2b0t3
0.438	0.99618	0.99575	0.98511	1.00000	0.00500	p1w2b2t1
0.440	0.99372	0.99329	0.98274	1.00000	0.00500	p1w2b3t1
0.572	0.99705	1.00012	0.99515	1.00000	0.00500	p3w2b0t1
0.643	1.00680	1.00907	1.00642	1.00000	0.00600	p3w2b5t1
0.665	1.00104	1.00441	1.00189	1.00000	0.00700	p4w2b0t1

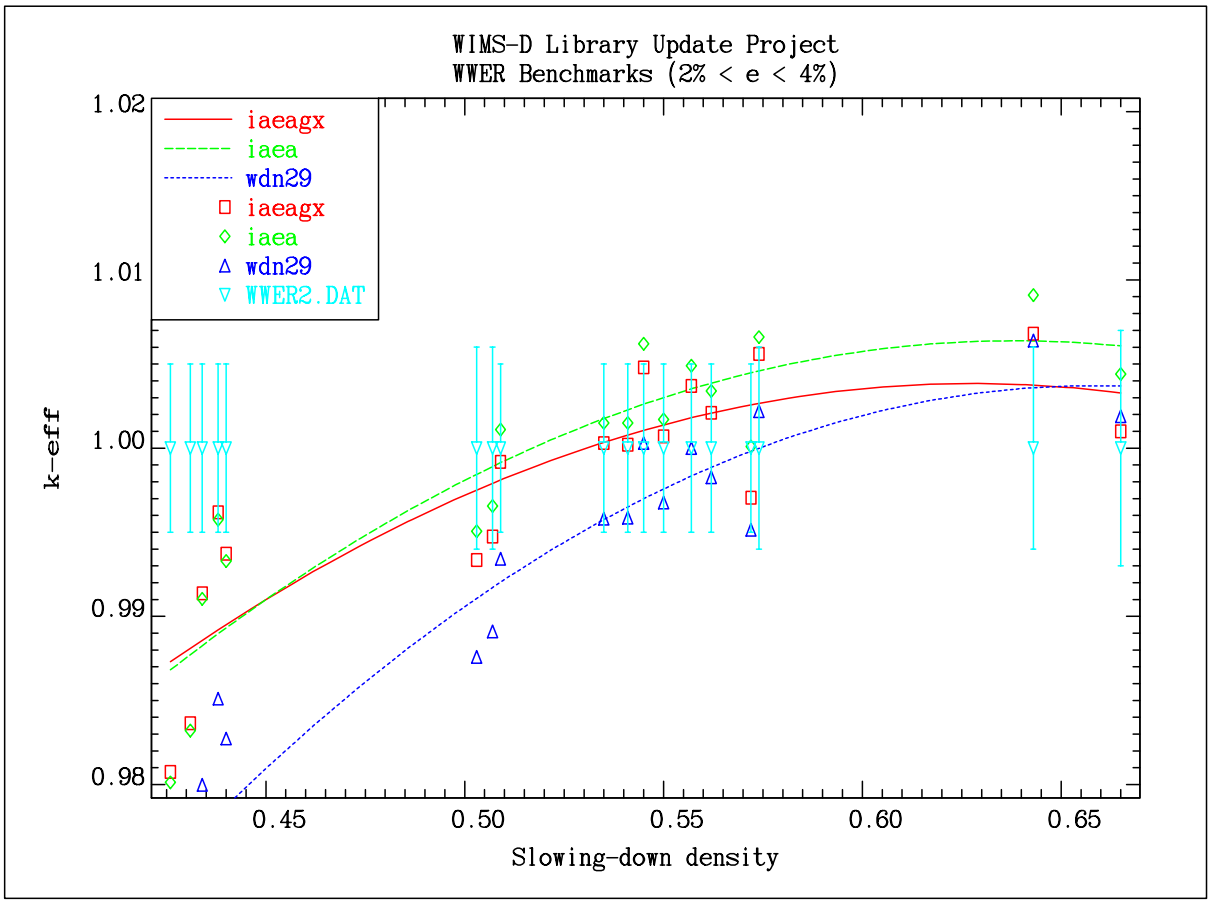

Fig. 14.7. H_2O-moderated WWER UO_2 lattices k_{eff} vs q. Enrichment B (> 2% and < 4% wt ^{235}U)standard criticality benchmarks.

WWER lattices with enrichment between 2 and 4% include 18 cases with q-values ranging from 0.43 to 0.66. Criticality condition is predicted within 1% for all lattices, except for 6 hard-spectrum cases with low q-values. The IAEA libraries perform significantly better.

(c) Enrichment C (> 4% and < 6% wt ^{235}U)

TABLE 14.10. k_{eff} vs. q-VALUE FOR WWER H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES - ENRICHMENT C (> 4%,< 6% WT ^{235}U)

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.485	0.99359	0.99546	0.98686	1.00000	0.00600	p2w3b0t1
0.490	1.00056	1.00234	0.99399	1.00000	0.00700	p2w3b1t1
0.538	1.01235	1.01344	1.00743	1.00000	0.00800	p2w3b7t1
0.547	0.99085	0.99401	0.98849	1.00000	0.00500	p3w3b0t1

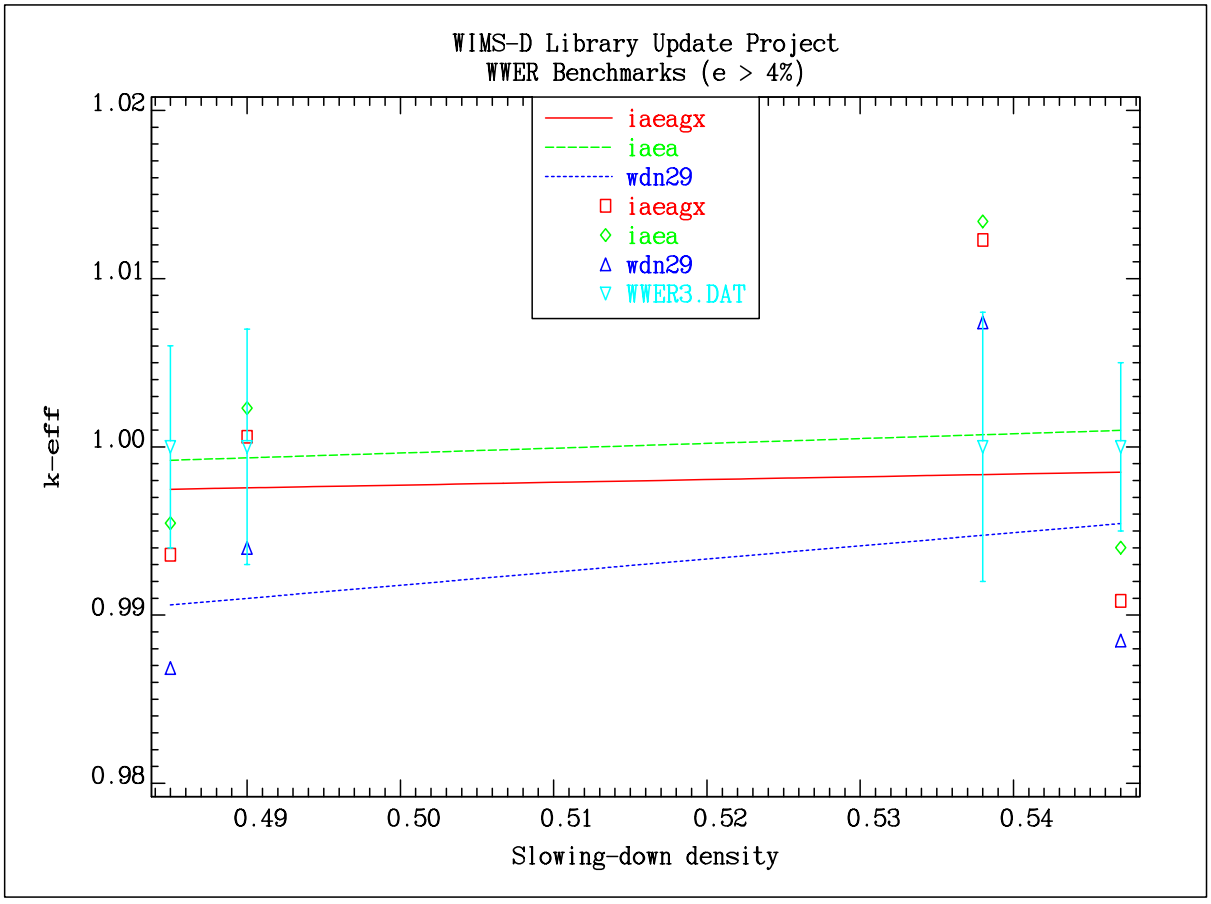

Fig. 14.8. H_2O-moderated WWER UO_2 lattices k_{eff} vs q. Enrichment C (> 4% and < 6% wt ^{235}U) standard criticality benchmarks.

WWER lattices with enrichment > 2% are represented by 4 cases with q-values ranging from 0.49 to 0.55. Criticality is predicted slightly better with the IAEA libraries.

14.9.4. H_2O-moderated UO_2-PuO_2 (MOX) critical lattices

(a) Enrichment A (< 2% wt fissile metal)

TABLE 14.11 k_{eff} vs. q-VALUE FOR MOX H_2O MODERATED CRITICAL LATTICES – ENRICHMENT < 2% FISSILE METAL

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.564	0.99833	0.99964	0.99819	1.00000	0.00500	ge_pu1
0.597	0.99933	1.00146	0.99782	1.00000	0.00300	ge_pu2
0.656	1.00238	1.00540	0.99963	1.00000	0.00100	ge_pu3
0.703	1.00165	1.00492	0.99835	1.00000	0.00100	ge_pu4
0.757	1.00260	1.00581	0.99886	1.00000	0.00100	ge_pu5
0.774	1.00372	1.00686	0.99991	1.00000	0.00100	ge_pu6

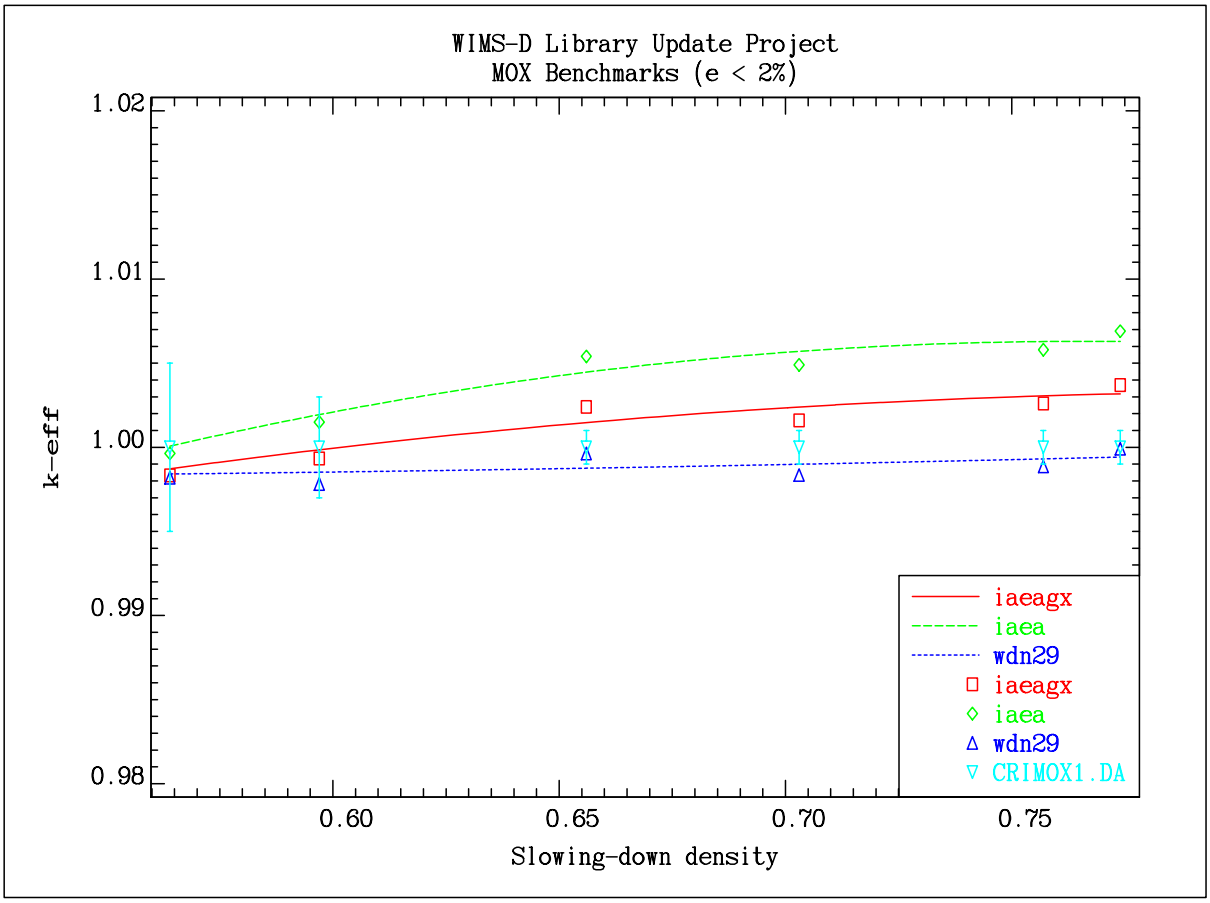

Fig. 14.9. H_2O-moderated MOX lattices k_{eff} vs q. Enrichment A (< 2% fissile metal) standard criticality benchmarks.

Mixed oxide lattices with fissile metal content < 2% include six cases with q-values ranging from 0.56 to 0.77. Results with all libraries are quite good, and the old WIMS86 library exhibits excellent agreement with measurements, what might be fortuitous due to the relatively small number of cases.

b) Enrichment A (> 2% wt fissile metal)

TABLE 14.12. k_{eff} vs. q-VALUE FOR MOX H_2O MODERATED CRITICAL LATTICES – ENRICHMENT > 2% FISSILE METAL

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.523	0.99705	0.99829	0.99602	1.00000	0.00340	wcrx_pu1
0.554	0.99303	0.99503	0.99132	1.00000	0.00270	wcrx_pu2
0.686	1.00217	1.00511	1.00211	1.00000	0.00310	wcrx_pu3
0.720	1.00118	1.00418	1.00094	1.00000	0.00200	wcrx_pu4
0.815	0.99676	0.99960	0.99575	1.00000	0.00080	wcrx_pu5
0.468	0.99465	0.99665	0.99643	1.00000	0.00350	wcrx_pu6
0.645	0.98402	0.98791	0.98638	1.00000	0.00100	jtca_pu1
0.667	0.98605	0.99004	0.98773	1.00000	0.00100	jtca_pu2
0.715	0.99001	0.99397	0.99060	1.00000	0.00100	jtca_pu3
0.763	0.99285	0.99657	0.99273	1.00000	0.00100	jtca_pu4
0.550	0.99120	0.99290	0.98931	1.00000	0.00120	bnw_pua1
0.599	1.00613	1.00889	1.00424	1.00000	0.00100	bnw_pua2
0.640	1.00820	1.01135	1.00633	1.00000	0.00110	bnw_pua3
0.674	1.00631	1.00957	1.00449	1.00000	0.00100	bnw_pua4
0.742	1.00223	1.00299	0.99823	1.00000	0.00100	bnw_pua5
0.752	1.00948	1.01257	1.00796	1.00000	0.00100	bnw_pua6
0.866	0.99245	0.99497	0.99211	1.00000	0.00500	bnw_pua7
0.872	0.98417	0.98671	0.98385	1.00000	0.00100	bnw_pua8
0.622	1.00618	1.00879	1.00558	1.00000	0.00100	bnw_pub1
0.665	1.00737	1.01038	1.00650	1.00000	0.00100	bnw_pub2
0.698	1.00958	1.01267	1.00863	1.00000	0.00100	bnw_pub3
0.769	1.00370	1.00666	1.00289	1.00000	0.00100	bnw_pub4
0.779	1.00996	1.01285	1.00924	1.00000	0.00100	bnw_pub5
0.592	0.99709	0.99846	0.99874	1.00000	0.00120	bnw_puc1
0.641	1.00241	1.00490	1.00280	1.00000	0.00100	bnw_puc2
0.684	1.00920	1.01208	1.00916	1.00000	0.00100	bnw_puc3
0.719	1.00470	1.00767	1.00448	1.00000	0.00100	bnw_puc4
0.792	0.99430	0.99714	0.99415	1.00000	0.00100	bnw_puc5
0.802	1.01032	1.01304	1.01033	1.00000	0.00100	bnw_puc6
0.535	0.99728	0.99885	0.99956	1.00000	0.00200	bnw_pud1
0.554	1.00493	1.00705	1.00675	1.00000	0.00100	bnw_pud2
0.580	1.00491	1.00764	1.00621	1.00000	0.00100	bnw_pud3
0.723	1.00286	1.00618	1.00339	1.00000	0.00100	bnw_pud4
0.847	0.99287	0.99560	0.99450	1.00000	0.00100	bnw_pud5

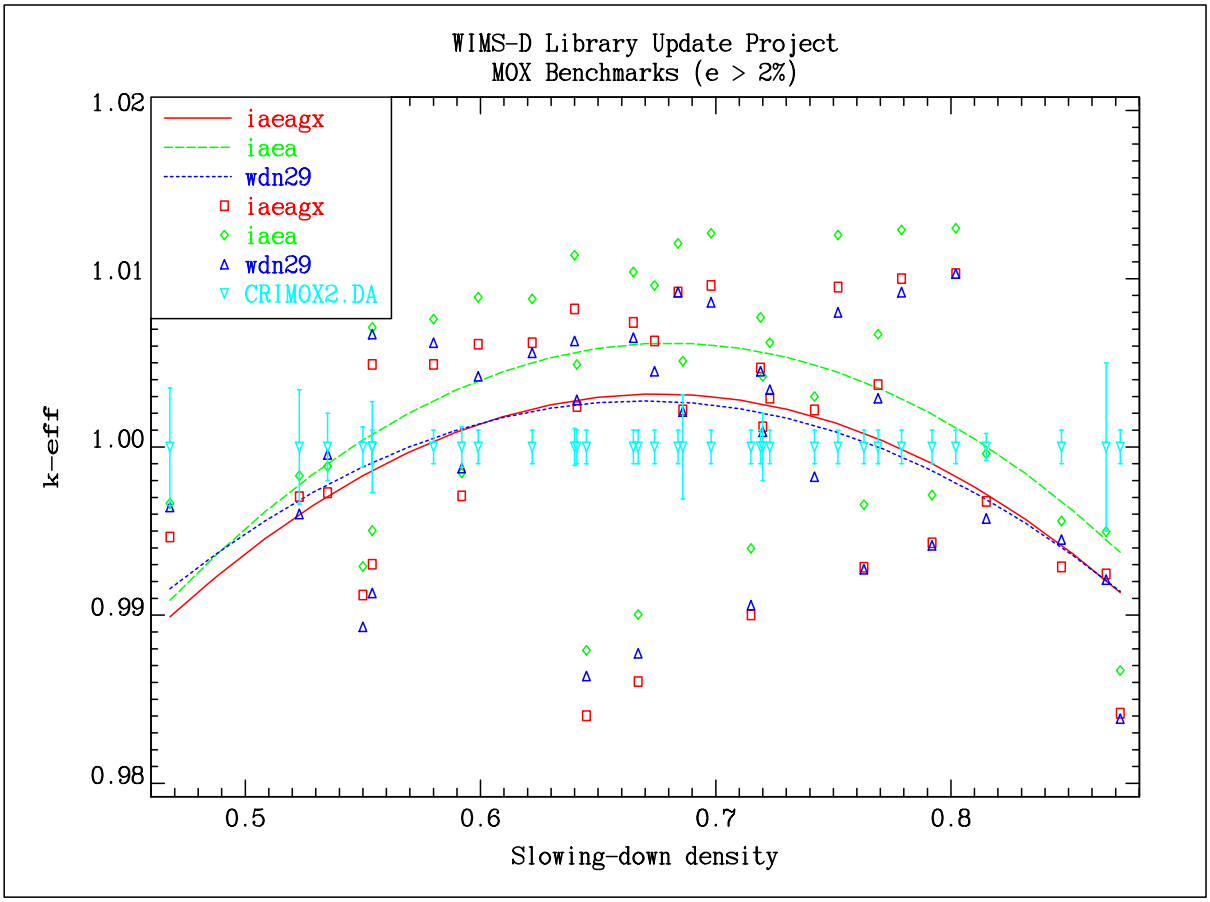

Fig. 14.10. H_2O-moderated MOX lattices k_{eff} vs q. Enrichment B (> 2% fissile metal) standard criticality benchmarks.

Mixed oxide lattices with fissile metal content > 2% encompass 34 cases with *q*-values ranging from 0.47 to 0.87. Criticality condition is predicted within 1% for the majority of cases with all libraries. All values of k_{eff} generated by the IAEA69 library are slightly higher than the corresponding values obtained with the IAEA172 and WIMS86 libraries.

14.9.5. Uranium and plutonium intermediate spectrum critical homogeneous systems

TABLE 14.13. k_{eff} vs. q-VALUE FOR INTERMEDIATE SPECTRUM CRITICAL HOMOGENEOUS SYSTEMS

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.137	1.03211	1.02373	0.99415	1.00000	0.00100	hiss1
0.071	1.01626	1.01701	1.04455	1.00000	0.00100	hiss2

These are only two cases representing intermediate spectrum lattices: HISS1 (^{235}U-mixture) and HISS2 (Pu-mixture). Predicted criticality with the IAEA libraries is too high, which is a feature of the basic evaluated data as verified by benchmarks results found in the literature when using more accurate code systems. The user is warned that the combination of IAEA libraries with the present data are not valid tor the analysis of intermediate spectrum lattices.

14.9.6. H_2O-moderated $^{233}UO_2$-ThO_2 critical lattices

TABLE 14.14 k_{eff} vs. q-VALUE FOR H_2O-MODERATED $^{233}UO_2$-ThO_2 CRIICAL LATTICES

q	aea172	iaea59	wims86	EXPKeff	EXPerror	name
0.503	1.01428	1.01595	0.99282	1.00000	0.00760	BNL_THH2O1
0.552	1.00879	1.01060	0.99203	1.00000	0.00450	BNL_THH2O2
0.583	1.00896	1.01085	0.99440	1.00000	0.00650	BNL_THH2O3
0.620	1.00782	1.00978	0.99523	1.00000	0.00490	BNL_THH2O4
0.670	1.00610	1.00809	0.99530	1.00000	0.00240	BNL_THH2O5
0.735	1.00598	1.00781	0.99647	1.00000	0.00290	BNL_THH2O6
0.849	1.00372	1.00496	0.99585	1.00000	0.00060	BNL_THH2O7
0.950	1.00119	1.00159	0.99517	1.00000	0.00100	BNL_THH2O8

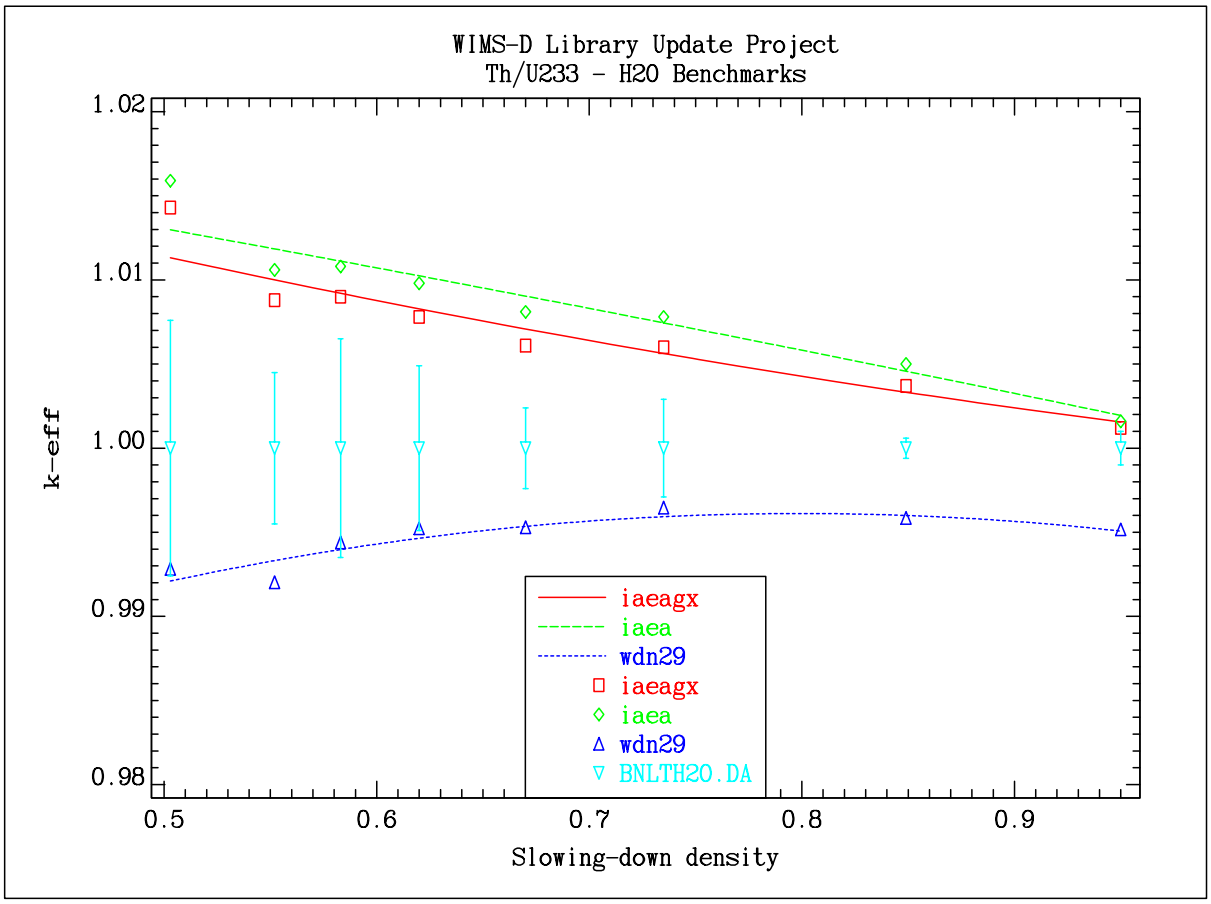

Fig. 14.11. H_2O-moderated ThO_2-$^{233}UO_2$ lattices k_{eff} vs q. Standard criticality benchmarks.

Light water moderated Th-^{233}U benchmarks consist of 8 cases, with q-values ranging from 0.50 to 0.95. Criticality predictions lie close to the uncertainty interval: they are overpredicted with the IAEA libraries, and underpredicted with the WIMS86 library. The old WIMS86 library is marginally better for hard spectrum lattices, while the IAEA libraries are slightly better for the well-moderated cases.

Spectral Index

Definitions of the parameters are given in the description of the benchmarks (Appendix IV). Only the Rho28 parameter is included with the experimental values. Table 14.15 lists the average differences between the calculations and experimental values for the IAEA libraries and WIMS86. On average the calculated values are significantly smaller than the experimental data.

TABLE 14.15. SPECTRAL INDEX RESULTS FOR H_2O MODERATED $^{233}UO_2$-ThO_2 CRITICAL LATTICES. AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES*

	Rho28	
	E(%)	Std.D
exp	3.66	
iaea172	-16.67	2.15
iaea69	-16.09	2.33
wims86	-9.83	2.13

(*) E(%) are experimental errors in the first line of data, while percent difference of the calculated values from experimental data are given on the other lines; Std.D are % standard deviations of these differences, and measure the spread of results.

14.9.7. D_2O-moderated $^{233}UO_2$-ThO_2 critical lattices

TABLE 14.16. k_{eff} vs. q-VALUE FOR D_2O-MODERATED $^{233}UO_2$-THO_2 CRITICAL LATTICES

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.351	1.01759	1.02095	0.97869	1.00000	0.00220	BNL-TD2O-1
0.586	0.98972	0.99056	0.97504	1.00000	0.00280	BNL-TD2O-2
0.631	0.99067	0.99117	0.97673	1.00000	0.00400	BNL-TD2O-3
0.711	0.98616	0.98612	0.97105	1.00000	0.00270	BNL-TD2O-4
0.741	0.99404	0.99378	0.97776	1.00000	0.00750	BNL-TD2O-5
0.788	0.98794	0.98739	0.96971	1.00000	0.00590	BNL-TD2O-6
0.820	1.00971	1.00888	0.98960	1.00000	0.00990	BNL-TD2O-7
0.856	1.01247	1.01141	0.99076	1.00000	0.00680	BNL-TD2O-8

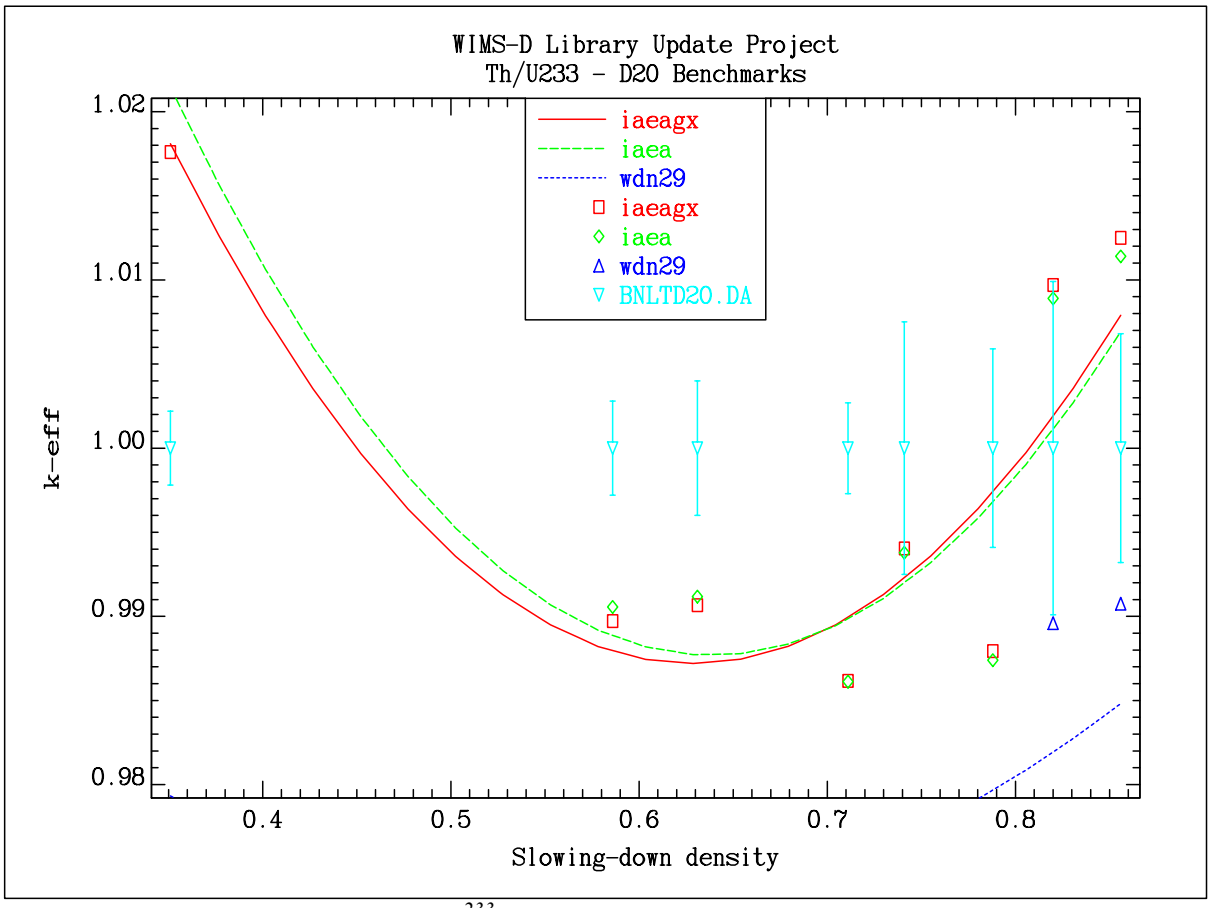

Fig. 14.12. D_2O-moderated ThO_2-$^{233}UO_2$ lattices k_{eff} vs q. Standard criticality benchmarks.

Heavy water moderated Th-^{233}U benchmarks consist of 8 cases, with q-values ranging from 0.35 to 0.86. Fairly large discrepancies are observed between measurements and calculations, with the IAEA libraries appearing to perform better.

Spectral Index

Definitions of the parameters are given in the description of the benchmarks (Appendix IV). Rho28 and Del28 are included with the experimental values. Table 14.17 lists the average differences between the calculated and experimental values for the IAEA libraries and WIMS86. On average all calculated values of Del28 are within the experimental errors, and the Rho28 values calculated with the IAEA libraries are somewhat too small.

TABLE 14.17. SPECTRAL INDEX RESULTS FOR D_2O MODERATED $^{233}UO_2$-THO_2 CRITICAL LATTICES. AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES*

	Rho28		Del28	
	E(%)	Std.D	E(%)	Std.D
exp	5.35		11.90	
iaea172	-7.48	6.91	-4.54	4.38
iaea69	-7.42	7.14	-4.92	4.39
wims86	0.42	6.83	-9.63	4.87

(*) E(%) are experimental errors in the first line of data, while percent difference of the calculated values from experimental data are given on the other lines; Std.D are % standard deviations of these differences, and measure the spread of results.

14.9.8. D_2O-moderated UO_2 critical lattices

TABLE 14.18. k_{eff} vs. q-VALUE FOR D_2O-MODERATED UO_2 CRITICAL LATTICES

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.823	1.00721	1.00528	1.00313	1.00000	0.00250	ZED2T1D2O
0.818	1.01076	1.00841	1.00609	1.00000	0.00250	ZED2T1Air
0.764	1.00043	0.99859	0.99723	1.00000	0.00250	ZED2T2p24
0.853	1.00823	1.00693	1.00362	1.00000	0.00250	ZED2T2p40
0.816	1.00580	1.00427	1.00074	1.00000	0.00250	ZED2T3p24
0.693	1.00017	0.99982	0.99578	1.00000	0.00250	ZED2T4D22
0.662	1.00360	1.00317	0.99939	1.00000	0.00250	ZED2T4A22
0.745	0.99885	0.99849	0.99592	1.00000	0.00250	ZED2T4D28
0.705	1.00001	0.99959	0.99699	1.00000	0.00250	ZED2T4A28
0.693	1.00081	1.00074	1.00060	1.00000	0.00250	DCAT1D22
0.766	1.00027	0.99994	0.99960	1.00000	0.00250	DCAT1A22

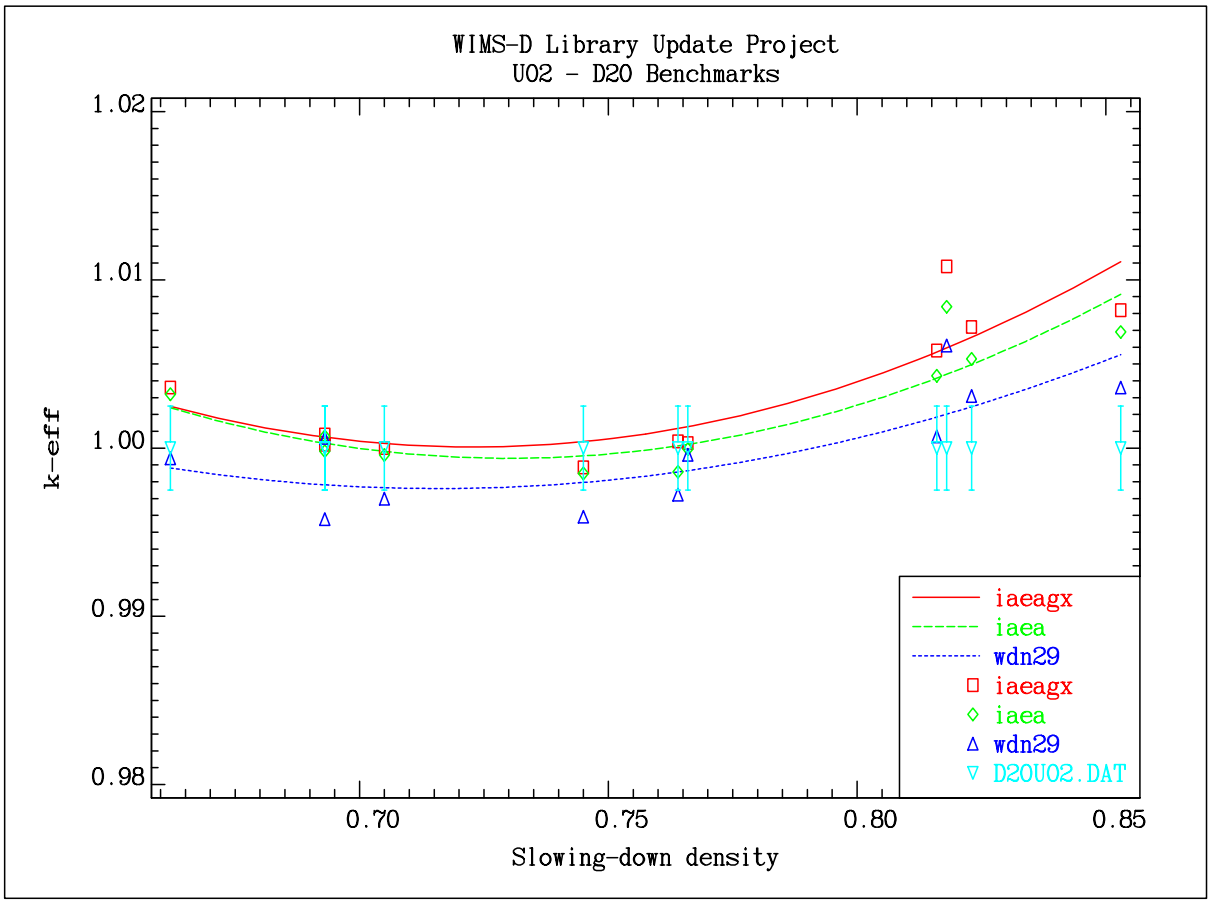

Fig. 14.13. D_2O-moderated UO_2 lattices k_{eff} vs q. Standard criticality benchmarks.

Results of these 11 cluster-type UO_2 lattices moderated with heavy water are close to or within the measurement uncertainties for all cases and libraries. The data derived with the old WIMS86 library are marginally better in well-moderated lattices.

Spectral Index

Definitions of the parameters are given in the description of the benchmarks (Appendix IV). Table 14.19 lists the average differences between the calculated and experimental values for the IAEA libraries and WIMS86. On average, Del is significantly overestimated, ConvR is slightly underestimated, CuA is within the experimental errors, and LuR is slightly overestimated by the IAEA libraries only.

TABLE 14.19. SPECTRAL INDEX RESULTS FOR D_2O MODERATED UO_2 CRITICAL LATTICES. AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES*

	Del		ConvR		CuA		LuR	
	E(%)	Std.D	E(%)	Std.D	E(%)	Std.D	E(%)	Std.D
exp	5.8		0.5		1.00		0.40	
Iaea172	16.2	25.7	-2.0	2.9	0.73	0.74	1.17	1.17
Iaea69	16.1	25.8	-1.7	2.8	0.69	0.71	1.37	1.37
Wims86	11.9	19.2	-1.5	2.3	0.87	0.98	0.05	0.29

(*) E(%) are experimental errors in the first line of data, while percent difference of the calculated values from experimental data are given on the other lines; Std.D are % standard deviations of these differences, and measure the spread of results.

Definitions of spectral parameters:

Del	Fast fission reaction ratio [^{238}U fission/^{235}U fission]
ConvR	Relative conversion ratio: [^{238}U capture/^{235}U fission fuel] / [^{238}U capture/^{235}U fission Maxwellian]
CuA	^{63}Cu absorption rate distribution
LuR	Lutetium-manganese activity ratio in the fuel and in a Maxwellian spectrum: [A(Lu)/A(Mn)fuel] / [A(Lu)/A(Mn)Maxwellian]

14.9.9. D_2O-moderated $^{235}UO_2$-ThO_2 critical lattices

TABLE 14.20. k_{eff} vs. q-VALUE FOR D_2O-MODERATED $^{235}UO_2$-ThO_2 CRITICAL LATTICES

q	iaea172	iaea69	wims86	EXPKeff	EXPerror	name
0.886	1.00109	1.00113	1.00126	1.00000	0.00250	DCAT1H22
0.883	1.00104	1.00085	1.00038	1.00000	0.00250	DCAT1D25
0.916	1.00114	1.00086	1.00041	1.00000	0.00250	DCAT1A25
0.916	1.00160	1.00169	1.00176	1.00000	0.00250	DCAT1H25

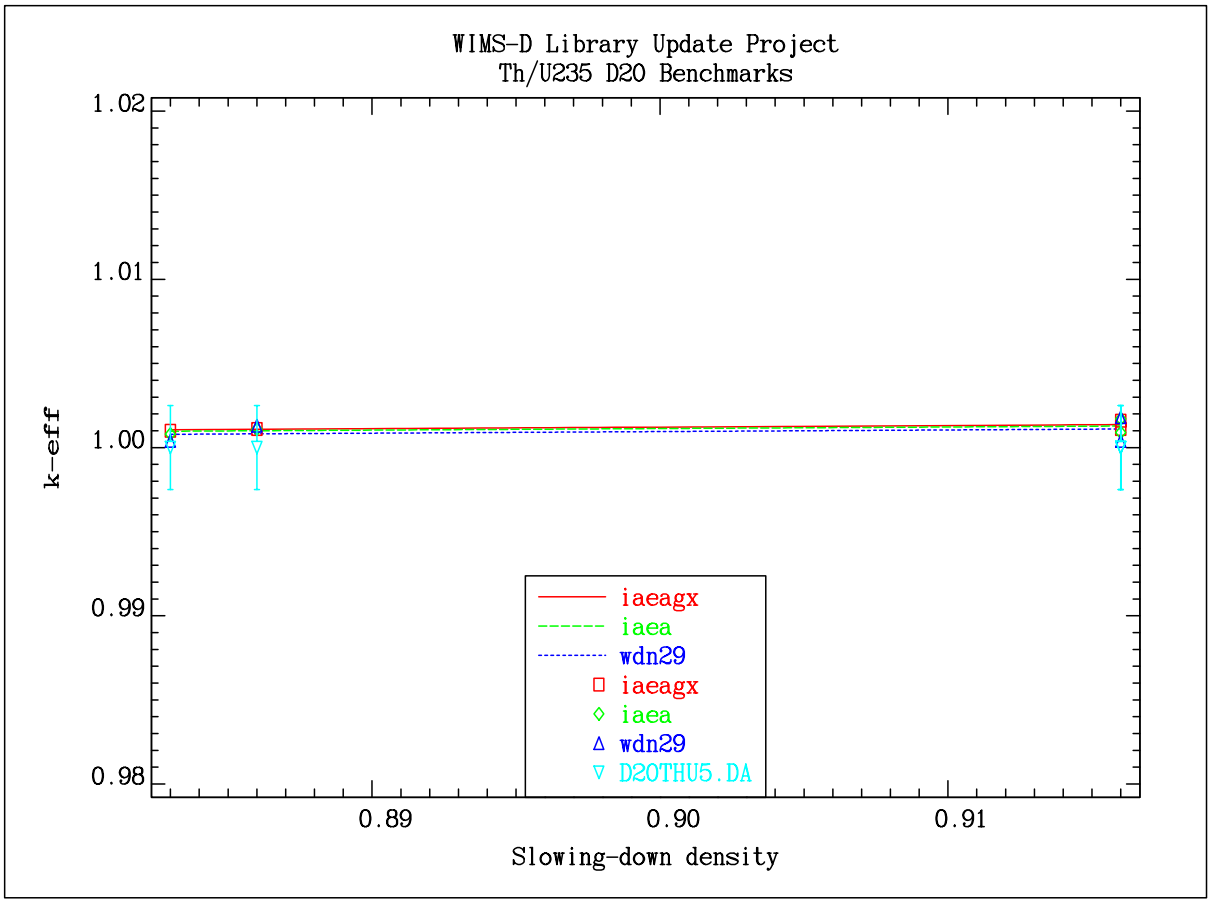

Fig. 14.14. D_2O-moderated ThO_2-$^{235}UO_2$ lattices k_{eff} vs q. Standard criticality benchmarks.

These four cases of cluster-type lattices with ThO_2-$^{235}UO_2$ fuel and moderated with heavy water are all within the experimental uncertainties for all libraries.

14.9.10. Standard Burnup Benchmark Specifications

(a) NPD 19-rod fuel clusters. D_2O-moderated uranium oxide lattices. Analysis of isotopic composition as a function of burnup.

Percent differences calculation-experiment of isotopic concentration ratios for the bundle average of 3 burnup steps (3250, 6500 and 10800 MWD/T) are shown in Figs. 14.15 to 14.17. The symbols represent:

N35/N38 = N(^{235}U)/N(^{238}U), N36/N38 = N(^{236}U)/N(^{238}U),
N49/N38 = N(^{239}Pu)/N(^{238}U), N40/N49 = N(^{240}Pu)/N(^{239}Pu),
N41/N49 = N(^{241}Pu)/N(^{239}Pu) and N42/N49 = N(^{242}Pu)/N(^{239}Pu).

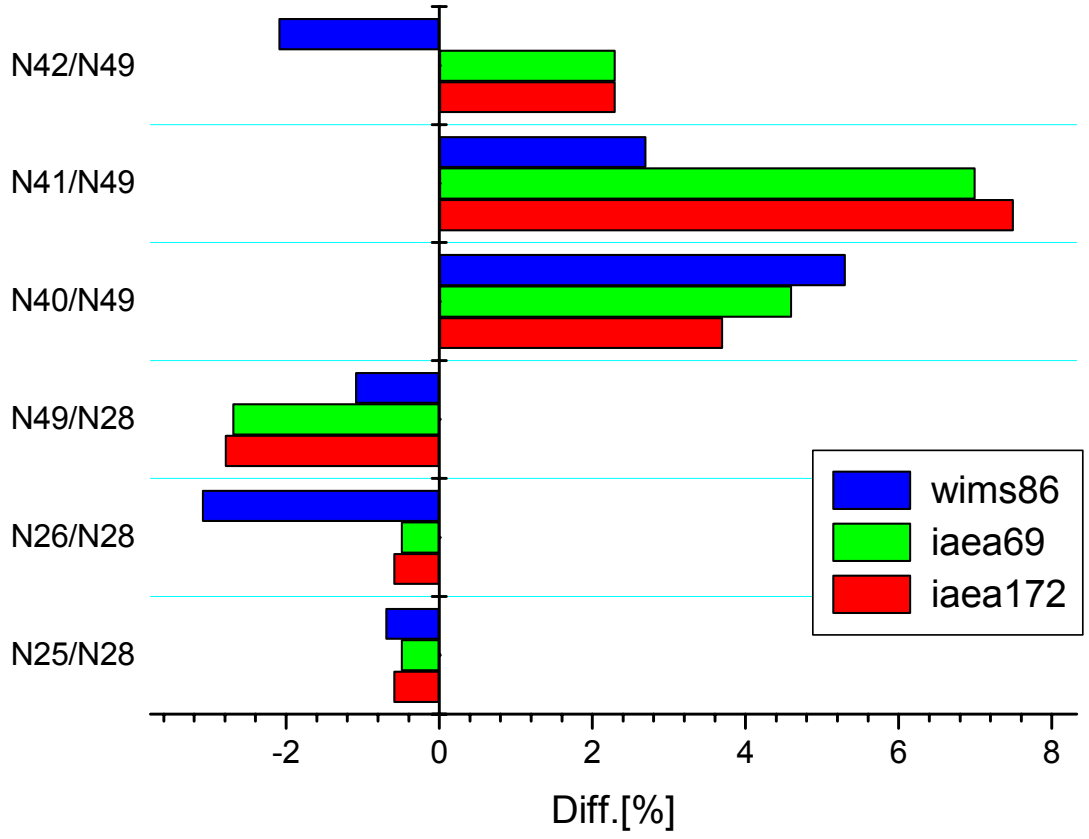

Fig. 14.15. NPD. D_2O-moderated uranium oxide lattice: Isotopic composition rates. Burnup 3250 Mwd/Tu.

The largest differences of between 3 and 7% for the IAEA libraries are for Pu ratios; these differences are smaller than 1% for U ratios. There is an important improvement in the ratio prediction for N(^{236}U)/N(^{238}U) with the IAEA libraries compared to WIMS86.

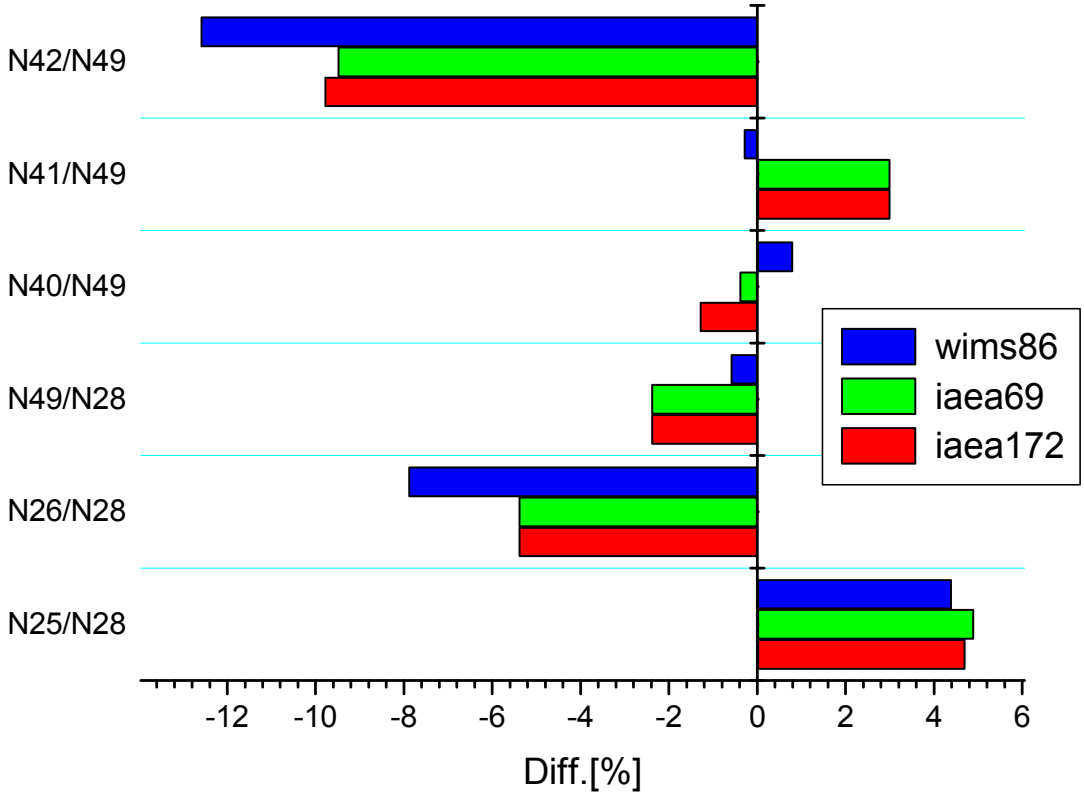

Fig. 14.16. NPD D_2O-moderated uranium oxide lattice: Isotopic composition rates. Burnup 6500 Mwd/Tu.

Pu ratio differences are smaller for this intermediate burnup case than for low burnup, and U ratio differences increase to 5% for N(^{236}U)/N(^{238}U).

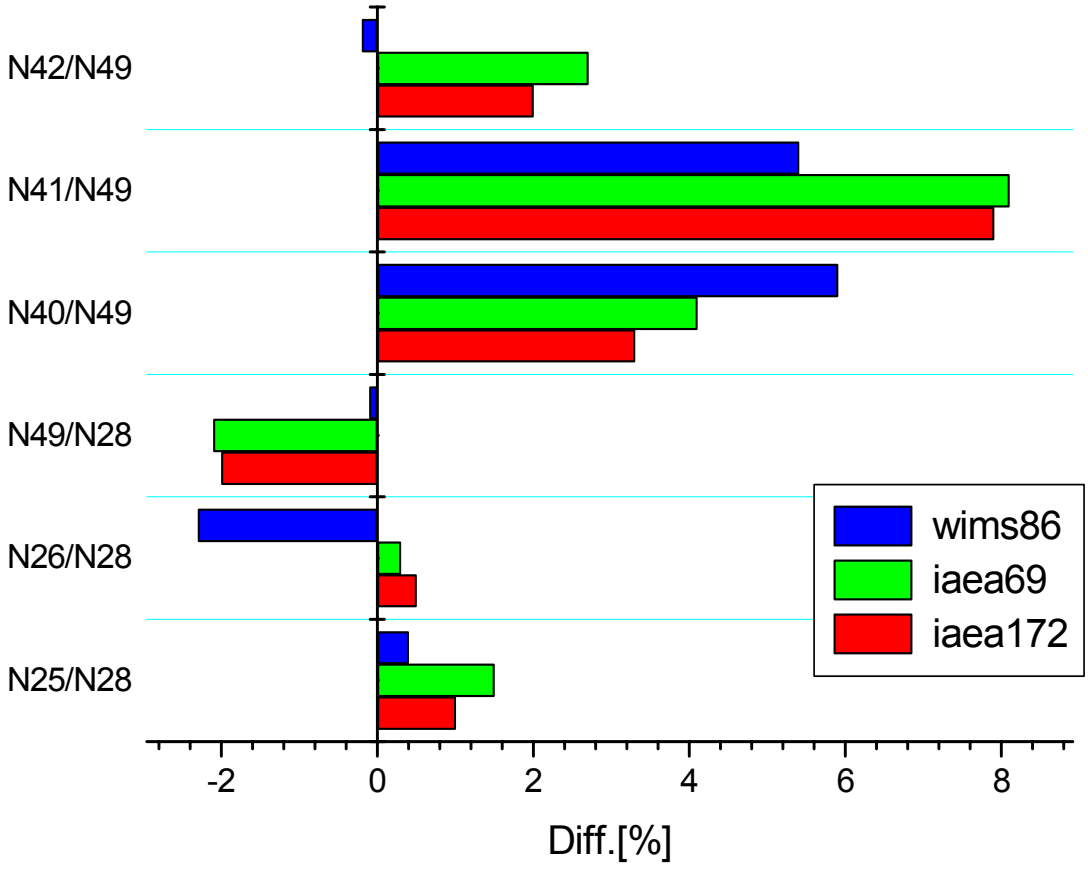

Fig. 14.17. NPD D_2O - moderated uranium oxide lattice. Isotopic composition rates. Burnup 10800 Mwd/Tu.

U ratio differences are small for this high burnup case, and Pu ratio differences are again larger than U ratio differences (similar to the case of small burnup).

(b) OECD/NEA burnup credit criticality benchmark: isotopic composition prediction

A benchmark was set up by the OECD/NEA to validate the isotopic composition as a function of burnup as predicted by different codes used in OECD countries [14.8]. Lattice cell geometry and operating conditions were chosen to represent as much as possible the geometry and conditions of a real reactor, for which measured concentrations of a number of nuclides were available. The reference nuclide concentrations are the average values from 21 different calculations contributed by 17 laboratories, and the uncertainty is the standard deviation from the mean.

Percent differences from the reference average isotopic concentrations were calculated from the measured data and values calculated with the WIMS-D libraries. Data for 3 burnup steps are available: 27.35, 37.12 and 44.35 GWd/tU, and they are shown in Figs. 14.18. to 14.20.

Generally, there is good agreement between the results. The main conclusions are as follows:

U-234 Results with all WIMS-D libraries are in good agreement with the reference average and measured values, except the WIMS86 results at higher burnups which drift towards the lower bound of the uncertainty interval.

U-235 Surprisingly, the uncertainty in the reference average value exceeds 5%; IAEA libraries give higher values with increasing burnup, which is supported by the measured values.

Pu-238 Significant improvement is observed compared to the WIMS86 library; the remaining discrepancy is caused mainly by the approximate treatment of the low energy Pu-242 resonance.

Pu-242 Concentration predicted with the IAEA libraries is much closer to the reference average, but still slightly lower than the benchmark measurement.

Np-237 Results with all WIMS-D libraries are in good agreement with each other, but slightly lower than the reference average; measured values support the WIMS results.

Mo-95 Results with the IAEA libraries are slightly better than with the WIMS86 library.

Ag-109 Results with all WIMS-D libraries are in good agreement, but slightly lower than the reference average. The fission yield of Ag-109 has changed in the evaluated data libraries since the release of ENDF/B-V. Since many of the codes constituting the reference average results are based on ENDF/B-V data, there might be a bias in the reference averager value; unfortunately, no measurement is available.

Cs-135 At low burnup; the WIMS calculations are in good agreement with each other and slightly lower than the reference average, but well within the uncertainty. The measured value seems to be even lower. With increasing burnup the agreement between measurement and calculations with the IAEA libraries improves, but the WIMS86 results tend to drift to somewhat lower values.

Sm-149 Note the large uncertainty in the reference average results for this important nuclide. WIMS calculations with the WIMS86 and the IAEA libraries lie close to the edge of the uncertainty interval, but on opposite sides of the reference average values. Measured values are 40 to 100% higher, but there is a possibility of a systematic error in these measurements.

Sm-150 All WIMS calculations are within the uncertainty interval of the reference average value. WIMS86 results seem to be somewhat closer to the measured value.

Sm-151 The uncertainty in the reference average value is extremely large. WIMS86 result is too high and lies outside the plot window, whereas the results with the new IAEA

libraries are much closer to the reference average value. No measured data are available.

Sm-152 Spectral effects seem to be important. Although all values from WIMS calculations lie within the uncertainty interval, the results with the IAEA 172-group library lie closer to the measured values.

Eu-153 Results with the IAEA libraries agree better with the reference average and measured values than the WIMS86 library results.

Gd-155 Results with the IAEA libraries lie within or close to the large uncertainty interval of the reference average value (note that uncertainty limits lie outside the plot window). A separate analysis has revealed that the cross sections of Eu-155 (precursor of Gd-155) are responsible for the discrepancy and the data spread. A similar observation has been reported in Ref. [14.9], concluding that the more recent cross sections for Eu-155 from the ENDF/B-VI evaluated data library are correct (these data were used to generate the WIMSD-IAEA libraries). The WIMS86 library does not include this nuclide. No measured value is available.

Prediction of the concentrations of other actinides and fission products are within the uncertainties, although a slight improvement is generally observed with the IAEA libraries.

The overall conclusion is that the IAEA libraries perform well for light water reactor lattices with uranium oxide fuel. They provide considerable improvements in the predictions of the concentrations of some fission products, and major improvements in the predictions of the actinide concentrations.

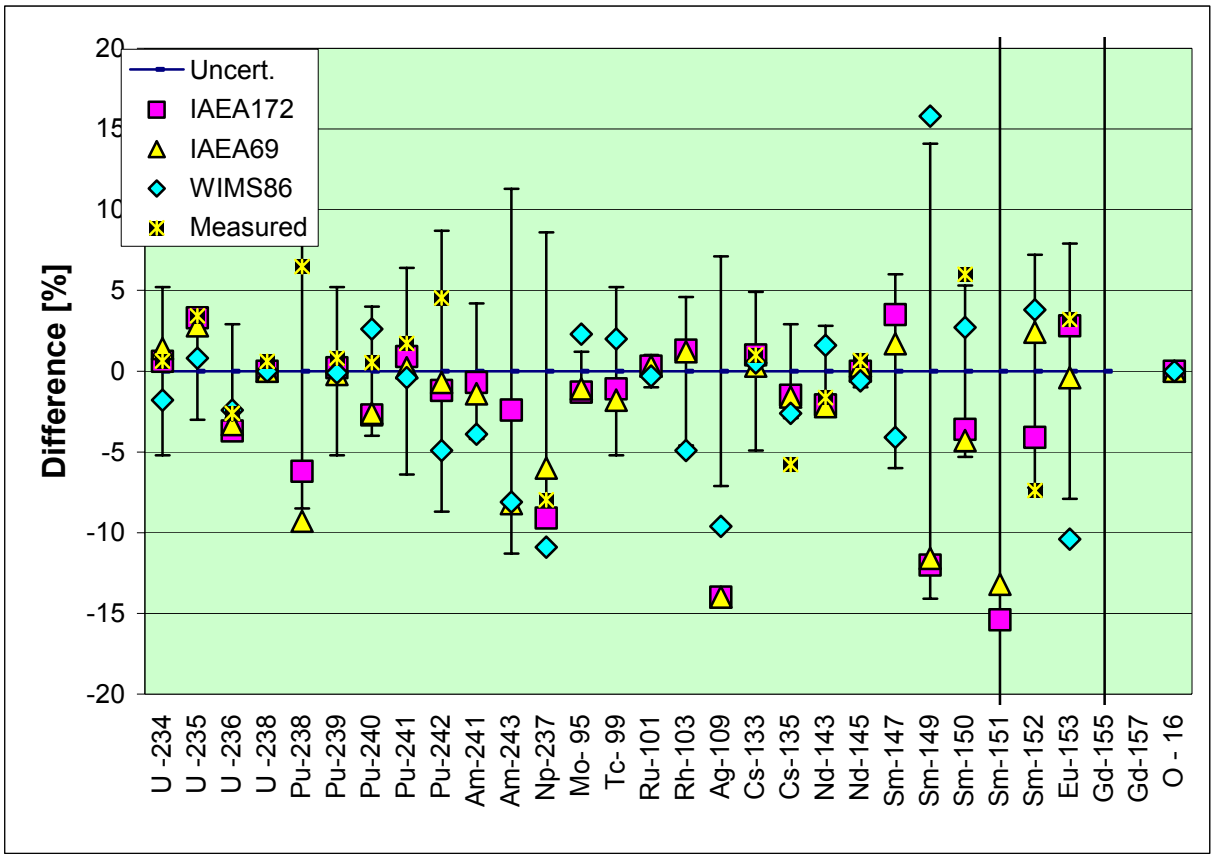

Fig. 14.18. OECD/NEA Burnup Credit Calculational Criticality Benchmark: Isotopic composition comparison, Burnup = 27.35 GWd/tU.

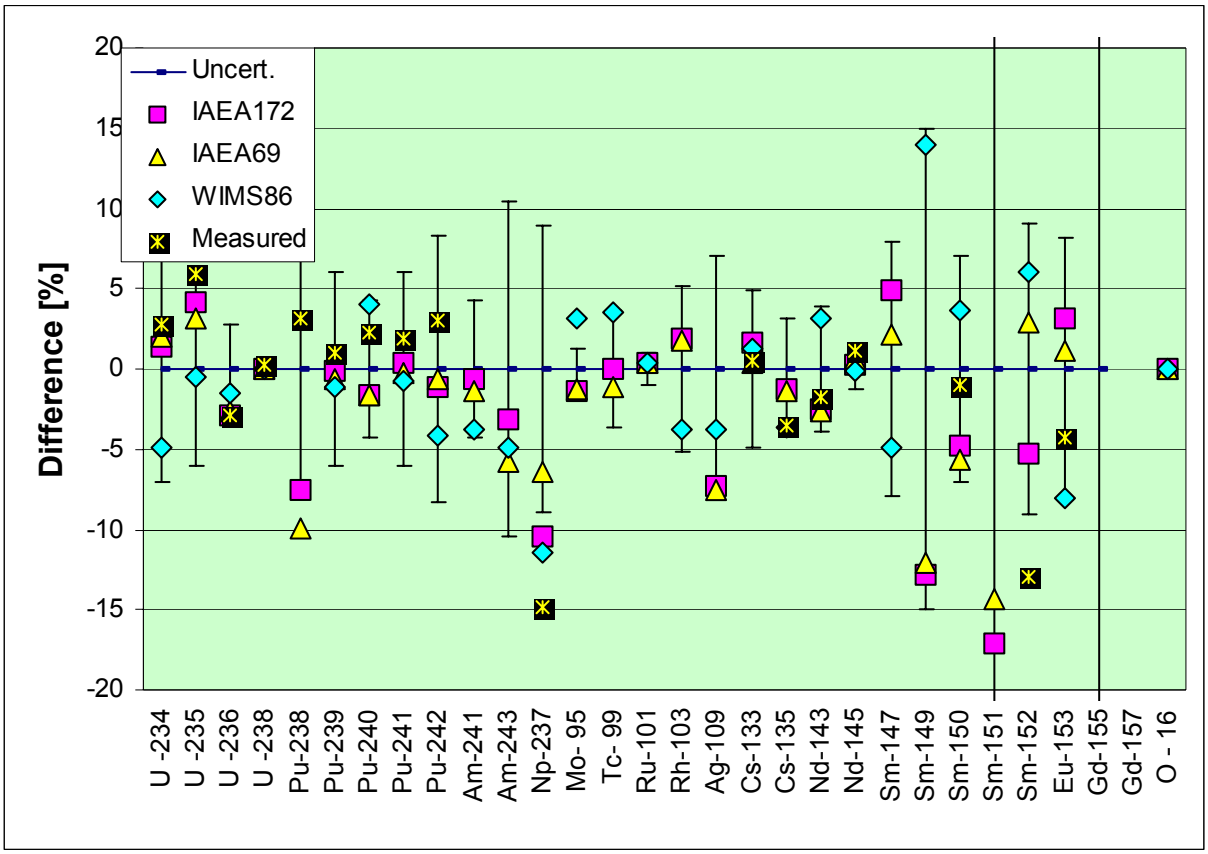

Fig. 14.19. OECD/NEA Burnup Credit Calculational Criticality Benchmark: Isotopic composition comparison, Burnup = 37.12 GWd/tU.

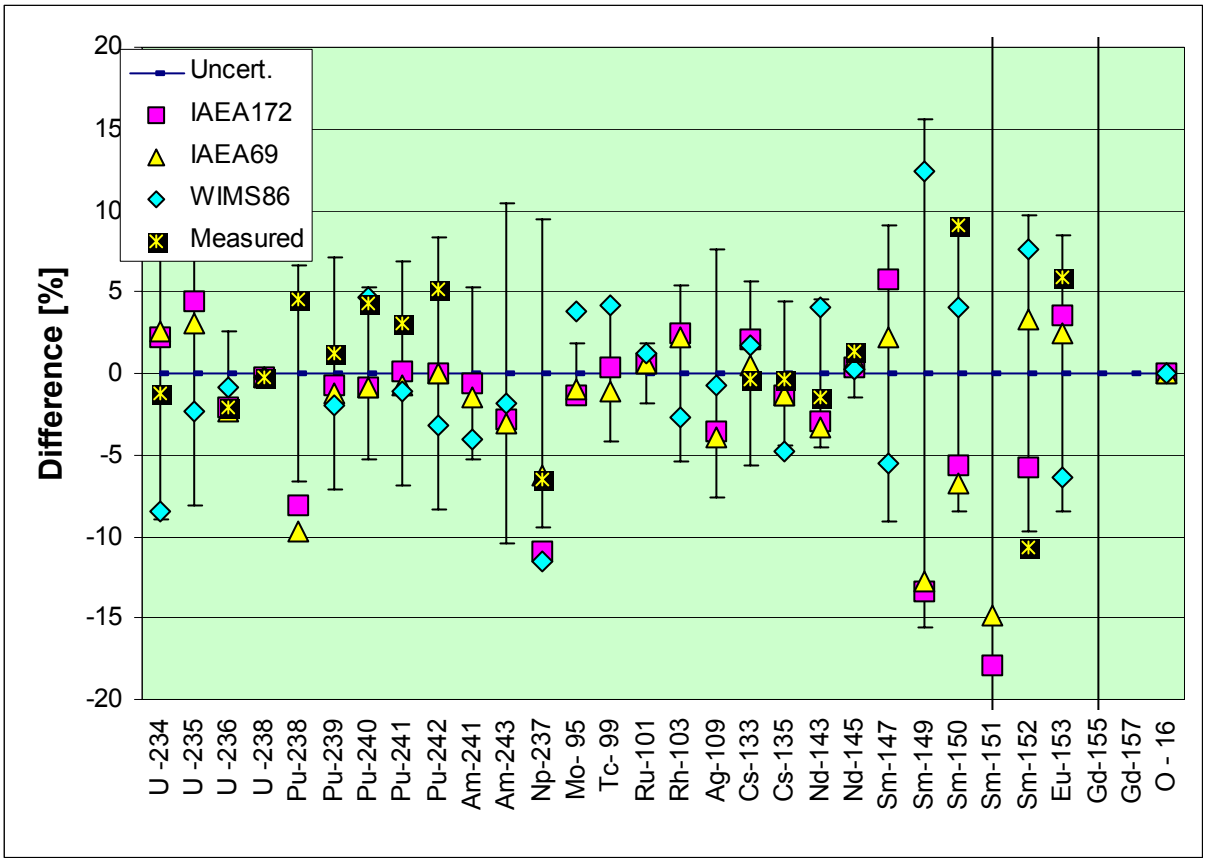

Fig. 14.20. OECD/NEA Burnup Credit Calculational Criticality Benchmark: Isotopic composition comparison, Burnup = 44.34 GWd/tU.

(c). NEA/CRP plutonium recycling benchmarks

Plutonium recycling benchmarks were designed to test the prediction capabilities of lattice and inventory codes applied to the problems of mixed oxide cores loaded with recycled plutonium [14.10]. No suitable experimental information is available, therefore the benchmarks are purely numerical. Case A represents a core containing highly-degraded (multiply-recycled) plutonium with a high fraction of the higher mass isotopes; Case B represents normal recycled plutonium. The reference average nuclide concentrations are the average values from 11 different calculations contributed by 10 laboratories, in which the uncertainty is the standard deviation. Results are shown in Figs. 14.21 and 14.22 for Cases A and B, respectively.

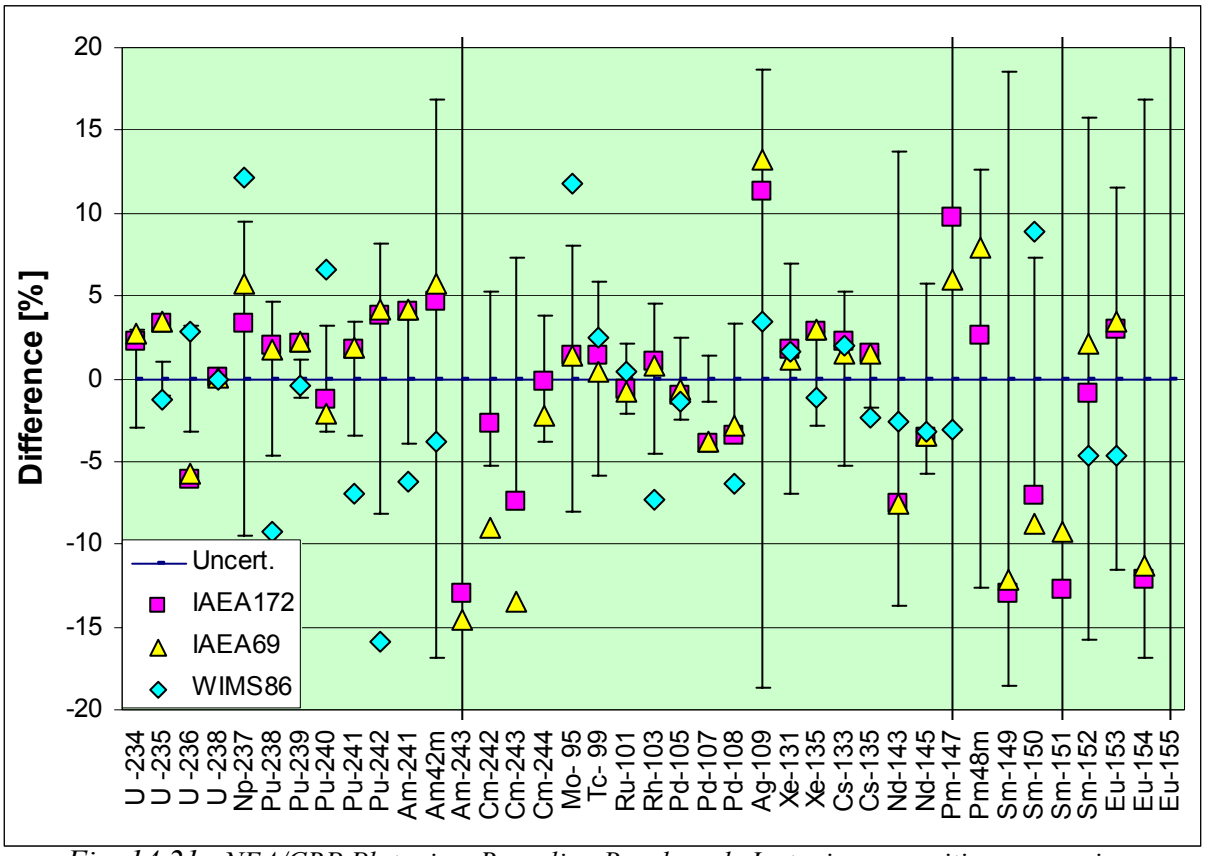

Fig. 14.21. NEA/CRP Plutonium Recycling Benchmark. Isotopic composition comparison Benchmark A – Highly-degraded Plutonium. Burnup = 50 GWd/tU.

The following observations can be made:

U-234 Good agreement with the reference average results is observed for the highly-degraded plutonium case; the uncertainty associated with the normal recycled plutonium is very large.

U-235 Differences most probably occur due to different measures of burnup (i.e., energy released per fission) rather than the cross sections. The WIMS86 data are in slightly better agreement with the reference average value.

U-236 Smaller burnout of U-235 results in a lower U-236 concentration with the IAEA libraries.

Np-237 Prediction with the IAEA libraries is slightly better and within the uncertainty of the reference average values.

Pu Prediction of Pu-238 with the WIMS86 library is poor, while the results with the IAEA libraries are within the uncertainty interval of the reference average value. A similar conclusion can also be drawn for other Pu isotopes, except Pu-239 (when similar arguments apply for the differences as for U-235).

Am Prediction of the concentrations of Am isotopes for highly-degraded plutonium improves with the IAEA libraries. Excellent agreement of the predicted concentration of Am-241 and Am-242m with the WIMS86 library might be a statistical coincidence, since the Am-243 prediction is poor.

Cm Isotopic concentrations calculated with the IAEA libraries are reasonable. Spectral effects would appear to be important, since improvements are observed with the 172-group library. Curium isotope data are not available in the WIMS86 library.

Prediction of the fission product concentrations is generally good with the IAEA libraries. A marked improvement is observed in many cases, compared with the WIMS86 library. Trends for individual isotopes are similar to those observed in the Burnup Credit Benchmark. The main advantage of the new IAEA libraries is the extended list of fission products and actinides.

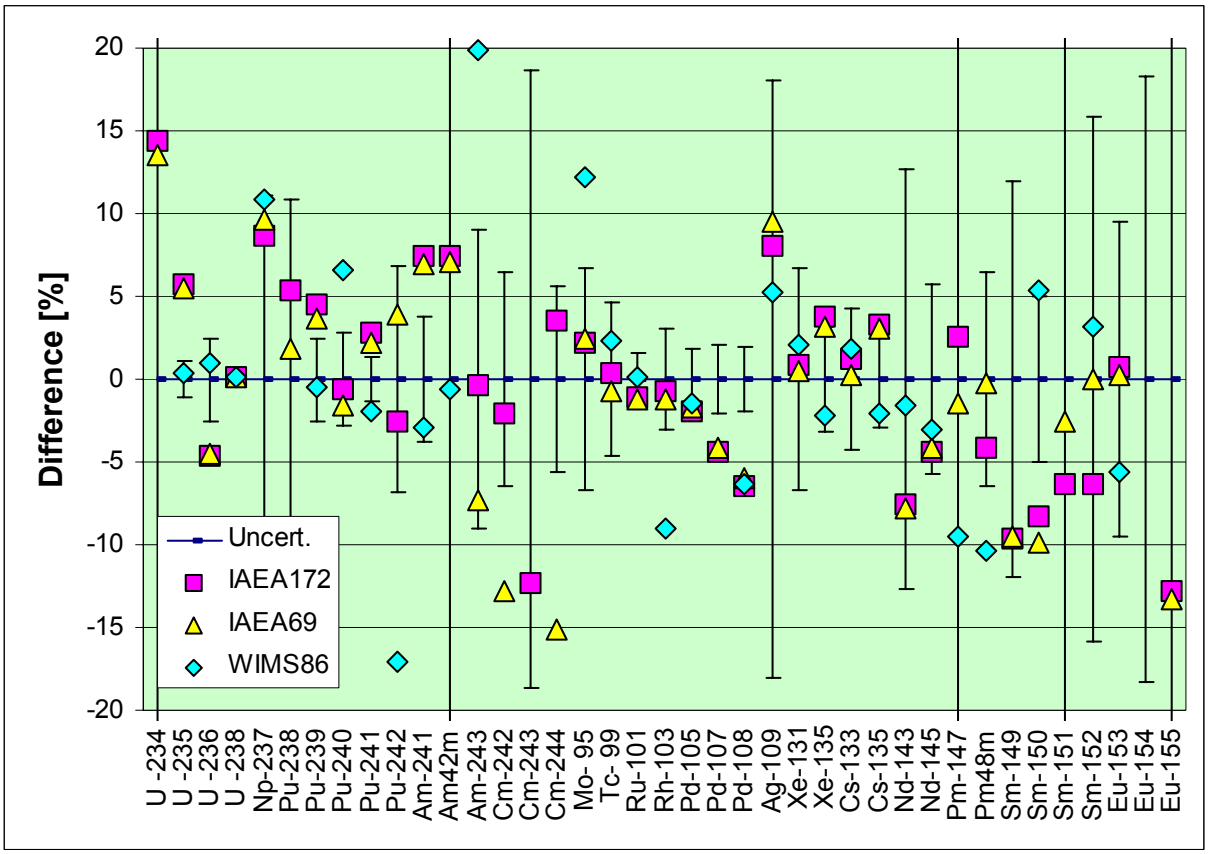

Fig. 14.22. NEA/CRP Plutonium Recycling Benchmark. Isotopic composition comparison Benchmark B – Normal PWR recycled Plutonium. Burnup = 50 GWd/tU.

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15. CONCLUSIONS AND RECOMMENDATIONS

15.1. Overall conclusions

The primary objective of WLUP to produce an updated and well tested WIMS-D multigroup data library has been accomplished. Results from benchmark tests have been used to demonstrate the good performance of the WIMSD-IAEA libraries with respect to the prediction of various integral parameters in a large variety of lattice configurations. Cross sections and other parameters in the library were generated from evaluated nuclear data files by first principles and consistently within the definitions used throughout the WIMS-D family of codes; no artificial adjustments of the constants were needed as in the older libraries like WIMS86 (part of the original WIMSD-5B package).

The benchmark tests prepared for WLUP and adopted to assess the WIMS-D libraries include more that 200 cases for over 10 different systems and combinations of fuels, moderators and geometries, applied to various core conditions and parameters.

The original objective of the project was enhanced with the generation of a library containing 172 energy groups, in addition to the standard 69-group library. Modifications were also succesfully made to the WIMSD-5B code for use with the 172-group library.

A set of programs and batch files were developed for the generation of the libraries and to run the benchmark cases. All this material is included on a CD-ROM and IAEA Web-page for free access and use.

Other achievements included:

(a) Precise definitions of the constants in the WIMS-D library have been prepared, which facilitates a better understanding of the physics and methods in the WIMS-D family of codes. The fact that no artificial adjustments were needed to prepare the libraries makes them suitable for various sensitivity and perturbation studies in the development and testing of improved evaluated nuclear data files.

(b) WIMS-D library users can utilise the procedures developed for generating the WIMS-D libraries to prepare special purposes libraries, or for updating the libraries when new data become available.

(c) The new libraries represent an improvements in several aspects compared to the last non-commercial WIMS86 library. These improvements are summarized below:

Number and types of materials

	WIMS86	WIMSD-IAEA libraries
Total number of materials	129	**173**
Moderators	3	**5**
Fission products	36	**58**
Burnable absorbers	18	**20**
Resonant materials	14	**28**
Actinides	18	**21**
Dosimetry reactions	11	**37**

Number and types of energy groups

	WIMS86	IAEA172-WIMSD library
Fast groups	14	**45**
Resonance groups	13	**47**
Thermal groups	42	**80**
Total	69	**172**

Burnup chains

- Special treatment for ^{232}U and ^{237}U production.
- Special treatment of capture and decay of Am isotopes.

Cross sections and related parameters

- Self-shielding of scattering cross sections with typical dilutions.
- Goldstein-Cohen factors re-calculated, and method documented.
- Three different condensation neutron spectra (for LWR, HWR and ThO_2-D_2O systems).
- Two different neutron current spectra for transport correction (for H_2O and D_2O moderators).
- Extended number of temperatures for thermal data.

Resonance integrals

- Extended number of temperatures for Doppler effect.
- Background cross sections revised for better interpolation between tabulated values.

15.2. Possible future developments

- Web page for the WIMSD-IAEA library that provides feedback from users.
- Scripts and programs to run under UNIX.
- Extended burnup schemes in the libraries.
- Include JENDL3.3 based libraries.
- Include CENDL3 based libraries.
- Revise IAEA libraries as necessary.
- Add new benchmarks (include more full core cases).
- Perform extensive, in-depth analysis of benchmark results.
- Implement further improvements to WIMSD-5B code.

Appendix I

Q-VALUE PROGRAM FOR ANALYSIS OF RESULTS

The *q*-value is used to characterize lattices, where "*q*" is defined as the number of fission neutrons that slow down below 2.6 eV. This threshold energy has been arbitrarily chosen, but is widely used and agreed upon for easier comparison of results.

The *q*-value characterizes the hardness of the spectrum and has a value of 1 for soft spectra in well-moderated low-absorbing lattices, and is smaller for hard spectrum lattices.

Thus, *q* is defined as:

$$q = \frac{\sum_{g>2.5eV} (\phi_g \sum_{h<2.6eV} \Sigma_{s,g\to h})}{\sum_g \phi_g \nu_g \Sigma_{fg}}$$

where

ϕ_g is the cell spectrum from the region edit of WIMS output,

$\Sigma_{s,g\to h}$ is the component of scattering matrix from group *g* to *h* (from WIMS output), and

$\nu_g \Sigma_{fg}$ is the macroscopic fission yield.

This summation is performed over scattering matrix elements of group *g* corresponding to energy > 2.5 eV, and group *h* corresponding to energies < 2.6 eV (i.e., scattering source to any energy below 2.6 eV). The summation in the denominator has to be undertaken over all of the energy range (groups "g").

A program QVALUE has been developed to analyse the WLUP Benchmark results by performing the following tasks:

(1) calculate the *q*-value for each WLUP-benchmark lattice processing WIMS-D outputs for one library, and
(2) prepare tables so that plots of k_{eff} vs. *q* can be produced (k_{eff} values are extracted from smrlib output).

The threshold energy can be chosen by the user, giving an input file QVALUE.INP with the defined number of "epithermal" groups (ngep) and a lower energy limit of the threshold energy. The value for this energy of 2.6 eV corresponds to ngep = 29 for the standard 69-group WIMS-D library. The number of groups (ng) of the WIMS-D library can also be changed in QVALUE.INP.

Input files

(1) QVALUE.INP - See the file included in the package for explanation. The input is standardised and is strongly related to other input files (names and order of data), so any modifications should be done with great care.

(2) SMRLIB.LST – The calculated k_{eff} values of WLUP-benchmarks are read from this file for plotting. It is normally produced by the SMRLIB program and contains the name of the library and the corresponding k_{eff} value for (one record for each library in Fortran format A10, F8.5), preceeded by a record that identifies the name of the benchmark (format: A10).

(3) wimsX.out. WIMS-D outputs of all the X-benchmarks included in SMRLIB.LST one of the WIMS-D libraries, from which the *q*-value are calculated (it is assumed that the *q*-values are independent of the library). The names "wimsX" must correspond to the names given in QVALUE.INP file.

Output files

benchY.dat contains tables of k_{eff} vs. *q*-value for all benchmarks given in QVALUE.INP. A file for each benchmark type is produced, with the name equal to the benchmark-type name specified in QVALUE.INP. Two columns are added to the graphs: ExpKeff (=1.0) and ExpError (absolute) extracted from SMRLIB.LST file, for plotting experimental error bars.

Steps for graphing k_{eff} vs. *q*:

(1) Run BNCHALL.BAT for one or several WIMS-libraries (do not delete the WIMS-D output files because they will be used as reference for *q*-value calculations).
(2) Run SMRLIB.EXE for including results of all libraries.
(3) Edit QVALUE.INP for adjusting to the actual case.
(4) Run QVALUE.EXE.
(5) Sort benchY.dat QVALUE-output files.
(6) Enter to the desired graph program and import each benchY.dat file as source of data.

Examples of graphs obtained from Benchmarks calculations with WLUP-WIMSD libraries and QVALUE results are included in Chapter 15.

Appendix II

WLUP CRITICALITY BENCHMARKS INDEX OF CASES

A list of the most relevant data of standard criticality benchmarks is included here. A line with several parameters is included for each of the 219 cases.

Titles of items included on the list

General parameters:

ENRu5: Enrichment on U235 (weight %)
Q-VAL: *q*-value for the case (the method of calculation is explained in Appendix 1)
FUELd: Fuel rod diameter (cm)
CL: Clad material (al: Aluminium;
ss: Stainless Steel;
z2: Zircaloy 2;
z4: Zircaloy 4)
PITCH: Lattice pitch (cm)
Vm/Vf: [(Volume of moderator) / (Volume of fuel)] of the lattice
Bm**2: Experimental material buckling ($1/(m^2)$)
TEMP: Temperature (C)
GE: Geometry of the lattice (sq: square;
he: hexagonal;
ho: homogeneous mixture)
Observs.: Observations (name of experiment if there is one;
E: Exponential/subciritcal experiments;
STANDARD: first benchmarks adopted for WLUP;
CANDU: benchmarks related with CANDU type clusters of rods)

Special parameters:

Bcon: Boron concentration (g/liter of boric acid-H3BO3 dissolved in light water) for UO2-LB (WWER).
%Pu: wt% PuO_2 in PuO_2-UO_2 mixture for MOX-LW.
Pu'aaa': wt% of ^{aaa}Pu in Pu where 'aaa' is the isotope mass number (applicable to MOX-LW)
ThO2: wt% ThO_2 in ThO_2-UO_2 mixture for Th3-LW, Th3-HW and Th5-HW.
coo: coolant (D_2O, H_2O, air) for UO2-HW and Th3-HW.
nr: total number of rods in the cluster for UO2-HW and Th3-HW.

1) UME-LW (CRITUME)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
UME-LW-AECL	-aecl_um	0.714	0.825	3.251	al	5.359	2.305	-19.3	20.0	sq	E
UME-LW-AERE	-aere_uma1	0.928	0.535	1.905	al	2.388	0.848	-6.1	20.0	sq	E
UME-LW-AERE	-aere_uma2	0.928	0.571	3.048	ss	3.81	0.896	-2.0	20.0	sq	E
UME-LW-AERE	-aere_uma3	0.928	0.639	3.048	al	4.267	1.402	24.1	20.0	sq	E
UME-LW-AERE	-aere_uma4	0.928	0.706	3.048	al	4.699	1.931	21.9	20.0	sq	E
UME-LW-AERE	-aere_uma5	0.928	0.723	3.048	ss	4.699	1.931	8.7	20.0	sq	E
UME-LW-HW	-hw_uma1	0.95	0.610	3.393	al	5.08	1.2	19.24	20.0	he	E
UME-LW-HW	-hw_uma2	0.95	0.648	3.393	al	5.334	1.46	22.57	20.0	he	E
UME-LW-HW	-hw_uma3	0.95	0.682	3.393	al	5.588	1.72	21.15	20.0	he	E
UME-LW-HW	-hw_uma4	0.95	0.748	3.393	al	6.096	2.28	14.74	20.0	he	E
UME-LW-HW	-hw_umb1	1.007	0.606	2.35	al	3.556	1.37	29.03	20.0	he	E
UME-LW-HW	-hw_umb2	1.007	0.669	2.35	al	3.937	1.94	33.57	20.0	he	E
UME-LW-HW	-hw_umb3	1.007	0.689	2.35	al	4.064	2.15	30.12	20.0	he	E
UME-LW-HW	-hw_umb4	1.007	0.546	4.216	al	5.588	0.86	16.39	20.0	he	E
UME-LW-HW	-hw_umb5	1.007	0.631	4.216	al	6.223	1.33	27.47	20.0	he	E
UME-LW-HW	-hw_umb6	1.007	0.708	4.216	al	6.858	1.85	22.05	20.0	he	E
UME-LW-BNL	-bnl_uma1	1.016	0.646	0.635	al	1.147	2.0	19.95	20.0	he	E
UME-LW-BNL	-bnl_uma2	1.016	0.712	0.635	al	1.297	3.0	24.35	20.0	he	E
UME-LW-BNL	-bnl_uma3	1.016	0.764	0.635	al	1.431	4.0	20.34	20.0	he	E
UME-LW-BNL	-bnl_uma4	1.016	0.602	0.983	al	1.586	1.5	19.70	20.0	he	E
UME-LW-BNL	-bnl_uma5	1.016	0.717	0.983	al	1.957	3.0	31.39	20.0	he	E
UME-LW-BNL	-bnl_uma6	1.016	0.542	1.524	al	2.168	1.0	9.9	20.0	he	E
UME-LW-BNL	-bnl_uma7	1.016	0.797	1.524	al	3.32	4.0	20.96	20.0	he	E
UME-LW-BNL	-bnl_umb1	1.027	0.599	0.635	al	1.064	1.5	12.14	20.0	he	E
UME-LW-BNL	-bnl_umb2	1.027	0.643	0.635	al	1.147	2.0	19.95	20.0	he	E
UME-LW-BNL	-bnl_umb3	1.027	0.709	0.635	al	1.297	3.0	25.15	20.0	he	E
UME-LW-BNL	-bnl_umb4	1.027	0.761	0.635	al	1.431	4.0	22.07	20.0	he	E
UME-LW-BNL	-bnl_umb5	1.027	0.599	0.983	al	1.586	1.5	19.7	20.0	he	E
UME-LW-BNL	-bnl_umb6	1.027	0.645	0.983	al	1.719	2.0	29.02	20.0	he	E
UME-LW-BNL	-bnl_umb7	1.027	0.714	0.983	al	1.957	3.0	31.39	20.0	he	E
UME-LW-BNL	-bnl_umb8	1.027	0.771	0.983	al	2.17	4.0	25.68	20.0	he	E
UME-LW-BNL	-bnl_umb9	1.027	0.540	1.524	al	2.168	1.0	9.90	20.0	he	E
UME-LW-BNL	-bnl_umb10	1.027	0.654	1.524	al	2.609	2.0	36.07	20.0	he	E
UME-LW-BNL	-bnl_umb11	1.027	0.729	1.524	al	2.985	3.0	33.15	20.0	he	E
UME-LW-BNL	-bnl_umb12	1.027	0.793	1.524	al	3.32	4.0	20.96	20.0	he	E
UME-LW-BNL	-bnl_umb13	1.027	0.592	1.905	al	2.868	1.334	28.9	20.0	he	E
UME-LW-BNL	-bnl_umb14	1.027	0.691	1.905	al	3.393	2.334	36.73	20.0	he	E

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
UME-LW-BNL	-bnl_umb15	1.027	0.731	1.905	al	3.628	2.834	33.35	20.0	he	E
UME-LW-BNL	-bnl_umb16	1.027	0.803	1.905	al	4.058	3.834	18.60	20.0	he	E
UME-LW-AERE	-aere_umb1	1.142	0.598	3.048	al	4.267	1.407	44.8	20.0	sq	E
UME-LW-AERE	-aere_umb2	1.142	0.660	3.048	al	4.75	1.937	43.6	20.0	sq	E
UME-LW-BNL	-bnl_umc1	1.143	0.733	0.635	al	1.431	4.0	36.05	20.0	he	E
UME-LW-BNL	-bnl_umc2	1.143	0.584	1.524	al	2.399	1.5	38.73	20.0	he	E
UME-LW-BNL	-bnl_umd1	1.299	0.555	0.983	al	1.586	1.5	40.51	20.0	he	E
UME-LW-BNL	-bnl_umd2	1.299	0.598	0.983	al	1.719	2.0	52.19	20.0	he	E
UME-LW-BNL	-bnl_umd3	1.299	0.661	0.983	al	1.957	3.0	59.25	20.0	he	E
UME-LW-BNL	-bnl_umd4	1.299	0.662	0.983	al	1.961	3.018	58.2	20.0	he	E
UME-LW-BNL	-bnl_umd5	1.299	0.711	0.983	al	2.17	4.0	54.69	20.0	he	E
UME-LW-BNL	-bnl_umd6	1.299	0.676	1.524	al	2.985	3.0	60.99	20.0	he	E
UME-LW-BNL	-bnl_umd7	1.299	0.734	1.524	al	3.32	4.0	50.38	20.0	he	E
UME-LW-BAPL	-trx_um1	1.3	0.621	0.983	al	1.81	2.35	57.0	20.0	he	STANDARD
UME-LW-BAPL	-trx_um2	1.3	0.711	0.983	al	2.17	4.02	54.69	20.0	he	STANDARD
UME-LW-HW	-hw_umc1	1.44	0.536	3.393	al	5.08	1.21	52.94	20.0	he	E
UME-LW-HW	-hw_umc2	1.44	0.569	3.393	al	5.334	1.46	56.78	20.0	he	E
UME-LW-HW	-hw_umc3	1.44	0.600	3.393	al	5.588	1.73	57.74	20.0	he	E
UME-LW-HW	-hw_umc4	1.44	0.660	3.393	al	6.096	2.3	51.15	20.0	he	E
UME-LW-HW	-hw_umc5	1.44	0.719	3.393	al	6.604	2.92	38.18	20.0	he	E
UME-LW-SRL	-srl_um1	3.0	0.423	5.08		6.35	0.99	102.0	20.0	sq	E
UME-LW-SRL	-srl_um2	3.0	0.496	5.08		6.985	1.43	109.1	20.0	sq	E
UME-LW-SRL	-srl_um3	3.0	0.558	5.08		7.62	1.87	102.4	20.0	sq	E
UME-LW-SRL	-srl_um4	3.0	0.325	7.62		8.255	0.496	70.9	20.0	sq	E
UME-LW-SRL	-srl_um5	3.0	0.401	7.62		8.89	0.738	87.9	20.0	sq	E
UME-LW-SRL	-srl_um6	3.0	0.462	7.62		9.525	0.99	96.4	20.0	sq	E
UME-LW-SRL	-srl_um7	3.0	0.523	7.62		10.16	1.27	91.0	20.0	sq	E

2) UO2_LW (CRITUO2)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
UO2-LW-BAPL	-bapl_trx1	1.31	0.646	0.973	al	1.56	1.43	32.59	20.0	he	STANDARD
UO2-LW-BAPL	-bapl_trx2	1.31	0.680	0.973	al	1.65	1.78	35.47	20.0	he	STANDARD
UO2-LW-BAPL	-bapl_trx3	1.31	0.729	0.973	al	1.81	2.40	34.22	20.0	he	STANDARD
UO2-LW-BAPL	-bapl_trx4	1.31	0.657	1.527	al	2.20	1.07	28.37	20.0	he	
UO2-LW-BAPL	-bapl_trx5	1.31	0.700	1.527	al	2.36	1.40	30.17	20.0	he	
UO2-LW-BAPL	-bapl_trx6	1.31	0.739	1.527	al	2.51	1.76	29.06	20.0	he	
UO2-LW-NAIG	-naig_nca	2.02	0.675	1.0	al	1.84	2.92	69.72	20.0	sq	
UO2-LW-CURL	-curl_zpr1	2.07	0.528	1.524	al	2.17	1.01	57.60	22.5	he	
UO2-LW-CURL	-curl_zpr2	2.07	0.623	1.524	al	2.62	2.02	83.20	21.5	he	
UO2-LW-CURL	-curl_zpr3	2.07	0.689	1.524	al	2.99	3.01	74.80	20.7	he	
UO2-LW-CURL	-curl_zpr4	2.07	0.748	1.524	al	3.33	4.02	60.60	20.0	he	
UO2-LW-BAW	-baw_bay2a	2.46	0.541	1.03	al	1.51	1.37	70.10	22.0	sq	
UO2-LW-BAW	-baw_cx10	2.46	0.579	1.03	al	1.64	1.84	86.10	21.0	sq	
UO2-LW-AERL	-aerl_ocf1	2.49	0.615	1.0	al	1.77	2.50	85.50	20.0	sq	
UO2-LW-AERL	-aerl_ocf2	2.49	0.665	1.0	al	1.98	3.50	83.40	20.0	sq	
UO2-LW-JAERI	-jaeri_tca1	2.60	0.563	1.071	al	1.66	1.76	92.20	21.0	sq	
UO2-LW-JAERI	-jaeri_tca2	2.60	0.580	1.071	al	1.73	2.00	96.40	20.8	sq	
UO2-LW-JAERI	-jaeri_tca3	2.60	0.603	1.071	al	1.82	2.38	100.80	16.0	sq	
UO2-LW-JAERI	-jaeri_tca4	2.60	0.544	1.25	al	1.85	1.50	83.30	20.0	sq	1.50U
UO2-LW-JAERI	-jaeri_tca5	2.60	0.570	1.25	al	1.96	1.83	94.30	20.0	sq	1.83U
UO2-LW-JAERI	-jaeri_tca6	2.60	0.611	1.25	al	2.15	2.48	98.30	20.0	sq	2.48U
UO2-LW-JAERI	-jaeri_tca7	2.60	0.639	1.25	al	2.29	3.00	95.20	20.0	sq	3.00U
UO2-LW-WAPD	-wapd_crxa1	2.70	0.539	0.762	ss	1.03	1.05	40.70	20.0	sq	
UO2-LW-WAPD	-wapd_crxa2	2.70	0.558	0.762	ss	1.06	1.20	47.50	20.0	sq	
UO2-LW-WAPD	-wapd_crxa3	2.70	0.578	0.762	ss	1.11	1.40	53.20	20.0	sq	
UO2-LW-WAPD	-wapd_crxa4	2.70	0.614	0.762	ss	1.19	1.85	63.30	20.0	sq	
UO2-LW-WAPD	-wapd_crxa5	2.70	0.635	0.762	ss	1.25	2.17	68.80	20.0	sq	
UO2-LW-WAPD	-wapd_crxa6	2.70	0.763	0.762	ss	1.69	4.98	51.00	23.0	sq	
UO2-LW-AEEW	-aeew_juno	3.003	0.613	1.012	ss	1.87	2.60	102.30	20.0	he	
UO2-LW-AEEW	-r1100h	3.003	0.453	1.012	ss	1.320	1.001	66.00	20.0	sq	STANDARD
UO2-LW-AEEW	-r2100h	3.003	0.488	1.012	ss	1.866	3.163	100.44	20.0	sq	STANDARD
UO2-LW-AEEW	-r3100h	3.003	0.637	1.012	ss	1.251	0.779	50.96	20.0	sq	STANDARD
UO2-LW-BNL	-bnluo2_1	3.01	0.581	1.128	ss	1.72	1.32	56.60	20.0	he	
UO2-LW-BNL	-bnluo2_2	3.01	0.609	1.128	ss	1.82	1.63	65.81	20.0	he	
UO2-LW-BNL	-bnluo2_3	3.01	0.643	1.128	ss	1.96	2.09	70.49	20.0	he	
UO2-LW-BNL	-bnluo2_4	3.01	0.688	1.128	ss	2.17	2.86	70.22	20.0	he	
UO2-LW-BNL	-bnluo2_5	3.01	0.749	1.128	ss	2.47	4.07	61.73	20.0	he	

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
UO2-LW-ANL	-anl_zpr7a1	3.04	0.354	0.935	al	1.17	0.43	24.36	20.0	he	
UO2-LW-ANL	-anl_zpr7a2	3.04	0.435	0.935	al	1.27	0.75	55.38	20.0	he	
UO2-LW-ANL	-anl_zpr7a3	3.04	0.467	0.935	al	1.24	0.96	70.76	20.0	sq	
UO2-LW-ANL	-anl_zpr7a4	3.04	0.510	0.935	ss	1.24	0.96	47.47	20.0	sq	
UO2-LW-ANL	-anl_zpr7a5	3.04	0.511	0.935	al	1.35	1.37	91.82	20.0	sq	
UO2-LW-NPY	-npy_nora1	3.41	0.551	1.27	ss	1.90	1.66	91.80	20.0	sq	
UO2-LW-NPY	-npy_nora2	3.41	0.633	1.27	ss	2.31	3.03	98.80	20.0	sq	
UO2-LW-NPY	-npy_nora3	3.41	0.701	1.27	ss	2.69	4.51	86.40	20.0	sq	
UO2-LW-WAPD	-wapd_crxb1	3.70	0.505	0.754	ss	1.06	1.23	68.30	20.0	sq	
UO2-LW-WAPD	-wapd_crxb2	3.70	0.579	0.754	ss	1.25	2.21	95.10	20.0	sq	
UO2-LW-SCKBN	-sck_venus1	4.01	0.515	0.89	ss	1.30	1.52	99.10	20.0	sq	
UO2-LW-SCKBN	-sck_venus2	4.01	0.648	0.89	ss	1.84	4.25	114.18	20.0	sq	
UO2-LW-BAW	-baw_bay2b1	4.02	0.465	1.128	ss	1.45	0.96	79.00	22.0	sq	
UO2-LW-BAW	-baw_bay2b2	4.02	0.488	1.128	ss	1.51	1.14	88.00	15.0	sq	
UO2-LW-WAPD	-wapd_crxc	4.43	0.505	0.762	ss	1.11	1.35	79.70	16.0	sq	
UO2-LW-ANL	-anl_zpr7b1	4.95	0.450	0.871	ss	1.27	1.14	91.47	20.0	he	
UO2-LW-ANL	-anl_zpr7b2	4.95	0.486	0.871	ss	1.27	1.50	107.63	20.0	sq	
UO2-LW-WAPD	-wapd_crxd1	5.74	0.466	0.907	ss	1.32	1.50	117.60	19.2	sq	
UO2-LW-WAPD	-wapd_crxd2	5.74	0.497	0.907	ss	1.42	1.93	127.10	18.0	sq	
UO2-LW-WAPD	-wapd_crxd3	5.74	0.619	0.907	ss	2.01	5.07	136.80	17.3	sq	

3) UO2_LB (WWERCR)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Bcon	Obsevs.
UO2-LB-CRIP	-wwer_cra01	1.6	0.633	0.76	zr	1.27	3.079	50.57	21	he	0.0	p2w1b0t1
UO2-LB-CRIP	-wwer_cra02	1.6	0.670	0.76	zr	1.27	3.079	33.32	21	he	1.85	p2w1b4t1
UO2-LB-CRIP	-wwer_cra03	1.6	0.717	0.76	zr	1.5	4.295	48.90	21	he	0.0	p3w1b0t1
UO2-LB-CRIP	-wwer_cra04	3.6	0.510	0.76	zr	1.27	3.079	100.41	21	he	0.0	p2w2b0t1
UO2-LB-CRIP	-wwer_cra05	3.6	0.508	0.76	zr	1.27	3.079	96.55	80	he	0.0	p2w2b0t2
UO2-LB-CRIP	-wwer_cra06	3.6	0.504	0.76	zr	1.27	3.079	90.27	130	he	0.0	p2w2b0t3
UO2-LB-CRIP	-wwer_cra07	3.6	0.547	0.76	zr	1.27	3.079	74.16	21	he	4.0	p2w2b5t1
UO2-LB-CRIP	-wwer_cra08	3.6	0.543	0.76	zr	1.27	3.079	72.07	80	he	4.0	p2w2b5t2
UO2-LB-CRIP	-wwer_cra09	3.6	0.537	0.76	zr	1.27	3.079	67.63	130	he	4.0	p2w2b5t3
UO2-LB-CRIP	-wwer_cra10	3.6	0.563	0.76	zr	1.27	3.079	64.95	21	he	5.8	p2w2b6t1
UO2-LB-CRIP	-wwer_cra11	3.6	0.559	0.76	zr	1.27	3.079	61.69	80	he	5.8	p2w2b6t2
UO2-LB-CRIP	-wwer_cra12	3.6	0.552	0.76	zr	1.27	3.079	59.02	130	he	5.8	p2w2b6t3
UO2-LB-CRIP	-wwer_cra13	3.6	0.576	0.76	zr	1.27	3.079	56.54	21	he	7.2	p2w2b7t1
UO2-LB-CRIP	-wwer_cra14	3.6	0.436	0.76	zr	1.1	2.310	66.01	21	he	0.0	p1w2b0t1
UO2-LB-CRIP	-wwer_cra15	3.6	0.433	0.76	zr	1.1	2.310	64.02	80	he	0.0	p1w2b0t2
UO2-LB-CRIP	-wwer_cra16	3.6	0.427	0.76	zr	1.1	2.310	59.76	130	he	0.0	p1w2b0t3
UO2-LB-CRIP	-wwer_cra17	3.6	0.440	0.76	zr	1.1	2.310	62.14	21	he	1.0	p1w2b2t1
UO2-LB-CRIP	-wwer_cra18	3.6	0.442	0.76	zr	1.1	2.310	61.70	21	he	1.41	p1w2b3t1
UO2-LB-CRIP	-wwer_cra19	3.6	0.574	0.76	zr	1.5	4.295	120.36	21	he	0.0	p3w2b0t1
UO2-LB-CRIP	-wwer_cra20	3.6	0.645	0.76	zr	1.5	4.295	70.25	21	he	4.0	p3w2b5t1
UO2-LB-CRIP	-wwer_cra21	3.6	0.666	0.76	zr	1.905	6.930	108.20	21	he	0.0	p4w2b0t1
UO2-LB-CRIP	-wwer_cra22	4.4	0.487	0.76	zr	1.27	3.079	112.58	21	he	0.0	p2w3b4t1
UO2-LB-CRIP	-wwer_cra23	4.4	0.491	0.76	zr	1.27	3.079	106.60	21	he	0.64	p2w3b0t1
UO2-LB-CRIP	-wwer_cra24	4.4	0.540	0.76	zr	1.27	3.079	69.03	21	he	7.2	p2w3b1t1
UO2-LB-CRIP	-wwer_cra25	4.4	0.549	0.76	zr	1.5	4.295	136.80	21	he	0.0	p3w3b0t1

4) MOX_LW (CRITMOX)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	%Pu	P238	Pu239	Pu240	P241	P242	Obsevs.
MOX-LW-GE	-ge_pu1	0.22	0.563	0.945	z2	1.397	1.10	48.0	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-GE	-ge_pu2	0.22	0.595	0.945	z2	1.524	1.558	65.1	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-GE	-ge_pu3	0.22	0.654	0.945	z2	1.803	2.704	78.5	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-GE	-ge_pu4	0.22	0.701	0.945	z2	2.032	3.789	74.9	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-GE	-ge_pu5	0.22	0.754	0.945	z2	2.286	5.144	60.9	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-GE	-ge_pu6	0.22	0.771	0.945	z2	2.362	5.580	55.2	20.0	he	1.5	0.0	91.41	7.83	0.73	0.03	
MOX-LW-WAPD	-wcrx_pu1	0.72	0.522	1.283	z2	1.75	1.12	69.56	20.0	sq	2.0	0.0	92.0	8.0	0.7	0.03	
MOX-LW-WAPD	-wcrx_pu2	0.72	0.553	1.283	z2	1.90	1.56	90.00	20.0	sq	2.0	0.0	92.0	8.0	0.7	0.03	
MOX-LW-WAPD	-wcrx_pu3	0.72	0.684	1.283	z2	2.48	3.50	79.50	20.0	sq	2.0	0.0	72.0	23.0	4.0	0.7	
MOX-LW-WAPD	-wcrx_pu4	0.72	0.718	1.283	z2	2.69	4.37	73.30	20.0	sq	2.0	0.0	72.0	23.0	4.0	0.7	
MOX-LW-WAPD	-wcrx_pu5	0.72	0.813	1.283	z2	3.51	8.26	50.30	20.0	sq	2.0	0.0	92.0	8.0	0.7	0.03	
MOX-LW-WAPD	-wcrx_pu6	0.72	0.468	0.857	z4	1.32	1.68	108.80	25.8	sq	6.6	0.0	90.0	9.0	0.9	0.04	
MOX-LW-JAERI	-jtca_pu1	0.72	0.641	1.065	z2	1.83	2.42	80.64	20.0	sq	3.0	0.49	68.18	22.02	7.26	2.04	2.42Pu
MOX-LW-JAERI	-jtca_pu2	0.72	0.663	1.065	z2	1.96	2.98	83.11	20.0	sq	3.0	0.49	68.18	22.02	7.26	2.04	2.98Pu
MOX-LW-JAERI	-jtca_pu3	0.72	0.710	1.065	z2	2.22	4.24	77.82	20.0	sq	3.0	0.49	68.18	22.02	7.26	2.04	4.24Pu
MOX-LW-JAERI	-jtca_pu4	0.72	0.758	1.065	z2	2.47	5.55	64.91	20.0	sq	3.0	0.49	68.18	22.02	7.26	2.04	5.55Pu
MOX-LW-BNW	-bnw_pua1	0.72	0.548	1.290	z2	2.032	1.486	88.0	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua2	0.72	0.597	1.290	z2	2.362	2.447	102.9	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua3	0.72	0.639	1.290	z2	2.667	3.463	103.4	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua4	0.72	0.672	1.290	z2	2.903	4.335	97.8	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua5	0.72	0.740	1.290	z2	3.352	6.196	76.8	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua6	0.72	0.750	1.290	z2	3.420	6.501	70.0	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua7	0.72	0.864	1.290	z2	4.064	9.696	31.7	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pua8	0.72	0.870	1.290	z2	4.089	9.831	32.7	20.0	he	2.0	0.0	91.62	7.65	0.70	0.03	
MOX-LW-BNW	-bnw_pub1	0.72	0.621	1.290	z2	2.362	2.447	88.4	20.0	he	2.0	0.0	81.11	16.54	2.15	0.2	
MOX-LW-BNW	-bnw_pub2	0.72	0.663	1.290	z2	2.667	3.463	89.0	20.0	he	2.0	0.0	81.11	16.54	2.15	0.2	
MOX-LW-BNW	-bnw_pub3	0.72	0.696	1.290	z2	2.903	4.335	81.9	20.0	he	2.0	0.0	81.11	16.54	2.15	0.2	
MOX-LW-BNW	-bnw_pub4	0.72	0.766	1.290	z2	3.352	6.196	61.8	20.0	he	2.0	0.0	81.11	16.54	2.15	0.2	
MOX-LW-BNW	-bnw_pub5	0.72	0.777	1.290	z2	3.420	6.501	55.5	20.0	he	2.0	0.0	81.11	16.54	2.15	0.2	
MOX-LW-BNW	-bnw_puc1	0.72	0.590	1.290	z2	2.032	1.486	62.4	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_puc2	0.72	0.639	1.290	z2	2.362	2.447	78.9	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_puc3	0.72	0.682	1.290	z2	2.667	3.463	77.1	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_puc4	0.72	0.717	1.290	z2	2.903	4.335	72.2	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_puc5	0.72	0.790	1.290	z2	3.352	6.196	53.6	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_puc6	0.72	0.800	1.290	z2	3.420	6.501	44.0	20.0	he	2.0	0.0	71.76	23.50	4.08	0.66	
MOX-LW-BNW	-bnw_pud1	0.72	0.534	1.264	z2	2.032	1.564	84.8	20.0	he	4.0	0.28	75.38	18.10	5.08	1.15	
MOX-LW-BNW	-bnw_pud2	0.72	0.553	1.264	z2	2.159	1.929	94.7	20.0	he	4.0	0.28	75.38	18.10	5.08	1.15	

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	%Pu	P238	Pu239	Pu240	P241	P242	Obsevs.
MOX-LW-BNW	-bnw_pud3	0.72	0.579	1.264	z2	2.362	2.563	107.9	20.0	he	4.0	0.28	75.38	18.10	5.08	1.15	
MOX-LW-BNW	-bnw_pud4	0.72	0.721	1.264	z2	3.519	7.271	87.6	20.0	he	4.0	0.28	75.38	18.10	5.08	1.15	
MOX-LW-BNW	-bnw_pud5	0.72	0.844	1.264	z2	4.318	11.58	41.1	20.0	he	4.0	0.28	75.38	18.10	5.08	1.15	

5.1) U-MI (CRITISP)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
U -MI-AEEW	-hiss1	92.3	0.145					0.0	20.0	ho	STANDARD

5.2) Pu-MI (CRITISP)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
Pu -MI-AEEW	-hiss2	0.0	0.145					0.0	20.0	ho	STANDARD

6) Th3-LW (CRITHTH)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	ThO2	Obsevs.
Th3-LW-BNL	-bnl_thh2o1	0.0	0.503	1.092	z2	3.033	0.997	75.88	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o2	0.0	0.552	1.092	z2	3.274	1.384	86.06	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o3	0.0	0.584	1.092	z2	3.465	1.713	89.34	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o4	0.0	0.621	1.092	z2	3.728	2.194	90.35	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o5	0.0	0.671	1.092	z2	4.132	3.004	85.54	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o6	0.0	0.736	1.092	z2	4.696	4.272	69.80	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o7	0.0	0.851	1.092	z2	5.670	6.845	32.20	20.0	he	97.0	E
Th3-LW-BNL	-bnl_thh2o8	0.0	0.952	1.092	z2	6.456	9.275	-1.22	20.0	he	97.0	E

7) Th3-HW (CRITDTH)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	ThO2	Obsevs.
Th3-HW-BNL	-bnl_thd2o1	0.0	0.350	1.092	z2	2.170	3.005	20.54	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o2	0.0	0.586	1.092	z2	3.758	11.716	29.85	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o3	0.0	0.631	1.092	z2	4.338	16.050	28.64	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o4	0.0	0.711	1.092	z2	5.738	29.113	25.0	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o5	0.0	0.740	1.092	z2	6.507	37.828	22.32	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o6	0.0	0.788	1.092	z2	7.821	55.226	19.13	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o7	0.0	0.819	1.092	z2	8.462	81.312	14.67	20.0	he	97.0	E
Th3-HW-BNL	-bnl_thd2o8	0.0	0.855	1.092	z2	11.48	120.49	11.29	20.0	he	97.0	E

8) UO2-HW (CRITD2O)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	coo	nr	Obsevs.
UO2-HW-AECL	-ZED2T1D2O	0.72	0.823	1.21	z4	28.58		2.7	20.0	sq	d2o	37	CANDU
UO2-HW-AECL	-ZED2T1Air	0.72	0.818	1.21	z4	28.58		2.0	20.0	sq	air	37	CANDU
UO2-HW-AECL	-ZED2T2p24	0.72	0.766	1.42	z2	24.0		2.80	23.0	he	d2o	28	CANDU
UO2-HW-AECL	-ZED2T2p40	0.72	0.854	1.42	z2	40.0		2.77	23.0	he	d2o	28	CANDU
UO2-HW-AECL	-ZED2T3p24	0.72	0.817	1.42	z2	28.57		3.77	23.0	sq	d2o	28	CANDU
UO2-HW-JNCDI	-DCAT1D22	1.2	0.693	1.48	al	22.5		10.13	22.0	sq	d2o	28	CANDU
UO2-HW-JNCDI	-DCAT1A22	1.2	0.663	1.48	al	22.5		8.83	22.0	sq	air	28	CANDU
UO2-HW-JNCDI	-DCAT1H22	1.2	0.746	1.48	al	22.5		11.06	22.0	sq	h2o	28	CANDU
UO2-HW-JNCDI	-DCAT1D25	1.2	0.705	1.48	al	25.0		10.28	22.0	sq	d2o	28	CANDU
UO2-HW-JNCDI	-DCAT1A25	1.2	0.693	1.48	al	25.0		9.56	22.0	sq	air	28	CANDU
UO2-HW-JNCDI	-DCAT1H25	1.2	0.766	1.48	al	25.0		9.72	22.0	sq	h2o	28	CANDU

9) Th5-HW (CRITD2O)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	coo	nr	ThO2	Obsevs.
Th5-HW-AECL	-ZED2T4D22	93.0	0.886	1.153	z2	22.0		2.4	25.0	he	d2o	19	98.5	CANDU
Th5-HW-AECL	-ZED2T4A22	93.0	0.882	1.153	z2	22.0		2.3	25.0	he	air	19	98.5	CANDU
Th5-HW-AECL	-ZED2T4D28	93.0	0.915	1.153	z2	28.0		1.5	25.0	he	d2o	19	98.5	CANDU
Th5-HW-AECL	-ZED2T4A28	93.0	0.915	1.153	z2	28.0		1.6	25.0	he	air	19	98.5	CANDU

Appendix III

WIMSD-IAEA LIBRARY MATERIALS AND BENCHMARKS

First, a short list of all WIMS library materials benchmarked is included. Then, WIMS library materials used in benchmark cases are listed, ordered by WIMS library material (material number and symbol), temperature, in K (TEM), component (C), material type (MAT), atomic density, in atoms/(barn*cm) (At.DENS.), benchmark type (B), and name of benchmark case (NAME/S). Finally, a list of materials not-benchmarked is included.

WIMS library materials are classified on Light elements, Structural materials, Fission products, Actinides, and Dosimetry reactions and others.

WIMSD-IAEA library materials benchmarked

Light elements	Structural materials	Fission products		Actinides	Dosimetry reactions and others
3001 H-H2O	52 Cr	2154 Gd154b/fp	4108 Pd108fp	2232 Th232	1000 1/v absorber
5001 H-ZrH	55 Mn	2155 Gd155b/fp	4109	9233 U233	3000 const,=1 absorber
D-D2O	2056 Fe	2156 Gd156b/fp	Ag109fp	234 U234	176 Lu-176(n,g)Lu-177
1010 B10	58 Ni	2157 Gd157b/fp	4113 Cd113fp	2235 U235	
1011 B	3063 Cu	2158 Gd158b/fp	4115 In115fp	236 U236	
2012 C-graphite	91 Zr	160 Dy160b/fp	4125 Sb125fp	4927 U237pseudofp	
14 N	93 Nb93	161 Dy161b/fp	5127 Te127fp	927 U237	
6016 O	2113 Cd	162 Dy162b/fp	4127 I127fp	8238 U238	
24 Mg	118 Sn	163 Dy163b/fp	4131 Xe131fp	937 Np237	
27 Al	1059 Co59	164 Dy164b/fp	4133 Cs133fp	1939 Np239	
29 Si	96 Mo	165 Dy165b/fp	4134 Cs134fp	948 Pu238	
9 Be		178 Hf294	4137 Cs137fp	6239 Pu239	
10 B10 burnable		4083 Kr83fp	6135 I135fp	1240 Pu240	
		4095 Mo95fp	5134 Xe134fp	1241 Pu241	
		4099 Tc99fp	4135 Xe135fp	242 Pu242HSS	
		4101 Ru101fp	5135 Cs135fp	1242 Pu242LSS	
		5103 Ru103fp	4136 Xe136fp	951 Am241	
		4106 Ru106fp	4143Nd143fp	1952 Am242fp	
		4103 Rh103fp	4145	952 Am242m	
		4105 Rh105fp	Nd145fp	953 Am243	
		5105 Pd105fp	4147Pm147fp	962 Cm242	
		4107 Pd107fp	5147Pm147fp	963 Cm243	
			6147Sm147fp	964 Cm244	

Benchmarked materials detailed list

Conventions

TEM : Temperature, in K,
C : Component,
1 : fuel
2 : clad
3 : coolant
4 : other structural components
5 : moderator.
MAT : Material type,
At.DENS. : Atomic density, in atoms/(barn*cm),
B : Benchmark type,
1-9 :standard criticality benchmarks;
b: standard burnup benchmarks;
S: supplemental benchmarks.
NAME/S : Name of benchmark case.

(a) Light elements

3001 H-H2O

TEM	C	MAT	AT.DENS.	B	NAME/S
288	3	h2o	6.676E-02	2	baw_bay2b2
					wapd_crxc
290	3	h2o	6.678E-02	2	wapd_crxd2,3
292	3	h2o	6.676E-02	2	wapd_crxd1
293	1	U-mixt	1.126E-04	5	hiss1
		Pu-mixt	1.077E-04	5	hiss2
	3	h2o	6.675E-02	1	aecl_um
					aere_um
					hw_um
					bnl_um
					trx_um
					srl_um
				2	bapl1-3
					bapl_trx
					naig_nca
					aerl_ocf
					jaeri_tca
					curl_zpr4
					wapd_crxa1-5,b
					aeew_juno
					aeew_dimple(rn100h)
					bnl_uo2
					anl_zpr7
					npy_nora
					sck_venus
				4	ge_pu
					wcrx_pu1-5
					bnw_pua,b,d
					jtca_pu
				6	bnl_thh2o
				S	3rtc_nora.1
				S	3rtc_r1100h.1
				S	3rtc_vver1,2.1
				S	4d2o_Gd

```
                          S 5mtr_owr
      h2o+b               S 3rtc_kritz.1
      d2o      3.656E-04  S 4d2o_Gd
    4 d2o      3.656E-04  S 4d2o_Gd
294 1 mixture  1.600E-02  S 1iae_maria1 (numerical benchmark)
    3 h2o      6.673E-02  2 curl_zpr2,3
                            baw_cx10
                          3 wwer_a11,23;b1,16,21,25;c13,24
                          S 3rtc_vver1,2.1
               6.687E-02  S 1iae_maria2 (numerical benchmark)
      h2o+b1   6.671E-02  3 wwer_c14
      h2o+b2   6.671E-02  3 wwer_b19
      h2o+b3   6.671E-02  3 wwer_b20
      h2o+b4   6.671E-02  3 wwer_a12
      h2o+b5   6.670E-02  3 wwer_b4,22
                          S 3rtc_vver3.1
      h2o+b6   6.669E-02  3 wwer_b7
                          S 3rtc_vver4.1
      h2o+b7   6.668E-02  3 wwer_b10,c15
    4 Be_mix   2.882E-03  S 1iae_maria2 (numerical benchmark)
295 3 h2o      6.671E-02  2 curl_zpr1
                            baw_bay2a,b1
                          8 dcat1h
      d2o      1.914E-04  8 zed2t1d
                            zed2t2,4d
               3.656E-04  8 dcat1d
    5 d2o      3.656E-04  8 dcat1
               1.914E-04  8 zed2t1,2,4
296 3 h2o      6.671E-02  2 wapd_crxa6
      d2o      1.452E-04  8 zed2t2,3
    5 d2o      1.452E-04  8 zed2t2,3
299 3 h2o      6.666E-02  4 wcrx_pu6
311 5 d2o      1.472E-04  b 1dca
333 3 h2o      6.578E-02  S 3rtc_nora.2
353 3 h2o      6.497E-02  3 wwer_b2,17
                          S 3rtc_r1100h.2
      h2o+b5   6.495E-02  3 wwer_b5
      h2o+b6   6.494E-02  3 wwer_b8
403 3 h2o      6.248E-02  3 wwer_b3,18
                          S 3rtc_vver1,2.2
      h2o+b5   6.246E-02  3 wwer_b6
                          S 3rtc_vver3.2
      h2o+b6   6.245E-02  3 wwer_b9
                          S 3rtc_vver3.2
483 3 h2o+b    5.710E-02  S rtc_3rtc_kritz1.2
509 3 h2o+b    5.484E-02  S rtc_3rtc_kritz219.2
516 3 h2o+b    5.412E-02  S rtc_3rtc_kritz213.2
521 3 h2o+b    5.360E-02  S rtc_3rtc_kritz21.2
532 3 d2o      1.158E-04  b 1dca
558 3 h2o+b    5.062E-02  b 2nea-bucr1b
579 3 h2o+b    4.771E-02  b 3nea-purecya (numerical benchmark)
583 3 h2o      4.711E-02  S 5thburn  (numerical benchmark)
600 3 h2o+b    4.423E-02  S 2doppler (numerical benchmark)
```

3002 D-D2O

```
TEM C MAT      AT.DENS.   B NAME/S
293 3 d2o      6.637E-02  7 bnl_thd2o
                          S 4d2o_Gd
    4 d2o      6.637E-02  S 4d2o_Gd
295 3 d2o      6.627E-02  8 zed2t1d,2,4d
               6.612E-02  8 dcat1d
```

```
    5 d2o     6.627E-02 8 zed2t1,2,4
              6.612E-02 8 dcat1
296 3 d2o     6.631E-02 8 zed2t2,3
    5 d2o     6.631E-02 8 zed2t2,3
311 5 d2o     6.607E-02 b 1dca
532 3 d2o     5.200E-02 b 1dca
```

9 Be

```
TEM C MAT     AT.DENS.  B NAME/S
294 1 mixture 8.000E-02 S 1iae_maria1 (numerical benchmark)
    4 Be_mix  1.168E-01 S 1iae_maria2 (numerical benchmark)
```

10 B10b

```
TEM C MAT     AT.DENS.  B NAME/S
600 3 h2o+b   1.021E-05 S 2doppler (numerical benchmark)
```

1010 B10

```
TEM C MAT     AT.DENS.  B NAME/S
294 1 mixture 6.000E-06 S 1iae_maria1 (numerical benchmark)
295 4 1050al  9.257E-07 8 zed2t1
      6068al  9.257E-07 8 zed2t4
```

1011 B

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 mox       3.036E-07 4 jtca_pu
      U-mixt    2.907E-04 5 hiss1
      Pu-mixt   5.101E-04 5 hiss2
      u3o2-tho2 2.200E-06 6 bnl_thh2o,d2o
    2 zry2      5.300E-07 6 bnl_thh2o,d2o
    3 h2o+b     9.727E-06 S 3rtc_kritz1.1
              1.212E-05 S 3rtc_kritz21.1
              2.514E-05 S 3rtc_kritz213.1
              2.779e-07 S 3rtc_kritz219.1
294 3 h2o+b1    6.231E-06 3 wwer_c14
      h2o+b2    9.734E-06 3 wwer_b19
      h2o+b3    1.372E-05 3 wwer_b20
      h2o+b4    1.800E-05 3 wwer_a12
      h2o+b5    3.888E-05 3 wwer_b4,22
                          S 3rtc_vver3.1
      h2o+b6    5.632E-05 3 wwer_b7
                          S 3rtc_vver4.1
      h2o+b7    6.986E-05 3 wwer_b10,c15
353 3 h2o+b5    3.766E-05 3 wwer_b5
      h2o+b6    5.484E-05 3 wwer_b8
403 3 h2o+b5    3.640E-05 3 wwer_b6
                          S 3rtc_vver3.1
      h2o+b6    5.274E-05 3 wwer_b9
                          S 3rtc_vver4.1
483 3 h2o+b     8.571E-06 S 3rtc_kritz1.2
509 3 h2o+b     2.742e-07 S 3rtc_kritz219.2
516 3 h2o+b     1.264E-05 S 3rtc_kritz213.2
521 3 h2o+b     1.161E-06 S 3rtc_kritz21.2
558 3 h2o+b     1.395E-05 b 2nea-bucr1b
579 3 h2o+b     1.986E-05 b 3nea-purecya(N)
```

2012 C-graphite

```
TEM C MAT     AT.DENS.  B NAME/S
293 1 U-mixt  7.565E-02 5 hiss1
      Pumixt  7.090E-02 5 hiss2
```

```
    2 ss      6.026E-02 2 aeew_dimple(rn100h)
              4.697E-05 S 3rtc_r1100h.1
353 2 ss      4.697E-05 S 3rtc_r1100h.2
841 1 uo2     9.134E-06 b 2nea-bucr1b
```

14 N

```
TEM C MAT     AT.DENS.  B NAME/S
841 1 UO2     1.041E-05 b 2nea-bucr1b
```

6016 O

```
TEM C MAT       AT.DENS.  B NAME/S
288 1 uo2       4.221E-02 2 baw_bay2b2
    3 h2o       3.341E-02 2 baw_bay2b2
                            wapd_crxc
289 1 uo2       4.539E-02 2 wapd_crxc
290 1 uo2       4.552E-02 2 wapd_crxd2,3
    3 h2o       3.339E-02 2 wapd_crxd2,3
292 1 uo2       4.552E-02 2 wapd_crxd1
293 1 uo2       4.695E-02 2 bapl1-3
                3.359E-02 2 bapl_trx
                4.626E-02 2 naig_nca
                4.632E-02 2 curl_zpr4
                3.338E-02 2 aerl_ocf
                4.644E-02 2 jaeri_tca
                4.542E-02 2 wapd_crxa1-5
                4.658E-02 2 aeew_juno
                            aeew_dimple(rn100h)
                4.149E-02 2 bnl_uo2
                4.538E-02 2 anl-zpr7a
                4.640E-02 2 npy_nora
                          2 wapd_crxb
                4.592E-02 2 sck_venus
                4.552E-02 2 anl_zpr7b
      mox       4.304E-02 4 ge_pu
                4.255E-02 4 wcrx_pu1-5
                2.784E-02 4 jtca_pu
                4.255E-02 4 bnw_pu
      U-mixt    1.650E-03 5 hiss1
      Pu-mixt   2.707E-03 5 hiss2
      u3o2-puo2 4.088E-02 6 bnl_thh2o,d2o
      uo2       4.500E-02 S 3rtc_kritz.1
                4.635E-02 S 3rtc_nora.1
                4.659E-02 S 3rtc_r1100h.1
                4.739E-02 S 4d2o_Gd
    3 h2o       3.331E-02 S 3rtc_nora.1
                          S 5mtr_owr
                3.339E-02 1 aecl_um
                            aere_um
                            hw_um
                            bnl_um
                            trx_um
                          1 srl_um
                          2 bapl1-3
                            bapl_trx
                            naig_nca
                            curl_zpr4
                            aerl_ocf
                            jaeri_tca
                            wapd_crxa1-5,b,d1
                            aeew_juno
                            aeew_dimple(rn100h)
```

```
                                bnl-uo2
                                anl-zpr7
                                npy_nora
                                sck_venus
                              4 ge_pu
                                wcrx_pu1-5
                                bnw_pua,b,d
                                jtca_pu
                              6 bnl_thh2o
                              S 3rtc_r1100h.1
      h2o+b                   S 3rtc_kritz.1
      d2o       3.325E-02 7 bnl_thd2o
                3.338E-02 S 4d2o_Gd
    4 d2o       3.228E-02 S 4d2o_Gd
294 1 uo2       4.632E-02 2 curl_zpr2,3
                                baw_cx10
                4.537E-02 3 wwer_a
                4.587E-02 3 wwer_b1,4,7,10,16,19,20,21,22
                              S 3rtc_vver.1
      mixture   8.000E-03 S 1iae_maria1 (numerical benchmark)
    3 h2o       3.336E-02 2 curl_zpr2,3
                                baw_cx10
                              3 wwer_a11,23;b1,16,21,25;c13,24
                              S 3rtc_vver1,2.1
                3.344E-02 S 1iae_maria2 (numerical benchmark)
      h2o+b1    3.337E-02 3 wwer_c14
      h2o+b2    3.337E-02 3 wwer_b19
      h2o+b3    3.337E-02 3 wwer_b20
      h2o+b4    3.330E-02 3 wwer_a12
      h2o+b5    3.341E-02 3 wwer_b4,22
                              S 3rtc_vver3.1
      h2o+b6    3.343E-02 3 wwer_b7
                              S 3rtc_vver4.1
      h2o+b7    3.345E-02 3 wwer_b10,c15
    4 Be_mix    1.851E-03 S 1iae_maria2 (numerical benchmark)
295 1 uo2       4.632E-02 2 curl_zpr1
                4.568E-02 2 baw_bay2a
                4.221E-02 2 baw_bay2b1
                4.709E-02 8 zed2t1
                4.741E-02 8 dcat1
      u5o2-puo2 4.293E-02 8 zed2t4
    3 h2o       3.336E-02 2 curl_zpr1
                                baw_bay2a,b1
      d2o       3.325E-02 8 zed2t1d,2,4d
                                dcat1d
    5 d2o       3.325E-02 8 zed2t1,2,4
                3.326E-02 8 dcat1
      h2o       3.338E-02 8 dcat1h
296 1 uo2       4.542E-02 2 wapd_crxa6
                4.476E-02 8 zed2t2,3
296 3 h2o       3.336E-02 2 wapd_crxa6
      d2o       3.324E-02 8 zed2t2,3
    5 d2o       3.324E-02 8 zed2t2,3
299 1 mox       4.803E-02 4 wcrx_pu6
    2 zry4      3.232E-04 4 wcrx_pu6
    3 h2o       3.333E-02 4 wcrx_pu6
311 5 d2o       3.314E-02 b 1dca
333 1 uo2       4.635E-02 S 3rtc_nora.2
    3 h2o       3.289E-02 S 3rtc_nora.2
                3.289E-02 S 3rtc_nora.2
                              S 3rtc_nora.2
353 1 uo2       4.587E-02 3 wwer_b2,5,8,17
```

```
                4.655E-02 S 3rtc_r1100h.2
    3 h2o       3.249E-02 3 wwer_b2,17
                          S 3rtc_r1100h.2
      h2o+b5    3.253E-02 3 wwer_b5
      h2o+b6    3.255E-02 3 wwer_b8
403 1 uo2       4.587E-02 3 wwer_b3,6,9,18
                4.605E-02 3 wwer_c
                          S 3rtc_vver.2
    3 h2o       3.124E-02 3 wwer_b3,18
                          S 3rtc_vver1,2.2
      h2o+b5    3.128E-02 3 wwer_b6
                          S 3rtc_vver3.2
      h2o+b6    3.130E-02 3 wwer_b9
                          S 3rtc_vver4.2
483 1 uo2       4.500E-02 S rtc_3rtc_kritz1.2
    3 h2o+b     2.855E-02 S rtc_3rtc_kritz1.2
509 1 uo2       4.500E-02 S rtc_3rtc_kritz219.2
    3 h2o+b     5.284E-02 S rtc_3rtc_kritz219.2
516 1 uo2       4.500E-02 S rtc_3rtc_kritz213.2
    3 h2o+b     2.706E-02 S rtc_3rtc_kritz213.2
521 1 uo2       4.500E-02 S rtc_3rtc_kritz21.2
    3 h2o+b     2.680E-02 S rtc_3rtc_kritz21.2
532 3 d2o       2.607E-02 b 1dca
558 3 h2o+b     2.531E-02 b 2nea-bucr1b
579 3 h2o+b     2.386E-02 b 3nea-purecya(N)
583 3 h2o       2,357E-02 S 5thburn (numerical benchmark)
600 1 uo2       4.613E-02 S 2doppler (numerical benchmark)
    3 h2o+b     2.212E-02 S 2doppler (numerical benchmark)
780 1 uo2       4.495E-02 b 1dca
841 1 uo2       4.482E-02 b 2nea-bucr1b
900 1 uo2       4.576E-02 S 2doppler (numerical benchmark)
      Tho2-uo2  4.258E-02 S 5thburn (numerical benchmark)
933 1 uo2+Pu    4.585E-02 b 3nea-purecya(N)
```

24 Mg

```
TEM C MAT       AT.DENS.  B NAME/S
294 4 Be_mix    2.231E-06 S 1iae_maria2 (numerical benchmark)
296 4 al65s     6.691E-04 8 zed2t2,3
      al50s     6.022E-04 8 zed2t2,3
```

27 Al

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      5.810e-02 S 5mtr_owr
    2 al        6.026E-02 1 aecl_um
                            aere_uma1,3,4
                            aere_umb
                            hw_um
                            bnl_um
                            trx_um
                          2 bapl1-3
                            bapl_trx
                            naig_nca
                            aerl_ocf
                            jaeri_tca
                            aeew-dimple(rn100h)
                          S 4d2o_Gd
                          S 5mtr_owr
      6071-76Al 6.026E-02 2 curl_zpr4
                            anl_zpr7a1-3,5
      zry2      9.271E-03 4 ge_pu
                            wcrx_pu1-5
```

```
                              bnw_pu
    4 Al        2.659E-02 S 3rtc_r1100h.1
      6071-76Al 6.026E-02 S 4d2o_Gd
294 1 mixture   7.000E-03 S 1iae_maria1 (numerical benchmark)
      U_Al      4.847E-02 S 1iae_maria2 (numerical benchmark)
    2 6071-76Al 6.026E-02 2 curl_zpr2,3
      6061-Al   6.026E-02   baw_cx10
      Al        6.020E-02 S 1iae_maria2 (numerical benchmark)
    4 Be_mix    1.594E-05 S 1iae_maria2 (numerical benchmark)
295 2 6071-76Al 6.026E-02 2 curl_zpr1
      6061-Al   6.026E-02 2 baw_bay2a
      al        6.027E-02 8 dcat1
    4 1050al    6.027E-02 8 zed2t1
      al        6.027E-02 8 dcat1
      6068al    6.027E-02 8 zed2t4
296 2 zry2      9.271E-03 8 zed2t2,zed2t3
    4 al65s     5.851E-02 8 zed2t2,zed2t3
      al50s     5.861E-02 8 zed2t2,zed2t3
311 4 57s-al    6.027E-02 b 1dca
353 4 Al        2.659E-02 S 3rtc_r1100h.2
```

29 Si

```
TEM C MAT       AT.DENS.  B NAME/S
288 2 304ss     3.345E-04 2 baw_bay2b2
                            wapd_crxc
290 2 304ss     3.345E-04 2 wapd_crxd2,3
292 2 304ss     3.345E-04 2 wapd_crxd1
293 2 ss        3.345E-04 1 aere_uma2,5
                4.202E-04 2 aeew-dimple(rn100h)
                9.900E-04 S 3rtc_nora.1
                4.179E-04 S 3rtc_r1100h.1
      304ss     3.345E-04 2 wapd_crxa1-5.b
                            bnl_uo2
                            anl_zpr7a4,b
                            npy_nora
                            sck_venus
      18/8/1SS  3.345E-04 2 aeew_juno
294 4 Be_mix    7.655E-06 S 1iae_maria2 (numerical benchmark)
295 2 304ss     3.345E-04 2 baw_bay2b1
296 2 304ss     3.345E-04 2 wapd_crxa6
    4 al65s     3.474E-04 8 zed2t2,zed2t3
      al50s     5.790E-04 8 zed2t2,zed2t3
333 2 ss        9.900E-04 S 3rtc_nora.2
353 4 Al        4.179E-04 S 3rtc_r1100h.2
```

(b) Structural materials

52 Cr

```
TEM C MAT       AT.DENS.  B NAME/S
288 2 304ss     1.726E-02 2 baw_bay2b2
                            wapd_crxc
290 2 304ss     1.726E-02 2 wapd_crxd2,3
292 2 304ss     1.726E-02 2 wapd_crxd1
293 2 ss        1.726E-02 1 aere_uma2,5
                          2 wapd_crxa1-5
                            bnl_uo2
                            anl_zpr7a4,b
                            npy_nora
                            sck_venus
                1.735E-02   aeew-dimple(rn100h)
```

```
      18/8/1ss  1.726E-02 2 aeew_juno
      zry2      7.405E-05 4 jtca_pu
                7.920E-05 6 bnl_thh2o,d2o
      zry       1.800E-04 S 3rtc_kritz.1
      ss        1.600E-02 S 3rtc_nora.1
                1.720E-02 S 3rtc_r1100h.1
294 4 Be_mix    6.204E-06 S 1iae_maria2 (numerical benchmark)
295 2 304ss     1.726E-02 2 baw_bay2b1
296 2 304ss     1.726E-02 2 wapd_crxa6
    4 al65s     6.255E-05 8 zed2t2,zed2t3
      al50s     1.564E-05 8 zed2t2,zed2t3
299 2 zry4      7.645E-05 4 wcrx_pu6
333 2 ss        1.600E-02 S 3rtc_nora.2
353 2 ss        1.720E-02 S 3rtc_r1100h.2
483 2 zry       1.800E-04 S rtc_3rtc_kritz1.2
509 2 zry       1.800E-04 S rtc_3rtc_kritz219.2
516 2 zry       1.800E-04 S rtc_3rtc_kritz213.2
521 2 zry       1.800E-04 S rtc_3rtc_kritz21.2
621 2 zry       1.800E-04 S 5thburn (numerical benchmark)
```

55 Mn

```
TEM C MAT       AT.DENS.  B NAME/S
288 2 304ss     1.599E-03 2 baw_bay2b2
                            wapd_crxc
290 2 304ss     1.599E-03 2 wapd_crxd2,3
292 2 304ss     1.599E-03 2 wapd_crxd1
293 2 ss        1.599E-03 1 aere_uma2,5
                1.607E-03   aeew-dimple(rn100h)
                1.200E-03 S 3rtc_nora.1
                1.600E-03 S 3rtc_r1100h.1
      304ss     1.599E-03 2 wapd_crxa1-5,b
      304ss     1.599E-03 2 bnl_uo2
                            anl_zpr7a4,b
                            npy_nora
                            sck_venus
      18/8/1ss  1.599E-03 2 aeew_juno
294 4 Be_mix    3.914E-06 S 1iae_maria1,2 (numerical benhmarks)
295 2 304ss     1.599E-03 2 baw_bay2b1
296 2 304ss     1.599E-03 2 wapd_crxa6
    4 al65s     4.440E-05 8 zed2t2,3
      al50s     2.960E-05 8 zed2t2,3
333 2 ss        1.200E-03 S 3rtc_nora.2
```

2056 Fe

```
TEM C MAT       AT.DENS.  B NAME/S
288 2 304ss     5.676E-02 2 baw_bay2b2
                            wapd_crxc
290 2 304ss     5.676E-02 2 wapd_crxd2,3
292 2 304ss     5.676E-02 2 wapd_crxd1
293 2 ss        5.676E-02 1 aere_uma2,5
                5.704E-02   aeew-dimple(rn100h)
                5.790E-03 S 3rtc_nora.1
                5.670E-02 S 3rtc_r1100h.1
      304ss     5.676E-02 2 wapd_crxa1-5,b
                            bnl_uo2
                            anl_zpr7a4,b
                            npy_nora
                            sck_venus
      18/8/1ss  5.676E-02 2 aeew_juno
      zry2      9.919E-05 4 jtca_pu
```

```
                9.580E-05 6 bnl_thh2o,d2o
      zry       1.300E-04 S rtc_3rtc_kritz.1
294 4 Be_mix    1.925E-05 S 1iae_maria2 (numerical benchmark)
295 2 304ss     5.676E-02 2 baw_bay2b1
296 2 304ss     5.676E-02 2 wapd_crxa6
    4 al65s     2.038E-04 8 zed2t2,zed2t3
      al50s     1.747E-04 8 zed2t2,zed2t3
299 2 zry4      1.566E-04 4 wcrx_pu6
333 2 ss        5.790E-03 S 3rtc_nora.2
353 2 ss        5.670E-02 S 3rtc_r1100h.2
483 2 zry       1.300E-04 S rtc_3rtc_kritz1.2
509 2 zry       1.300E-04 S rtc_3rtc_kritz219.2
516 2 zry       1.300E-04 S rtc_3rtc_kritz213.2
521 2 zry       1.300E-04 S rtc_3rtc_kritz21.2
620 2 zry2      3.532E-04 b 2nea-bucr1b
621 2 zry       3.500E-04 S 5thburn (numerical benchmark)
```

58 Ni

```
TEM C MAT       AT.DENS.  B NAME/S
288 2 304ss     8.644E-03 2 baw_bay2b2
                            wapd_crxc
290 2 304ss     8.644E-03 2 wapd_crxd2,3
292 2 304ss     8.644E-03 2 wapd_crxd1
293 2 ss        8.644E-03 1 aere_uma2,5
                8.686E-02 2 aeew-dimple(rn100h)
                8.030E-03 S 3rtc_nora.1
                8.640E-03 S 3rtc_r1100h.1
      304ss     8.644E-03 2 wapd_crxa1-5,b
                            bnl_uo2
                            anl_zpr7a4,b
                            npy_nora
                            sck_venus
      18/8/1ss  8.644E-03 2 aeew_juno
      zry2      4.016E-05 4 jtca_pu
                3.510E-05 6 bnl_thh2o,d2o
294 4 Be_mix    1.832E-06 S 1iae_maria2 (numerical benchmark)
295 2 304ss     8.644E-03 2 baw_bay2b1
296 2 304ss     8.644E-03 2 wapd_crxa6
333 2 ss        8.030E-03 S 3rtc_nora.2
353 2 ss        8.640E-03 S 3rtc_r1100h.2
621 2 zry       4.000E-05 S 5thburn (numerical benchmark)
```

3063 Cu

```
TEM C MAT       AT.DENS.  B NAME/S
294 4 Be_mix    2.539E-06 S 1iae_maria2 (numerical benchmark)
296 4 al65s     6.910E-05 8 zed2t2,3
      al50s     2.559E-05 8 zed2t2,3
```

91 Zr

```
TEM C MAT       AT.DENS.  B NAME/S
293 2 zry2      4.449E-02 4 ge_pu
                            wcrx_pu1-5
                            bnw_pu
                4.230E-02 4 jtca_pu
                4.435E-02 6 bnl_thh2o,d2o
      zry       4.200E-02 S rtc_3rtc_kritz.1
294 2 zr        4.279E-02 3 wwer_a;b1,4,7,10,16,19,20,21,22;c
                          S 3rtc_vver.1
295 2 zry4      4.325E-02 8 zed2t1
296 2 zry2      4.449E-02 8 zed2t2,3
```

```
299 2 zry4      4.275E-02 4 wcrx_pu6
353 2 zr        4.279E-02 3 wwer_b2,5,8,17
403 2 zr        4.279E-02 3 wwer_b3,6,9,18
                          S 3rtc_vver.2
483 2 zry       4.200E-02 S rtc_3rtc_kritz1.2
509 2 zry       4.200E-02 S rtc_3rtc_kritz219.2
516 2 zry       4.200E-02 S rtc_3rtc_kritz213.2
521 2 zry       4.200E-02 S rtc_3rtc_kritz21.2
532 4 zry2      4.338E-02 b 1dca
573 2 zry2      4.338E-02 b 1dca
579 2 zr        4.325E-02 b 3nea-purecya(N)
600 2 zr        3.832E-02 S 2doppler (numerical benchmark)
620 2 zry2      4.234E-02 b 2nea-bucr1b
621 2 zry       4.500E-02 S 5thburn (numerical benchmark)
```

93 Nb93

```
TEM C MAT       AT.DENS.  B NAME/S
294 2 zr        4.246E-04 3 wwer_a;b1,4,7,10,16,19,20,21,22;c
                          S 3rtc_vver.1
295 2 zry2      4.325E-02 8 zed2t4
353 2 zr        4.246E-04 3 wwer_b2,5,8,17
403 2 zr        4.246E-04 3 wwer_b3,6,9,18
                          S 3rtc_vver.2
```

96 Mo

```
TEM C MAT       AT.DENS.  B NAME/S
293 2 ss        1.700E-04 S 3rtc_nora.1
333 2 ss        1.700E-04 S 3rtc_nora.2
```

1059 Co59

```
TEM C MAT       AT.DENS.  B NAME/S
293 2 ss        1.400E-04 S 3rtc_nora.1
333 2 ss        1.400E-04 S 3rtc_nora.2
```

2113 Cd

```
TEM C MAT       AT.DENS.  B NAME/S
293 2 zry2      2.000E-08 6 bnl_thh2o,d2o
```

118 Sn

```
TEM C MAT       AT.DENS.  B NAME/S
293 2 zry2      4.959E-04 4 jtca_pu
299 2 zry4      4.916E-04 4 wcrx_pu6
621 2 zry       4.900E-04 S 5thburn (numerical benchmark)
```

(c) Fission products

2154 Gd154b/fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 uo2(1.5)  1.209E-06 S 4d2o_Gd1
                6.045E-06 S 4d2o_Gd2
                1.209E-05 S 4d2o_Gd3
      U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

2155 Gd155b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 uo2(1.5)   5.082E-06 S 4d2o_Gd1
                 2.537E-05 S 4d2o_Gd2
                 5.082E-05 S 4d2o_Gd3
      U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

2156 Gd156b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 uo2(1.5)   1.026E-05 S 4d2o_Gd1
                 5.132E-05 S 4d2o_Gd2
                 1.026E-04 S 4d2o_Gd3
      U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

2157 Gd157b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 uo2(1.5)   5.311E-06 S 4d2o_Gd1
                 2.667E-05 S 4d2o_Gd2
                 5.311E-05 S 4d2o_Gd3
      U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

2158 Gd158b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 uo2(1.5)   1.226E-04 S 4d2o_Gd1
                 1.226E-05 S 4d2o_Gd2
                 6.128E-05 S 4d2o_Gd3
      U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

160 Dy160b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

161 Dy161b/fp

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 U_Al       FP        S 5mtr_owr
780 1 uo2(nat)   FP        b 1dca
841 1 uo2(3.0)   FP        b 2nea-bucr1b
900 1 tho2-uo2   FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP        b 3nea-purecya(N)
```

162 Dy162b/fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

163 Dy163b/fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

164 Dy164b/fp

```
TEM C MAT       AT.DENS.  B NAME/S
295 1 U_Al      FP        S 5mtr_owr
    R Reaction rate       S 4d2o_Gd
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

165 Dy165b/fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

178 Hf294

```
TEM C MAT       AT.DENS.  B NAME/S
294 2 zr        6.630E-06 3 wwer_a;b1,4,7,10,16,19,20,21,22;c
                          S 3rtc_vver.1
353 2 zr        6.630E-06 3 wwer_b2,5,8,17
403 2 zr        6.630E-06 3 wwer_b3,6,9,18
                          S 3rtc_vver.2
```

4083 Kr83fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4095 Mo95fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4099 Tc99fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4101 Ru101fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

5103 Ru103fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4106 Ru106fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4103 Rh103fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4105 Rh105fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

5105 Pd105fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat) FP b 1dca
841 1 uo2(3.0) FP b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu   FP b 3nea-purecya(N)
```

4107 Pd107fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4108 Pd108fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4109 Ag109fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4113 Cd113fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4115 In115fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4125 Sb125fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

5127 Te127fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4127 I127fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4131 Xe131fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4133 Cs133fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4134 Cs134fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4137 Cs137fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

6135 I135fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

5134 Xe134fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4135 Xe135fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

5135 Cs135fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4136 Xe136fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4143 Nd143fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4145 Nd145fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

4147 Pm147fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

5147 Pm147fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

6147 Sm147fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4148 Pm148mfp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

5148 Pm148fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

6148 Sm148fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

5149 Pm149fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4149 Sm149fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4150 Sm150fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4151 Sm151fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4152 Sm152fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

5151 Eu151fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

5152 Eu152fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4153 Eu153fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4154 Eu154fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4155 Eu155fp

```
TEM C MAT        AT.DENS.   B NAME/S
293 1 U_Al       FP         S 5mtr_owr
780 1 uo2(nat)   FP         b 1dca
841 1 uo2(3.0)   FP         b 2nea-bucr1b
900 1 tho2-uo2   FP         S 5thburn (numerical benchmark)
933 1 uo2+Pu     FP         b 3nea-purecya(N)
```

4902 lumpedfp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al      FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

(d) Actinides

2232 Th232

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 u3o2-puo2 1.981E-02 6 bnl_thh2o,d2o
295 1 u5o2-puo2 2.115E-02 8 zed2t4
900 1 tho2-uo2  1.612E-02 S 5thburn (numerical benchmark)
```

1231 Pa231

```
TEM C MAT       AT.DENS.  B NAME/S
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
```

1233 Pa233

```
TEM C MAT       AT.DENS.  B NAME/S
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
```

232 U232

```
TEM C MAT       AT.DENS.  B NAME/S
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
```

9233 U233

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 u3o2-puo2 6.102E-04 6 bnl_thh2o,d2o
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
```

234 U234

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 uo2(2.6)   4.887E-06 2 jaeri_tca
      mox(nat)   7.175E-07 4 jtca_pu
      U-mixt(92) 3.120E-06 5 hiss1
      u3o2-puo2  9.090E-06 6 bnl_thh2o,d2o
      uo2        2.675E-06 S 3rtc_kritz1,21,213.1
      U_Al(93)   1.240E-05 S 5mtr_owr
294 1 uo2(1.6)   2.314E-06 3 wwer_a
      uo2(3.6)   8.050E-06 3 wwer_b1,4,7,10,16,19,20,21,22
                           S 3rtc_vver.1
353 1 uo2(3.6)   8.050E-06 3 wwer_b2,5,8,17
403 1 uo2(3.6)   8.050E-06 3 wwer_b3,6,9,18
                           S 3rtc_vver.2
      uo2(4.4)   7.920E-06 3 wwer_c
483   uo2        2.675E-06 S 3rtc_kritz1.2
516   uo2        2.675E-06 S 3rtc_kritz213.2
521   uo2        2.675E-06 S 3rtc_kritz21.2
780 1 uo2(nat)   1.235E-06 b 1dca
841 1 uo2(3.0)   6.152E-06 b 2nea-bucr1b
900 1 tho2-uo2   8.245E-06 S 5thburn (numerical benchmark)
```

2235 U235

```
TEM C MAT         AT.DENS.  B NAME/S
288 1 uo2(4.02)   8.485E-04 2 baw_bay2b2
```

```
289 1 uo2(4.43)   1.005E-03 2 wapd_crxc
290 1 uo2(5.74)   1.307E-03 2 wapd_crxd2,3
292 1 uo2(5.74)   1.307E-03 2 wapd_crxd1
293 1 umet(nat)   3.423E-04 1 aecl_um
      umet(0.928) 4.414E-04 1 aere_uma1
                  4.383E-04 1 aere_uma2-5
      umet(0.95)  4.543E-04 1 hw_uma
      umet(1.007) 4.838E-04 1 hw_umb
      umet(1.016) 4.858E-04 1 bnl_uma
      umet(1.027) 4.911E-04 1 bnl_umb
      umet(1.142) 5.409E-04 1 aere_umb
      umet(1.142) 5.466E-04 1 bnl_umc1
      umet(1.142) 5.472E-04 1 bnl_umc2
      umet(1.299) 6.212E-04 1 bnl_umd
      umet(1.3)   6.253E-04 1 trx_um
      umet(1.44)  6.886E-04 1 hw_umc
      umet(3.0)   1.435E-03 1 srl_um
      uo2(1.31)   3.112E-04 2 bapl1-3
                  2.202E-04 2 bapl_trx
      uo2(2.02)   4.672E-04 2 naig_nca
      uo2(2.49)   5.777E-04 2 aerl_ocf
      uo2(2.60)   6.023E-04 2 jaeri_tca
      uo2(2.70)   6.131E-04 2 wapd_crxa1-5
      uo2(3.0)    6.914E-04 2 aeew_juno
                  7.082E-04 2 aeew_dimple(rn100h)
      uo2(3.01)   6.236E-04 2 bnl_uo2
      uo2(3.04)   6.962E-04 2 anl_zpr7a
      uo2(3.41)   7.912E-04 2 npy_nora
      uo2(3.7)    8.585E-04 2 wapd_crxb
      uo2(4.01)   9.206E-04 2 sck_venus
      uo2(4.95)   1.127E-03 2 anl_zpr7b
      mox(0.22)   4.664E-05 4 ge_pu
      mox(nat)    1.501E-04 4 wcrx_pu1-5
      mox(nat)    9.393E-05 4 jtca_pu
      mox(nat)    1.501E-04 4 bnw_pu
      U-mixt(92)  2.562E-04 5 hiss1
      u3o2-puo2   2.700E-07 6 bnl_thh2o,d2o
      uo2         3.130E-04 S 3rtc_kritz1.1
                  4.260E-04 S 3rtc_kritz21,213.1
                  3.410E-05 S 3rtc_kritz219.1
                  8.000E-04 S 3rtc_nora.1
                  7.082E-04 S 3rtc_r1100h.1
      uo2(1.5)    3.500E-04 S d2o_Gd
      U_Al(93)    1.620E-03 S 5mtr_owr
294 1 uo2(2.46)   5.617E-04 2 baw_cx10
      uo2(1.6)    3.629E-04 3 wwer_a
      uo2(3.6)    8.256E-04 3 wwer_b1,4,7,10,16,19,20,21,221
                            S 3rtc_vver.1
      mixture(84) 4.000E-05 S 1iae_maria1 (numerical benchmark)
      U_Al(84)    2.615E-03 S 1iae_maria2 (numerical benchmark)
295 1 uo2(2.07)   4.794E-04 2 curl_zpr
      uo2(2.46)   5.617E-04 2 baw_bay2a
      uo2(4.02)   8.485E-04 2 baw_bay2b1
      uo2(nat)    1.695E-04 8 zed2t1
      uo2(1.2)    2.806E-04 8 dcat1
      u5o2-puo2   2.961E-04 8 zed2t4
296 1 uo2(2.70)   6.131E-04 2 wapd_crxa6
      uo2(nat)    1.610E-04 8 zed2t2,zed2t3
299 1 mox(nat)    1.615E-04 4 wcrx_pu6
333 1 uo2         8.000E-04 S 3rtc_nora.2
353 1 uo2(3.6)    8.256E-04 3 wwer_b2,5,8,17
      uo2         7.076E-04 S 3rtc_r1100h.2
```

```
403 1 uo2(3.6)     8.256E-04 3 wwer_b3,6,9,18
                             S 3rtc_vver.2
      uo2(4.4)     1.013E-03 3 wwer_c
483 1 uo2          3.126E-04 S 3rtc_kritz1.2
509 1 uo2          3.391E-05 S 3rtc_kritz219.2
516 1 uo2          4.246E-04 S 3rtc_kritz213.2
521 1 uo2          4.246E-04 S 3rtc_kritz21.2
600 1 uo2(nat)     1.661E-04 S 2doppler1 (numerical benchmark)
      uo2(1.6)     3.737E-04 S 2doppler2 (numerical benchmark)
      uo2(2.4)     5.606E-04 S 2doppler3 (numerical benchmark)
      uo2(3.1)     7.241E-04 S 2doppler4 (numerical benchmark)
      uo2(3.9)     9.110E-04 S 2doppler5 (numerical benchmark)
780 1 uo2(nat)     1.617E-04 b 1dca
841 1 uo2(3.0)     6.892E-04 b 2nea-bucr1b
900 1 uo2(nat)     1.647E-04 S 2doppler1 (numerical benchmark)
      uo2(1.6)     3.707E-04 S 2doppler2 (numerical benchmark)
      uo2(2.4)     5.560E-04 S 2doppler3 (numerical benchmark)
      uo2(3.1)     7.182E-04 S 2doppler4 (numerical benchmark)
      uo2(3.9)     9.035E-04 S 2doppler5 (numerical benchmark)
      tho2-uo2     1.036E-03 S 5thburn (numerical benchmark)
933 1 uo2+Pu       1.446E-04 b 3nea-purecya(N)
```

236 U236

```
TEM C MAT          AT.DENS.  B NAME/S
293 1 U-mixt(92)   4.267E-07 5 hiss1
      uo2          2.191E-06 S 3rtc_kritz1,21,213.1
483   uo2          2.195E-06 S 3rtc_kritz1.1
516   uo2          2.195E-06 S 3rtc_kritz213.2
521   uo2          2.195E-06 S 3rtc_kritz21.2
780 1 uo2(nat)     AP        b 1dca
841 1 uo2(3.0)     3.163E-06 b 2nea-bucr1b
900 1 tho2-uo2     AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu       AP        b 3nea-purecya(N)
```

4927 U237pseudofp

```
TEM C MAT          AT.DENS.  B NAME/S
293 1 U_Al(93)     AP        S 5mtr_owr
780 1 uo2(nat)     AP        b 1dca
841 1 uo2(3.0)     AP        b 2nea-bucr1b
900 1 tho2-uo2     AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu       AP        b 3nea-purecya(N)
```

927 U237

```
TEM C MAT          AT.DENS.  B NAME/S
293 1 U_Al(93)     FP        S 5mtr_owr
780 1 uo2(nat)     FP        b 1dca
841 1 uo2(3.0)     FP        b 2nea-bucr1b
900 1 tho2-uo2     AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu       FP        b 3nea-purecya(N)
```

8238 U238

```
TEM C MAT          AT.DENS.  B NAME/S
288 1 uo2(4.02)    2.026E-02 2 baw_bay2b2
289 1 uo2(4.43)    2.169E-02 2 wapd_crxc
290 1 uo2(5.74)    2.145E-02 2 wapd_crxd2,3
292 1 uo2(5.74)    2.145E-02 2 wapd_crxd1
293 1 umet(nat)    4.760E-02 1 aecl_um
      umet(0.928)  4.712E-02 1 aere_uma1
                   4.680E-02 1 aere_uma2-5
      umet(0.95)   4.736E-02 1  hw_uma
```

```
      umet(1.007) 4.756E-02 1 hw_umb
      umet(1.016) 4.733E-02 1 bnl_uma
      umet(1.027) 4.733E-02 1 bnl_umb
      umet(1.142) 4.682E-02 1 aere_umb
      umet(1.142) 4.727E-02 1 bnl_umc1
      umet(1.142) 4.732E-02 1 bnl_umc2
      umet(1.299) 4.720E-02 1 bnl_umd
      umet(1.3)   4.720E-02 1 trx_um
      umet(1.44)  4.713E-02 1 hw_umc
      umet(3.0)   4.640E-02 1 srl_um
      uo2(1.31)   2.313E-02 2 bapl1-3
                  1.657E-02 2 bapl_trx
      uo2(2.02)   2.266E-02 2 naig_nca
      uo2(1.5)    2.200E-02 S d2o_Gd
      uo2(2.49)   2.262E-02 2 aerl_ocf
      uo2(2.60)   2.260E-02 2 jaeri_tca
      uo2(2.70)   2.253E-02 2 wapd_crxa1-5
      uo2(3.0)    2.259E-02 2 aeew_juno
      uo2(3.0)    2.259E-02 2 aeew_dimple(rn100h)
      uo2(3.01)   2.012E-02 2 bnl_uo2
      uo2(3.04)   2.200E-02 2 anl_zpr7a
      uo2(3.41)   2.241E-02 2 npy_nora
      uo2(3.7)    2.234E-02 2 wapd_crxb
      uo2(4.01)   2.204E-02 2 sck_venus
      uo2(4.95)   2.163E-02 2 anl_zpr7b
      mox(0.22)   2.115E-02 4 ge_pu
      mox(nat)    2.070E-02 4 wcrx_pu1-5
      mox(nat)    1.295E-02 4 jtca_pu
      mox(nat)    2.070E-02 4 bnw_pu
      U-mixt(92)  1.719E-05 5 hiss1
      u3o2-puo2   6.550E-06 6 bnl_thh2o,d2o
      uo2         2.220E-02 S 3rtc_kritz1,21,213.1
      uo2         2.100E-02 S 3rtc_kritz219.1
                  2.259E-02 S 3rtc_r1100h.1
      U_Al(93)    1.050E-04 S 5mtr_owr
294 1 uo2(2.46)   2.228E-02 2 baw_cx10
      uo2(1.6)    2.232E-02 3 wwer_a
      uo2(3.6)    2.210E-02 3 wwer_b1,4,7,10,16,19,20,21,22
                            S 3rtc_vver.1
      mixture(84) 1.000E-05 S 1iae_maria1 (numerical benchmark)
      U_Al(84)    6.454E-04 S 1iae_maria2 (numerical benchmark)
295 1 uo2(2.07)   2.268E-02 2 curl_zpr
      uo2(2.46)   2.228E-02 2 baw_bay2a
      uo2(4.02)   2.026E-02 2 baw_bay2b1
      uo2(nat)    2.336E-02 2 zed2t1
      uo2(1.2)    2.275E-02 8 dcat1
      u5o2-puo2   2.201E-05 8 zed2t4
296 1 uo2(2.70)   2.253E-02 2 wapd_crxa6
      uo2(nat)    2.221E-02 8 zed2t2,zed2t3
299 1 mox(nat)    2.227E-02 4 wcrx_pu6
353 1 uo2(3.6)    2.210E-02 3 wwer_b2,5,8,17
      uo2         2.257E-02 S 3rtc_r1100h.2
403 1 uo2(3.6)    2.210E-02 3 wwer_b3,6,9,18
                            S 3rtc_vver.2
      uo2(4.4)    2.200E-02 3 wwer_c
483   uo2         2.250E-02 S 3rtc_kritz1.2
509   uo2         2.094E-02 S 3rtc_kritz219.2
516   uo2         2.212E-02 S 3rtc_kritz213.2
521   uo2         2.212E-02 S 3rtc_kritz21.2
600 1 uo2(nat)    2.296E-02 S 2doppler1 (numerical benchmark)
      uo2(1.6)    2.269E-02 S 2doppler2 (numerical benchmark)
      uo2(2.4)    2.251E-02 S 2doppler3 (numerical benchmark)
```

```
      uo2(3.1)    2.235E-02 S 2doppler4 (numerical benchmark)
      uo2(3.9)    2.211E-02 S 2doppler5 (numerical benchmark)
780 1 uo2(nat)    2.230E-02 b 1dca
841 1 uo2(3.0)    2.171E-02 b 2nea-bucr1b
900 1 uo2(nat)    2.271E-02 S 2doppler1 (numerical benchmark)
      uo2(1.6)    2.251E-02 S 2doppler2 (numerical benchmark)
      uo2(2.4)    2.237E-02 S 2doppler3 (numerical benchmark)
      uo2(3.1)    2.217E-02 S 2doppler4 (numerical benchmark)
      uo2(3.9)    2.298E-02 S 2doppler5 (numerical benchmark)
      tho2-uo2    4.300e-03 S 5thburn (numerical benchmark)
933 1 uo2+Pu      1.994e-02 b 3nea-purecya(N)
```

937 Np237

```
TEM C MAT         AT.DENS.  B NAME/S
293 1 U_Al(93)    AP        S 5mtr_owr
780 1 uo2(nat)    AP        b 1dca
841 1 uo2(3.0)    AP        b 2nea-bucr1b
900 1 tho2-uo2    AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu      AP        b 3nea-purecya(N)
```

1939 Np239

```
TEM C MAT         AT.DENS.  B NAME/S
293 1 U_Al(93)    AP        S 5mtr_owr
780 1 uo2(nat)    AP        b 1dca
841 1 uo2(3.0)    AP        b 2nea-bucr1b
900 1 tho2-uo2    AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu      AP        b 3nea-purecya(N)
```

948 Pu238

```
TEM C MAT         AT.DENS.  B NAME/S
293 1 mox(nat)    2.000E-06 4 jtca_pu
293 1 U_Al(93)    AP        S 5mtr_owr
780 1 uo2(nat)    AP        b 1dca
841 1 uo2(3.0)    AP        b 2nea-bucr1b
900 1 tho2-uo2    AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu      1.147E-04 b 3nea-purecya(N)
```

6239 Pu239

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 mox(0.22) 2.939E-04 4 ge_pu
      mox(nat)  3.882E-04 4 wcrx_pu1,2,5
                3.038E-04 4 wcrx_pu3,4
      mox(nat)  3.883E-04 4 bnw_pua
      mox(nat)  3.436E-04 4 bnw_pub
      mox(nat)  3.038E-04 4 bnw_puc
      mox(nat)  6.331E-04 4 bnw_pud
      mox(nat)  1.429E-03 4 wcrx_pu6
      Pumixt    2.735E-04 5 hiss2
      uo2       2.918E-04 S 3rtc_kritz219.1
      U_Al(93)  AP        S 5mtr_owr
299   mox(nat)  2.749E-04 4 jtca_pu
509   uo2       2.908E-04 S 3rtc_kritz219.2
780 1 uo2(nat)  AP        b 1dca
841 1 uo2(3.0)  AP        b 2nea-bucr1b
900 1 tho2-uo2    AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu      1.028E-03 b 3nea-purecya(N)
```

1240 Pu240

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 mox(0.22) 2.517E-05 4 ge_pu
      mox(nat)  3.244E-05 4 wcrx_pu1,2,5
                9.950E-05 4 wcrx_pu3,4
      mox(nat)  8.842E-05 4 jtca_pu
      mox(nat)  3.242E-05 4 bnw_pua
      mox(nat)  7.006E-05 4 bnw_pub
      mox(nat)  9.950E-05 4 bnw_puc
      mox(nat)  1.520E-04 4 bnw_pud
      Pumixt    1.549E-05 5 hiss2
      uo2       2.499E-05 S 3rtc_kritz219.1
      U_Al(93)  AP        S 5mtr_owr
299 1 mox(nat)  1.353E-04 4 wcrx_pu6
509   uo2       2.491E-05 S 3rtc_kritz219.2
780 1 uo2(nat)  AP        b 1dca
841 1 uo2(3.0)  AP        b 2nea-bucr1b
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    7.966E-04 b 3nea-purecya(N)
```

1241 Pu241

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 mox(0.22) 2.347E-06 4 ge_pu
      mox(nat)  2.971E-06 4 wcrx_pu1,2,5
                1.727E-05 4 wcrx_pu3,4
      mox(nat)  2.792E-05 4 jtca_pu
      mox(nat)  2.966E-06 4 bnw_pua
      mox(nat)  9.107E-06 4 bnw_pub
293 1 mox(nat)  1.727E-05 4 bnw_puc
      mox(nat)  4.266E-05 4 bnw_pud
      Pumixt    1.072E-06 5 hiss2
      uo2       1.414E-06 S 3rtc_kritz219.1
      U_Al(93)  AP        S 5mtr_owr
299 1 mox(nat)  1.405E-05 4 wcrx_pu6
509   uo2       1.410E-06 S 3rtc_kritz219.2
780 1 uo2(nat)  AP        b 1dca
841 1 uo2(3.0)  AP        b 2nea-bucr1b
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    3.400E-04 b 3nea-purecya(N)
```

242 Pu242HSS

```
TEM C MAT        AT.DENS.  B NAME/S
933 1 uo2+Pu    5.639E-04 b 3nea-purecya(N)
```

1242 Pu242LSS

```
TEM C MAT        AT.DENS.  B NAME/S
293 1 mox(0.22) 9.645E-08 4 ge_pu
      mox(nat)  1.314E-07 4 wcrx_pu1,2,5
                2.778E-06 4 wcrx_pu3,4
      mox(nat)  8.123E-06 4 jtca_pu
      mox(nat)  1.271E-07 4 bnw_pua
293 1 mox(nat)  8.472E-07 4 bnw_pub
      mox(nat)  2.794E-06 4 bnw_puc
      mox(nat)  9.658E-06 4 bnw_pud
      Pumixt    5.800E-08 5 hiss2
      uo2       9.578E-08 S 3rtc_kritz219.1
      U_Al(93)  AP        S 5mtr_owr
299 1 mox(nat)  6.315E-07 4 wcrx_pu6
509   uo2       9.578E-08 S 3rtc_kritz219.2
```

```
780 1 uo2(nat)  AP        b 1dca
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
```

951 Am241

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 mox(nat)  1.353E-06 4 jtca_pu
      uo2       9.156E-07 S 3rtc_kritz219.1
      U_Al(93)  AP        S 5mtr_owr
509   uo2       9.127E-07 S 3rtc_kritz219.2
780 1 uo2(nat)  AP        b 1dca
841 1 uo2(3.0)  AP        b 2nea-bucr1b
900 1 tho2-uo2  AP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    AP        b 3nea-purecya(N)
```

1952 Am242fp

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

952 Am242m

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

953 Am243

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

962 Cm242

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

963 Cm243

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

964 Cm244

```
TEM C MAT       AT.DENS.  B NAME/S
293 1 U_Al(93)  FP        S 5mtr_owr
780 1 uo2(nat)  FP        b 1dca
```

```
841 1 uo2(3.0)  FP        b 2nea-bucr1b
900 1 tho2-uo2  FP        S 5thburn (numerical benchmark)
933 1 uo2+Pu    FP        b 3nea-purecya(N)
```

(e) Dosimetry reactions and others

1000 1/v absorber

```
TEM C MAT       AT.DENS.  B NAME/S
620 2 zry2      8.005E-05 b 2nea-bucr1b
```

3000 constant=1 absorber

```
TEM C MAT       AT.DENS.  B NAME/S
620 2 zry2      2.143E-04 b 2nea-bucr1b
```

176 Lu-176(n,g)Lu-177

```
TEM C MAT       AT.DENS.  B NAME/S
295 R Reaction rate       8 zed2t1
```

Not-benchmarked materials

Light elements	Structural materials	Medium elements	Actinides	Dosimetry reactions and others
3 He3	19 F	3109 Ag	-	1999 res.part of 1/v
4 He4	23 Na	2115 In		2000 –1/v absorber
6 Li6	31 P	121 Sb121		4000 inv.leth.interv.
7 Li7	32 S	123 Sb123		2212 C-damage
11 B11b	35 Cl	152 Eu160		1091 Zr-amage
	40 Ca	2166 Er166b		1055 Mn-55(n,g)Mn-56
	48 Ti	2167 Er167b		1054 Fe-54(n,p)Mn-54
	51 V	2176 Hf176b		3058 Fe-58(n,g)Fe-59
		2177 Hf177b		2059 Co-59(n,g)Co-60
		2178 Hf178b		1058 Ni-58(n,p)Co-58
		2179 Hf179b		1063 Cu-63(n,g)Cu-64
		2180 Hf180b		84 Kr-84(n,g)Kr-85
		181 Ta		2103 Rh-103(n,n')Rh-103m
		183 W		1115 In-115(n,n')In-115m
		207 Pb		3115 In-115(n,g)In-116m
				1151 Eu-151(n,g)Eu-152
				1164 Dy-164(n,g)Dy-165
				197 Au-197(n,g)Au-198
				1232 Th-232(n,g)Th-233
				3232 Th-232(n,f)
				1235 U-235(n,g)U-236
				1003 U-235(n,f)
				1238 U-238(n,g)U-239
				3238 U-238(n,f)
				1237 Np-237(n,f)
				1239 Pu-239(n,f)
				1632 Th-232(n,2n)
				1633 U-233(n,2n)
				1635 U-235(n,2n)
				1638 U-238(n,2n)
				1639 Pu-239(n,2n)
				1640 Pu-240(n,2n)
				1641 Pu-241(n,2n)
				1642 Pu-242(n,2n)

Appendix IV

STANDARD BENCHMARK SPECIFICATIONS

IV.1. H_2O-moderated uranium metal lattices-UME-LW (CRITUME)

Index

1.01) UME-LW-BAPL-TRX
1.02) UME-LW-AECL-AECLea
1.03) UME-LW-AERE-AEREea
1.04) UME-LW-BNL-BNLea
1.05) UME-LW-HW-HWea
1.06) UME-LW-SRL-SRLea

List of benchmarks by U-235 enrichment

Benchmark identification	wt% u235	# cases	.win	Short name
1.02) UME-LW-AECL -AECLea	0.714	1	aecl_um	aecl_um
1.03) UME-LW-AERE -AEREea	a)0.928	5	aere_uma	aere_uma1-5
1.05) UME-LW-HW -HWea	a)0.95	4	hw_uma	hw_uma1-4
1.05) UME-LW-HW -HWea	b)1.007	6	hw_umb	hw_umb1-6
1.04) UME-LW-BNL -BNLea	a)1.016	7	bnl_uma	bnl_uma1-7
1.04) UME-LW-BNL -BNLea	b)1.027	16	bnl_umb	bnl_umb1-16
1.03) UME-LW-AERE -AEREea	b)1.142	2	aere_umb	aere_umb1-2
1.04) UME-LW-BNL -BNLea	c)1.143	2	bnl_umc	bnl_umc1-2
1.04) UME-LW-BNL -BNLea	d)1.299	7	bnl_umd	bnl_umd1-7
1.01) UME-LW-BAPL –TRX	1.3	2	trx_um	trx_um1-2
1.05) UME-LW-HW -HWea	c)1.44	5	hw_umc	hw_umc1-5
1.06) UME-LW-SRL -SRLea	3.0	7	srl_um	srl_um1-7

1.01) UME-LW-BAPL-TRX
H_2O-moderated uranium critical metal lattices

Laboratory: BAPL Bettis Atomic Power Laboratory, Westinghouse (USA)

Facility: TRX

These benchmarks consist of two H_2O moderated lattices of slightly enriched uranium metal rods in a triangular pattern. Material bucklings and several spectral indexes were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-238 capture reaction rate

b. δ^{25} : ratio of epithermal to thermal U-235 fission reaction rate

c. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate

d. C^* : ratio of U-238 capture to U-235 fission reaction rate

(thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) $\boldsymbol{\rho^{28}}$
3) $\boldsymbol{\delta^{25}}$
4) $\boldsymbol{\delta^{28}}$
5) $\mathbf{C}^*$

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he : hexagonal)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-BAPL–trx_um1	1.3	0.621	0.983	al	1.81	2.35	57.0	20.0	he
UME-LW-BAPL–trx_um2	1.3	0.711	0.983	al	2.17	4.02	54.69	20.0	he

General data

Pitch (cm)	trx_um1: 1.8060 trx_um2: 2.1740
Lattice geometry	Hexagonal
Water/fuel volume ratio	trx_um1: 2.35 trx_um2: 4.02
Moderator	H2O
Fuel material	U-met (1.3 wt% enrichment)
Fuel Isotopic Concentration (10^{24} Atoms/cm^3)	U-235: 0.0006253 U-238: 0.047205
Radius of fuel rods (cm)	0.4915
Clad material	Al
Clad Isotopic Concentration (10^{24} Atoms/cm^3)	Al: 0.06025
Outer radius of clad (cm)	0.5753
Thickness of clad (cm)	0.0711
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	trx_um1: 0.0057 ± 0.0001 trx_um2: 0.005469 ± 0.000036

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	trx_um
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

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[5] BROWN J.R., HARRIS D.R. *et al.*, Kinetics and Buckling Measurements on Lattices of Slightly Enriched Uranium and UO_2 Rods in light Water, WAPD-176, January 1958.

[6] SHER, R., FIARMAN, S., Studies of Thermal Reactor Benchmark Data Interpretation: Experimental Corrections, EPRI-NP-209, October 1976.

1.02) UME-LW-AECL-AECLea
H_2O-moderated uranium metal lattice (exponential experiment)

Laboratory: AECL Atomic Energy of Canada Limited (Canada)

This benchmark is an exponential experiment with H_2O moderated lattice of uranium metal rods (0.714 wt% U235) in a square pattern. Material buckling was measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB	Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-AECL–	aecl_um	0.714	0.825	3.251	al	5.359	2.305	-19.3	20.0	sq

General data

Pitch (cm)	5.359
Lattice geometry	Square
Water/fuel volume ratio	2.305
Moderator	H2O
Fuel material	U-met (0.714 wt% U-235)
Fuel Density (g/cm^3)	18.95
Radius of fuel rods (cm)	1.6255
Clad material	Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	1.7475
Thickness of clad (cm)	0.102
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	-0.00193 ± 0.00008

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	aecl_um
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

REFERENCES

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1.03) UME-LW-AERE-AEREea
H_2O-moderated uranium metal lattices (exponential experiments)

Laboratory: AERE Atomic Energy Research Establishment, Harwell (UK)

These benchmarks consist of seven exponential experiments with H_2O moderated lattices of enriched uranium metal rods. Two different enriched fuels were used: 0.928 and 1.142 wt% in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium; ss: stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : Lattice pitch (cm)
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-AERE–aere_uma1	0.928	0.535	1.905	al	2.388	0.848	–6.1	20.0	sq
UME-LW-AERE-aere_uma2	0.928	0.571	3.048	ss	3.81	0.896	–2.0	20.0	sq
UME-LW-AERE-aere_uma3	0.928	0.639	3.048	al	4.267	1.402	24.1	20.0	sq
UME-LW-AERE-aere_uma4	0.928	0.706	3.048	al	4.699	1.931	21.9	20.0	sq
UME-LW-AERE-aere_uma5	0.928	0.723	3.048	ss	4.699	1.931	8.7	20.0	sq
UME-LW-AERE–aere_umb1	1.142	0.598	3.048	al	4.267	1.407	44.8	20.0	sq
UME-LW-AERE–aere_umb2	1.142	0.660	3.048	al	4.75	1.937	43.6	20.0	sq

General data

Pitch (cm)	aere_uma1:	2.388
	aere_uma2:	3.81
	aere_uma3,umb1:	4.267
	aere_uma4,5:	4.699
	aere_umb2:	4.750
Lattice geometry	Square	
Water/fuel volume ratio	aere_uma1:	0.848
	aere_uma2:	0.896
	aere_uma3:	1.402
	aere_umb1:	1.407
	aere_uma4,5:	1.931
	aere_umb2:	1.937

Moderator	H2O
Fuel material	U-met aere_uma: 0.928 wt% U-235 aere_umb: 1.142 wt% U-235
Fuel Density (g/cm^3)	aere_uma1: 18.80 aere_uma2-5: 18.67 aere_umb: 18.72
Radius of fuel rods (cm)	aere_uma1: 0.9525 aere_uma2-5;umb: 1.524
Clad material	aere_uma1,3,4;umb: Al aere_uma2,5: Stainless steel
Clad Density (g/cm^3)	aere_uma1,3,4;umb: 2.6999 aere_uma2,5: 7.806
Outer radius of clad (cm)	aere_uma1: 1.0225 aere_uma2-5;umb: 1.556
Thickness of clad (cm)	aere_uma1: 0.053 aere_uma2,5: 0.048 aere_uma3,4;umb: 0.051
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	aere_uma1: -0.00061 ± 0.00023 aere_uma2: -0.0002 ± 0.00019 aere_uma3: 0.00241 ± 0.00012 aere_uma4: 0.00219 ± 0.0001 aere_uma5: 0.00087 ± 0.0001 aere_umb1: 0.00448 ± 0.00026 aere_umb2: 0.00436 ± 0.0001

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	aere_uma aere_umb
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

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[1] HELLENS, R.L., PRICE, G.A., Reactor Physics Data for Water-Moderated Lattices of Slightly Enriched Uranium Reactor Technology, Selected Reviews, 529, 1964.

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1.04) UME-LW-BNL-BNLea
H_2O-moderated uranium metal lattices (exponential experiments)

Laboratory: BNL Brookhaven National laboratory (USA)

Facility: BNL Exponential Assemblies

These benchmarks consist of 32 exponential experiments with H_2O moderated lattices of enriched uranium metal rods. Four different enriched fuels were used: 1.016, 1.027, 1.143 and 1.299 wt% in hexagonal patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (al: aluminium)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	(Volume of moderator/Volume of fuel) of the lattice
TEMP	:	(Volume of moderator/Volume of fuel) of the lattice
GE	:	Geometry of the lattice (he : hexagonal)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-BNL -bnl_uma1	1.016	0.646	0.635	al	1.147	2.0	19.95	20.0	he
UME-LW-BNL -bnl_uma2	1.016	0.712	0.635	al	1.297	3.0	24.35	20.0	he
UME-LW-BNL -bnl_uma3	1.016	0.764	0.635	al	1.431	4.0	20.34	20.0	he
UME-LW-BNL -bnl_uma4	1.016	0.602	0.983	al	1.586	1.5	19.70	20.0	he
UME-LW-BNL -bnl_uma5	1.016	0.717	0.983	al	1.957	3.0	31.39	20.0	he
UME-LW-BNL -bnl_uma6	1.016	0.542	1.524	al	2.168	1.0	9.9	20.0	he
UME-LW-BNL -bnl_uma7	1.016	0.797	1.524	al	3.32	4.0	20.96	20.0	he
UME-LW-BNL -bnl_umb1	1.027	0.599	0.635	al	1.064	1.5	12.14	20.0	he
UME-LW-BNL -bnl_umb2	1.027	0.643	0.635	al	1.147	2.0	19.95	20.0	he
UME-LW-BNL -bnl_umb3	1.027	0.709	0.635	al	1.297	3.0	25.15	20.0	he
UME-LW-BNL -bnl_umb4	1.027	0.761	0.635	al	1.431	4.0	22.07	20.0	he
UME-LW-BNL -bnl_umb5	1.027	0.599	0.983	al	1.586	1.5	19.7	20.0	he
UME-LW-BNL -bnl_umb6	1.027	0.645	0.983	al	1.719	2.0	29.02	20.0	he
UME-LW-BNL -bnl_umb7	1.027	0.714	0.983	al	1.957	3.0	31.39	20.0	he
UME-LW-BNL -bnl_umb8	1.027	0.771	0.983	al	2.17	4.0	25.68	20.0	he
UME-LW-BNL -bnl_umb9	1.027	0.540	1.524	al	2.168	1.0	9.90	20.0	he
UME-LW-BNL -bnl_umb10	1.027	0.654	1.524	al	2.609	2.0	36.07	20.0	he
UME-LW-BNL -bnl_umb11	1.027	0.729	1.524	al	2.985	3.0	33.15	20.0	he
UME-LW-BNL -bnl_umb12	1.027	0.793	1.524	al	3.32	4.0	20.96	20.0	he
UME-LW-BNL -bnl_umb13	1.027	0.592	1.905	al	2.868	1.334	28.9	20.0	he
UME-LW-BNL -bnl_umb14	1.027	0.691	1.905	al	3.393	2.334	36.73	20.0	he
UME-LW-BNL -bnl_umb15	1.027	0.731	1.905	al	3.628	2.834	33.35	20.0	he

UME-LW-BNL -bnl_umb16	1.027	0.803	1.905 al	4.058	3.834	18.60	20.0	he
UME-LW-BNL -bnl_umc1	1.143	0.733	0.635 al	1.431	4.0	36.05	20.0	he
UME-LW-BNL -bnl_umc2	1.143	0.584	1.524 al	2.399	1.5	38.73	20.0	he
UME-LW-BNL -bnl_umd1	1.299	0.555	0.983 al	1.586	1.5	40.51	20.0	he
UME-LW-BNL -bnl_umd2	1.299	0.598	0.983 al	1.719	2.0	52.19	20.0	he
UME-LW-BNL -bnl_umd3	1.299	0.661	0.983 al	1.957	3.0	59.25	20.0	he
UME-LW-BNL -bnl_umd4	1.299	0.662	0.983 al	1.961	3.018	58.2	20.0	he
UME-LW-BNL -bnl_umd5	1.299	0.711	0.983 al	2.17	4.0	54.69	20.0	he
UME-LW-BNL -bnl_umd6	1.299	0.676	1.524 al	2.985	3.0	60.99	20.0	he
UME-LW-BNL -bnl_umd7	1.299	0.734	1.524 al	3.32	4.0	50.38	20.0	he

General data

Pitch (cm)	bnl-umb1: 1.064 bnl-uma1,umb2: 1.147 bnl-uma2,umb3: 1.297 bnl-uma3,b4,c1: 1.431 bnl-uma4,umb5: 1.586 bnl-umd1: 1.589 bnl-umb6,umd2: 1.719 bnl-uma5,b7,d3: 1.957 bnl-umd4: 1.961 bnl-uma6,umb9: 2.168 bnl-umb8,umd5: 2.170 bnl-umc2: 2.399 bnl-umb10: 2.609 bnl-umb13: 2.868 bnl-umb11,umd6: 2.985 bnl-uma7,b12,d7: 3.320 bnl-umb14: 3.393 bnl-umb15: 3.628 bnl-umb16: 4.058
Lattice geometry	Hexagonal
Water/fuel volume ratio	bnl-uma6,umb9: 1.0 bnl-umb13: 1.334 bnl-uma4;umb1,5;umc1;umd1: 1.5 bnl-uma1;umb2,6,10;umd2: 2.0 bnl-umb14: 2.334 bnl-umb15: 2.834 bnl-uma2,5;umb3,7,11;umd3,6: 3.0 bnl-umd4: 3.018 bnl-umb16: 3.834 bnl-uma3,7;b4,8,12;c1;d5,7: 4.0
Moderator	H2O
Fuel material	U-met bnl-uma: 1.016 w% bnl-umb: 1.027 w% bnl-umc: 1.143 w% bnl-umd: 1.299 w%
Fuel Density (g/cm^3)	18.90

Radius of fuel rods (cm)	bnl-uma1-3;b1-4;c1: 0.3175 bnl-uma4,5;b5-8;d1-5: 0.4915 bnl-uma6,7;b9-12;c2;d6,7: 0.762 bnl-umb13-16: 0.9525
Clad material	Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	bnl-uma1-3;b1-4;c1: 0.4015 bnl-uma4,5;b5-8;d1-5: 0.5755 bnl-uma6,7;b9-12;c2;d6,7: 0.846 bnl-umb13-16: 1.0285
Thickness of clad (cm)	bnl-uma1-3;b1-4;c1: 0.079 bnl-uma4,7;b5-12;c2;d1-7: 0.071 bnl-umb13-16: 0.076
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	bnl-uma1: 0.001995 ± 0.000047 bnl-uma2: 0.002435 ± 0.000019 bnl-uma3: 0.002034 ± 0.000043 bnl-uma4: 0.001970 ± 0.000034 bnl-uma5: 0.003139 ± 0.000019 bnl-uma6: 0.000990 ± 0.000054 bnl-uma7: 0.002096 ± 0.000026 bnl-umb1: 0.001214 ± 0.000103 bnl-umb2: 0.001995 ± 0.000047 bnl-umb3: 0.002515 ± 0.000027 bnl-umb4: 0.002207 ± 0.000021 bnl-umb5: 0.001970 ± 0.000034 bnl-umb6: 0.002902 ± 0.000034 bnl-umb7: 0.003139 ± 0.000019 bnl-umb8: 0.002568 ± 0.000024 bnl-umb9: 0.000990 ± 0.000054 bnl-umb10:0.003607 ± 0.000039 bnl-umb11:0.003315 ± 0.000031 bnl-umb12:0.002096 ± 0.000026 bnl-umb13:0.00289 ± 0.00005 bnl-umb14:0.003673 ± 0.000048 bnl-umb15:0.003335 ± 0.000113 bnl-umb16:0.00186 ± 0.00006 bnl-umc1: 0.003605 ± 0.000019 bnl-umc2: 0.003873 ± 0.000082 bnl-umd1: 0.004051 ± 0.000030 bnl-umd2: 0.005219 ± 0.000036 bnl-umd3: 0.005925 ± 0.000033 bnl-umd4: 0.00582 ± 0.00010 bnl-umd5: 0.005469 ± 0.000036 bnl-umd6: 0.006099 ± 0.000026 bnl-umd7: 0.005038 ± 0.000027

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	bnl_uma
	bnl_umb
	bnl_umc
	bnl_umd
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

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1.05) UME-LW-HW-HWea
H_2O-moderated uranium metal lattices (exponential experiments)

Laboratory: HW Hanford Works, Richland (USA)

These benchmarks consist of 15 exponential experiments with H_2O moderated lattices of enriched uranium metal rods. Three different enriched fuels were used: 0.95, 1.007 and 1.44 wt% in hexagonal patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he : hexagonal)

FUE-CO-LAB	-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-HW	-hw_uma1	0.95	0.610	3.393	al	5.08	1.2	19.24	20.0	he
UME-LW-HW	-hw_uma2	0.95	0.648	3.393	al	5.334	1.46	22.57	20.0	he
UME-LW-HW	-hw_uma3	0.95	0.682	3.393	al	5.588	1.72	21.15	20.0	he
UME-LW-HW	-hw_uma4	0.95	0.748	3.393	al	6.096	2.28	14.74	20.0	he
UME-LW-HW	-hw_umb1	1.007	0.606	2.35	al	3.556	1.37	29.03	20.0	he
UME-LW-HW	-hw_umb2	1.007	0.669	2.35	al	3.937	1.94	33.57	20.0	he
UME-LW-HW	-hw_umb3	1.007	0.689	2.35	al	4.064	2.15	30.12	20.0	he
UME-LW-HW	-hw_umb4	1.007	0.546	4.216	al	5.588	0.86	16.39	20.0	he
UME-LW-HW	-hw_umb5	1.007	0.631	4.216	al	6.223	1.33	27.47	20.0	he
UME-LW-HW	-hw_umb6	1.007	0.708	4.216	al	6.858	1.85	22.05	20.0	he
UME-LW-HW	-hw_umc1	1.44	0.536	3.393	al	5.08	1.21	52.94	20.0	he
UME-LW-HW	-hw_umc2	1.44	0.569	3.393	al	5.334	1.46	56.78	20.0	he
UME-LW-HW	-hw_umc3	1.44	0.600	3.393	al	5.588	1.73	57.74	20.0	he
UME-LW-HW	-hw_umc4	1.44	0.660	3.393	al	6.096	2.3	51.15	20.0	he
UME-LW-HW	-hw_umc5	1.44	0.719	3.393	al	6.604	2.92	38.18	20.0	he

General data

Pitch (cm)	hw-umb1: 3.556 hw-umb2: 3.937 hw-umb3: 4.064 hw-uma1,umc1: 5.08 hw-uma2,umc2: 5.334 hw-uma3,b4,c3: 5.588 hw-uma4,umc4: 6.096 hw-umb5: 6.223 hw-umc5: 6.604 hw-umb6: 6.858
Lattice geometry	Hexagonal
Water/fuel volume ratio	hw-umb4: 0.86 hw-uma1: 1.20 hw-umc1: 1.21 hw-umb5: 1.33 hw-umb1: 1.37 hw-uma2: 1.46 hw-umc2: 1.46 hw-uma3: 1.72 hw-umc3: 1.73 hw-umb6: 1.85 hw-umb2: 1.94 hw-umb3: 2.15 hw-uma4: 2.28 hw-umc4: 2.30 hw-umc5: 2.92
Moderator	H2O
Fuel material	U-met hw-uma: 0.95 wt%, hw-umb: 1.007 wt%, hw-umc: 1.44 wt%
Fuel Density (g/cm^3)	hw-uma,umc: 18.9 hw-umb: 18.99
Radius of fuel rods (cm)	hw-umb1-3: 1.175 hw-uma,umc: 1.6965 hw-umb4-6: 2.108
Clad material	Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	hw-umb1-3: 1.27 hw-uma,umc: 1.905 hw-umb4-6: 2.191
Thickness of clad (cm)	hw-umb4-6: 0.071 hw-umb1-3: 0.089 hw-uma,umc: 0.124
Temperature (all components) (K)	293.0

Experimental buckling B^2 (cm^{-2})	hw-uma1: 0.001924 ± 0.000040 hw-uma2: 0.002257 ± 0.000032 hw-uma3: 0.002115 ± 0.000022 hw-uma4: 0.001474 ± 0.000034 hw-umb1: 0.002903 ± 0.000016 hw-umb2: 0.003357 ± 0.000025 hw-umb3: 0.003012 ± 0.000021 hw-umb4: 0.001639 ± 0.000036 hw-umb5: 0.002747 ± 0.000007 hw-umb6: 0.002205 ± 0.000011 hw-umc1: 0.005294 ± 0.000021 hw-umc2: 0.005678 ± 0.000027 hw-umc3: 0.005774 ± 0.000003 hw-umc4: 0.005115 ± 0.000005 hw-umc5: 0.003818 ± 0.000010

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	hw_uma hw_umb hw_umc
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

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1.06) UME-LW-SRL-SRLea
H_2O-moderated uranium metal lattices (exponential experiments)

Laboratory: SRL Savannah River Laboratory (USA)

These benchmarks consist of seven exponential experiments with H_2O moderated lattices of 3 wt% enriched uranium metal rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UME-LW-SRL -srl_um1	3.0	0.423	5.08		6.35	0.99	102.0	20.0	sq
UME-LW-SRL -srl_um2	3.0	0.496	5.08		6.985	1.43	109.1	20.0	sq
UME-LW-SRL -srl_um3	3.0	0.558	5.08		7.62	1.87	102.4	20.0	sq
UME-LW-SRL -srl_um4	3.0	0.325	7.62		8.255	0.496	70.9	20.0	sq
UME-LW-SRL -srl_um5	3.0	0.401	7.62		8.89	0.738	87.9	20.0	sq
UME-LW-SRL -srl_um6	3.0	0.462	7.62		9.525	0.99	96.4	20.0	sq
UME-LW-SRL -srl_um7	3.0	0.523	7.62		10.16	1.27	91.0	20.0	sq

General data

Pitch (cm)	srl-um1: 6.350 srl-um2: 6.985 srl-um3: 7.620 srl-um4: 8.255 srl-um5: 8.890 srl-um6: 9.525 srl-um7: 10.16
Lattice geometry	Square

Water/fuel volume ratio	srl-um1: 0.990 srl-um2: 1.430 srl-um3: 1.870 srl-um4: 0.496 srl-um5: 0.738 srl-um6: 0.990 srl-um7: 1.270
Moderator	H2O
Fuel material	U-met (3 wt% U-235 enriched)
Fuel Density (g/cm^3)	18.9
Radius of fuel rods (cm)	srl-um1-3: 2.54 srl-um4-7: 3.81
Clad material	None
Temperature (all components)(K)	293.0
Experimental buckling B^2 (cm^{-2})	srl-um1: 0.01020 ± 0.00011 srl-um2: 0.01091 ± 0.00011 srl-um3: 0.01024 ± 0.00011 srl-um4: 0.00709 ± 0.00011 srl-um5: 0.00879 ± 0.00011 srl-um6: 0.00964 ± 0.00011 srl-um7: 0.00910 ± 0.00011

Keyword and files

Keyword	CRITUME
WIMS Input (.WIN)	srl_um
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUME (called from smrdif.exe)

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[1] ROGERS, W.B., KINARD, F.E., Material Buckling and Critical Masses of Uranium Rods Containing 3 wt% U-235 in H_2O, Nucl. Sci. and Eng., 20, 266 (1964).

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IV. 2. H_2O-moderated uranium oxide critical lattices-UO2-LW (CRITUO2)

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2.01) UO2-LW-BAPL-TRX
2.02) UO2-LW-AEEW-DIMPLE
2.03) UO2-LW-NAIG-NCA
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2.05) UO2-LW-BAW-BAY2
2.06) UO2-LW-BAW-CX10
2.07) UO2-LW-AERL-OCF
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2.14) UO2-LW-SCKBN-VENUS

List of benchmarks by U-235 enrichment

Benchmark identification	wt% u235	# cases	.win	Short name
2.01) UO2-LW-BAPL -TRX	1.31	6	bapl1_3,bapl_trx	bapl1-6
2.03) UO2-LW-NAIG -NCA	2.02	1	naig_nca	naig_nca
2.04) UO2-LW-CURL -ZPR	2.07	4	curl_zpr	curl_zpr1-4
2.05) UO2-LW-BAW -BAY2	a) 2.46	1	bawbay2a	baw_bay2a
2.06) UO2-LW-BAW -CX10	2.46	1	baw_cx10	baw_cx10
2.07) UO2-LW-AERL -OCF	2.49	2	aerl_ocf	aerl_ocf1-2
2.08) UO2-LW-JAERI-TCA	2.6	7	jaeritca	jaeritca1-7
2.09) UO2-LW-WAPD -CRX	a) 2.7	6	wapdcrxa	wapd_crxa1-6
2.10) UO2-LW-AEEW -JUNO	3.0	1	aeewjuno	aeewjuno
2.02) UO2-LW-AEEW -	3.0	3	rn100h	r1-3100h
DIMPLE	3.04	5	bnluo2	bnluo2_1-5
2.11) UO2-LW-BNL -BNLea	a) 3.04	5	anlzpr7a	anl_zpr7a1-5
2.12) UO2-LW-ANL -ZPR7	3.41	3	npy_nora	npy_nora1-3
2.13) UO2-LW-NPY -NORA	b) 3.7	2	wapdcrxb	wapd_crxb1-2
2.09) UO2-LW-WAPD -CRX				
2.14) UO2-LW-SCKBN-	4.01	2	sckvenus	sckvenus1-2
VENUS	b)4.02	2	bawbay2b	baw_bay2b1-2
2.05) UO2-LW-BAW -BAY2	c)4.43	1	wapdcrxc	wapd_crxc
2.09) UO2-LW-WAPD -CRX	b)4.95	2	anlzpr7b	anl_zpr7b1-2
2.12) UO2-LW-ANL -ZPR7	d)5.74	3	wapdcrxd	wapd_crxd1-3
2.09) UO2-LW-WAPD -CRX				

2.01) UO2-LW-BAPL-TRX
H_2O-moderated uranium oxide critical lattices

Laboratory: BAPL Bettis Atomic Power Laboratory, Westinghouse (USA)

Facility: TRX

These benchmarks are three standard (BAPL/1-3) and three additional (BAPL/4-6) cases of H_2O moderated lattices with slightly enriched uranium oxide rods in a triangular pattern. Material bucklings and several spectral indexes were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-238 capture reaction rate (*)
b. δ^{25} : ratio of epithermal to thermal U-235 fission reaction rate (*)
c. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate
(thermal cutoff: 0.625 eV)
(*):for BAPL/1-3 only

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) ρ^{28} (*)
3) δ^{25} (*)
4) δ^{28}
(*) for BAPL/1-3 only

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of : the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he : hexagonal)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-BAPL–bapl_trx1	1.31	0.646	0.973	al	1.56	1.43	32.59	20.0	he
UO2-LW-BAPL-bapl_trx2	1.31	0.680	0.973	al	1.65	1.78	35.47	20.0	he
UO2-LW-BAPL-bapl_trx3	1.31	0.729	0.973	al	1.81	2.40	34.22	20.0	he
UO2-LW-BAPL-bapl_trx4	1.31	0.657	1.527	al	2.20	1.07	28.37	20.0	he
UO2-LW-BAPL-bapl_trx5	1.31	0.700	1.527	al	2.36	1.40	30.17	20.0	he
UO2-LW-BAPL-bapl_trx6	1.31	0.739	1.527	al	2.51	1.76	29.06	20.0	he

General data

Pitch (cm)	bapl_trx1: 1.5578 bapl_trx2: 1.6523 bapl_trx3: 1.8057 bapl_trx4: 2.20 bapl_trx5: 2.36 bapl_trx6: 2.51
Lattice geometry	Hexagonal
Water/fuel volume ratio	bapl_trx1: 1.43 bapl_trx2: 1.78 bapl_trx3: 2.40 bapl_trx4: 1.07 bapl_trx5: 1.40 bapl_trx6: 1.76
Moderator	H2O
Fuel material	UO2 (1.311 wt% enrichment)
Fuel Isotopic Concentration (10^{24} Atoms/cm^3)	O : 0.046946 U-235: 0.0003112 U-238: 0.023127
Radius of fuel rods (cm)	bapl_trx1-3: 0.4864 bapl_trx4-6: 0.7635
Clad material	Al
Clad Isotopic Concentration (10^{24} Atoms/cm^3)	Al: 0.06025
Outer radius of clad (cm)	bapl_trx1-3: 0.5753 bapl_trx4-6: 0.8465
Thickness of clad (cm)	0.0711
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	bapl_1: 0.003259 ± 0.000015 bapl_2: 0.003547 ± 0.000015 bapl_3: 0.003422 ± 0.000013 bapl_4: 0.002837 ± 0.00006 bapl_5: 0.003017 ± 0.00006 bapl_6: 0.002906 ± 0.00007

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	bapl1_3 bapl_trx
Batch Files (.BAT)	BNCHONE (c4alled from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

[1] HELLENS, R.L., PRICE, G.A., Reactor Physics Data for Water-Moderated Lattices of Slightly Enriched Uranium Reactor Technology, Selected Reviews, 529, 1964.

[2] BROWN, J.R., HARIS, D.R. *et al*., Kinetics and Buckling Measurements on Lattices of Slightly Enriched Uranium and UO_2 Rods in light Water, WAPD-176, January 1958.

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2.02) UO2-LW-AEEW-DIMPLE
H_2O-moderated uranium oxide lattices enriched to 3.003 wt% in U-235

Laboratory: AEEW Atomic Energy Establishment, Winfrith (UK)

Facility: DIMPLE

These benchmarks are three H_2O moderated lattices of UO_2 fuel rods clad in stainless steel and enriched to 3.003 wt.% in U-235, arranged in square patterns. The gap between the clad and fuel region contained an aluminium wrapper for the fuel. Material bucklings were measured. δ^{28} and RCR (spectral indexes) were measured also for R1/100H and R3/100H.

Experimental results
(for R1/100H and R3/100H):

a. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate
b. RCR : ratio of U-238 capture to U-235 fission reaction rate, ratio of lattice to Maxwellian (thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) $\boldsymbol{\delta^{28}}$ (*)
3) **RCR** (*)
(*) for R1/100H and R3/100H only

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Fuel rod diameter (cm)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-AEEW–r1100h	3.003	0.453	1.012	ss	1.320	1.001	66.00	20.0	sq
UO2-LW-AEEW–r2100h	3.003	0.488	1.012	ss	1.866	3.163	100.44	20.0	sq
UO2-LW-AEEW–r3100h	3.003	0.637	1.012	ss	1.251	0.779	50.96	20.0	sq

General data

Pitch (cm)	R1100H: 1.320 R2100H: 1.866 R3100H: 1.2506
Lattice geometry	Square
Water/fuel volume ratio	R1100H: 1.001 R2100H: 3.163 R3100H: 0.779
Moderator	H2O
Fuel material	UO2 (3.003 wt% enrichment)
Fuel Isotopic Concentration (10^{24} Atoms/cm^3)	O : 0.04659 U-235: 0.0007082 U-238: 0.02259
Radius of fuel rods (cm)	0.506
Wrapper material	Al
Outer radius of wrapper (cm)	0.51955
Clad material	stainless steel
Clad Density (g/cm^3)	8.293
Outer radius of clad (cm)	0.54625
Thickness of clad (cm)	0.0267
Temperature (all components)(K)	293.0
Experimental buckling B^2 (cm^{-2})	R1100H: 0.0066 ± 0.000022 R2100H: 0.010044 ± 0.000064 R3100H: 0.005096 ± 0.000030

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	RN100H
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCE

[1] BROWN, W.A.V., FOX, W.N., SKILLINGS, D.J., GEORGE, C.F., BURHOLT, G.D., Measurements of Material Buckling and Detailed Reaction Rates in a Series of Low Enrichment UO_2 Fuelled Cores Moderated by Light Water, UKAEA Report AEEW-R502 (1967).

2.03) UO2-LW-NAIG-NCA
H_2O-moderated uranium oxide critical lattice

Laboratory: NAIG Nippon Atomic Industries Group (Japan)

Facility: NCA

This benchmark is an H_2O moderated lattice of 2.02 wt% enriched uranium oxide rods in a square pattern. Material buckling was measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-NAIG–naig_nca	2.02	0.675	1.0	al	1.84	2.92	69.72	20.0	sq

General data

Pitch (cm)	1.84 (square)
Water/fuel volume ratio	2.918
Moderator	H2O
Fuel material	UO2 (2.02 wt% enrichment)
Fuel Density (g/cm^3)	10.37
Radius of fuel rods (cm)	0.50
Clad material	Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	0.59
Thickness of clad (cm)	0.08
Temperature (all components) (K)	293.0
Experimental buckling B^2 (cm^{-2})	0.006972 ± 0.000136

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	naig_nca
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.04) UO2-LW-CURL -ZPR
H_2O-moderated uranium oxide critical lattices

Laboratory: CURL Cornell University Nuclear Reactor Laboratory (USA)

Facility: ZPR

These benchmarks are four H_2O moderated lattices of 2.07 wt% enriched uranium oxide rods in a triangular pattern. Material bucklings were measured. δ^{28} was measured for CURL_ZPR3 only.

Experimental results
(for curl_zpr3 only)

δ^{28}: ratio of U-238 fission to U-235 fission reaction rate (thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) δ^{28} (for CURL_ZPR3 only)

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (al: aluminium)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (he : hexagonal)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-CURL–curl_zpr1	2.07	0.528	1.524	al	2.17	1.01	57.60	22.5	he
UO2-LW-CURL-curl_zpr2	2.07	0.623	1.524	al	2.62	2.02	83.20	21.5	he
UO2-LW-CURL-curl_zpr3	2.07	0.689	1.524	al	2.99	3.01	74.80	20.7	he
UO2-LW-CURL-curl_zpr4	2.07	0.748	1.524	al	3.33	4.02	60.60	20.0	he

General data

Pitch (cm)	curl_zpr1: 2.174 curl_zpr2: 2.616 curl_zpr3: 2.990 curl_zpr4: 3.325
Lattice geometry	Hexagonal

Water/fuel volume ratio	curl_zpr1: 1.012 curl_zpr2: 2.017 curl_zpr3: 3.011 curl_zpr4: 4.016
Moderator	H2O
Fuel material	UO2 (2.07 wt% enrichment)
Fuel Density (g/cm^3)	10.382
Radius of fuel rods (cm)	0.762
Clad material	6061-76 Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	0.846
Thickness of clad (cm)	0.071
Temperature (all components)(K)	293.0
Experimental buckling B^2 (cm^{-2})	curl_zpr1: 0.00576 ± 0.00030 curl_zpr2: 0.00832 ± 0.00020 curl_zpr3: 0.00748 ± 0.00055 curl_zpr4: 0.00606 ± 0.00035

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	curl_zpr
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.05)UO2-LW-BAW-BAY2
H_2O-moderated uranium oxide critical lattices

Laboratory: BAW Babcock & Wilcox Company (USA)

Facility: BAY-2

These benchmarks are three H_2O moderated lattices of enriched uranium oxide rods in a square pattern. Material bucklings and ρ^{28} were measured.

Experimental results

ρ^{28} : ratio of epithermal to thermal U-238 capture reaction rate (thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) ρ^{28}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium; ss: stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-BAW –baw_bay2a	2.46	0.541	1.03	al	1.51	1.37	70.10	22.0	sq
UO2-LW-BAW –baw_bay2b1	4.02	0.465	1.128	ss	1.45	0.96	79.00	22.0	sq
UO2-LW-BAW –baw_bay2b2	4.02	0.488	1.128	ss	1.51	1.14	88.00	15.0	sq

General data

Pitch (cm)	Baw_bay2a: 1.5113 baw_bay2b1: 1.4503 baw_bay2b2: 1.5113
Lattice geometry	Square
Water/fuel volume ratio	Baw_bay2a: 1.3710 baw_bay2b1: 0.959 baw_bay2b2: 1.140
Moderator	H2O
Fuel material	UO2;baw_bay2a: 2.459wt% enr.; baw/bay2b: 4.02wt% enr.)

Fuel Density (g/cm^3)	baw_bay2a: 10.24 baw_bay2b: 9.46
Radius of fuel rods (cm)	baw_bay2a: 0.5150 baw_bay2b: 0.5639
Clad material	baw_bay2a: 6061 al baw/bay2b: 304-ss
Outer radius of clad (cm)	baw_bay2a: 0.6030 baw_bay2b: 0.6039
Thickness of clad (cm)	baw_bay2a: 0.0813 baw_bay2b: 0.0406
Temperature (all components)(K)	baw_bay2a,b1: 295 baw_bay2b2: 288
Experimental buckling B^2 (cm^{-2})	baw_bay2a: 0.00701 ± 0.00007 baw_bay2b1: 0.00790 ± 0.00010 baw_bay2b2: 0.00880 ± 0.00004

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	BAW_BAY2
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.06) UO2-LW-BAW-CX10
H_2O-moderated uranium oxide critical lattice

Laboratory: BAW Babcock & Wilcox Company (USA)

Facility: CX-10

This benchmark is an H_2O moderated lattice of 2.459 wt% enriched uranium oxide rods in a square pattern. Material buckling and ρ^{28} were measured.

Experimental results

ρ^{28} : ratio of epithermal to thermal U-238 capture reaction rate (thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) ρ^{28}

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-BAW –baw_cx10	2.46	0.579	1.03	al	1.64	1.84	86.10	21.0	sq

General data

Pitch (cm)	1.6358 (square)
Water/fuel volume ratio	1.841
Moderator	H2O
Fuel material	UO2 (2.459 wt% enr.)
Fuel Density (g/cm^3)	10.24
Radius of fuel rods (cm)	0.515
Clad material	6061-Al
Outer radius of clad (cm)	0.603
Thickness of clad (cm)	0.0813
Temperature (all components) (K)	294
Experimental buckling B^2 (cm^{-2})	0.00861 ± 0.00004

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	baw_cx10
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.07) UO2-LW-AERL-OCF
H_2O-moderated uranium oxide critical lattices

Laboratory: AERL Atomic Energy Research Laboratory, Ozeny (Japan)

Facility: OCF

These benchmarks are two H_2O moderated lattices of 2.49 wt% enriched uranium oxide rods in a square pattern. Material bucklings, ρ^{28} and δ^{28} were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-238 capture reaction rate
b. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate
(thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) ρ^{28}
3) δ^{28}

Summary data

Titles

ENRu5 : Enrichment on U235 (at %)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-AERL–aerl_ocf1	2.49	0.615	1.0	al	1.77	2.50	85.50	20.0	sq
UO2-LW-AERL–aerl_ocf2	2.49	0.665	1.0	al	1.98	3.50	83.40	20.0	sq

General data

Pitch (cm)	aerl_ocf1: 1.77 aerl_ocf2: 1.98
Lattice geometry	Square
Water/fuel volume ratio	aerl_ocf1: 2.50 aerl_ocf2: 3.50
Moderator	H2O
Fuel material	UO2 (2.49 wt% enr.)
Fuel Density (g/cm^3)	10.4
Radius of fuel rods (cm)	0.50

Clad material	Al
Clad Density (g/cm^3)	2.6999
Outer radius of clad (cm)	0.61
Thickness of clad (cm)	0.08
Temperature (all components) (K)	291
Experimental buckling B^2 (cm^{-2})	aerl_ocf1: 0.00855 ± 0.00007 aerl_ocf2: 0.00834 ± 0.00048

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	aerl_ocf
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

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2.08) UO2-LW-JAERI-TCA
H_2O-moderated uranium oxide critical lattices

Laboratory: JAERI Japan Atomic Energy Research Institute,
Tokai Research Establishment (Japan)

Facility: TCA Tank type Critical Assembly

These benchmarks are seven H_2O moderated lattices of enriched uranium oxide rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (al: aluminium)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-JAERI–jaeri_tca1	2.60	0.563	1.071	al	1.66	1.76	92.20	21.0	sq
UO2-LW-JAERI–jaeri_tca2	2.60	0.580	1.071	al	1.73	2.00	96.40	20.8	sq
UO2-LW-JAERI–jaeri_tca3	2.60	0.603	1.071	al	1.82	2.38	100.80	16.0	sq
UO2-LW-JAERI–jaeri_tca4	2.60	0.544	1.25	al	1.85	1.50	83.30	20.0	sq
UO2-LW-JAERI–jaeri_tca5	2.60	0.570	1.25	al	1.96	1.83	94.30	20.0	sq
UO2-LW-JAERI–jaeri_tca6	2.60	0.611	1.25	al	2.15	2.48	98.30	20.0	sq
UO2-LW-JAERI–jaeri_tca7	2.60	0.639	1.25	al	2.29	3.00	95.20	20.0	sq

General data

Pitch (cm)	jaeri_tca1: 1.660 jaeri_tca2: 1.725 jaeri_tca3: 1.820 jaeri_tca4: 1.849 jaeri_tca5: 1.956 jaeri_tca6: 2.150 jaeri_tca7: 2.930
Lattice geometry	Square

Water/fuel volume ratio	jaeri_tca1: 1.760 jaeri_tca2: 2.000 jaeri_tca3: 2.380 jaeri_tca4: 1.50 jaeri_tca5: 1.83 jaeri_tca6: 2.48 jaeri_tca7: 3.00
Moderator	H2O
Fuel material	UO2 jaeri_tca1-3: 2.588 wt% enr. jaeri_tca4-7: 2.596 wt% enr.
Fuel Density (g/cm^3)	10.40
Radius of fuel rods (cm)	jaeri_tca1-3: 0.5355 jaeri_tca4-7: 0.6250
Clad material	Al
Clad Density(g/cm^3)	2.6999
Outer radius of clad (cm)	jaeri_tca1-3: 0.6115 jaeri_tca4-7: 0.7085
Thickness of clad (cm)	jaeri_tca1-3: 0.070 jaeri_tca4-7: 0.076
Temperature (all components) (K)	jaeri_tca1,2: 294 jaeri_tca3: 289 jaeri_tca4-7: 293
Experimental buckling B^2 (cm^{-2})	jaeri_tca1: 0.00922 jaeri_tca2: 0.00964 jaeri_tca3: 0.01008 jaeri_tca4: 0.00833 ± 0.0001 jaeri_tca5: 0.00943 ± 0.00013 jaeri_tca6: 0.00983 ± 0.00008 jaeri_tca7: 0.00952 ± 0.00014

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	Jaeritca
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.09) UO2-LW-WAPD-CRX
H_2O-moderated uranium oxide critical lattices

Laboratory: WAPD Westinghouse Atomic Power Department (USA)

Facility: CRX

These benchmarks are twelve H_2O moderated lattices of enriched (from 2.7 wt% to 5.74 wt%) uranium oxide rods in square patterns. Material bucklings and several spectral indexes were measured.

Experimental results

a. δ^{25} : ratio of epithermal to thermal U-235 fission reaction rate
(for WAPD_CRX 3,4 only)
b. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate
(for WAPD_CRX 3,4,7,9 only)
c. C^* : ratio of U-238 capture to U-235 fission reaction rate
(for WAPD_CRX 5,8 only)
(thermal cutoff: 0.625 eV)

Calculated parameter

1) Effective Multiplication Factor k_{eff}
2) δ^{25} (for WAPD_CRX 3,9 only)
3) δ^{28} (for WAPD_CRX 3,4,7,9 only)
4) C^* (for WAPD_CRX 5,8 only)

Summary data

Titles
ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (ss: stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-WAPD-wapd_crxa1	2.70	0.539	0.762	ss	1.03	1.05	40.70	20.0	sq
UO2-LW-WAPD-wapd_crxa2	2.70	0.558	0.762	ss	1.06	1.20	47.50	20.0	sq
UO2-LW-WAPD-wapd_crxa3	2.70	0.578	0.762	ss	1.11	1.40	53.20	20.0	sq
UO2-LW-WAPD-wapd_crxa4	2.70	0.614	0.762	ss	1.19	1.85	63.30	20.0	sq
UO2-LW-WAPD-wapd_crxa5	2.70	0.635	0.762	ss	1.25	2.17	68.80	20.0	sq
UO2-LW-WAPD-wapd_crxa6	2.70	0.763	0.762	ss	1.69	4.98	51.00	23.0	sq
UO2-LW-WAPD-wapd_crxb1	3.70	0.505	0.754	ss	1.06	1.23	68.30	20.0	sq
UO2-LW-WAPD-wapd_crxb2	3.70	0.579	0.754	ss	1.25	2.21	95.10	20.0	sq
UO2-LW-WAPD-wapd_crxc	4.43	0.505	0.762	ss	1.11	1.35	79.70	16.0	sq

UO2-LW-WAPD-wapd_crxd1	5.74	0.466	0.907	ss	1.32	1.50	117.6	19.2	sq
UO2-LW-WAPD-wapd_crxd2	5.74	0.497	0.907	ss	1.42	1.93	127.1	18.0	sq
UO2-LW-WAPD-wapd_crxd3	5.74	0.619	0.907	ss	2.01	5.07	136.8	17.3	sq

General data

Pitch (cm)	wapd_crxa1: 1.0290 wapd_crxa2: 1.0617 wapd_crxa3: 1.1050 wapd_crxa4: 1.1940 wapd_crxa5: 1.2520 wapd_crxa6: 1.6890 wapd_crxb1: 1.0617 wapd_crxb2: 1.2520 wapd_crxc: 1.1050 wapd_crxd1: 1.3208 wapd_crxd2: 1.4224 wapd_crxd3: 2.0116
Lattice geometry	Square
Water/fuel volume ratio	wapd_crxa1: 1.048 wapd_crxa2: 1.200 wapd_crxa3: 1.405 wapd_crxa4: 1.853 wapd_crxa5: 2.166 wapd_crxa6: 4.984 wapd_crxb1: 1.225 wapd_crxb2: 2.212 wapd_crxc: 1.346 wapd_crxd1: 1.502 wapd_crxd2: 1.934 wapd_crxd3: 5.067
Moderator	H2O
Fuel material	UO2 wapd_crxa: 2.7 wt% enr., wapd_crxb: 3.7 wt% enr., wapd_crxc: 4.43 wt% enr., wapd_crxd: 5.742 wt% enr.
Fuel Density (g/cm^3)	wapd_crxa: 10.18 wapd_crxb: 10.40 wapd_crxc: 10.17 wapd_crxd: 10.20
Radius of fuel rods (cm)	wapd_crxa,c: 0.3810 wapd_crxb: 0.3770 wapd_crxd: 0.4534
Clad material	304 SS

Outer radius of clad (cm)	wapd_crxa: 0.4295 wapd_crxb: 0.4298 wapd_crxc: 0.4395 wapd_crxd: 0.4965
Thickness of clad (cm)	wapd_crxa,b: 0.0409 wapd_crxc: 0.0550 wapd_crxd: 0.0380
Temperature (all components) (K)	wapd_crxa1-5,b: 293 wapd_crxa6: 296 wapd_crxc: 289 wapd_crxd1: 292 wapd_crxd2: 291 wapd_crxd3: 290
Experimental buckling B^2 (cm^{-2})	wapd_crxa1: 0.00407 ± 0.00004 wapd_crxa2: 0.00475 ± 0.00004 wapd_crxa3: 0.00532 ± 0.00007 wapd_crxa4: 0.00633 ± 0.00004 wapd_crxa5: 0.00688 ± 0.00005 wapd_crxa6: 0.00510 ± 0.00005 wapd_crxb1: 0.00683 ± 0.00003 wapd_crxb2: 0.00951 ± 0.00007 wapd_crxc: 0.00797 ± 0.00008 wapd_crxd1: 0.01176 ± 0.00018 wapd_crxd2: 0.01271 ± 0.00014 wapd_crxd3: 0.01368 ± 0.00009

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	wapdcrxa wapdcrxb wapdcrxc wapdcrxd
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

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2.10) UO2-LW-AEEW-JUNO

H_2O-moderated uranium oxide critical lattice

Laboratory: AEEW Atomic Energy Establishment, Winfrith (UK)

Facility: JUNO

This benchmark is an H_2O moderated lattice of 3.003 wt% enriched uranium oxide rods in a hexagonal pattern. Material buckling was measured.

Calculated parameters

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (ss: stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he : hexagonal)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-AEEW-aeew_juno	3.003	0.613	1.012	ss	1.87	2.60	102.30	20.0	he

General data

Pitch (cm)	1.87 (hexagonal)
Water/fuel volume ratio	2.597
Moderator	H2O
Fuel material	UO2 (3.003 wt% enr.)
Fuel Density (g/cm^3)	10.44
Radius of fuel rods (cm)	0.506
Clad material	18/8/1-SS
Outer radius of clad (cm)	0.54625
Thickness of clad (cm)	0.0267
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	0.01023 ± 0.00009

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	aeewjuno
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCE

[1] BERNOCCHI, E., MARTINELLI, R. (Editors), Light Water Lattice Data, p. 49, Comitato Nazionale per L'Energia Nucleare, Dipartamento Ricerca Tecnologica di Base ed Avanzata, Quaderno RIT/FIS(77)1, NEACRP-U-190 (1977).

2.11) UO2-LW-BNL-BNLea
H_2O-moderated uranium oxide lattices

Laboratory: BNL Brookhaven National laboratory (USA)

Facility: BNL Exponential Assemblies

These benchmarks are five H_2O moderated lattices of 3.006 wt% enriched uranium oxide rods in hexagonal patterns. Material bucklings, ρ^{28} and δ^{28} were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-235 fission reaction rate
(for BNL 1,2,4 only)
b. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate

(thermal cutoff: 0.625 eV)

Calculated parameter

1) Effective Multiplication Factor k_{eff}
2) ρ^{28} (for BNL 1,2,4 only)
3) δ^{28}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (ss: stainless steel)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (he : hexagonal)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-BNL-bnluo2_1	3.01	0.581	1.128	ss	1.72	1.32	56.60	20.0	he
UO2-LW-BNL-bnluo2_2	3.01	0.609	1.128	ss	1.82	1.63	65.81	20.0	he
UO2-LW-BNL-bnluo2_3	3.01	0.643	1.128	ss	1.96	2.09	70.49	20.0	he
UO2-LW-BNL-bnluo2_4	3.01	0.688	1.128	ss	2.17	2.86	70.22	20.0	he
UO2-LW-BNL-bnluo2_5	3.01	0.749	1.128	ss	2.47	4.07	61.73	20.0	he

General data

Pitch (cm)	bnluo2_1: 1.719 bnluo2_2: 1.819 bnluo2_3: 1.957 bnluo2_4: 2.169 bnluo2_5: 2.466
Lattice geometry	Hexagonal
Water/fuel volume ratio	bnluo2_1: 1.319 bnluo2_2: 1.632 bnluo2_3: 2.091 bnluo2_4: 2.863 bnluo2_5: 4.071
Moderator	H2O
Fuel material	UO2 (3.006 wt%)
Fuel Density (g/cm^3)	9.30
Radius of fuel rods (cm)	0.564
Clad material	304-SS
Outer radius of clad (cm)	0.6335
Thickness of clad (cm)	0.070
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	bnluo2_1: 0.005660 ± 0.000050 bnluo2_2: 0.006581 ± 0.000052 bnluo2_3: 0.007049 ± 0.000060 bnluo2_4: 0.007022 ± 0.000055 bnluo2_5: 0.006173 ± 0.000051

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	Bnluo2
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

[1] HELLENS, R.L., PRICE, G.A., Reactor Physics Data for Water Moderated Lattices of Slightly Enriched Uranium Reactor Technology, Selected Reviews - 1964, USAEC-TID 8540, pp. 529-609 (1964).

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2.12) UO2-LW-ANL-ZPR7

H_2O-moderated uranium oxide critical lattices

Laboratory: ANL Argonne National laboratory (USA)

Facility: ZPR-7

These benchmarks are seven H_2O moderated lattices of enriched uranium oxide rods in hexagonal and square patterns. Material bucklings and some spectral indexes were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-235 fission reaction rate (ANL_ZPR7a4 only)
b. δ^{25} : ratio of epithermal to thermal U-235 fission reaction rate (ANL_ZPR7b2 only)
c. δ^{28} : ratio of U-238 fission to U-235 fission reaction rate (ANL_ZPR7b2 only)

(thermal cutoff: 0.625 eV)

Calculated parameters

1) Effective Multiplication Factor k_{eff}
2) ρ^{28} (for ANL_ZPR7a4 only)
3) δ^{25} (for ANL_ZPR7b2 only)
4) δ^{28} (for ANL_ZPR7b2 only)

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium; ss: stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he: hexagonal; sq: square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-ANL-anl_zpr7a1	3.04	0.354	0.935	al	1.17	0.43	24.36	20.0	he
UO2-LW-ANL-anl_zpr7a2	3.04	0.435	0.935	al	1.27	0.75	55.38	20.0	he
UO2-LW-ANL-anl_zpr7a3	3.04	0.467	0.935	al	1.24	0.96	70.76	20.0	sq
UO2-LW-ANL-anl_zpr7a4	3.04	0.510	0.935	ss	1.24	0.96	47.47	20.0	sq
UO2-LW-ANL-anl_zpr7a5	3.04	0.511	0.935	al	1.35	1.37	91.82	20.0	sq
UO2-LW-ANL-anl_zpr7b1	4.95	0.450	0.871	ss	1.27	1.14	91.47	20.0	he
UO2-LW-ANL-anl_zpr7b2	4.95	0.486	0.871	ss	1.27	1.50	107.63	20.0	sq

General data

Pitch (cm)	anl_zpr7a1: 1.166 (hexagonal) anl_zpr7a2: 1.270 (hexagonal) anl_zpr7a3: 1.240 (square) anl_zpr7a4: 1.240 (square) anl_zpr7a5: 1.349 (square) anl_zpr7b1: 1.270 (hexagonal) anl_zpr7b2: 1.270 (square)
Water/fuel volume ratio	anl_zpr7a1: 0.4347 anl_zpr7a2: 0.7544 anl_zpr7a3: 0.9596 anl_zpr7a4: 0.9620 anl_zpr7a5: 1.3710 anl_zpr7b1: 1.1410 anl_zpr7b2: 1.5040
Moderator	H2O
Fuel material	UO2 - anl_zpr7a: 3.042 wt% anl_zpr7b: 4.95 wt%
Fuel Density (g/cm^3)	anl_zpr7a: 10.17 anl_zpr7b: 10.2
Radius of fuel rods (cm)	anl_zpr7a: 0.4675 anl_zpr7b: 0.4355
Clad material	anl_zpr7a1-3,5: 6061-T6Al anl_zpr7a4,b: 304-SS
Outer radius of clad (cm)	anl_zpr7a1-3,5: 0.5290 anl_zpr7a4: 0.5285 ANL/ZPR7b: 0.4775
Thickness of clad (cm)	ANL/ZPR7a1-3,5: 0.0480 ANL/ZPR7a4: 0.0496 ANL/ZPR7b: 0.0381
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	anl_zpr7a1: 0.002436±0.00001 anl_zpr7a2: 0.005538±0.000024 anl_zpr7a3: 0.007076±0.000071 anl_zpr7a4: 0.004747±0.000027 anl_zpr7a5: 0.009182±0.00008 anl_zpr7b1: 0.009147±0.000068 anl_zpr7b2: 0.010763±0.00019

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	bnlzpr7a
	bnlzpr7b
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

[1] HELLENS, R.L., PRICE, G.A., Reactor Physics Data for Water Moderated Lattices of Slightly Enriched Uranium Reactor Technology, Selected Reviews - 1964, USAEC-TID 8540, pp. 529-609 (1964).

[2] PRICE, G.A., Uranium-Water Lattice Compilation Part I, BNL Exponential Assemblies USAEC Report BNL 50035 (T-449) (Reactor Technology-4500), Brookhaven National Laboratory (1966).

[3] WINDSOR, H.H., Buckling Measurements in Water-Moderated and Reflected Exponential Experiments, Nucl. Sci. Eng., 5, 61 (1959).

[4] BERNOCCHI, E., MARTINELLI, R. (Editors), Light Water Lattice Data, pp. 59, 61, 63-65, 81, 82, Comitato Nazionale per L'Energia Nucleare, Dipartamento Ricerca Tecnologica di Base ed Avanzata, Quaderno RIT/FIS(77)1, NEACRP-U-190 (1977).

2.13)UO2-LW-NPY-NORA
H_2O-moderated uranium oxide critical lattices

Laboratory: NPY Norway-Poland-Yugoslavia Association, Kjeller (Norway)

Facility: NORA

These benchmarks are three H_2O moderated lattices of 3.41 wt% enriched uranium oxide rods in square patterns. Material bucklings and spectral indexes were measured.

Experimental results

a. ρ^{28} : ratio of epithermal to thermal U-235 fission reaction rate
(for NPY_NORA 2,3 only)
b. δ^{28}: ratio of U-238 fission to U-235 fission reaction rate
(for NPY_NORA 1 only)

(thermal cutoff: 0.625 eV)

Calculated parameter

1) Effective Multiplication Factor k_{eff}
2) ρ^{28} (for NPY_NORA 2,3 only)
3) δ^{28} (for NPY/NORA 1 only)

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (ss : stainless steel)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (sq : square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-NPY-npy_nora1	3.41	0.551	1.27	ss	1.90	1.66	91.80	20.0	sq
UO2-LW-NPY-npy_nora2	3.41	0.633	1.27	ss	2.31	3.03	98.80	20.0	sq
UO2-LW-NPY-npy_nora3	3.41	0.701	1.27	ss	2.69	4.51	86.40	20.0	sq

General data

Pitch (cm)	npy_nora1: 1.900 npy_nora2: 2.314 npy_nora3: 2.687
Lattice geometry	Square
Water/fuel volume ratio	npy_nora1: 1.66 npy_nora2: 3.03 npy_nora3: 4.51
Moderator	H2O
Fuel material	UO2 (3.410 wt%)
Fuel Density (g/cm^3)	10.4
Radius of fuel rods (cm)	0.635
Clad material	304-SS
Outer radius of clad (cm)	0.694
Thickness of clad (cm)	0.048
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	npy_nora1: 0.00918 ± 0.00017 npy_nora2: 0.00988 ± 0.00012 npy_nora3: 0.00864 ± 0.0001

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	npy_nora
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

[1] KAPLAN, I. *et al*., The Measurements of Reactor Parameters in Slightly Enriched Uranium Heavy Water Moderated Miniature Lattices, MIT-2344-8, Massachusetts Institute of Technology (1966).

[2] ANDERSEN, E. *et al*., Topics in Light Water Reactor Physics: Final Report of the NORA Project Technical Report Series No. 113, International Atomic Energy Agency (1970).

[3] BERNOCCHI, E., MARTINELLI, R. (Editors), Light Water Lattice Data, pp. 68-70, Comitato Nazionale per L'Energia Nucleare, Dipartamento Ricerca Tecnologica di Base ed Avanzata, Quaderno RIT/FIS(77)1, NEACRP-U-190 (1977).

2.14) UO2-LW-SCKBN-VENUS

H_2O-moderated uranium oxide critical lattices

Laboratory: SCK-BN Studie Centrum voor Kernenergie
Belgonucleaire Association (Belgium)

Facility: VENUS

These benchmarks are two H_2O moderated lattices of 4.01 wt% enriched uranium oxide rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (ss : stainless steel)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 ($1/(m^2)$)
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq : square)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
UO2-LW-SCKBN-sck_venus1	4.01	0.515	0.89	ss	1.30	1.52	99.10	20.0	sq
UO2-LW-SCKBN-sck_venus2	4.01	0.648	0.89	ss	1.84	4.25	114.18	20.0	sq

General data

Pitch (cm)	sck_venus1: 1.303 sck_venus2: 1.843
Lattice geometry	Square
Water/fuel volume ratio	sck_venus1: 1.522 sck_venus2: 4.252
Moderator	H2O
Fuel material	UO2 (4.01 wt%)
Fuel Density (g/cm^3)	10.29
Radius of fuel rods (cm)	0.445
Clad material	304-SS
Outer radius of clad (cm)	0.489
Thickness of clad (cm)	0.038
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	sck_venus1: 0.009910 ± 0.000170 sck_venus2: 0.011418 ± 0.000041

Keyword and files

Keyword	CRITUO2
WIMS Input (.WIN)	sckvenus
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRUO2 (called from smrdif.exe)

REFERENCES

[1] BINDLER, L. *et al*., Experimental and Theoretical Physics Work on Plutonium Enriched LWR's Lattices, BLG-440, BN-7006-03, Belgonucleaire Studie Centrum voor Kernenenergie Association (1970).

[2] BERNOCCHI, E., MARTINELLI, R. (Editors) Light Water Lattice Data, pp. 73, 74, Comitato Nazionale per L'Energia Nucleare, Dipartamento Ricerca Tecnologica di Base ed Avanzata, Quaderno RIT/FIS(77)1, NEACRP-U-190 (1977).

IV.3. WWER-type UO_2-H_2O critical lattices- UO2-LB (WWER)

Index

3.01) UO2-LB-CRIP –ZR6

List of benchmarks by U-235 enrichment

Benchmark identification	wt% U235	# cases	.win	Short name
3.01) UO2-LB-CRIP –ZR6	a) 1.6	3	wwercra	Wwercra1-3
3.01) UO2-LB-CRIP –ZR6	b) 3.6	18	wwercrb	Wwercrb4-21
3.01) UO2-LB-CRIP –ZR6	c) 4.4	4	wwercrc	Wwercrc22-25

3.01) UO2-LB-CRIP –ZR6

WWWER-type lattice criticality benchmarks

Laboratory: Central Research Institute for Physics of the Hungarian Academy of Sciences, Budapest (Hungary)

Facility: ZR-6

These benchmarks are 25 regular WWER-type UO_2-H_2O lattices. Material bucklings were measured. Lattices are identified by lattice pitch, atomic enrichment, boron concentration, and temperature.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (at%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (zr : zirconium)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he : hexagonal)
Bcon : Boron concentration (g/litre of boric acid-H3BO3 dissolved in light water)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Bcon
UO2-LB-CRIP-wwer_cra01	1.6	0.633	0.76	zr	1.27	3.079	50.57	21	he	0.0
UO2-LB-CRIP-wwer_cra02	1.6	0.670	0.76	zr	1.27	3.079	33.32	21	he	1.85
UO2-LB-CRIP-wwer_cra03	1.6	0.717	0.76	zr	1.5	4.295	48.90	21	he	0.0
UO2-LB-CRIP-wwer_cra04	3.6	0.510	0.76	zr	1.27	3.079	100.41	21	he	0.0
UO2-LB-CRIP-wwer_cra05	3.6	0.508	0.76	zr	1.27	3.079	96.55	80	he	0.0

UO2-LB-CRIP-wwer_cra06	3.6	0.504	0.76	zr	1.27	3.079	90.27	130	he	0.0
UO2-LB-CRIP-wwer_cra07	3.6	0.547	0.76	zr	1.27	3.079	74.16	21	he	4.0
UO2-LB-CRIP-wwer_cra08	3.6	0.543	0.76	zr	1.27	3.079	72.07	80	he	4.0
UO2-LB-CRIP-wwer_cra09	3.6	0.537	0.76	zr	1.27	3.079	67.63	130	he	4.0
UO2-LB-CRIP-wwer_cra10	3.6	0.563	0.76	zr	1.27	3.079	64.95	21	he	5.8
UO2-LB-CRIP-wwer_cra11	3.6	0.559	0.76	zr	1.27	3.079	61.69	80	he	5.8
UO2-LB-CRIP-wwer_cra12	3.6	0.552	0.76	zr	1.27	3.079	59.02	130	he	5.8
UO2-LB-CRIP-wwer_cra13	3.6	0.576	0.76	zr	1.27	3.079	56.54	21	he	7.2
UO2-LB-CRIP-wwer_cra14	3.6	0.436	0.76	zr	1.1	2.310	66.01	21	he	0.0
UO2-LB-CRIP-wwer_cra15	3.6	0.433	0.76	zr	1.1	2.310	64.02	80	he	0.0
UO2-LB-CRIP-wwer_cra16	3.6	0.427	0.76	zr	1.1	2.310	59.76	130	he	0.0
UO2-LB-CRIP-wwer_cra17	3.6	0.440	0.76	zr	1.1	2.310	62.14	21	he	1.0
UO2-LB-CRIP-wwer_cra18	3.6	0.442	0.76	zr	1.1	2.310	61.70	21	he	1.41
UO2-LB-CRIP-wwer_cra19	3.6	0.574	0.76	zr	1.5	4.295	120.36	21	he	0.0
UO2-LB-CRIP-wwer_cra20	3.6	0.645	0.76	zr	1.5	4.295	70.25	21	he	4.0
UO2-LB-CRIP-wwer_cra21	3.6	0.666	0.76	zr	1.905	6.930	108.20	21	he	0.0
UO2-LB-CRIP-wwer_cra22	4.4	0.487	0.76	zr	1.27	3.079	112.58	21	he	0.0
UO2-LB-CRIP-wwer_cra23	4.4	0.491	0.76	zr	1.27	3.079	106.60	21	he	.64
UO2-LB-CRIP-wwer_cra24	4.4	0.540	0.76	zr	1.27	3.079	69.03	21	he	7.2
UO2-LB-CRIP-wwer_cra25	4.4	0.549	0.76	zr	1.5	4.295	136.80	21	he	0.0

General data

Lattices are identified by a code, P/E/B/T, where
P: LATTICE PITCH [cm]
E: ATOMIC ENRICHMENT [at%]
B: BORON CONCENTRATION [g H3BO3/l]
T: TEMPERATURE [°C]

Index		0	1	2	3	4	5	6	7
Values	P		1.10	1.27	1.50	1.905			
	E		1.6	3.6	4.4				
	B	0.0	0.64	1.0	1.41	1.85	4.0	5.8	7.2
	T		21	80	130				

Lattice name, code, experimental buckling B^2 and deviation ($10^{-4}cm^{-2}$)

Name	Code	B^2	Deviation
wwer_cra11	p2w1b0t1	50.57	1.15
wwer_cra12	p2w1b4t1	33.32	1.30
wwer_cra23	p3w1b0t1	48.90	0.65
wwer_cra01	p2w2b0t1	100.41	0.40
wwer_cra02	p2w2b0t2	96.55	1.29
wwer_cra03	p2w2b0t3	90.27	0.91
wwer_cra04	p2w2b5t1	74.16	0.34
wwer_cra05	p2w2b5t2	72.07	0.21
wwer_cra06	p2w2b5t3	67.63	0.20
wwer_cra07	p2w2b6t1	64.95	0.26
wwer_cra08	p2w2b6t2	61.69	0.20
wwer_cra09	p2w2b6t3	59.02	0.13
wwer_cra10	p2w2b7t1	56.54	0.39
wwer_cra16	p1w2b0t1	66.01	0.47
wwer_cra17	p1w2b0t2	64.02	0.49
wwer_cra18	p1w2b0t3	59.76	0.31
wwer_cra19	p1w2b2t1	62.14	0.62
wwer_cra20	p1w2b3t1	61.70	0.53
wwer_cra21	p3w2b0t1	120.36	0.65
wwer_cra22	p3w2b5t1	70.25	0.81
wwer_cra25	p4w2b0t1	108.20	1.56
wwer_cra13	p2w3b0t1	112.58	1.65
wwer_cra14	p2w3b1t1	106.60	1.84
wwer_cra15	p2w3b7t1	69.03	1.06
wwer_cra24	p3w3b0t1	136.80	0.64

Other data

Lattice geometry	Hexagonal
Moderator	H2O with different concentrations of H3BO3
Fuel material	UO2
Radius of fuel rods (cm)	0.3800
Clad material	Zr
Outer radius of clad (cm)	0.4525
Thickness of clad (cm)	0.0650

Keyword and files

Keyword	WWER
WIMS Input (.WIN)	Wwercra
	Wwercrb
	Wwercrc
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	WWERCR (called from smrdif.exe)

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[3] NUCLEAR ENERGY AGENCY, The WWER Experiments: Regular and Perturbed Hexagonal Lattces of Low-Enriches UO_2 Fuel Rods in Light Water NEA/NSC/DOC/(95)03/IV, Volume IV, LEU-COMP-THERM-015, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition Nuclear Science Committee, Nuclear Energy Agency, OECD (2001).

IV.4. H_2O-moderated UO_2-PuO_2 (MOX) critical lattices-MOX-LW (CRITMOX)

Index

4.01) MOX-LW-WAPD -CRX
4.02) MOX-LW-JAERI-TCA
4.03) MOX-LW-GE-GEea
4.04) MOX-LW-BNW-BNWea

List of benchmarks by U-235 enrichment

Benchmark identification	wt% u235	# cases	.win	Short name
4.03) MOX-LW-GE-GEea	0.22	6	ge_pu	ge_pu1-6
4.01) MOX-LW-WAPD-CRX	0.72	6	wcrx_pu	wcrx_pu1-6
4.02) MOX-LW-JAERI-TCA	0.72	4	jtca_pu	jtca_pu1-4
4.04) MOX-LW-BNW-BNWea	0.72	24		
a) wt%Pu240/Pu: 7.65		(8)	bnw_pua	bnw_pua1-8
b) wt%Pu240/Pu:16.54		(5)	bnw_pub	bnw_pub1-5
c) wt%Pu240/Pu:23.50		(6)	bnw_puc	bnw_puc1-6
d) wt%Pu240/Pu:18.10		(5)	bnw_pud	bnw_pud1-5

4.01) MOX-LW-WAPD-CRX
H_2O-moderated UO_2-PuO_2 critical lattices

Laboratory: WAPD Westinghouse Atomic Power Department (USA)

Facility: CRX

These benchmarks are six H_2O moderated lattices of natural uranium oxide-plutonium oxide rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (wt %)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z2: zircaloy-2; z4: zircaloy-4)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)
%Pu : wt% PuO2 in PuO2-UO2 mixture
Pu238 : wt% Pu238 in Pu
Pu239 : wt% Pu239 in Pu
Pu240 : wt% Pu240 in Pu
Pu241 : wt% Pu241 in Pu
Pu242 : wt% Pu242 in Pu

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
MOX-LW-WAPD-wcrx_pu1	0.72	0.522	1.283	z2	1.75	1.12	69.56	20.0	sq
MOX-LW-WAPD-wcrx_pu2	0.72	0.553	1.283	z2	1.90	1.56	90.00	20.0	sq
MOX-LW-WAPD-wcrx_pu3	0.72	0.684	1.283	z2	2.48	3.50	79.50	20.0	sq
MOX-LW-WAPD-wcrx_pu4	0.72	0.718	1.283	z2	2.69	4.37	73.30	20.0	sq
MOX-LW-WAPD-wcrx_pu5	0.72	0.813	1.283	z2	3.51	8.26	50.30	20.0	sq
MOX-LW-WAPD-wcrx_pu6	0.72	0.468	0.857	z4	1.32	1.68	108.80	25.8	sq

FUE-CO-LAB -Short_Name	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242
MOX-LW-WAPD-wcrx_pu1	2.0	0.0	92.0	8.0	0.7	0.03
MOX-LW-WAPD-wcrx_pu2	2.0	0.0	92.0	8.0	0.7	0.03
MOX-LW-WAPD-wcrx_pu3	2.0	0.0	72.0	23.0	4.0	0.70
MOX-LW-WAPD-wcrx_pu4	2.0	0.0	72.0	23.0	4.0	0.70
MOX-LW-WAPD-wcrx_pu5	2.0	0.0	92.0	8.0	0.7	0.03
MOX-LW-WAPD-wcrx_pu6	6.6	0.0	90.0	9.0	0.9	0.04

General data

Pitch (cm)	wcrx_pu1: 1.752 wcrx_pu2: 1.905 wcrx_pu3: 2.479 wcrx_pu4: 2.695 wcrx_pu5: 3.505 wcrx_pu6: 1.321
Lattice geometry	Square
Water/fuel volume ratio	wcrx_pu1: 1.123 wcrx_pu2: 1.556 wcrx_pu3: 3.502 wcrx_pu4: 4.367 wcrx_pu5: 8.257 wcrx_pu6: 1.683
Moderator	H2O
Fuel material	wcrx_pu1-5: UO2(natural)+2.0wt%PuO2 wcrx_pu6: UO2(natural)+6.6wt%PuO2
Fuel Density (g/cm^3)	wcrx_pu1-5: 9.54 wcrx_pu6: 10.77
Radius of fuel rods (cm)	wcrx_pu1-5: 0.6415 wcrx_pu6: 0.4285
Clad material	wcrx_pu1-5: Zr-2 wcrx_pu6: Zr-4
Outer radius of clad (cm)	wcrx_pu1-5: 0.7175 wcrx_pu6: 0.4965
Thickness of clad (cm)	wcrx_pu1-5: 0.0762 wcrx_pu6: 0.0590
Temperature (all components) (K)	wcrx_pu1-5: 293 wcrx_pu6: 299
Experimental buckling B^2 (cm^{-2})	wcrx_pu1: 0.006956 ± 0.000100 wcrx_pu2: 0.009000 ± 0.000090 wcrx_pu3: 0.007950 ± 0.000110 wcrx_pu4: 0.007330 ± 0.000070 wcrx_pu5: 0.005030 ± 0.000030 wcrx_pu6: 0.010880 ± 0.000130

Pu isotopic composition (wt%)	wcrx_pu1-2,5	Pu239: 91.610 Pu240: 7.654 Pu241: 0.701 Pu242: 0.031
	wcrx_pu3,4	Pu239: 71.760 Pu240: 23.500 Pu241: 4.080 Pu242: 0.656
	wcrx_pu6	Pu239: 90.490 Pu240: 8.570 Pu241: 0.890 Pu242: 0.040

Keyword and files

Keyword	CRITMOX
WIMS Input (.WIN)	wcrx_pu
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRMOX (called from smrdif.exe)

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4.02) MOX-LW-JAERI-TCA
H_2O-moderated UO_2-PuO_2 critical lattices

Laboratory: JAERI Japan Atomic Energy Research Institute,
Tokai Research Establishment (Japan)

Facility: TCA Tank type Critical Assembly

These benchmarks are four H_2O moderated lattices of natural uranium oxide-plutonium oxide rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (z2: zircaloy-2)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (sq: square)
%Pu	:	wt% PuO2 in PuO2-UO2 mixture
Pu238	:	wt% Pu238 in Pu
Pu239	:	wt% Pu239 in Pu
Pu240	:	wt% Pu240 in Pu
Pu241	:	wt% Pu241 in Pu
Pu242	:	wt% Pu242 in Pu

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
MOX-LW-JAERI-jtca_pu1	0.72	0.641	1.065	z2	1.83	2.42	80.64	20.0	sq
MOX-LW-JAERI-jtca_pu2	0.72	0.663	1.065	z2	1.96	2.98	83.11	20.0	sq
MOX-LW-JAERI-jtca_pu3	0.72	0.710	1.065	z2	2.22	4.24	77.82	20.0	sq
MOX-LW-JAERI-jtca_pu4	0.72	0.758	1.065	z2	2.47	5.55	64.91	20.0	sq

FUE-CO-LAB-Short_Name	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242
MOX-LW-JAERI-jtca_pu1	3.0	0.49	68.18	22.02	7.26	2.04
MOX-LW-JAERI-jtca_pu2	3.0	0.49	68.18	22.02	7.26	2.04
MOX-LW-JAERI-jtca_pu3	3.0	0.49	68.18	22.02	7.26	2.04
MOX-LW-JAERI-jtca_pu4	3.0	0.49	68.18	22.02	7.26	2.04

General data

Pitch (cm)	jtca_pu1: 1.825 jtca_pu2: 1.956 jtca_pu3: 2.225 jtca_pu4: 1.474
Lattice geometry	Square
Water/fuel volume ratio	jtca_pu1: 2.42 jtca_pu2: 2.98 jtca_pu3: 4.24 jtca_pu4: 5.55
Moderator	H2O
Fuel material	UO2(natural) + 3.01%PuO2
Americium-241 content	530 ppm in PuO_2 (1)
Impurity content	0.9 ppm equivalent boron concentration in PuO2-UO2
Fuel Density (g/cm^3)	6.056
Radius of fuel rods (cm)	0.5325
Clad material	Zr-2
Cladding density (g/cm^3)	6.523
Outer radius of clad (cm)	0.6115
Thickness of clad (cm)	0.0700
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	jtca_pu1: 0.008064 ± 0.000005 jtca_pu2: 0.008311 ± 0.000006 jtca_pu3: 0.007782 ± 0.000002 jtca_pu4: 0.006491 ± 0.000004
Pu isotopic composition (wt%)	Pu238: 0.494 Pu239: 68.180 Pu240: 22.020 Pu241: 7.260 Pu242: 2.040

(1) on 1971-8-16

Keyword and files

Keyword	CRITMOX
WIMS Input (.WIN)	jtca_pu
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRMOX (called from smrdif.exe)

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4 .03) MOX-LW-GE-GEea
H_2O-moderated UO_2-PuO_2 lattices (exponential experiments)

Laboratory: GE - General Electric Company (USA)

These benchmarks are six H_2O moderated lattices of depleted uranium oxide (0.22 wt% U235)-plutonium oxide rods in hexagonal patterns. Material bucklings were measured from exponential experiments.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (wt%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z2: zircaloy-2)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he: hexagonal)
%Pu : wt% PuO2 in PuO2-UO2 mixture
Pu238 : wt% Pu238 in Pu
Pu239 : wt% Pu239 in Pu
Pu240 : wt% Pu240 in Pu
Pu241 : wt% Pu241 in Pu
Pu242 : wt% Pu242 in Pu

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
MOX-LW-GE-ge_pu1	0.22	0.563	0.945	z2	1.397	1.10	48.0	20.0	he
MOX-LW-GE-ge_pu2	0.22	0.595	0.945	z2	1.524	1.558	65.1	20.0	he
MOX-LW-GE-ge_pu3	0.22	0.654	0.945	z2	1.803	2.704	78.5	20.0	he
MOX-LW-GE-ge_pu4	0.22	0.701	0.945	z2	2.032	3.789	74.9	20.0	he
MOX-LW-GE-ge_pu5	0.22	0.754	0.945	z2	2.286	5.144	60.9	20.0	he
MOX-LW-GE-ge_pu6	0.22	0.771	0.945	z2	2.362	5.580	55.2	20.0	he

FUE-CO-LAB-Short_Name	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242
MOX-LW-GE-ge_pu1	1.5	0.0	91.41	7.83	0.73	0.03
MOX-LW-GE-ge_pu2	1.5	0.0	91.41	7.83	0.73	0.03
MOX-LW-GE-ge_pu3	1.5	0.0	91.41	7.83	0.73	0.03
MOX-LW-GE-ge_pu4	1.5	0.0	91.41	7.83	0.73	0.03
MOX-LW-GE-ge_pu5	1.5	0.0	91.41	7.83	0.73	0.03
MOX-LW-GE-ge_pu6	1.5	0.0	91.41	7.83	0.73	0.03

General data

Pitch (cm)	ge_pu1: 1.397 ge_pu2: 1.524 ge_pu3: 1.803 ge_pu4: 2.032 ge_pu5: 2.286 ge_pu6: 2.362
Lattice geometry	Hexagonal
Water/fuel vol.ratio	ge_pu1: 1.100 ge_pu2: 1.558 ge_pu3: 2.704 ge_pu4: 3.789 ge_pu5: 5.144 ge_pu6: 5.580
Moderator	H2O
Fuel material	UO2(0.22 wt% U235)+1.5 wt% PuO2
Fuel Density (g/cm^3)	9.65
Radius of fuel rods (cm)	0.4725
Clad material	Zry-2
Outer radius of clad (cm)	0.541
Thickness of clad (cm)	0.069
Temperature (all components) (K)	293
Experimental buckling B^2(cm^{-2})	ge_pu1: 0.00480 ± 0.00012 ge_pu2: 0.00651 ± 0.00008 ge_pu3: 0.00785 ± 0.00003 ge_pu4: 0.00749 ± 0.00003 ge_pu5: 0.00609 ± 0.00002 ge_pu6: 0.00552 ± 0.00002
Pu isotopic composition (wt%)	Pu239: 91.41 Pu240: 7.83 Pu241: 0.73 Pu242: 0.03

Keyword and files

Keyword	CRITMOX
WIMS Input (.WIN)	ge_pu
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRMOX (called from smrdif.exe)

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[1] UOTINEN, V.O., LAUBY, J.H., SCHMID, L.C., STINSON, W.P., Lattices of Plutonium-Enriched Rods in Light Water-Part I: Experimental Results, Nucl. Technol., 15, 257 (1972).

[2] PETERSON, R.E., WINEGARDNER, W.K., WITTENBROCK, N.G., Plutonium Recycle Critical Facility Final Safeguards Analysis Supplement: Supplement II: Analysis of Light Water Moderation, HW-69168 SUP (1964).

[3] LIIKALA, R.C., UOTINEN, V.O., JENQUIN, U.P., Lattices of Plutonium-Enriched Rods in Light Water-Part II: Theoretical Analysis of Plutonium-Fueled Systems, Nucl. Technol., 15, 272 (1972).

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4.04) MOX-LW-BNW-BNWea
H_2O-moderated UO_2-PuO_2 lattices (exponential experiments)

Laboratory: BNW - Battelle NorthWest Laboratory (USA)

These benchmarks are 24 H_2O moderated lattices of natural uranium oxide -plutonium oxide rods in hexagonal patterns. Material bucklings were measured from exponential experiments.

Calculated parameter

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (wt%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z2: zircaloy-2)
PITCH : Lattice pitch (cm)
Vm/Vf : (Volume of moderator/Volume of fuel) of the lattice
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he: hexagonal)
%Pu : wt% PuO2 in PuO2-UO2 mixture
Pu238 : wt% Pu238 in Pu
Pu239 : wt% Pu239 in Pu
Pu240 : wt% Pu240 in Pu
Pu241 : wt% Pu241 in Pu
Pu242 : wt% Pu242 in Pu

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
MOX-LW-BNW –bnw_pua1	0.72	0.548	1.290	z2	2.032	1.486	88.0	20.0	he
MOX-LW-BNW –bnw_pua2	0.72	0.597	1.290	z2	2.362	2.447	102.9	20.0	he
MOX-LW-BNW –bnw_pua3	0.72	0.639	1.290	z2	2.667	3.463	103.4	20.0	he
MOX-LW-BNW –bnw_pua4	0.72	0.672	1.290	z2	2.903	4.335	97.8	20.0	he
MOX-LW-BNW –bnw_pua5	0.72	0.740	1.290	z2	3.352	6.196	76.8	20.0	he
MOX-LW-BNW –bnw_pua6	0.72	0.750	1.290	z2	3.420	6.501	70.0	20.0	he
MOX-LW-BNW –bnw_pua7	0.72	0.864	1.290	z2	4.064	9.696	31.7	20.0	he
MOX-LW-BNW –bnw_pua8	0.72	0.870	1.290	z2	4.089	9.831	32.7	20.0	he
MOX-LW-BNW –bnw_pub1	0.72	0.621	1.290	z2	2.362	2.447	88.4	20.0	he
MOX-LW-BNW –bnw_pub2	0.72	0.663	1.290	z2	2.667	3.463	89.0	20.0	he
MOX-LW-BNW –bnw_pub3	0.72	0.696	1.290	z2	2.903	4.335	81.9	20.0	he
MOX-LW-BNW –bnw_pub4	0.72	0.766	1.290	z2	3.352	6.196	61.8	20.0	he
MOX-LW-BNW –bnw_pub5	0.72	0.777	1.290	z2	3.420	6.501	55.5	20.0	he
MOX-LW-BNW –bnw_puc1	0.72	0.590	1.290	z2	2.032	1.486	62.4	20.0	he
MOX-LW-BNW –bnw_puc2	0.72	0.639	1.290	z2	2.362	2.447	78.9	20.0	he
MOX-LW-BNW –bnw_puc3	0.72	0.682	1.290	z2	2.667	3.463	77.1	20.0	he
MOX-LW-BNW –bnw_puc4	0.72	0.717	1.290	z2	2.903	4.335	72.2	20.0	he
MOX-LW-BNW –bnw_puc5	0.72	0.790	1.290	z2	3.352	6.196	53.6	20.0	he
MOX-LW-BNW –bnw_puc6	0.72	0.800	1.290	z2	3.420	6.501	44.0	20.0	he

MOX-LW-BNW –bnw_pud1	0.72	0.534	1.264	z2	2.032	1.564	84.8	20.0	he
MOX-LW-BNW –bnw_pud2	0.72	0.553	1.264	z2	2.159	1.929	94.7	20.0	he
MOX-LW-BNW –bnw_pud3	0.72	0.579	1.264	z2	2.362	2.563	107.9	20.0	he
MOX-LW-BNW –bnw_pud4	0.72	0.721	1.264	z2	3.519	7.271	87.6	20.0	he
MOX-LW-BNW –bnw_pud5	0.72	0.844	1.264	z2	4.318	11.58	41.1	20.0	he

FUE-CO-LAB-Short_Name	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242
MOX-LW-BNW-bnw_pua1	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua2	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua3	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua4	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua5	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua6	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua7	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pua8	2.0	0.0	91.62	7.65	0.70	0.03
MOX-LW-BNW-bnw_pub1	2.0	0.0	81.11	16.54	2.15	0.20
MOX-LW-BNW-bnw_pub2	2.0	0.0	81.11	16.54	2.15	0.20
MOX-LW-BNW-bnw_pub3	2.0	0.0	81.11	16.54	2.15	0.20
MOX-LW-BNW-bnw_pub4	2.0	0.0	81.11	16.54	2.15	0.20
MOX-LW-BNW-bnw_pub5	2.0	0.0	81.11	16.54	2.15	0.20
MOX-LW-BNW-bnw_puc1	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_puc2	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_puc3	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_puc4	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_puc5	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_puc6	2.0	0.0	71.76	23.50	4.08	0.66
MOX-LW-BNW-bnw_pud1	4.0	0.28	75.38	18.10	5.08	1.15
MOX-LW-BNW-bnw_pud2	4.0	0.28	75.38	18.10	5.08	1.15
MOX-LW-BNW-bnw_pud3	4.0	0.28	75.38	18.10	5.08	1.15
MOX-LW-BNW-bnw_pud4	4.0	0.28	75.38	18.10	5.08	1.15
MOX-LW-BNW-bnw_pud5	4.0	0.28	75.38	18.10	5.08	1.15

General data

Pitch (cm)	bnw_pua1,c1,d1:	2.032
	bnw_pud2:	2.159
	bnw_pua2,b1,c2,d3:	2.362
	bnw_pua3,b2,c3:	2.667
	bnw_pua4,b3,c4:	2.903
	bnw_pua5,b4,c5:	3.352
	bnw_pua6,b5,c6:	3.420
	bnw_pud4:	3.519
	bnw_pua7:	4.064
	bnw_pua8:	4.089
	bnw_pud5:	4.318
Lattice geometry	Hexagonal	

Water/fuel volume ratio	bnw_pua1,c1: 1.486 bnw_pud1: 1.564 bnw_pud2: 1.929 bnw_pua2,b1,c2: 2.447 bnw_pud3: 2.563 bnw_pua3,b2,c3: 3.463 bnw_pua4,b3,c4: 4.335 bnw_pua5,b4,c5: 6.196 bnw_pua6,b5,c6: 6.501 bnw_pud4: 7.271 bnw_pua7: 9.696 bnw_pua8: 9.831 bnw_pud5: 11.58
Moderator	H2O
Fuel material	bnw_pua-c: Natural UO2+2.0 wt% PuO2 bnw_pud: Natural UO2+4.0 wt% PuO2
Fuel Density (g/cm^3)	bnw_pua-c: 9.54 bnw_pud: 9.46
Radius of fuel rods (cm)	bnw_pua-c: 0.645 bnw_pud: 0.632
Clad material	Zr-2
Outer radius of clad (cm)	bnw_pua-c: 0.7215 bnw_pud: 0.7175
Thickness of clad (cm)	bnw_pua-c: 0.076 bnw_pud: 0.086
Temperature (all components) (K)	293

Experimental buckling B^2 (cm^{-2})	bnw_pua1: 0.00880 ± 0.00003 bnw_pua2: 0.01029 ± 0.00003 bnw_pua3: 0.01034 ± 0.00006 bnw_pua4: 0.00978 ± 0.00004 bnw_pua5: 0.00768 ± 0.00003 bnw_pua6: 0.00700 ± 0.00004 bnw_pua7: 0.00317 ± 0.00018 bnw_pua8: 0.00327 ± 0.00004 bnw_pub1: 0.00884 ± 0.00003 bnw_pub2: 0.00890 ± 0.00005 bnw_pub3: 0.00819 ± 0.00003 bnw_pub4: 0.00618 ± 0.00002 bnw_pub5: 0.00555 ± 0.00003 bnw_puc1: 0.00624 ± 0.00003 bnw_puc2: 0.00789 ± 0.00003 bnw_puc3: 0.00771 ± 0.00003 bnw_puc4: 0.00722 ± 0.00002 bnw_puc5: 0.00536 ± 0.00002 bnw_puc6: 0.00440 ± 0.00001 bnw_pud1: 0.00848 ± 0.00005 bnw_pud2: 0.00947 ± 0.00003 bnw_pud3: 0.01079 ± 0.00003 bnw_pud4: 0.00876 ± 0.00005 bnw_pud5: 0.00414 ± 0.00002	
Pu isotopic composition (wt %)	bnw_pua	Pu238: 0.0 Pu239: 91.62 Pu240: 7.65 Pu241: 0.70 Pu242: 0.03
	bnw_pub	Pu238: 0.0 Pu239: 81.11 Pu240: 16.54 Pu241: 2.15 Pu242: 0.20
	bnw_puc	Pu238: 0.0 Pu239: 71.76 Pu240: 23.50 Pu241: 4.08 Pu242: 0.66
	bnw_pud	Pu238: 0.28 Pu239: 75.38 Pu240: 18.10 Pu241: 5.08 Pu242: 1.15

Keyword and files

Keyword	CRITMOX
WIMS Input (.WIN)	bnw_pua
	bnw_pub
	bnw_puc
	bnw_pud
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat)
	WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRMOX (called from smrdif.exe)

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[1] STINSON, W.P., LAUBY, J.H., Approach-to-Critical Experiments with UO_2 - 4 wt.% PuO_2-H_2O Lattices in Plutonium, Utilization Program Technical Activities Quarterly Report September-November 1968, BNWL-963, Pacific Northwest Laboratories (1969).

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[9] NUCLEAR ENERGY AGENCY, Hexagonal Lattices of Mixed Oxide Fuel Pins UO_2 2 wt% PuO_2 (16% ^{240}Pu), Natural Uranium, NEA/NSC/DOC(95)03/VI, Volume VI, MIX-COMP-THERM-007, Nuclear Science Committee, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition, Nuclear Energy Agency, OECD (2001).

[10] NUCLEAR ENERGY AGENCY, Hexagonal Lattices of Mixed Oxide Fuel Pins UO_2 – 2.0 wt% PuO_2, 24% ^{240}Pu, Natural Uranium NEA/NSC/DOC(95)03/VI, Volume VI, MIX-COMP-THERM-008, Nuclear Science Committee, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition, Nuclear Energy Agency, OECD (2001).

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IV.5. Uranium and Plutonium intermediate spectrum critical homogeneous systems – U-MI , Pu-MI (CRITISP)

Index

5.01)U-MI-AEEW–HECTOR
5.02)Pu–MI-AEEW –HECTOR

List of benchmarks by U-235 enrichment

Benchmark identification	wt% U235	# cases	.win	Short name
5.02) Pu–MI-AEEW–HECTOR	0.0	1	hiss	hiss2
5.01) U -MI-AEEW–HECTOR	92.3	1		hiss1

5.01) U-MI-AEEW–HECTOR
Uranium enriched to 92.3 at% in U-235 intermediate spectrum critical homogeneous system

This benchmark is an assembly were the central region experiment is modeled as one infinite homogeneous critical mixture of U-Graphite-boron.

Calculated parameter

Effective Multiplication Factor k_{eff}

General data

Material	U mixture (92.3 at% enrichment)
Mixture Isotopic Concentration (10^{24} Atoms/cm^3)	H : 1.126E-04 B-nat : 2.907E-04 C-nat : 7.565E-02 O : 1.630E-03 U-234: 3.120E-06 U-235: 2.502E-04 U-236: 4.267E-07 U-238: 1.719E-05
Temperature (K)	293.0
Experimental buckling B^2 (cm^{-2})	0.0

Keyword and files

Keyword	CRITISP
WIMS Input (.WIN)	Hiss
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRISP (called from smrdif.exe)

REFERENCES

[1] FOX, W.N., KING, D.C., PITCHER, H.H.W., SANDERS, J.E., Reactor Physics Measurements on ^{235}U and ^{239}Pu Fuels in An Intermediate Spectrum Assembly, J. British Nucl. Energy Soc., Volume 9, pp. 15-27 (1970).

[2] NUCLEAR DATA AGENCY, K_∞ Experiments in Intermediate Neutron Spectra for ^{235}U, NEA/NSC/DOC(95)03/II, Volume II, HEU-COMP-INTER-004, Nuclear Science Committee, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition, Nuclear Energy Agency, OECD (2001).

5.02) Pu–MI-AEEW –HECTOR
Plutonium intermediate spectrum critical homogeneous system

This benchmark is an assembly were the central region experiment is modeled as one infinite homogeneous critical mixture of Pu-Graphite-boron.

Calculated parameter

Effective Multiplication Factor k_{eff}

General data

Material	Pu mixture
Mixture Isotopic Concentration (10^{24} Atoms/cm^3)	H : 1.077E-04 B-nat : 5.101E-04 C-nat : 7.090E-02 O : 2.707E-03 Pu-239: 2.735E-04 Pu-240: 1.549E-05 Pu-241: 1.072E-06 Pu-242: 5.800E-08
Temperature (K)	293.0
Experimental buckling B^2 (cm^{-2})	0.0

Keyword and files

Keyword	CRITISP
WIMS Input (.WIN)	hiss
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from bnchall.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	EXPCRISP (called from smrdif.exe)

REFERENCES

[1] FOX, W. N., KING, D. C., PITCHER, H. H.W., SANDERS, J. E., Reactor Physics Measurements on ^{235}U and ^{239}Pu Fuels in An Intermediate Spectrum Assembly, J. British Nucl. Energy Soc., Volume 9, pp. 15-27 (1970).

[2] NUCLEAR ENERGY AGENCY, K_∞ Experiments in Intermediate Neutron Spectra for ^{239}PU**,** NEA/NSC/DOC(95)03/I, Volume I, PU-COMP-INTER-001, Nuclear Science Committee, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition, Nuclear Energy Agency, OECD (2001).

IV.6. H_2O-moderated $^{233}UO_2$-ThO_2 lattices - Th3-LW (BNLTH2O)

Laboratory: BNL Brookhaven National laboratory (USA)

Facility: BNL Exponential Assemblies

These benchmarks are eight H_2O moderated subcritical lattices of 3% $^{233}UO_2$ - 97% ThO_2 rods in hexagonal patterns. Material bucklings were measured.

Experimental results

ρ_c^{02} : ratio of epithermal to thermal Th-232 capture reaction rate.
For all cases except case 6
(thermal cutoff: 0.625 eV)

Calculated parameter

1) Effective Multiplication Factor k_{eff}
2) ρ_c^{02}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (z2: zircalocy-2)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (he : hexagonal)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
Th3–LW-BNL –bnl_thh2o1	0.0	0.503	1.092	z2	3.033	0.9970	75.88	20.0	he
Th3–LW-BNL –bnl_thh2o2	0.0	0.552	1.092	z2	3.274	1.3840	86.06	20.0	he
Th3–LW-BNL –bnl_thh2o3	0.0	0.584	1.092	z2	3.465	1.7134	89.34	20.0	he
Th3–LW-BNL –bnl_thh2o4	0.0	0.621	1.092	z2	3.728	2.1943	90.35	20.0	he
Th3–LW-BNL –bnl_thh2o5	0.0	0.671	1.092	z2	4.132	3.0043	85.54	20.0	he
Th3–LW-BNL –bnl_thh2o6	0.0	0.736	1.092	z2	4.696	4.2722	69.80	20.0	he
Th3–LW-BNL –bnl_thh2o7	0.0	0.851	1.092	z2	5.670	6.8449	32.20	20.0	he
Th3–LW-BNL –bnl_thh2o8	0.0	0.952	1.092	z2	6.456	9.2747	-1.22	20.0	he

General data

Pitch (cm)	bnl_thh2o1: 3.0328 bnl_thh2o2: 3.2736 bnl_thh2o3: 3.4654 bnl_thh2o4: 3.7278 bnl_thh2o5: 4.1322 bnl_thh2o6: 4.6959 bnl_thh2o7: 5.6699 bnl_thh2o8: 6.4563
Lattice geometry	Hexagonal
Water/fuel volume ratio	bnl_thh2o1: 0.9970 bnl_thh2o2: 1.3840 bnl_thh2o3: 1.7134 bnl_thh2o4: 2.1943 bnl_thh2o5: 3.0043 bnl_thh2o6: 4.2722 bnl_thh2o7: 6.8449 bnl_thh2o8: 9.2747
Moderator	H2O
Fuel material	3wt% $^{233}UO_2$ – 97wt% ThO_2
Fuel Density (g/cm^3)	8.9618
Radius of fuel rods (cm)	0.5461
Clad material	Zircaloy-2
Clad Density (g/cm^3)	6.8365
Outer radius of clad (cm)	0.63373
Thickness of clad (cm)	0.08763
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	bnl_thh2o1: 0.007588 ± 0.000200 bnl_thh2o2: 0.008606 ± 0.000130 bnl_thh2o3: 0.008934 ± 0.000200 bnl_thh2o4: 0.009035 ± 0.000160 bnl_thh2o5: 0.008554 ± 0.000080 bnl_thh2o6: 0.006980 ± 0.000100 bnl_thh2o7: 0.003220 ± 0.000020 bnl_thh2o8:-0.000122 ± 0.000030

Keyword and files

Keyword	CRITHTH
WIMS Input (.WIN)	bnlth2o
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDI2 (called from bnchall.bat) WEDOG2 (called from bnchon2.bat)
Reference file (.REF)	EXPBNLH (called from smrdi2.exe)

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IV.7. D_2O-moderated $^{233}UO_2$-ThO_2 lattices - Th3-HW (BNLTD2O)

Laboratory: BNL Brookhaven National laboratory (USA)

Facility: BNL Exponential Assemblies

These benchmarks are eight D_2O moderated subcritical lattices of 3% $^{233}UO_2$ - 97% ThO_2 rods in hexagonal patterns. Material bucklings were measured.

Experimental results

a. ρ_c^{02}: ratio of epithermal to thermal Th-232 capture reaction rate.

b. δ_{02}^{23}: ratio of fissions in Th-232 to those in U-233.
For cases 1-3 only
(thermal cutoff: 0.625 eV)

Calculated parameter

1) Effective Multiplication Factor k_{eff}
2) ρ_c^{02}
3) δ_{02}^{23}

Summary data

Titles

ENRu5	:	Enrichment on U235 (at%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (z2: zircaloy-2)
PITCH	:	Lattice pitch (cm)
Vm/Vf	:	(Volume of moderator/Volume of fuel) of the lattice
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (he : hexagonal)

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
Th3–HW-BNL-bnl_thd2o1	0.0	0.350	1.092	z2	2.170	3.0047	20.54	20.0	he
Th3–HW-BNL-bnl_thd2o2	0.0	0.586	1.092	z2	3.758	11.7159	29.85	20.0	he
Th3–HW-BNL-bnl_thd2o3	0.0	0.631	1.092	z2	4.338	16.0505	28.64	20.0	he
Th3–HW-BNL-bnl_thd2o4	0.0	0.711	1.092	z2	5.738	29.1127	25.0	20.0	he
Th3–HW-BNL-bnl_thd2o5	0.0	0.740	1.092	z2	6.507	37.8276	22.32	20.0	he
Th3–HW-BNL-bnl_thd2o6	0.0	0.788	1.092	z2	7.821	55.2258	19.13	20.0	he
Th3–HW-BNL-bnl_thd2o7	0.0	0.819	1.092	z2	8.462	81.3123	14.67	20.0	he
Th3–HW-BNL-bnl_thd2o8	0.0	0.855	1.092	z2	11.481	120.4907	11.29	20.0	he

General data

Pitch (cm)	bnl_thd2o1: 2.170 bnl_thd2o2: 3.758 bnl_thd2o3: 4.338 bnl_thd2o4: 5.738 bnl_thd2o5: 6.507 bnl_thd2o6: 7.821 bnl_thd2o7: 8.462 bnl_thd2o8: 11.481
Lattice geometry	Hexagonal
Water/fuel volume ratio	bnl_thd2o1: 3.0047 bnl_thd2o2: 11.7159 bnl_thd2o3: 16.0505 bnl_thd2o4: 29.1127 bnl_thd2o5: 37.8276 bnl_thd2o6: 55.2258 bnl_thd2o7: 81.3123 bnl_thd2o8: 120.4907
Moderator	D2O
Fuel material	3wt% ^{233}UO2 – 97wt% ThO_2
Fuel Density (g/cm^3)	8.9618
Radius of fuel rods (cm)	0.5461
Clad material	Zircaloy-2
Clad Density (g/cm^3)	6.8365
Outer radius of clad (cm)	0.63373
Thickness of clad (cm)	0.08763
Temperature (all components) (K)	293
Experimental buckling B^2 (cm^{-2})	bnl_thd2o1: 0.002054 ± 0.000020 bnl_thd2o2: 0.002985 ± 0.000022 bnl_thd2o3: 0.002864 ± 0.000029 bnl_thd2o4: 0.002500 ± 0.000016 bnl_thd2o5: 0.002232 ± 0.000014 bnl_thd2o6: 0.001913 ± 0.000027 bnl_thd2o7: 0.001467 ± 0.000037 bnl_thd2o8:-0.001129 ± 0.000020

Keyword and files

Keyword	CRITDTH
WIMS Input (.WIN)	bnltd2o
Batch Files (.BAT)	BNCHONE (called from bnchall.bat)
Programs (.EXE<-.FOR)	SMRDI2 (called from bnchall.bat) WEDOG2 (called from bnchon2.bat)
Reference file (.REF)	EXPBNLD (called from smrdi2.exe)

REFERENCES

[1] SEHGAL, B.R., Brookhaven $^{233}UO_2$-ThO_2 Thermal Lattice Experiments presented at EACRP Tokyo Meeting, October 1967.

[2] WINDSOR, H.H., TUNNE, W.J., PRICE, G.A., Exponential Experiments with Lattices of Uranium-233 Oxide and Thorium Oxide in Light and Heavy Water, Nucl. Sci. Eng., 42, 150-161 (1970).

IV.8. D_2O-moderated uranium oxide critical lattices- UO2-HW (CRITD2O)

Index

8.01) UO2–HW-AECL–ZED2
8.02) UO2–HW-JNCDI–DCA ZED2

List of benchmarks by U-235 enrichment

Benchmark identification	wt% U235	# cases	.win	Short name
8.01)UO2–HW-AECL–ZED2	0.72	5		
a)37 rods-square		(2)	e1t1d2od	zed2t1d2o
			e1t1aird	zed2t1air
b)28 rods-hexag.		(2)	e1t2p24d	zed2t2p24
			e1t2p40d	zed2t2p40
c)28 rods-square		(1)	e1t3000d	zed2t3p24
8.02)UO2–HW-JNCDI–DCA	1.2	6	e2t1d22d	dcat1d22
			e2t1a22d	dcat1a22
			e2t1h22d	dcat1h22
			e2t1d25d	dcat1d25
			e2t1a25d	dcat1a25
			e2t1h25d	dcat1h25

8.01) UO2–HW-AECL–ZED2
D_2O-moderated uranium oxide critical lattices

Laboratory: AECL Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario (Canada)

Facility: ZED-2

Numerous experiments with different fuel elements of CANDU type have been performed in the Canadian heavy water reactor ZED-2. They were made using UO_2 (natural) fuel on (a) 37 and (b) 28 hexagonal and (c) square fuel clusters, including buckling measurements and several parameters of the cells. Three of these experiments were selected for the present work.

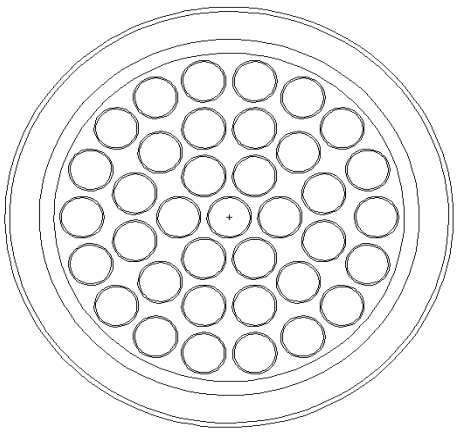
a) Analysis of Experiments with 37-rod Fuel clusters

Measurements have been made at a single pitch 28.58 cm square, UO_2 (natural) fuel, using heavy water and air as coolants.

Experimental results

a. Fast fission ratio [U-238 fis./U-235 fis.]
b. Relative conversion ratio
[U-238 cap./U-235 fis.]fuel/
(U-238 cap./U-235fis.)Maxw.fl.]
c. U-235 fission rate distribution
d. Cu-63 absorption rate distribution
e. Lutetium-manganese ratio
[(ALu/Amn)fuel/(AMn/Alu)Maxw.fl.; A:activation rates]
(a-e,for the four rings and average)

Cluster geometry



Calculated parameters

1. Effective Multiplication Factor k_{eff}
2. Fast Fission Ratio **δ=U238fiss/U235fiss)**
3. Initial Conversion Ratio **C=Cx/Cth**;
   Cx=[U238capt/U235fiss]x; Cth=Thermal Ref.value
4. U-235 Fission Rate **U5FR=(U235fiss)x/(U235fiss)FA**
5. Relative Copper Activity **RCA=(Cu63abs)**
6. Lutetium-Manganese Activity Ratio **LMAR=LMARx/LMARth**
   LMARx=(Lu176abss)x/(Mnabss)x;
   LMARth=Thermal Ref.value
   x: position of fuel rods A,B,C,D (from innner to outer annulus); FA: fuel average

Summary data

Titles

ENRu5 : Enrichment on U235 (wt%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z4: zircaloy-4)
PITCH : Lattice pitch (cm)
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)
COO : Geometry of the lattice (sq: square)

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Bm**2	TEMP	GE	COO
UO2–HW-AECL-ZED2T1D2O	0.72	0.823	1.21	z4	28.58	2.7	20	sq	d2o
UO2–HW-AECL-ZED2T1Air	0.72	0.818	1.21	z4	28.58	2.0	20	sq	air

General data

Pitch (cm)	28.58 (square)
Coolants	zed2t1d2o : D2O zed2t1air : Air
Moderator	D2O
Number of rods	37 (1/6/12/18)
Radius of rod centers (cm)	0.0/1.4885/2.8755/4.3305
Fuel material	UO2-nat
Density of fuel material(g/cm^2)	10.50
Radius of fuel rods (cm)	Central: 0.5965 Others: 0.6050
Sheath material	Zry-4
Density of sheath material (g/cm^2)	6.55
Internal radius of sheath (cm)	0.61
Thickness of sheath (cm)	0.045
Material of pressure and calandria tubes	1050 Al alloy
Density of pressure and calandria Tubes (g/cm^2)	2.7
Internal radius of pressure tube (cm)	5.195

Thickness of pressure tube (cm)	0.315
Internal radius of calandria tube (cm)	6.35
Thickness of calandria tube (cm)	0.32
Temperature (all components)(K)	294.8
Experimental buckling (cm^{-2})	zed2t1d2o : 0.00027 zed2t1air : 0.00020

Keyword and files

Keyword	D2OCRIT
WIMS Input (.WIN)	e1t1d2od
	e1t1aird
	e1t1ther
Batch Files (.BAT)	D2ORUNW (called from bnchall.bat)
	WIMSONE (called from d2orunw.bat)
Programs (.EXE<-.FOR)	E1T1 (called from d2orunw.bat)
	D2OSMR (called from bnchall.bat)
Reference file (.REF)	E1T1 (called from e1t1.exe)

REFERENCES

[1] INTERNATIOAL ATOMIC ENERGY AGENCY, In-core fuel management benchmarks for PHWRs, IAEA-TECDOC-887, Task 9.1, pp.111-117, 1996.

[2] KAY, R.E., Lattice Measurements with 37-Element Bruce Reactor Fuel in Heavy Water Moderator: Detailed Lattice Cell Parameters, AECL-5307,1976.

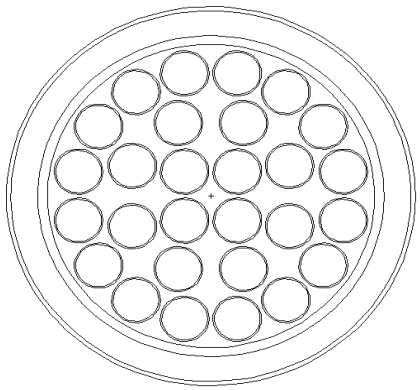
b) Analysis of Experiments with 28-rod Fuel Clusters (hexagonal pitches)

Measurements were made using UO_2 (natural) fuel, heavy water and air as coolants. Buckling measurements were performed at 8 triangular lattice pitches of 24, 26, 28, 30, 32, 34, 36 and 40 cm for both the coolants, and detailed reaction rate measurements were carried out at 4 lattice pitches of 24, 28, 32 and 40 cm only.

Experimental results

a. Material bucklings
b. Fast fission ratio
c. Initial conversion ratio [U-238 cap./U-235 abs.]
d. Neutron density distribution [Npt/Nf, Nct/Nf, Nm/Nf]
pt: pres.tube; ct: calandria tube; m: moderator; f : fuel

Cluster geometry



Calculated parameters

1. Effective Multiplication Factor k_{eff}
2. Fast Fission Ratio **δ = U238fiss/U235fiss)fa**
3. Initial Conversion Ratio **C = Cfa/Cth**;
Cfa=[U238capt/U235abss]fa; Cth=Thermal Ref.value
fa: fuel average; capt: absorption – fission; abss: capture + fission

Summary data

Titles

ENRu5	:	Enrichment on U235 (wt%)
Q-VAL	:	*q*-value for the case
FUELd	:	Fuel rod diameter (cm)
CL	:	Clad material (z2: zircaloy-2)
PITCH	:	Lattice pitch (cm)
Bm**2	:	Experimental material Buckling**2 (1/(m^2))
TEMP	:	Temperature (°C)
GE	:	Geometry of the lattice (he: hexagonal)
COO	:	Coolant

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Bm**2	TEMP	GE	COO
UO2–HW-AECL-ZED2T2P24	0.72	0.766	1.42	z2	24.0	2.80	23	he	d2o
UO2–HW-AECL-ZED2T2P40	0.72	0.854	1.42	z2	40.0	2.77	23	he	d2o

General data

Pitch (cm)	zed2t2p24: 24.0 zed2t2p40: 40.0
Lattice geometry	Hexagonal
Coolant	D2O
Moderator	D2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.163/2.652/4.206
Fuel material	UO2-nat
Density of fuel material (g/cm^2)	10.45
Radius of fuel rods (cm)	0.71
Sheath material	Zry-2
Density of sheath material (g/cm^2)	6.55
Internal radius of sheath (cm)	0.715
Thickness of sheath (cm)	0.045
Material of pressure tube	65s Al alloy
Material of calandria tube	50s Al alloy
Density of pressure and calandria tubes (g/cm^2)	2.7
Internal radius of pressure tube (cm)	5.095
Thickness of pressure tube (cm)	0.295
Internal radius of calandria tube (cm)	6.23
Thickness of calandria tube (cm)	0.14
Temperature (all components) (K)	296.0
Experimental buckling (cm^{-2})	zed2t2p24: 0.0002804 zed2t2p40: 0.0002772

Keyword and files

Keyword	D2OCRIT
WIMS Input (.WIN)	e1t2p24d, e1t2p40d
Batch Files (.BAT)	D2ORUNW (called from bnchall.bat)
	WIMSONE (called from d2orunw.bat)
Programs (.EXE<-.FOR)	E1T2 (called from d2orunw.bat)
	D2OSMR (called from bnchall.bat)
Reference file (.REF)	E1T2 (called from e1t2.exe)

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, In-core fuel management benchmarks for PHWRs, IAEA-TECDOC-887, Task 9.2, pp.117-122, 1996.

[2] SERDULA, K.J., AECL-2606, 1966.

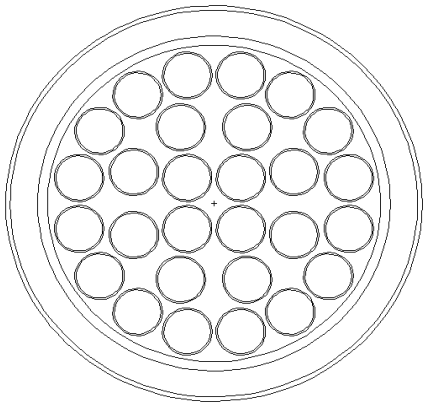
c) Analysis of Experiments with 28-rod Fuel Clusters (square pitch)

Measurement of material buckling has been made at a single pitch 28.575 cm square, using UO_2 (natural) fuel and heavy water as coolant.

Experimental result

Material bucklings

Cluster geometry



Calculated parameters

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (wt%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z2: zircaloy-2)
PITCH : Lattice pitch (cm)
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)
COO : Coolant

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Bm**2	TEMP	GE	COO
UO2–HW-AECL-ZED2T3P24	0.72	0.817	1.42	z2	28.57	3.77	23	sq	d2o

General data

Pitch (cm)	28.575 (square)
Coolant	D2O
Moderator	D2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.163/2.652/4.206
Fuel material	UO2-nat

Density of fuel material (g/cm^2)	10.0277
Radius of fuel rods (cm)	0.7105
Sheath material	Zry-2
Density of sheath material (g/cm^2)	6.55
Internal radius of sheath (cm)	0.7155
Thickness of sheath (cm)	0.0454
Material of pressure tube	65s Al alloy
Material of calandria tube	50s Al alloy
Density of pressure and calandria tubes(g/cm^2)	2.7
Internal radius of pressure tube (cm)	5.0965
Thickness of pressure tube (cm)	0.296
Internal radius of calandria tube (cm)	6.23
Thickness of calandria tube (cm)	0.139
Temperature (all components) (K)	296.0
Experimental buckling (cm^{-2})	0.000377

Keyword and files

Keyword	CRITD2O
WIMS Input (.WIN)	e1t3000d
Batch Files (.BAT)	D2ORUNW (called from bnchall.bat)
	WIMSONE (called from d2orunw.bat)
Programs (.EXE<-.FOR)	E1T3 (called from d2orunw.bat)
	D2OSMR (called from bnchall.bat)
Reference file (.REF)	-

REFERENCE

[1] JONES, R.T., AECL-5853, 1977.

8.02) UO2–HW-JNCDI–DCA
D_2O-moderated uranium oxide critical lattices

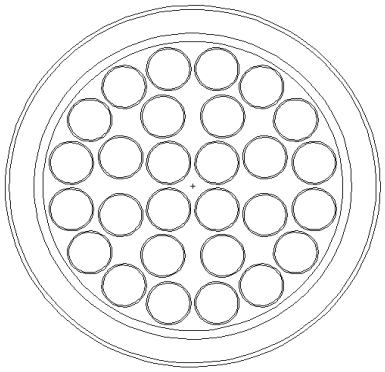
Laboratory: Japan Nuclear Cycle Development Institute (Japan)
Facility: DCA Deuterium Critical Assembly

DCA is a Japanese critical facility with 28 fuel elements of CANDU type. The fuel is made of UO_2 with slightly enriched uranium (1.2 wt% U235). Experiments were made including buckling measurements with different coolants: heavy water, air and light water. Buckling measurements were performed at two square lattice pitches of 22.5 and 25.0 cm.

Experimental result

Material bucklings

Cluster geometry



Calculated parameters

Effective Multiplication Factor k_{eff}

Summary data

Titles

ENRu5 : Enrichment on U235 (wt %)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (al: aluminium)
PITCH : Lattice pitch (cm)
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (sq: square)
COO : Coolant

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Bm**2	TEMP	GE	COO
UO2–HW-JNCDI-DCAT1D22	1.2	0.693	1.48	al	22.5	10.13	22	sq	d2o
UO2–HW-JNCDI-DCAT1A22	1.2	0.663	1.48	al	22.5	8.83	22	sq	air
UO2–HW-JNCDI-DCAT1H22	1.2	0.746	1.48	al	22.5	11.06	22	sq	h2o
UO2–HW-JNCDI-DCAT1D25	1.2	0.705	1.48	al	25.0	10.28	22	sq	d2o
UO2–HW-JNCDI-DCAT1A25	1.2	0.693	1.48	al	25.0	9.56	22	sq	air
UO2–HW-JNCDI-DCAT1H25	1.2	0.766	1.48	al	25.0	9.72	22	sq	h2o

General data

Pitch (cm)	dcat1d22,a22,h22: 22.5 dcat1d25,a25,h25: 25.0
Lattice geometry	Square
Coolants	dcat1d : D2O dcat1a: Air dcat1h: H2O
Moderator	D2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.3125/3.0/4.7575
Fuel material	UO2-1.2wt%
Density of fuel material (g/cm^2)	10.36
Radius of fuel rods (cm)	0.74
Sheath material	Al
Density of sheath material (g/cm^2)	2.7
Internal radius of sheath (cm)	0.7515
Thickness of sheath (cm)	0.0850
Material of pressure and calandria tubes	Al
Density of pressure and calandria tubes (g/cm^2)	2.7
Internal radius of pressure tube (cm)	5.84
Thickness of pressure tube (cm)	0.20
Internal radius of calandria tube (cm)	6.625
Thickness of calandria tube (cm)	0.20
Temperature (all components) (K)	295.15
Experimental bucklings (cm^{-2}) (1) Void fraction: 87 % (99.82 atom % of D2O) (2) Void fraction: 70 % (88.88 atom % of D2O)	dcat1d22(1): Br^2= 0.000247 Bz^2= 0.000766 dcat1a22(1): Br^2= 0.000236 Bz^2= 0.000647 dcat1h22(1): Br^2= 0.000247 Bz^2= 0.000859 dcat1d25(2): Br^2= 0.000247 Bz^2= 0.000781 dcat1a25(2): Br^2= 0.000231 Bz^2= 0.000725 dcat1h25(2): Br^2= 0.000245 Bz^2= 0.000727

Keyword and files

Keyword	D2OCRIT
WIMS Input (.WIN)	e2t1a22d e2t1a25d e2t1d22d e2t1d25d e2t1h22d e2t1h25d
Batch Files (.BAT)	D2ORUNW (called from bnchall.bat) WIMSONE (called from d2orunw.bat)
Programs (.EXE<-.FOR)	E2T1 (called from d2orunw.bat) D2OSMR (called from bnchall.bat)
Reference file (.REF)	E2T1 (called from e2t1.exe)

REFERENCES

[1] SHIBA, K., Substitution measurements on 28-fuel-rod-critical clusters in D_2O and their analysis by the second-order perturbation method Nucl. Sci. Eng., 65, 492-507 (1978).

[2] KOWATA, Y., FUKUMURA, N., Nucl. Sci. and Eng., 99, 299-312 (1988).

[3] LERNER, A.M., Evaluation of neutronic parameters in heavy water and slightly enriched uranium; comparison between calculated values with WIMS code and measurements performed in DCA facility, CNEA-RE-CA 94-07, 1994 (in Spanish).

IV.9. D_2O-moderated $^{235}UO_2$-ThO_2 critical lattices - Th5-HW - (CRITD2O)

Index

9.01) Th5–HW-AECL–ZED2

List of benchmarks by U-235 enrichment

Benchmark identification	wt% u235	# cases	.win	Short name
9.01) Th5–HW-AECL –ZED2	93.0	4	e1t4d22d	zed2t4d22
			e1t4a22d	zed2t4a22
			e1t4d28d	zed2t4d28
			e1t4a28d	zed2t4a28

9.01) Th5–HW-AECL–ZED2

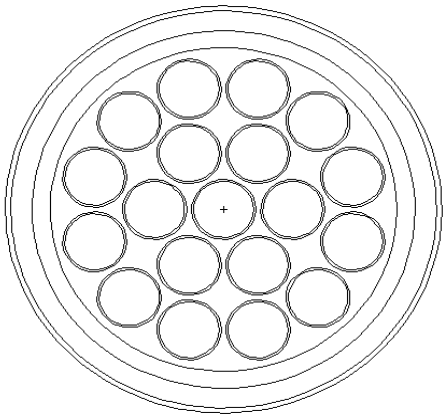
Analysis of Lattice Experiments with 19-rod Clusters with ThO_2-UO_2 Fuel

Measurements were made with ThO_2 fuel containing 1.5 wt% enriched UO_2 (93.02 at% U235) using heavy water and air coolants. Buckling measurements were performed at four triangular lattice pitches of 22, 24, 28 and 32 cm and detailed reaction rate measurements were carried out at 22 and 28 cm only.

Experimental results

a. Material bucklings
b. Th232fis/U235fis
c. Th232cap/U235fis

Cluster geometry



Calculated parameters

1. Effective Multiplication Factor k_{eff}
2. Th232/U235 Fission Ratio
   δ=Th232fiss/U235fiss)fa
3. Conversion Ratio
   C=[Th232capt/U235fiss]fa
   fa: fuel average; capt: absorption – fission

Summary data

Titles

ENRu5 : Enrichment on U235 (wt%)
Q-VAL : *q*-value for the case
FUELd : Fuel rod diameter (cm)
CL : Clad material (z2: zircaloy-2)
PITCH : Lattice pitch (cm)
Bm**2 : Experimental material Buckling**2 (1/(m^2))
TEMP : Temperature (°C)
GE : Geometry of the lattice (he: hexagonal)
COO : Coolant

FUE-CO-LAB -Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Bm**2	TEMP	GE	COO
Th5–HW-AECL-ZED2T4D22	93.0	0.886	1.153	z2	22.0	2.4	25	he	d2o
Th5–HW-AECL-ZED2T4A22	93.0	0.882	1.153	z2	22.0	2.3	25	he	air
Th5–HW-AECL-ZED2T4D28	93.0	0.915	1.153	z2	28.0	1.5	25	he	d2o
Th5–HW-AECL-ZED2T4A28	93.0	0.915	1.153	z2	28.0	1.6	25	he	air

General data

Pitch (cm)	zed2t4d22,a22: 22.0 zed2t4d28,a28: 28.0
Lattice geometry	Hexagonal
Coolant	zed2t4d22,d28: D2O zed2t4a22,a28: Air
Moderator	D2O
Number of rods	19 (1/6/12)
Radius of rod centers (cm)	0.0/1.468/2.837
Fuel material	[ThO2(98.5wt%)]- [UO2-93at%(1.5wt%)]
Density of fuel material (g/cm^2)	9.33
Radius of fuel rods (cm)	0.5765
Sheath material	Zry-2
Density of sheath material (g/cm^2)	6.55
Internal radius of sheath (cm)	0.5815
Thickness of sheath (cm)	0.0406
Material of coolant tube	Alcan 6068 Al alloy
Density of coolant tube (g/cm^2)	2.7
Internal radius of coolant tube (cm)	3.683
Thickness of coolant tube (cm)	0.127

Temperature (all components) (K)	294.8
Experimental bucklings (cm^{-2})	zed2t4d22: 0.00024 zed2t4a22: 0.00023 zed2t4d28: 0.00015 zed2t4a28: 0.00016

Keyword and files

Keyword	D2OCRIT
WIMS Input (.WIN)	e1t4d22d e1t4a22d e1t4d28d e1t4a28d
Batch Files (.BAT)	D2ORUNW (called from bnchall.bat) WIMSONE (called from d2orunw.bat)
Programs (.EXE<-.FOR)	E1T4 (called from d2orunw.bat) D2OSMR (called from bnchall.bat)
Reference file (.REF)	E1T4 (called from e1t4.exe)

REFERENCES

[1] OKAZAKI, A., DURRANI, S. A., AECL-2778, 1967.

[2] OKAZAKI, A., AECL-2779, 1968.

[3] KRISHNANI, P. D., Analysis of Lattice Experiments with ThO_2-UO_2 Fuel using WIMS Library, Ann. Nucl. Energy, Vol.16, No.3, pp. 151-155, 1989.

IV.10. Standard burnup benchmark specifications

1) NPD 19-rod Fuel Clusters
   D_2O-moderated uranium oxide lattices. Analysis of isotopic composition as a function of burnup (D2OE3)

2) NEA Burnup Credit Criticality Benchmark
   H_2O-moderated uranium oxide lattices. Analysis of Isotopic composition as a function of burnup (BUCR1A,BUCR1B)

3) LWR-Pu recycling benchmarks
   H_2O-moderated mixed oxide lattices. Analysis of Isotopic composition as a function of burnup (PURECY)

1) NPD 19-rod fuel clusters

D_2O-moderated uranium oxide lattices. Analysis of Isotopic Composition as a function of burnup.

Laboratory: AECL Atomic Energy of Canada Limited (Canada)

Facility: NPD Nuclear Power Demonstration reactor

NPD is a Canadian demonstration PHWR (25 MW electrical power) shut down on 1987. The moderator and coolant were heavy water. The fuel was in the form of 19 natural UO_2 rod CANDU type clusters.

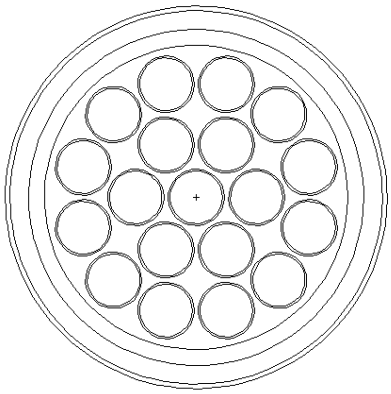
Analysis of isotopic composition for 19-rod fuel cluster

Isotopic measurements of irradiated 19 element fuel bundles have been done in 1971 at the CEA in France. The measurements included a series of eight bundles with irradiation in the range 1000-10000 MWd/TU which were analysed by mass-spectroscopy.

Experimental results

Isotopic concentration ratios for the fuel pins of each ring and bundle average for N235/N238, N236/N238, N239/N238, N240/N239, N241/N239 and N242/N239 for 8 burnups ranged from 1000 to 10000 MWD/T.

Geometry



Calculated parameters

Ni/Nj in function of burnup.

General data

Pitch (cm)	26.035 (square)
Coolants	D2O
Moderator	D2O
Number of rods	19 (1/6/12)
Radius of rod centers (cm)	0.0/1.65/3.18755

Angular dist.from reference axis (radians)	0.0/0.0/0.2617994
Fuel material	UO2-nat
Density of fuel material (g/cm^2)	10.0704
Radius of fuel rods (cm)	0.71247
Sheath material	Zry-2
Density of sheath material (g/cm^2)	6.57
Internal radius of sheath (cm)	0.71505
Thickness of sheath (cm)	0.04191
Material of pressure tube	Zry-2
Density of pressure Tube (g/cm^2)	6.556
Internal radius of pressure tube (cm)	4.1402
Thickness of pressure tube (cm)	0.4318
Material of calandria tube	57S Al alloy
Density of calandria Tube (g/cm^2)	2.68
Internal radius of calandria tube (cm)	5.08
Thickness of calandria tube (cm)	0.12827
Effective fuel Temperature (K)	778.2
Effective coolant Temperature (K)	531.7
Temperature of moderator (K)	311.0
Experimental buckling (cm^2)	0.000173

Keyword and files

Keyword	D2OE3
WIMS Input (.WIN)	E300D2OD
Batch Files (.BAT)	D2ORUNB (called from bnchall.bat) WIMSONE (called from d2orunb.bat)
Programs (.EXE<-.FOR)	E3 (called from d2orunb.bat) D2OE3B (called from bnchall.bat)
Reference file (.REF)	E3 (called from e3.exe)

REFERENCES

[1] DURET, M.F. *et.al*., Plutonium Production in NPD: a Comparison Between Experiment and Calculation, AECL-3995, 1971.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, In-core fuel management benchmarks for PHWRs, IAEA-TECDOC-887, Task 9.3, pp.122-127, 1996.

2) NEA burnup credit criticality benchmark

LWR-Burnup credit criticality benchmark. Isotopic composition prediction

Laboratory: Pacific Northwest Laboratory, Richland, Washington (USA)

Facility: ATM-104 Approved Testing Material, Combustion Engineering (CE) 14x14 assembly

This benchmark compares the computed nuclide inventories for a simple pin cell calculation. The fuel and operating specifications are based on data given in the references for the Combustion Engineering (CE) 14 x 14 assembly designated as Approved Testing Material ATM-104, for a series of experiments designed to characterize spent fuel for light water reactors. The chemical assay data measured in these experiments are of particular value in validating the isotopic predictions used in burnup credit.

Experimental results

Isotopic concentrations (mg/g fuel) on the fuel pin for U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241,Pu-242, Np-237, Cs-133, Cs-135,Nd-143, Nd-145, Sm-149, Sm-150, Sm-152 and Eu-153, for 3 cumulative burnups: 27.35, 37.12 and 44.34 GWd/MTU.

Calculated parameters

Isotopic concentrations (mg/g fuel) on the fuel pin for:
U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241,Pu-242, Np-237, Cs-133, Cs-135,Nd-143, Nd-145, Sm-149, Sm-150, Sm-152, Eu-153
for 3 cumulative burnups: 27.35, 37.12 and 44.34 GWd/MTU.

General data

Cell radius (cm)	0.879346
Moderator	H2O
Moderator Density (g/cm^3)	0.7569
Moderator Temperature (K)	558
Fuel material	UO2 (3% at. U235 enrichment)
Density of fuel material (g/cm^3)	10.045
Effective fuel Temperature (K)	841
Radius of fuel rods (cm)	0.47815
Clad material	Zry-2
Density of clad material (g/cm^3)	6.55
Internal radius of clad (cm)	0.493
Thickness of clad (cm)	0.066
Clad Temperature (K)	620
Cycle 1 avg boron concentration (ppm)	331

Operating history data for isotopic calculation

OPERATING CYCLE	BURN days	DOWN days	BORON % cycle 1
1	306.0	71.0	100.0
2	381.7	83.1	141.9
3	466.0	85.0	152.3
4	461.1	1870.0	148.8

BURN is the fuel irradiation time
DOWN is the downtime between cycles except for cycle 4 where it includes the decay time from reactor to measurement (cooling time).
BORON is the cycle-average boron concentration as a percent of the cycle 1 concentration

Specific power

OPERATING CYCLE	Specific Power Kw/kgU		
	Sample 1	Sample 2	Sample 3
1	17.24	24.72	31.12
2	19.43	26.76	32.51
3	17.04	22.84	26.20
4	14.57	18.87	22.12
Cumulative Burnup GWd/MTU	27.35	37.12	44.34

Initial fuel number densities

Nuclide	Number Density Ats./(cmx10^{24})
U-234	6.15165E-06
U-235	6.89220E-04
U-236	3.16265E-06
U-238	2.17104E-02
C-12	9.13357E-06
N-14	1.04072E-05
O	4.48178E-02

Cycle 1 coolant number densities

Nuclide	Number Density Ats./(cmx10^{24})
H-1	5.06153E-02
O-16	2.53076E-02
B-10	2.75612E-06
B-11	1.11890E-05

Keyword and files

Keyword	BUCR1A,BUCR1B
WIMS Input (.WIN)	BUCR1A,BUCR1B1,BUCR1B2,BUCR1B3
Batch Files (.BAT)	-
Programs (.EXE<-.FOR)	WEDB1A (called from bnchall.bat) WEDB1B (called from bnchall.bat)
Reference file (.REF)	BUCR1BA (called from wedb1b.exe) BUCR1BM (called from wedb1b.exe)

REFERENCES

[1] NUCLEAR ENERGY AGENCY, Burnup Credit Criticality Benchmark, Isotopic Composition Prediction, NEA/NSC/DOC(92)/10, NEA 1401/02, 1992.

[2] GUENTHER, R.J. *et al*, Characterization of Spent Fuel Approved Testing Material-ATM-104, Pacific Northwest Laboratory report PNL-5109-104, Richland, Washington, December 1991.

[3] BIERMAN, S.R., Spent Reactor Fuel Benchmark. Composition Data for Code Validation. Proceeding of the International Conference on Nuclear Criticality Safety-ICNC'91, Oxford, UK, p. II-113, September 9-13, 1991.

3) LWR-Pu recycling benchmarks

LWR-Pu recycling benchmarks

These numerical benchmarks compare the computed nuclide inventories for simple pin cell calculations, for two cases: A) highly degraded plutonium, and B) normal recycled plutonium.

Reference results

Isotopic concentrations (mg/g fuel) on the fuel pin for U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241,Pu-242, Am-241, Am-242m, Am-243, Cm-242, Cm-243, Cm-244, Cm-245, Mo-95, Tc-99, Ru-101, Rh-103, Pd-105, Pd-107, Pd-108, Ag-109, Xe-131, Xe-135, Cs-133, Cs-135, Nd-143, Nd-145, Pm-147, Pm-148m, Sm-149, Sm-150, Sm-151, Sm-152, Eu-153, Eu-154, Eu-155, for cases A and B, at 50 GWd/MTU burnup.

Calculated parameters

Isotopic concentrations (mg/g fuel) on the fuel pin for:
U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241,Pu-242, Am-241, Am-242m, Am-243, Cm-242, Cm-243, Cm-244,
Mo-95, Tc-99, Ru-101, Rh-103, Pd-105, Pd-107, Pd-108, Ag-109, Xe-131, Xe-135, Cs-133, Cs-135, Nd-143, Nd-145, Pm-147, Pm-148m, Sm-149, Sm-150, Sm-151, Sm-152, Eu-153, Eu-154, Eu-155
for cases A and B, at 50 GWd/MTU burnup.

General data

Pitch (cm)	1.3133 (square)
Moderator	H2O(+Bnat)
Moderator Temperature (K)	579
Fuel material	UO2-PuO2
Effective fuel Temperature (K)	933
Radius of fuel rods (cm)	0.4095
Clad material	Zr
Atomic Density of clad material (ats./10^{-24}cm^3)	0.043248
Radius of clad (cm)	0.4750
Clad Temperature (K)	579

Initial fuel number densities

Nuclide	Number Density Ats./(cmx10^{24})	
	A	B
U-234	-	2.4626E-07
U-235	1.4456E-04	5.1515E-05
U-238	1.9939E-02	2.0295E-02
Pu-238	1.1467E-04	2.1800E-05
Pu-239	1.0285E-03	7.1155E-04
Pu-240	7.9657E-04	2.7623E-04
Pu-241	3.3997E-04	1.4591E-04
Pu-242	5.6388E-04	4.7643E-05
O	4.5851E-02	4.3100E-02

Coolant number densities

Nuclide	Number Density Ats./(cmx10^{24})
H-1	4.7716E-02
O-16	2.3858E-02
B-nat	1.98606E-05

Keyword and files

Keyword	PURECY
WIMS Input (.WIN)	PURECYA,PURECYB
Batch Files (.BAT)	-
Programs (.EXE<-.FOR)	WEDB1B (called from bnchall.bat)
Reference file (.REF)	PURECYA (called from wedb1b.exe) PURECYB (called from wedb1b.exe)

REFERENCE

[1] NUCLEAR ENERGY AGENCY, Package ID: NEA 1505/01.

Appendix V

SUPPLEMENTARY BENCHMARK SPECIFICATIONS

List of benchmarks:

1. MARIA tubular fuel -with moderator of Be- benchmark.
   Be-moderated 80% enriched uranium-aluminium tubular fuel.
   Multiplication factor (K) comparison with results obtained with MCNP code with standard library based on ENDF/B-6, for heterogeneous and homogenized cases (BE)

2. DOPPLER numerical benchmark.
   H_2O-moderated uranium oxide lattices.
   Reactivity temperature coefficient comparison with results obtained with MCNP code with standard library based on ENDF/B-VI (DOPPLER)

3. RTC experimental benchmarks.
   H_2O-moderated mixed oxide lattices.
   Reactivity temperature coefficient differences between calculated and experimental values obtained from measured buckling of 4 experimental facilities: KRITZ, NORA, R1100H and VVER (RTC)
   3.1 KRITZ
   3.2 NORA
   3.3 R1100H
   3.4 VVER

4. DCA experimental benchmark with Gd poisoned rods.
   D_2O-moderated cluster with 54 uranium oxide rods.
   Analysis of critical experiments on gadolinium poisoned cluster-type fuel assemblies of 54 Rods in Heavy Water Lattices of DCA Facility.
   Comparison of measured and calculated thermal flux spatial distribution (D2OGD)

5. OWR-MTR experimental and numerical burnup benchmark.
   H_2O-moderated 94% enriched uranium-aluminium fuel plates.
   Analysis of spent U235 isotope in function of burnup, and numerical comparison of isotopic concentration of actinides at end of cycle (MTRBURN)

6. PWR thorium pin cell numerical burnup benchmark.
   H_2O-moderated ThO_2(75 w/o)-UO_2(25 w/o - 19.5 w/o U-235) mixture fuel rods.
   Numerical comparison of k_∞ eigenvalue and isotopic concentrations of Actinides and fission products as a function of burnup,

7. TRIGA-IJS full core calculation benchmark.

V.1. MARIA tubular fuel benchmark (with Be moderator). Be-moderated 80% enriched uranium-aluminium tubular fuel.

Laboratory: IAE Institute of Atomic Energy, Poland

Facility: MARIA reactor

The details of MARIA reactor and MCNP calculations can be found in the reference. It is strongly recommended to read that referenced document for understanding the characteristics of MARIA reactor. Geometry and material data included in this section were extracted from the reference.

The benchmark consist of two cases:

a. Homogeneous mixture of MARIA cell materials rounded off and with admixed boron to achieve criticality (berhom)
b. Heterogeneous tubular elementary MARIA cell (ber-tubes).

The benchmark is purely computational with reference result calculated by MCNP code with it standard library based on ENDF/B-VI.

MCNP if used for a cell which is a part of an infinite lattice, and calculates really the k-infinity of that lattice. It has no a buckling concept and a reflected or white boundary conditions have to be used. Thus in the case of a tubular cell, the parameter compared is the k-infinity. The case of a homogenised cell is the same as the tubular case, with materials mixed with volume weights. The k-infinity calculated there is lower as the system have made critical by adding boron into the homogenised mixture. Boron has been added as boron rods are used in the reactor for safety and control.

Reference results

Calculated with MCNP-C code with standard library based on ENDF/B-VI. Rev.7.

1) K_{inf} : Infinity Multiplication Factor

2) $$\rho_{28} = \frac{\text{epithermal U - 238 captures}}{\text{thermal U - 238 captures}}$$

3) $$\delta_{25} = \frac{\text{epithermal U - 235 fissions}}{\text{thermal U - 235 fissions}}$$

4) $$\delta_{28} = \frac{\text{U - 238 fissions}}{\text{U - 235 fissions}}$$

5) $$C^* = \frac{\text{U - 238 captures}}{\text{U - 235 fissions}}$$

MCNP calculations were carried out in 3-D with reflective boundary condition applied at all boundaries. The square boundary of the elementary cell was preserved.
The uncertainty for k-infinity has been taken as the standard deviation printed by the code.
The uncertainties for other integral parameters have been obtained from Monte Carlo standard deviations using the fact of dependence of each calculated reaction rate on the calculated

neutron flux. An approximate formula has been used:

$$\frac{\delta x(\phi)}{x(\phi)} = \sqrt{\left(\left(\frac{\delta\phi_{epi}}{\phi_{epi}}\right)^2 + \left(\frac{\delta\phi_{th}}{\phi_{th}}\right)^2\right)}, \qquad x = \rho_{28} \text{ or } x = \delta_{25}$$

$$\frac{\delta y(\phi)}{y(\phi)} = \sqrt{\left(\left(\frac{\delta\phi_{tot}}{\phi tot}\right)^2 * 2\right)}, \qquad y = \delta_{28} \text{ or } y = C^*.$$

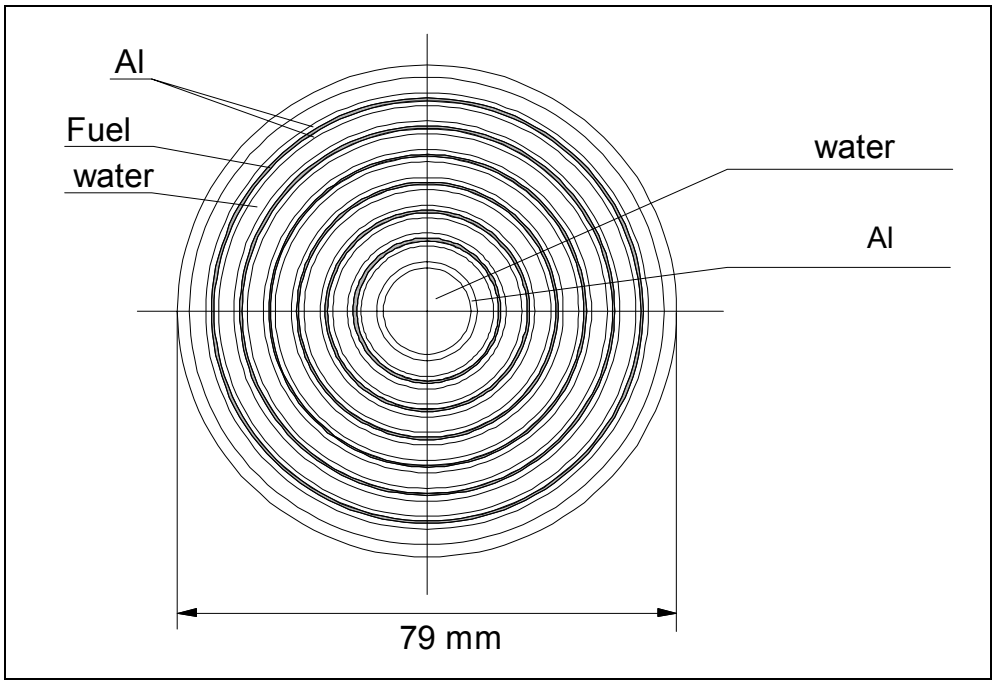


Figure V.1.1 Geometry of benchmark b horizontal cross section of the fuel assembly.

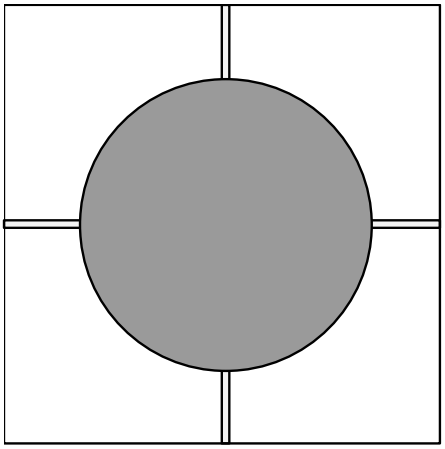


Figure V.1.2 Elementary MARIA cell used in MC lattice calculations.

The elementary cell has a side size equal to 13cm i.e. the average size of the beryllium block used in the beryllium matrix with its adjacent water gap. In the center of Fig. 1.2 there is a fuel channel, in the middle of which the fuel element is placed (cf. Fig. 1.1) in an aluminium guiding tube. Four water gaps separating beryllium blocks are directed outwards from the channel.

Calculated parameters

1) K_{inf} : Infinity Multiplication Factor
2) ρ^{28}
3) δ^{25}
4) δ^{28}
5) C^{*}

Number densities (at/b-cm)

Isotope	Homogeneous test cell (case a)	Tubular test cell (case b)			
		Fuel	Can	Coolant	Moderator(*)
H	1.6E-02				2.8823E-3
Be	8.0E-02			6.6873E-02	1.1668E-1
B-10	6.0E-06				
Al.	7.0E-03	4.847E-02	6.02E-02		1.5939E-5
O	8.0E-03			3.3436E-02	1.8510E-3
Si					7.6550E-6
Cr					6.2040E-6
Mn					3.9136E-6
Fe					1.9251E-5
Ni					1.8319E-6
Cu					2.5389E-6
Mg					2.2309E-6
U-235	4.0E-05	2.615E-03			
U-238	1.0E-05	6.454E-04			

(*) fresh beryllium blocks homogenized with water gaps (at/b-cm)

General data

Pitch (cm)	13.0 (square)
Moderator to fuel volume	42.717 (*)
Coolant	H2O
Moderator material	Be
Fuel material	U-Al (80 wt% enriched)

Radius of each annulus and material for case b (see Figs. 1.1 and 1.2) (cm) Material 1: fuel Material 2: can Material 3: water Material 4: beryllium with impurities	Annulus	Radius	Mat.
	1	0.7	3
	2	0.8	2
	3	1.05	3
	4	1.13	2
	5	1.17	1
	6	1.25	2
	7	1.5	3
	8	1.58	2
	9	1.62	1
	10	1.7	2
	11	1.95	3
	12	2.03	2
	13	2.07	1
	14	2.15	2
	15	2.4	3
	16	2.48	2
	17	2.52	1
	18	2.6	2
	19	2.85	3
	20	2.93	2
	21	2.97	1
	22	3.05	2
	23	3.3	3
	24	3.38	2
	25	3.42	1
	26	3.5	2
	27	3.75	3
	28	3.95	2
	29	4.1	3
	30	7.33446	4
Temperature (all components) (K)	294		

(*)Vm/Vf has been calculated with the volume of both: water coolant and beryllium moderator.
For beryllium moderator Vm(Be)/Vf is 32.122.

Keyword and files

Keyword	BE
WIMS Input (.WIN)	bermar berhom
Batch Files (.BAT)	BNCHONE (called from supbench.bat)
Programs (.EXE<-.FOR)	SMRDIF (called from supbench.bat) WEDOG2 (called from bnchone.bat)
Reference file (.REF)	BERMAR (called from smrdif.exe)

REFERENCE

[1] ANDRZEJEWSKI, K., KULIKOWSKA, T., Reference Monte Carlo Calculations of MARIA Reactor Core, IAEA, 2002.

V.2. DOPPLER numerical benchmark. H_2O-moderated uranium oxide lattices.

An infinite array of infinitely long PWR pin cells at beginning of life.

Reactivity temperature coefficient comparison with results obtained with MCNP code with standard library based on ENDF/B-VI (DOPPLER)

This benchmark consist of 5 different enrichment values for fuel pins. The two thermal conditions considered were that of hot zero power (HZP) i.e. 600K and hot full power (HFP); and 900K.

Calculated parameter

Effective Multiplication Factor k_{eff} and Doppler coefficient $\mathbf{C_D}$ which is defined by:

$$C_D = \frac{k_{eff}^{HFP} - k_{eff}^{HZP}}{k_{eff}^{HFP} \cdot k_{eff}^{HZP} \cdot \Delta T} \quad \text{with} \quad \Delta T = T^{HFP} - T^{HZP}$$

Composition

Fuel Temp. (K)	Fuel Enrichment (wt%)	Number density in fuel (atom/b.cm)		
		^{16}O	^{235}U	^{238}U
600 HZP)	0.711	0.0461309	0.000166078	0.0228994
	1.6	0.0461355	0.000373729	0.0226940
	2.4	0.0461397	0.000560588	0.0225093
	3.1	0.0461433	0.000724086	0.0223476
	3.9	0.0461475	0.000910933	0.0221163
900 (HFP)	0.711	0.0457561	0.000164729	0.0227133
	1.6	0.0457607	0.000370693	0.0225096
	2.4	0.0457648	0.000556033	0.0223264
	3.1	0.0457684	0.00071802	0.0221660
	3.9	0.0457725	0.000903532	0.0219827

Fuel temperature (K)	Temperature of the cladding and moderator (K)	Number of density in cladding and moderator (atom/b.cm)			
		natural Zirconium	^{1}H	^{10}B	^{16}O
600	600	0.0383243	0.0442326	0.0000102133	0.0221163
900	600	0.0389087			

Geometry of calculation

Fuel pellet radius (cm)	Outer cladding radius (cm)	Pitch (cm)	Equivalent cell radius (cm)
0.39306	0.45802	1.26209	0.71206

General data

Pitch (cm)	1.26209 (square)
Equivalent pin cell radius (cm)	0.71206
Moderator	H2O
Fuel material and enrichement	UO2 wt% enr. 0.711. 1.6 2.4 3.1 3.9
Radius of fuel rods (cm)	0.39306
Clad material (a)	Natural Zr
Outer radius of clad (cm)	0.45802 (*)
Fuel Temperature (K)	HZP: 600 HFP: 900
Cladding temperature (K)	HZP: 600 HFP: 600
Moderator temperature (K)	HZP: 600 HFP: 600

(*) the gap between the fuel pellet and the cladding is homogenized with the cladding to form a single region.

Keyword and files

Keyword	DOPPLER
WIMS Input (.WIN)	Doppler
Batch Files (.BAT)	RUNDOP (called from supbench.bat)
Programs (.EXE<-.FOR)	DOPBENCH (called from rundop.bat) DOPBEN (called from supbench.bat)
Reference file (.REF)	DOPPLER (+doppler.e, doppler.t) (called from dopbench.exe)

REFERENCES

[1] RAHNEMA, F., GHEORGHIU, H. N. M., ENDF/B-VI Benchmark Calculations for the Doppler Coefficient of Reactivity, Ann. Nucl. Energy, Vol. 23, No. 12, pp. 1011-1019, 1996.

[2] MOSTELLER, R. D., EISENHART, L. D., LITTLE, R. C., EICH, W. J., CHAO, Benchmark Calculations for the Doppler Coefficient of Reactivity, Nuc. Sci. Eng., 107, pp. 265-271 (1991).

V.3. RTC experimental benchmarks.
H_2O-moderated mixed oxide lattices.

Reactivity temperature coefficient differences between calculated and experimental values obtained from measured buckling of 4 experimental facilities: KRITZ, NORA, R1100H and VVER

The D-ALPHA parameter (reactivity temperature coefficient difference between calculated and experimental value), obtained from effective multiplication factors, is defined as follows:

$$D - ALPHA = \frac{k_{eff}^{T} - k_{eff}^{T0}}{k_{eff}^{T} . k_{eff}^{T0} . \Delta T} \quad \text{with} \quad \Delta T = T^{T} - T^{T0}$$

As the P1 matrices in the WIMS library are not tabulated for temperatures, the calculations are performed using the transport approximation in order to calculate the reactivity temperature coefficient. So, the obtained k-effective values are not valid for the criticality prediction.

The following cases were analyzed: KRITZ , NORA, R1100H and VVER.

V.3.1. KRITZ benchmark

H_2O-moderated uranium, and uranium-plutonium oxide critical lattices

Laboratory: Studsvik, Sweeden

Facility: KRITZ tank type Critical Assembly

These benchmarks are 4 H_2O moderated lattices of enriched uranium oxide and MOX rods in square patterns. Material bucklings were measured at different temperatures.

Calculated parameter

Effective Multiplication Factor k_{eff} at different temperatures and, from these values, D-ALPHA parameter (reactivity temperature coefficient difference between calculated and experimental value)

General data

Pitch (cm)	KRITZ_1 : 1.8 KRITZ_2.1 : 1.485 KRITZ_2.13: 1.635 KRITZ_2.19: 1.8
Lattice geometry	Square
Water/fuel volume ratio	KRITZ_1 : 1.44 KRITZ_2.1 : 1.17 KRITZ_2.13: 1.7 KRITZ_2.19: 3.32

Moderator	H2O
Fuel material	KRITZ_1 : UO2 e:1.3532%wt KRITZ_2.1 : UO2 e:1.86%wt KRITZ_2.13: UO2 e:1.86%wt KRITZ_2.19: UO2-PuO2 (1.5%wt Pu) U-235/U: 0.16 Pu-239/Pu: 91.41 Pu-240/Pu: 7.83 Pu-241/Pu: 0.73 Pu-242/Pu: 0.03
Fuel Density (g/cm^3)	KRITZ_1 : 10.26 KRITZ_2.1 : 10.145 KRITZ_2.13: 10.145 KRITZ_2.19: 9.58
Radius of fuel rods (cm)	KRITZ_1 : 0.619 KRITZ_2.1 : 0.529 KRITZ_2.13: 0.529 KRITZ_2.19: 0.4725
Clad material	Zircaloy2
Outer diameter of clad (cm)	KRITZ_1 : 1.386 KRITZ_2.1 : 1.225 KRITZ_2.13: 1.225 KRITZ_2.19: 1.079
Thickness of clad (cm)	KRITZ_1 : 0.063 KRITZ_2.1 : 0.074 KRITZ_2.13: 0.074 KRITZ_2.19: 0.067
Temperature (all components) (°C)	T1 T2 KRITZ_1 : 20. 210. KRITZ_2.1 : 20. 248.5 KRITZ_2.13: 22.1 243.0 KRITZ_2.19: 21. 236.

REFERENCE

[1] JOHANSSON, E., Data and results from KRITZ experiments on regular water moderated fuel pin lattices at temperatures up to 245°C, Studsvik/NS-90/133 (1990).

V.3.2. NORA benchmark

H_2O-moderated UO_2 critical lattices

Laboratory: Institute for Atomenergi at Kjeller, Norway

Facility: Zero power reactor NORA

The selected benchmark consists of two H_2O moderated lattices of uranium oxide rods in square patterns. Material bucklings were measured.

Calculated parameter

Effective Multiplication Factor k_{eff} at 20°C and 60°C and, from these values, D-ALPHA parameter (reactivity temperature coefficient difference between calculated and experimental value)

General data

Pitch (cm)	Core I : 2.314 (square) Core III: 1.9 (square)
Water/fuel volume ratio	Core I : 1.66 Core III: 3.03
Moderator	H2O
Fuel material	UO2 e: 3.41%wt
Fuel Density (g/cm^3)	10.40
Radius of fuel rods (cm)	0.635
Clad material	SS-304
Outer radius of clad (cm)	0.694
Thickness of clad (cm)	0.048
Temperature (all components)(°C)	20 60

REFERENCES

[1] Topics light water reactor physics: Final report of NORA project, Technical reports series N° 113, IAEA-R-104-F (1970).

[2] MOUNIER, C., Contribution à l'étude du coefficient de température des réacteurs à eau légère, PhD Thesis, University of Paris Orsay (1993).

V.3.3. R1-100H benchmark

H_2O-moderated UO_2 critical lattice

Laboratory: Atomic Energy Establishment Winfrith, United Kingdom

Facility: Zero power reactors DIMPLE and JUNO

The selected benchmark consists of a H_2O moderated lattice of uranium oxide rods in square patterns. Material buckling were measured in hot and cold conditions.

Calculated parameter

Effective Multiplication Factor k_{eff} at 20°C and 80°C and, from these values, D-ALPHA parameter (reactivity temperature coefficient difference between calculated and experimental value)

General data

Pitch (cm)	1.32 (square)
Water/fuel volume ratio	0.995
Moderator	H2O
Fuel material	UO2 e: 3.003%wt
Fuel Density (g/cm^3)	10.44
Radius of fuel rods (cm)	0.508
Clad material	SS-304
Clad density (g/cm^3)	7.8
Outer radius of clad (cm)	0.5461
Thickness of clad (cm)	0.0267
Temperature (all components) (°C)	20 80

REFERENCE

[1] AUSTIN, J.W. , BROWN, W.AV. , BURHOLT, G.D. , FOX, W.N., SKILLINGS, D.J., Measurements of the temperature variation of the material buckling in light water moderated lattice fuelled with 3% U235 enriched UO_2, AEEW-R-455 (1966).

V.3.4. WWER benchmarks

WWER-type lattice criticality benchmarks

Laboratory: Central Research Institute for Physics of the Hungarian Academy of Sciences, Budapest (Hungary)

Facility: ZR-6

These benchmarks are four cases (two temperatures in each case) extracted from the 25 regular WWER-type UO_2-H_2O lattices (see WLUP-Standard Benchmarks). Material bucklings were measured. Lattices are identified by lattice pitch, atomic enrichment, boron concentration, and temperature. Material bucklings were measured in hot and cold conditions.

Calculated parameter

Effective Multiplication Factor k_{eff} at 21°C and 130°C and, from these values, D-ALPHA parameter (reactivity temperature coefficient difference between calculated and experimental value)

General data

Lattices are identified by a code, P/E/B/T, where
P: LATTICE PITCH [cm]
E: ATOMIC ENRICHMENT [at%]
B: BORON CONCENTRATION [g H3BO3/l]
T: TEMPERATURE [°C]

Index		0	1	2	3	4	5	6	7
Values	P		1.10	1.27	1.50	1.905			
	E		1.6	3.6	4.4				
	B	0.0	0.64	1.0	1.41	1.85	4.0	5.8	7.2
	T		21	80	130				

Lattice name, code, experimental buckling B^2 and deviation ($10^{-4}cm^{-2}$)

Name	Code	B^2	Deviation
wwer_1	p1w2b0t1	66.01	0.47
	p1w2b0t3	59.76	0.31
wwer_2	p2w2b0t1	100.41	0.40
	p2w2b0t3	90.27	0.91
wwer_3	p2w2b5t1	74.16	0.34
	p2w2b5t3	67.63	0.20
wwer_4	p2w2b6t1	64.95	0.26
	p2w2b6t3	59.02	0.13

Other data

Lattice geometry	Hexagonal
Moderator	H2O with different concentrations of H3BO3
Fuel material	UO2
Radius of fuel rods (cm)	0.3800
Clad material	Zr
Outer radius of clad (cm)	0.4525
Thickness of clad (cm)	0.0650

Keyword and files

Keyword	RTC
WIMS Input (.WIN)	Kritz1, kritz21, kritz213, kritz219 nora, r1100h vver1,vver2,vver3,vver4
Batch Files (.BAT)	RUNRTC.BAT (called from supbench.bat)
Programs (.EXE<-.FOR)	PINTCR (called from runtcr.bat) RTCBEN (called from supbench.bat)
Reference file (.T)	KRITZ1,KRITZ21,KRITZ213,KRITZ219 NORA (+NORA.C) R1100H VVER, VVER1(+VVER1.C), VVER2,VVER3,VVER4 (called from pintcr.exe)

REFERENCES

[1] Final Report of TIC: Experimental Investigations of the Physical Properties of WWER Type Uranium-Water Lattices, Volume 1, Akademiai Kiado, Bupapest 1985.

[2] Final Report of TIC: Experimental Investigations of the Physical Properties of WWER Type Uranium-Water Lattices, Volume 3, Akademiai Kiado, Budapest 1991.

[3] NUCLEAR ENERGY AGENCY, The WWER Experiments: Regular and Perturbed Hexagonal Lattices of Low-enriched UO_2 Fuel Rods in Light Water, NEA/NSC/DOC/(95)03/IV, Volume IV, LEU-COMP-THERM-015, International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2001 Edition**,** Nuclear Science Committee, Nuclear Energy Agency, OECD (2001).

V.4. DCA experimental benchmark with Gd poisoned rods. D_2O-moderated cluster with 54 uranium oxide rods.

Laboratory: Japan Nuclear Cycle Development Institute (Japan)
Facility: DCA Deuterium Critical Assembly

A test fuel cluster of 54 fuel pins composed of UO_2 enriched to 1.5 wt% in U235 was placed in the centre of the DCA experimental reactor and was surrounded by 1.2 wt% U-235 enriched UO_2 fuel clusters of 28 pins each. To investigate the effect of burnable poison in fuel pellets, a few fuel pins of the test cluster were replaced with 1.5 wt% enriched UO_2 pins containing 0.1, 0.5 or 1.0 wt% Gd_2O_3.

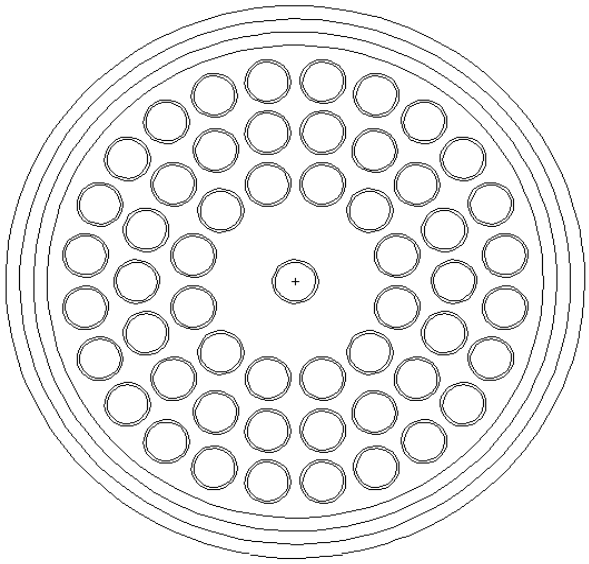
In this benchmark, a comparison of measured and calculated thermal flux spatial distribution is made.

Experimental results

a. Local power distribution,
b. Thermal neutron flux distribution,
c. Fine structure of the thermal neutron flux distribution on a pin cell within the moderator region,

on test fuel cluster at the center of DCA.

Geometry



Calculated parameters

1) Thermal neutron flux distribution in the cluster

2) Fine structure of thermal neutron flux distribution in the fuel pellets
(this is a pin cell calculation with 32 mesh intervals for detailed radial flux calculation, taking into account the resonance self-shielding)

General data

Pitch (cm)	40.0 (square)
Coolants	a)H2O; b)Air
Moderator	D2O
Number of rods	54 (12/18/24)
Radius of rod centers (cm)	3.825/5.76/7.68
Fuel material	i)Normal: UO2-1.5wt% ii)Poisoned fuel pins: UO2-1.5wt% + Gd2O3-0.1,0.5,or 1.0 wt%
Density of fuel material (g/cm^3)	i) 10.38; ii)10.30
Radius of fuel rods (cm)	i) 0.7385; ii)0.739
Sheath material	Al
Density of sheath material (g/cm^3)	2.7
Internal radius of sheath (cm)	i)0.7515; ii)0.7490
Thickness of sheath (cm)	i)0.0850; ii)0.1355
Material of pressure and calandria tubes	Al
Density of press.and caland.Tubes (g/cm^3)	2.7
Internal radius of pressure tube (cm)	9.0
Thickness of pressure tube (cm)	0.5
Internal radius of calandria tube (cm)	10.0
Thickness of calandria tube (cm)	0.5
Temperature (all components) (K)	293.15

Keyword and files

Keyword	D2OGD
WIMS Input (.WIN)	e2t2a00d, e2t2h00d, e2t2h12d e2t2d00d, e2t2d01d, e2t2d05d, e2t2d10d
Batch Files (.BAT)	D2OGD.BAT (called from supbench.bat)
Programs (.EXE<-.FOR)	E2T2 (called from d2ogd.bat) E2T2P (called from supbench.bat)
Reference file (.REF)	E2T2 (called from e2t2.exe)

REFERENCE

[1] WAKABAYASHI, T., MINATSUKI, I., Critical Experiments on Gadolinium Poisoned Cluster-Type Fuel Assemblies in Heavy Water Lattices, Nucl. Sci. Eng., 83, 50-62 (1983) .

V.5. OWR-MTR experimental and numerical burnup benchmark.

H_2O-moderated 94% enriched uranium-aluminium fuel plates.

Laboratory: Los Alamos National Laboratory, USA
Facility: OWR Omega West Reactor

Analysis of spent U235 isotope in function of burnup, and numerical comparison of isotopic concentration of actinides at end of cycle for a single plate cell calculation.

As explained in the reference, the analysed fuel element was subject to varying flux levels and spectra, core power level, spatial xenon distribution, control rod positions, core grid locations and other considerations. The recorded burnup history for one element and a measured vertical flux profile at a determined core grid position were used to determine the power density history at the locations of the minimum, maximum and average flux. The values adopted on this benchmark corresponds to the average values reported in the reference.

Experimental results

Measured mean % of initial U235 remaining by cycles, for 17 cycles.

Reference numerical results

Actinide nuclide inventory at the end of the last cycle, calculated with CINDER-2 and DANDE codes.

Calculated parameters

1) Mean % of initial U235 remaining by cycles, for 17 cycles.

2) Actinide nuclide inventory at the end of the last cycle.

General data

Type fuel	U-Al alloy (enrichment: 93.15 wt % U235)
Fuel density (g/cm^3)	2.702 (content of Al: 96.33 % of full fuel density)
Density of U in meat (g/cm^3)	0.6779
Fuel height (cm)	60.01
Fuel width (cm)	6.35
Fuel thickness (cm)	0.0508
Number of fuel plates x element	18
Element fuel meat volume (cm^3)	348.4
Effective fuel temperature (K)	293
Clad temperature (K)	293
Clad material	Al
Clad density (g/cm^3)	2.702
Water temperature (K)	293
Water thickness (cm)	0.4518

OWR Specific power by cycles

OPERATING CYCLE	BURN days	Specific Power MW/Tu
1	67	199.44
2	91	188.82
3	82	178.64
4	48	260.66
5	70	164.92
6	141	207.26
7	97	211.54
8	84	173.48
9	91	206.52
10	63	280.42
11	84	271.13
12	147	218.94
13	84	264.94
14	63	224.22
15	89	210.21
16	107	296.36
17	63	300.19
DOWN	631	-
Cumulative burnup GWd/MTU	-	330.6268

BURN is the fuel irradiation time
DOWN is the decay time from reactor to measurement (cooling time)

OWR initial number densities

Component	Nuclide	NumberDensity (ats/b-cm)
Fuel	U234	1.24E-05
	U235	1.62E-03
	U238	1.05E-04
	Al	5.81E-02
Clad	Al	6.03E-02
Colant	H	6.684E-02
	O	3.335E-02

OWR measured mean % of initial U235 remaining by cycles

CYCLE	% U235
1	91.7
2	89.9
3	88.4
4	87.1
5	85.9
6	82.8
7	80.6
8	79.1
9	77.1
10	75.3
11	72.9
12	69.5
13	67.1
14	65.7
15	63.7
16	60.4
17	58.4

OWR reference calculated actinide nuclide inventory

Nuclide	Number Density (ats/b-cm)
U234	1.12E-05
U235	9.28E-04
U236	1.02E-04
U238	1.04E-04
Np237	1.07E-06
Pu238	6.03E-08
Pu239	4.51E-07
Pu240	7.46E-08
Pu241	1.23E-08
Pu242	1.51E-09
Am241	1.54E-09
Am242	4.22E-17
Am242m	3.51E-12
Am243	3.12E-11
Cm242	2.36E-12
Cm243	1.31E-13
Cm244	1.13E-12

Keyword and files

Keyword	MTRBURN
WIMS Input (.WIN)	Mtrburn
Batch Files (.BAT)	MTRB.BAT (called from supbench.bat)
Programs (.EXE<-.FOR)	MTRBURN (called from mtrb.bat) MTRB2 (called from supbench.bat)
Reference file (.REF)	MTRBURN (called from e2t2.exe)

REFERENCE

[1] WILSON, W.B., ENGLAND, T.R., GEORGE, D.C., LABAUVE, R.J., Calculation of the Actinide Nuclide Inventory and Intrinsic Neutron Source Strength of an Omega West Reactor MTR-type Spent Fuel Element, Los Alamos National Laboratory, Applied Nuclear Science Group, Informal Report T-2-IR-86-2, 12 February 1986.

V. 6. PWR Thorium pin cell numerical burnup benchmark.

H_2O-moderated ThO_2(75 w/o)-UO_2(25 w/o - 19.5 w/o U-235) mixture fuel rods.
Numerical comparison of K-infinite eigenvalue and isotopic concentrations of Actinides and fission products as a function of burnup,

The basic geometry is a square infinite lattice pincell, with zero leakage - burned to in excess of 70 MW/d/kg at constant power using multigroup transport code.

Reference numerical results

a) Variation of k_∞ as a function of burnup
b) Isotopic concentration of actinides
calculated with CASMO-4 code, a fuel assembly burnup program from Studsvik Energiteknik.

Parameters to be calculated

a) Variation of k_∞ as a function of burnup up to about 70 MWD/kg. It is recommended that the burnup steps of Ref. 1 may be used for ready comparison of the results with earlier work. These burnup values in days and in MWD/kg are given in the table below.

Burnup Step (Days)	Burnup (Days)	Burnup (MWD/kg)
0	0	0
3	3	0.114
150	153	5.835
120	273	10.411
140	513	19.563
300	813	31.004
240	1053	40.156
240	1293	49.308
60	1353	51.596
240	1593	60.749
300	1893	72.189

b) Isotopic concentration of the actinides from ^{232}Th to ^{242}Pu at 60.749 MWd/kg which is at the upper limit of discharge burnup if a 3-batch core refuelling scheme is considered.

Geometry

Parameter	Units (mm)
Fuel pellet radius	4.1274
Cladding inner radius	4.1896
Cladding outer radius	4.7609
Pin pitch	12.626

Fuel material

The fuel is a ThO_2-UO_2 mixture with the heavy metal ratio of (Th:U) being 75:25 in weight percent. UO_2 is enriched to 19.5% ^{235}U. The ^{235}U weight fraction in total heavy metal is 4.869%. The isotopic composition of fuel, clad and coolant material is given in the following table.

1.

Material	Nuclide	Weight percent (%)	Number Density (10^{24} cm^{-3})
Fuel	^{232}Th	65.909	$1.61215 * 10^{-2}$
	^{234}U	0.034	$8.24518 * 10^{-6}$
	^{235}U	4.291	$1.03615 * 10^{-3}$
	^{238}U	17.740	$4.22957 * 10^{-3}$
	^{16}O	12.026	$4.26835 * 10^{-2}$
Clad	Zr-4	100	$4.31438 * 10^{-2}$
or			
Clad*	Sn	1.5	$4.9845 * 10^{-4}$
	Fe	0.2	$1.4127 * 10^{-4}$
	Cr	0.1	$7.5866 * 10^{-5}$
	Ni	0.007	$4.7051 * 10^{-6}$
	Zr	98.193	$4.2461 * 10^{-2}$
Coolant	^{1}H	11.19	$4.71053 * 10^{-2}$
	^{16}O	88.81	$2.35662 * 10^{-2}$

* Zr-4 composition is taken from S. Glasstone and A. Sesonske, "Nuclear Reactor Engineering", 3rd Edition, Van Nostrand Reinhold Co., New York, 1981.

Miscellaneous data

The density, temperature and heat rating data are as follows.

Parameter	
Fuel density (g/cm^3)	9.424
Cladding density (g/cm^3)	6.505
Coolant density (g/cm^3)	0.705
Fuel temperature (K)	900
Cladding temperature (K)	621.1
Coolant temperature (K)	583.1
Power density (kW/kgHM)	38.1347

REFERENCE

[1] ZHAO, X., PILAT, E. E., WEAVER, K. D., HEJZLAR, P., A PWR Thorium Pin Cell Burnup Benchmark, Session XI-C, PHYSOR' 2000 International Conference - American Nuclear (ANS) International Topical Meeting on "Advances in Reactor Physics and Mathematics and Computation into the Next Millennium", 7-11 May 2000, Pittsburgh, Pennsylvania, USA.

V.7. TRIGA-IJS Whole Core Calculation Benchmark

Two different benchmark core loading patterns (core number 133 and core number 134) with two different burnup values were considered in calculations. Core configurations are extensively described in Refs. [1 - 3].

TRIGLAV program package was used in the calculation [4]. The unit cell calculations in TRIGLAV are performed with WIMSD-5B code. WIMS input generation and output processing is completely automatically in the TRIGLAV package. The whole core calculation is performed in diffusion approximation in two-dimensional geometry using TRIGA2D module of TRIGLAV.

TRIGLAV program package with WIMS/D-4 is available trough NEA Data Bank [5]. In this benchmark modified updated version of TRIGLAV was used with WIMSD-5B. This version of TRIGLAV is currently available at Jožef Stefan Institute. WIMS-D libraries were taken from WLUP home page [6].

Benchmark run

Updated TRIGLAV code for MS-DOS platforms (runs also under Windows 95, 98 and 2000) is in archive `triglav5.zip`, together with test run case inputs (`testTRIGLAV.INP` and `testELEM.INP`). Test inputs should be copied on `triglav.inp` and `elem.inp` files. The code is run using batch procedure `triglav.bat`. The various WIMS-D libraries and WIMSD-5B code should be in WIMS subdirectory. WIMSD-5B library for TRIGLAV calculation is selected in `triglav.bat` file in lines from 41 to 59.

Benchmark filenames

Benchmark files in file `TRIGAbenchmark.zip`.

Fresh core 133	measured k_{eff} 1.00277 ± 0.00015	Fresh core 134	measured k_{eff} 1.0202 ± 0.002
`bM133.inp` `bM133elem.inp`	`triglav.inp` `elem.inp`	`bM134.inp` `bM134elem.inp`	`triglav.inp` `elem.inp`
Burned core 133 average core burnup 1.214 MWd	measured k_{eff} = 0.9842 ± 0.0016	Burned core 134 average core burnup 1.139 MWd	measured k_{eff} 1.00460 ± 0.00015
`bMb1331.inp` `bMb1331elem.inp`	`triglav.inp` `elem.inp`	`bMb1341.inp` `bMb1341elem.inp`	`triglav.inp` `elem.inp`

NOTE: TRIGLAV is 2-D program and k_{eff} calculations are relative due to free axial buckling parameter. In this benchmark buckling was set after first calculation (bM133 with enedf65.bin) to 0.0052 cm^{-2} and was fixed to his value in all other calculations.

NOTE: Test output files are also in file `TRIGAbenchmark.zip`.

REFERENCES

[1] RAVNIK, M., JERAJ, R., TRIGA Mark II Benchmark Critical Experiments, In: International Handbook of Evaluated Critical Safety Benchmark Experiments, IEU-OMP-THERM-003, 1999, OECD-Nuclear Energy Agency, France.

[2] PERŠIČ, A., RAVNIK, M., ŽAGAR, T., TRIGA Mark II Criticality Benchmark Experiment with Burned Fuel, Nucl. Technol., 132, 325-338 (2000).

[3] JERAJ, R. ŽAGAR. T., RAVNIK, M., Monte Carlo Simulation of the TRIGA Mark II Benchmark with Burned Fuel, Nucl. Technol., 137, 169-180 (2002).

[4] PERŠIČ, A., SLAVIČ, S., RAVNIK, M., ŽAGAR, T., TRIGLAV - A Program Package for Research Reactor Calculations, IJS-DP-7862, 1998, Jožef Stefan Institute, Ljubljana, Slovenia.

[5] PERŠIČ, A., SLAVIČ, S., RAVNIK, M., ŽAGAR, T., TRIGLAV - A Program Package for Research Reactor Calculations, IAEA 1370/01, 1998, OECD-Nuclear Energy Agency Data Bank, France.

[6] WLUP - WIMS Library Update Project, IAEA Coordinated Research Project, 2002.

WIMSD-5B BENCHMARK RESULTS FOR ALL LIBRARIES

Output of SMRLIB program is included, with results and comparisons of all benchmarks results with all libraries included on WLUP.

```
 #
 # WLUP STANDARD BENCHMARK SEQUENCE
 # --------------------------------
 #
 # Uranium criticality benchmarks
 # ------------------------------
 SMRDIF - Compare lattice spectr.indices
 =======================================

 Reference file                      : expcrume.ref
 Compared  file                      : iaeagx.smr
 Compared  file                      : iaea.smr
 Compared  file                      : wdn29.smr
 Compared  file                      : endfb6gx.smr
 Compared  file                      : endfb6.smr
 Compared  file                      : jendl3gx.smr
 Compared  file                      : jendl3.smr
 Compared  file                      : jef22gx.smr
 Compared  file                      : jef22.smr

   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
aecl_um    1.00000(~.24)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00492(0.49)  0.704        0.0654        0.1401        1.090
      iaea 1.00259(0.26)  0.719        0.0657        0.1389        1.100
     wdn29 1.01356(1.33)  0.704        0.0655        0.1418        1.090
  endfb6gx 1.00178(0.18)  0.703        0.0652        0.1430        1.102
    endfb6 0.99963(-.04)  0.717        0.0654        0.1420        1.112
  jendl3gx 1.00013(0.01)  0.705        0.0650        0.1376        1.100
    jendl3 0.99808(-.19)  0.720        0.0652        0.1367        1.109
   jef22gx 1.00043(0.04)  0.701        0.0656        0.1400        1.102
     jef22 0.99653(-.35)  0.717        0.0658        0.1376        1.113

aere_uma1  1.00000(~.80)  0.000        0.0000        0.0000        0.000
    iaeagx 1.01481(1.45)  2.366        0.2018        0.2031        1.493
      iaea 1.01105(1.09)  2.404        0.2025        0.2026        1.510
     wdn29 1.01994(1.94)  2.360        0.2012        0.2067        1.489
  endfb6gx 1.00930(0.92)  2.371        0.2020        0.2107        1.516
    endfb6 1.00596(0.59)  2.407        0.2026        0.2106        1.532
  jendl3gx 1.00676(0.67)  2.373        0.2005        0.1998        1.511
    jendl3 1.00343(0.34)  2.409        0.2011        0.1997        1.526
   jef22gx 1.01119(1.10)  2.357        0.2023        0.2037        1.508
     jef22 1.00548(0.54)  2.397        0.2029        0.2015        1.525

aere_uma2  1.00000(~.60)  0.000        0.0000        0.0000        0.000
    iaeagx 1.01313(1.29)  2.039        0.1843        0.2012        1.369
      iaea 1.00760(0.75)  2.092        0.1855        0.2013        1.392
     wdn29 1.01515(1.48)  2.055        0.1846        0.2054        1.373
  endfb6gx 1.00787(0.78)  2.043        0.1843        0.2089        1.389
    endfb6 1.00273(0.27)  2.093        0.1854        0.2093        1.411
  jendl3gx 1.00547(0.54)  2.046        0.1829        0.1979        1.384
    jendl3 1.00033(0.03)  2.096        0.1839        0.1983        1.406
   jef22gx 1.00871(0.86)  2.033        0.1848        0.2017        1.382
     jef22 1.00130(0.13)  2.087        0.1858        0.2000        1.406

aere_uma3  1.00000(~.33)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99957(-.04)  1.296        0.1168        0.1594        1.086
      iaea 0.99668(-.33)  1.324        0.1173        0.1585        1.099
     wdn29 0.99945(-.06)  1.301        0.1168        0.1623        1.087
  endfb6gx 0.99318(-.69)  1.296        0.1165        0.1641        1.100
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    endfb6 0.99045(-.97)  1.322        0.1170        0.1635        1.112
  jendl3gx 0.99383(-.62)  1.300        0.1159        0.1566        1.097
    jendl3 0.99115(-.90)  1.325        0.1164        0.1560        1.109
   jef22gx 0.99482(-.52)  1.291        0.1170        0.1593        1.097
     jef22 0.99060(-.95)  1.319        0.1175        0.1572        1.110

aere_uma4  1.00000(~.27)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99910(-.09)  0.974        0.0878        0.1370        0.954
      iaea 0.99726(-.27)  0.993        0.0882        0.1360        0.964
     wdn29 1.00127(0.13)  0.975        0.0878        0.1391        0.954
  endfb6gx 0.99353(-.65)  0.973        0.0876        0.1403        0.965
    endfb6 0.99178(-.83)  0.990        0.0879        0.1394        0.974
  jendl3gx 0.99460(-.54)  0.976        0.0872        0.1345        0.963
    jendl3 0.99292(-.72)  0.994        0.0875        0.1338        0.972
   jef22gx 0.99436(-.57)  0.970        0.0880        0.1367        0.964
     jef22 0.99143(-.87)  0.990        0.0883        0.1346        0.974

aere_uma5  1.00000(~.28)  0.000        0.0000        0.0000        0.000
    iaeagx 1.01215(1.19)  0.988        0.0895        0.1381        0.960
      iaea 1.00963(0.95)  1.011        0.0899        0.1371        0.971
     wdn29 1.01540(1.50)  0.992        0.0895        0.1402        0.961
  endfb6gx 1.00722(0.71)  0.987        0.0893        0.1413        0.971
    endfb6 1.00484(0.48)  1.008        0.0896        0.1405        0.982
  jendl3gx 1.00763(0.75)  0.990        0.0888        0.1355        0.969
    jendl3 1.00530(0.53)  1.011        0.0891        0.1348        0.979
   jef22gx 1.00726(0.72)  0.984        0.0897        0.1378        0.970
     jef22 1.00351(0.35)  1.007        0.0900        0.1357        0.982

hw_uma1    1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00218(0.22)  1.495        0.1370        0.1734        1.136
      iaea 0.99773(-.23)  1.536        0.1378        0.1731        1.154
     wdn29 1.00031(0.03)  1.511        0.1373        0.1775        1.141
  endfb6gx 0.99573(-.43)  1.495        0.1368        0.1793        1.151
    endfb6 0.99151(-.86)  1.534        0.1375        0.1793        1.168
  jendl3gx 0.99593(-.41)  1.499        0.1358        0.1706        1.148
    jendl3 0.99172(-.84)  1.538        0.1366        0.1706        1.165
   jef22gx 0.99801(-.20)  1.488        0.1371        0.1736        1.147
     jef22 0.99216(-.79)  1.530        0.1379        0.1719        1.166

hw_uma2    1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99978(-.02)  1.246        0.1143        0.1583        1.040
      iaea 0.99625(-.38)  1.278        0.1149        0.1577        1.055
     wdn29 0.99877(-.12)  1.257        0.1145        0.1616        1.044
  endfb6gx 0.99357(-.65)  1.245        0.1140        0.1631        1.053
    endfb6 0.99021(-.99)  1.276        0.1146        0.1627        1.067
  jendl3gx 0.99436(-.57)  1.249        0.1133        0.1556        1.050
    jendl3 0.99102(-.91)  1.279        0.1139        0.1553        1.064
   jef22gx 0.99555(-.45)  1.240        0.1144        0.1583        1.050
     jef22 0.99079(-.93)  1.273        0.1150        0.1564        1.066

hw_uma3    1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00240(0.24)  1.076        0.0988        0.1470        0.973
      iaea 0.99952(-.05)  1.103        0.0993        0.1462        0.985
     wdn29 1.00285(0.28)  1.084        0.0989        0.1497        0.975
  endfb6gx 0.99663(-.34)  1.074        0.0985        0.1510        0.984
    endfb6 0.99389(-.62)  1.100        0.0990        0.1504        0.996
  jendl3gx 0.99757(-.24)  1.078        0.0980        0.1444        0.982
    jendl3 0.99486(-.52)  1.104        0.0984        0.1439        0.994
   jef22gx 0.99814(-.19)  1.070        0.0989        0.1468        0.982
     jef22 0.99415(-.59)  1.099        0.0993        0.1449        0.995

hw_uma4    1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99757(-.24)  0.852        0.0783        0.1319        0.881
      iaea 0.99561(-.44)  0.872        0.0787        0.1310        0.891
     wdn29 1.00102(0.10)  0.857        0.0783        0.1339        0.883
  endfb6gx 0.99275(-.73)  0.850        0.0781        0.1348        0.891
    endfb6 0.99090(-.92)  0.869        0.0784        0.1341        0.900
  jendl3gx 0.99359(-.65)  0.854        0.0777        0.1295        0.889
    jendl3 0.99179(-.83)  0.872        0.0780        0.1288        0.898
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jef22gx	0.99327(-.68)	0.848	0.0784	0.1316	0.890
jef22	0.99032(-.98)	0.869	0.0787	0.1296	0.901
hw_umb1	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99973(-.03)	1.506	0.1304	0.1553	1.079
iaea	0.99614(-.39)	1.540	0.1310	0.1546	1.093
wdn29	0.99726(-.27)	1.515	0.1304	0.1586	1.081
endfb6gx	0.99254(-.75)	1.505	0.1303	0.1598	1.093
endfb6	0.98913(-1.1)	1.538	0.1308	0.1594	1.107
jendl3gx	0.99412(-.59)	1.509	0.1295	0.1526	1.089
jendl3	0.99072(-.94)	1.541	0.1300	0.1522	1.103
jef22gx	0.99553(-.45)	1.498	0.1306	0.1551	1.089
jef22	0.99072(-.94)	1.533	0.1312	0.1533	1.104
hw_umb2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99891(-.11)	1.091	0.0943	0.1292	0.925
iaea	0.99674(-.33)	1.113	0.0946	0.1283	0.934
wdn29	0.99813(-.19)	1.094	0.0943	0.1315	0.925
endfb6gx	0.99244(-.76)	1.089	0.0940	0.1321	0.935
endfb6	0.99037(-.98)	1.110	0.0944	0.1313	0.945
jendl3gx	0.99477(-.53)	1.093	0.0936	0.1268	0.933
jendl3	0.99272(-.74)	1.113	0.0939	0.1261	0.942
jef22gx	0.99475(-.53)	1.085	0.0944	0.1287	0.934
jef22	0.99168(-.84)	1.108	0.0948	0.1268	0.944
hw_umb3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00577(0.57)	0.995	0.0859	0.1223	0.888
iaea	1.00393(0.39)	1.014	0.0862	0.1214	0.896
wdn29	1.00605(0.60)	0.997	0.0859	0.1244	0.888
endfb6gx	0.99970(-.03)	0.993	0.0857	0.1249	0.898
endfb6	0.99794(-.21)	1.011	0.0860	0.1240	0.906
jendl3gx	1.00197(0.20)	0.996	0.0853	0.1200	0.895
jendl3	1.00022(0.02)	1.014	0.0856	0.1193	0.904
jef22gx	1.00162(0.16)	0.990	0.0861	0.1219	0.896
jef22	0.99891(-.11)	1.010	0.0864	0.1199	0.906
hw_umb4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00475(0.47)	2.084	0.1934	0.2062	1.272
iaea	0.99963(-.04)	2.139	0.1944	0.2064	1.294
wdn29	1.00259(0.26)	2.108	0.1936	0.2116	1.280
endfb6gx	0.99837(-.16)	2.086	0.1933	0.2150	1.291
endfb6	0.99362(-.64)	2.138	0.1942	0.2155	1.312
jendl3gx	0.99683(-.32)	2.091	0.1915	0.2030	1.287
jendl3	0.99208(-.80)	2.143	0.1924	0.2035	1.309
jef22gx	1.00040(0.04)	2.075	0.1935	0.2069	1.284
jef22	0.99355(-.65)	2.132	0.1944	0.2054	1.308
hw_umb5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00115(0.11)	1.371	0.1280	0.1694	1.026
iaea	0.99812(-.19)	1.403	0.1285	0.1688	1.041
wdn29	1.00044(0.04)	1.382	0.1280	0.1729	1.030
endfb6gx	0.99494(-.51)	1.369	0.1278	0.1751	1.039
endfb6	0.99210(-.80)	1.400	0.1282	0.1747	1.053
jendl3gx	0.99526(-.48)	1.375	0.1268	0.1665	1.037
jendl3	0.99245(-.76)	1.405	0.1273	0.1662	1.050
jef22gx	0.99654(-.35)	1.364	0.1282	0.1694	1.036
jef22	0.99220(-.79)	1.398	0.1286	0.1675	1.051
hw_umb6	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99578(-.42)	1.036	0.0971	0.1496	0.902
iaea	0.99391(-.61)	1.059	0.0973	0.1486	0.913
wdn29	0.99877(-.12)	1.041	0.0968	0.1519	0.904
endfb6gx	0.99065(-.95)	1.033	0.0967	0.1537	0.912
endfb6	0.98892(-1.1)	1.054	0.0970	0.1529	0.922
jendl3gx	0.99110(-.90)	1.038	0.0962	0.1469	0.911
jendl3	0.98940(-1.1)	1.059	0.0964	0.1462	0.920
jef22gx	0.99121(-.89)	1.031	0.0972	0.1494	0.911
jef22	0.98821(-1.2)	1.055	0.0974	0.1473	0.923

bnl_uma1	1.00000(~.16)	0.000	0.0000	0.0000	0.000
iaeagx	0.99269(-.74)	1.445	0.0983	0.1128	1.061
iaea	0.99269(-.74)	1.449	0.0980	0.1116	1.063
wdn29	0.99463(-.54)	1.429	0.0977	0.1147	1.054
endfb6gx	0.98656(-1.4)	1.441	0.0980	0.1146	1.072
endfb6	0.98669(-1.4)	1.444	0.0977	0.1135	1.074
jendl3gx	0.98925(-1.1)	1.443	0.0978	0.1108	1.069
jendl3	0.98940(-1.1)	1.445	0.0975	0.1098	1.071
jef22gx	0.99029(-.98)	1.433	0.0984	0.1124	1.069
jef22	0.98945(-1.1)	1.438	0.0981	0.1102	1.072
bnl_uma2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99401(-.60)	1.026	0.0670	0.0862	0.899
iaea	0.99472(-.53)	1.026	0.0668	0.0850	0.899
wdn29	0.99618(-.38)	1.013	0.0668	0.0876	0.893
endfb6gx	0.98889(-1.1)	1.022	0.0667	0.0869	0.907
endfb6	0.98966(-1.0)	1.021	0.0665	0.0859	0.907
jendl3gx	0.99196(-.81)	1.023	0.0667	0.0845	0.905
jendl3	0.99275(-.73)	1.023	0.0665	0.0835	0.905
jef22gx	0.99180(-.83)	1.017	0.0670	0.0856	0.906
jef22	0.99198(-.81)	1.018	0.0668	0.0837	0.907
bnl_uma3	1.00000(~.12)	0.000	0.0000	0.0000	0.000
iaeagx	0.99563(-.44)	0.812	0.0518	0.0716	0.812
iaea	0.99665(-.34)	0.810	0.0517	0.0705	0.812
wdn29	0.99850(-.15)	0.799	0.0517	0.0727	0.808
endfb6gx	0.99138(-.87)	0.808	0.0515	0.0719	0.819
endfb6	0.99242(-.77)	0.806	0.0514	0.0710	0.819
jendl3gx	0.99431(-.57)	0.809	0.0516	0.0701	0.817
jendl3	0.99537(-.47)	0.807	0.0515	0.0692	0.817
jef22gx	0.99348(-.66)	0.804	0.0518	0.0709	0.819
jef22	0.99408(-.60)	0.803	0.0517	0.0693	0.819
bnl_uma4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99640(-.36)	1.698	0.1271	0.1395	1.149
iaea	0.99519(-.48)	1.712	0.1270	0.1384	1.155
wdn29	0.99729(-.27)	1.687	0.1268	0.1420	1.143
endfb6gx	0.98952(-1.1)	1.696	0.1269	0.1428	1.163
endfb6	0.98851(-1.2)	1.708	0.1268	0.1418	1.168
jendl3gx	0.99146(-.86)	1.698	0.1264	0.1371	1.159
jendl3	0.99046(-.97)	1.710	0.1263	0.1362	1.164
jef22gx	0.99307(-.70)	1.687	0.1273	0.1393	1.158
jef22	0.99073(-.94)	1.702	0.1272	0.1370	1.165
bnl_uma5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99243(-.76)	0.920	0.0658	0.0900	0.854
iaea	0.99274(-.73)	0.924	0.0658	0.0889	0.856
wdn29	0.99383(-.62)	0.911	0.0657	0.0914	0.850
endfb6gx	0.98706(-1.3)	0.917	0.0656	0.0910	0.863
endfb6	0.98742(-1.3)	0.921	0.0656	0.0900	0.864
jendl3gx	0.99019(-.99)	0.919	0.0655	0.0882	0.860
jendl3	0.99056(-.96)	0.922	0.0655	0.0873	0.862
jef22gx	0.98941(-1.1)	0.914	0.0659	0.0894	0.862
jef22	0.98922(-1.1)	0.918	0.0659	0.0875	0.864
bnl_uma6	1.00000(~.17)	0.000	0.0000	0.0000	0.000
iaeagx	0.99856(-.14)	2.277	0.1863	0.1819	1.341
iaea	0.99495(-.51)	2.315	0.1869	0.1813	1.356
wdn29	0.99912(-.09)	2.277	0.1859	0.1856	1.339
endfb6gx	0.99163(-.85)	2.279	0.1864	0.1880	1.360
endfb6	0.98835(-1.2)	2.315	0.1869	0.1877	1.374
jendl3gx	0.99154(-.86)	2.282	0.1851	0.1789	1.355
jendl3	0.98826(-1.2)	2.316	0.1857	0.1787	1.369
jef22gx	0.99485(-.52)	2.266	0.1867	0.1822	1.352
jef22	0.98965(-1.1)	2.305	0.1872	0.1801	1.368
bnl_uma7	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99081(-.93)	0.655	0.0514	0.0831	0.746
iaea	0.99087(-.93)	0.660	0.0515	0.0820	0.749

wdn29	0.99418(-.59)	0.649	0.0515	0.0842	0.744
endfb6gx	0.98642(-1.4)	0.652	0.0512	0.0838	0.753
endfb6	0.98651(-1.4)	0.657	0.0513	0.0829	0.756
jendl3gx	0.98895(-1.1)	0.654	0.0511	0.0814	0.752
jendl3	0.98907(-1.1)	0.659	0.0512	0.0806	0.754
jef22gx	0.98707(-1.3)	0.651	0.0515	0.0824	0.754
jef22	0.98665(-1.4)	0.657	0.0516	0.0807	0.757
bnl_umb1	1.00000(~.49)	0.000	0.0000	0.0000	0.000
iaeagx	0.99304(-.70)	1.873	0.1317	0.1358	1.205
iaea	0.99257(-.75)	1.880	0.1313	0.1346	1.209
wdn29	0.99560(-.44)	1.854	0.1307	0.1383	1.197
endfb6gx	0.98653(-1.4)	1.870	0.1315	0.1387	1.219
endfb6	0.98627(-1.4)	1.875	0.1311	0.1377	1.222
jendl3gx	0.98846(-1.2)	1.871	0.1311	0.1336	1.214
jendl3	0.98821(-1.2)	1.877	0.1307	0.1326	1.217
jef22gx	0.99057(-.96)	1.859	0.1319	0.1357	1.214
jef22	0.98898(-1.1)	1.867	0.1315	0.1334	1.218
bnl_umb2	1.00000(~.17)	0.000	0.0000	0.0000	0.000
iaeagx	0.99614(-.39)	1.455	0.0990	0.1124	1.054
iaea	0.99613(-.39)	1.459	0.0987	0.1111	1.056
wdn29	0.99805(-.20)	1.439	0.0984	0.1143	1.047
endfb6gx	0.98998(-1.0)	1.451	0.0987	0.1141	1.064
endfb6	0.99011(-1.0)	1.454	0.0984	0.1130	1.066
jendl3gx	0.99269(-.74)	1.453	0.0985	0.1103	1.061
jendl3	0.99283(-.72)	1.456	0.0982	0.1093	1.063
jef22gx	0.99373(-.63)	1.444	0.0991	0.1120	1.062
jef22	0.99289(-.72)	1.448	0.0988	0.1098	1.064
bnl_umb3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99526(-.48)	1.033	0.0674	0.0859	0.892
iaea	0.99598(-.40)	1.034	0.0673	0.0848	0.893
wdn29	0.99735(-.27)	1.020	0.0672	0.0873	0.887
endfb6gx	0.99010(-1.0)	1.029	0.0671	0.0867	0.900
endfb6	0.99088(-.92)	1.029	0.0670	0.0856	0.900
jendl3gx	0.99324(-.68)	1.031	0.0671	0.0842	0.898
jendl3	0.99403(-.60)	1.030	0.0670	0.0833	0.898
jef22gx	0.99307(-.70)	1.025	0.0675	0.0853	0.899
jef22	0.99326(-.68)	1.025	0.0673	0.0834	0.900
bnl_umb4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99433(-.57)	0.818	0.0521	0.0714	0.806
iaea	0.99537(-.47)	0.816	0.0521	0.0703	0.806
wdn29	0.99708(-.29)	0.805	0.0521	0.0725	0.801
endfb6gx	0.99004(-1.0)	0.814	0.0519	0.0717	0.813
endfb6	0.99111(-.90)	0.812	0.0518	0.0708	0.812
jendl3gx	0.99306(-.70)	0.815	0.0519	0.0699	0.811
jendl3	0.99414(-.59)	0.813	0.0518	0.0690	0.810
jef22gx	0.99222(-.79)	0.810	0.0522	0.0708	0.813
jef22	0.99287(-.72)	0.809	0.0521	0.0691	0.813
bnl_umb5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99962(-.04)	1.710	0.1280	0.1390	1.141
iaea	0.99839(-.16)	1.724	0.1279	0.1378	1.147
wdn29	1.00047(0.05)	1.699	0.1276	0.1415	1.136
endfb6gx	0.99270(-.74)	1.708	0.1278	0.1422	1.155
endfb6	0.99167(-.84)	1.721	0.1277	0.1413	1.160
jendl3gx	0.99468(-.54)	1.711	0.1273	0.1365	1.151
jendl3	0.99366(-.64)	1.723	0.1272	0.1357	1.156
jef22gx	0.99629(-.37)	1.699	0.1282	0.1387	1.151
jef22	0.99394(-.61)	1.714	0.1281	0.1364	1.157
bnl_umb6	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99643(-.36)	1.319	0.0965	0.1157	0.998
iaea	0.99591(-.41)	1.327	0.0965	0.1146	1.002
wdn29	0.99687(-.31)	1.308	0.0963	0.1177	0.993
endfb6gx	0.98991(-1.0)	1.316	0.0963	0.1178	1.009
endfb6	0.98950(-1.1)	1.324	0.0962	0.1168	1.013

jendl3gx	0.99275(-.73)	1.318	0.0960	0.1136	1.006
jendl3	0.99235(-.77)	1.325	0.0960	0.1126	1.010
jef22gx	0.99321(-.69)	1.309	0.0967	0.1152	1.007
jef22	0.99187(-.82)	1.319	0.0966	0.1131	1.011
bnl_umb7	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99616(-.39)	0.927	0.0662	0.0896	0.848
iaea	0.99647(-.35)	0.931	0.0663	0.0885	0.850
wdn29	0.99755(-.25)	0.917	0.0662	0.0910	0.844
endfb6gx	0.99077(-.94)	0.924	0.0660	0.0906	0.856
endfb6	0.99113(-.90)	0.927	0.0660	0.0896	0.858
jendl3gx	0.99394(-.61)	0.925	0.0659	0.0878	0.854
jendl3	0.99431(-.57)	0.928	0.0659	0.0869	0.855
jef22gx	0.99316(-.69)	0.920	0.0663	0.0890	0.855
jef22	0.99296(-.71)	0.924	0.0664	0.0871	0.858
bnl_umb8	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99321(-.69)	0.731	0.0516	0.0757	0.769
iaea	0.99387(-.62)	0.732	0.0516	0.0747	0.770
wdn29	0.99572(-.43)	0.721	0.0516	0.0769	0.766
endfb6gx	0.98874(-1.1)	0.728	0.0514	0.0762	0.776
endfb6	0.98943(-1.1)	0.729	0.0514	0.0753	0.777
jendl3gx	0.99171(-.84)	0.729	0.0514	0.0742	0.775
jendl3	0.99243(-.76)	0.730	0.0514	0.0733	0.775
jef22gx	0.99023(-.99)	0.725	0.0517	0.0751	0.776
jef22	0.99053(-.96)	0.727	0.0517	0.0734	0.778
bnl_umb9	1.00000(~.17)	0.000	0.0000	0.0000	0.000
iaeagx	1.00154(0.15)	2.295	0.1876	0.1812	1.332
iaea	0.99790(-.21)	2.332	0.1882	0.1806	1.347
wdn29	1.00205(0.20)	2.295	0.1872	0.1849	1.330
endfb6gx	0.99456(-.55)	2.297	0.1877	0.1873	1.351
endfb6	0.99126(-.88)	2.332	0.1882	0.1870	1.365
jendl3gx	0.99452(-.55)	2.299	0.1865	0.1782	1.346
jendl3	0.99121(-.89)	2.334	0.1870	0.1780	1.360
jef22gx	0.99783(-.22)	2.284	0.1881	0.1815	1.344
jef22	0.99261(-.75)	2.323	0.1885	0.1794	1.360
bnl_umb10	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99530(-.47)	1.187	0.0944	0.1199	0.945
iaea	0.99394(-.61)	1.203	0.0946	0.1188	0.952
wdn29	0.99440(-.56)	1.184	0.0945	0.1220	0.943
endfb6gx	0.98859(-1.2)	1.185	0.0941	0.1222	0.956
endfb6	0.98732(-1.3)	1.200	0.0943	0.1213	0.962
jendl3gx	0.99149(-.86)	1.188	0.0938	0.1176	0.953
jendl3	0.99022(-.99)	1.202	0.0940	0.1168	0.960
jef22gx	0.99152(-.86)	1.180	0.0945	0.1194	0.954
jef22	0.98934(-1.1)	1.197	0.0948	0.1173	0.961
bnl_umb11	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99464(-.54)	0.833	0.0656	0.0954	0.809
iaea	0.99433(-.57)	0.842	0.0657	0.0943	0.813
wdn29	0.99590(-.41)	0.828	0.0657	0.0968	0.807
endfb6gx	0.98922(-1.1)	0.830	0.0654	0.0966	0.817
endfb6	0.98895(-1.1)	0.838	0.0655	0.0956	0.821
jendl3gx	0.99222(-.79)	0.833	0.0652	0.0935	0.815
jendl3	0.99196(-.81)	0.840	0.0653	0.0926	0.819
jef22gx	0.99100(-.91)	0.828	0.0657	0.0947	0.817
jef22	0.99015(-1.0)	0.837	0.0658	0.0929	0.821
bnl_umb12	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99475(-.53)	0.659	0.0517	0.0827	0.740
iaea	0.99481(-.52)	0.664	0.0518	0.0817	0.743
wdn29	0.99812(-.19)	0.653	0.0518	0.0839	0.738
endfb6gx	0.99034(-.98)	0.656	0.0515	0.0834	0.747
endfb6	0.99043(-.97)	0.661	0.0516	0.0825	0.750
jendl3gx	0.99291(-.72)	0.659	0.0514	0.0811	0.745
jendl3	0.99301(-.71)	0.663	0.0515	0.0802	0.748
jef22gx	0.99101(-.91)	0.655	0.0518	0.0821	0.747

jef22	0.99059(-.95)	0.661	0.0519	0.0804	0.750
bnl_umb13	1.00000(~.12)	0.000	0.0000	0.0000	0.000
iaeagx	0.99750(-.25)	1.645	0.1374	0.1545	1.109
iaea	0.99426(-.58)	1.676	0.1379	0.1538	1.122
wdn29	0.99523(-.48)	1.650	0.1374	0.1578	1.110
endfb6gx	0.99009(-1.0)	1.644	0.1373	0.1590	1.123
endfb6	0.98704(-1.3)	1.674	0.1377	0.1585	1.136
jendl3gx	0.99183(-.83)	1.647	0.1365	0.1518	1.120
jendl3	0.98878(-1.1)	1.677	0.1370	0.1514	1.132
jef22gx	0.99340(-.67)	1.636	0.1377	0.1544	1.119
jef22	0.98894(-1.1)	1.669	0.1382	0.1524	1.133
bnl_umb14	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99621(-.38)	0.983	0.0812	0.1129	0.866
iaea	0.99500(-.50)	0.998	0.0815	0.1119	0.873
wdn29	0.99616(-.39)	0.981	0.0813	0.1148	0.865
endfb6gx	0.99004(-1.0)	0.980	0.0810	0.1150	0.876
endfb6	0.98890(-1.1)	0.994	0.0813	0.1141	0.882
jendl3gx	0.99289(-.72)	0.983	0.0807	0.1107	0.873
jendl3	0.99176(-.83)	0.997	0.0810	0.1099	0.880
jef22gx	0.99224(-.79)	0.977	0.0814	0.1123	0.875
jef22	0.99032(-.98)	0.993	0.0817	0.1104	0.882
bnl_umb15	1.00000(~.29)	0.000	0.0000	0.0000	0.000
iaeagx	0.99270(-.74)	0.833	0.0688	0.1025	0.809
iaea	0.99201(-.81)	0.845	0.0690	0.1014	0.814
wdn29	0.99406(-.60)	0.830	0.0688	0.1040	0.807
endfb6gx	0.98720(-1.3)	0.831	0.0685	0.1040	0.817
endfb6	0.98655(-1.4)	0.841	0.0687	0.1031	0.822
jendl3gx	0.99000(-1.0)	0.833	0.0683	0.1005	0.815
jendl3	0.98936(-1.1)	0.844	0.0685	0.0996	0.820
jef22gx	0.98878(-1.1)	0.828	0.0689	0.1019	0.817
jef22	0.98747(-1.3)	0.841	0.0691	0.1000	0.822
bnl_umb16	1.00000(~.16)	0.000	0.0000	0.0000	0.000
iaeagx	0.99081(-.93)	0.654	0.0540	0.0897	0.738
iaea	0.99054(-.96)	0.662	0.0541	0.0887	0.742
wdn29	0.99493(-.51)	0.650	0.0540	0.0909	0.736
endfb6gx	0.98641(-1.4)	0.652	0.0537	0.0907	0.745
endfb6	0.98618(-1.4)	0.659	0.0539	0.0897	0.749
jendl3gx	0.98867(-1.2)	0.654	0.0536	0.0880	0.743
jendl3	0.98848(-1.2)	0.661	0.0538	0.0871	0.747
jef22gx	0.98674(-1.4)	0.650	0.0541	0.0891	0.746
jef22	0.98592(-1.4)	0.659	0.0542	0.0873	0.750
aere_umb1	1.00000(~.70)	0.000	0.0000	0.0000	0.000
iaeagx	1.00249(0.25)	1.508	0.1340	0.1525	0.951
iaea	0.99972(-.03)	1.541	0.1347	0.1517	0.963
wdn29	0.99896(-.10)	1.517	0.1341	0.1556	0.952
endfb6gx	0.99474(-.53)	1.507	0.1338	0.1571	0.962
endfb6	0.99208(-.80)	1.537	0.1344	0.1566	0.974
jendl3gx	0.99708(-.29)	1.511	0.1328	0.1497	0.960
jendl3	0.99444(-.56)	1.541	0.1335	0.1493	0.971
jef22gx	0.99775(-.23)	1.501	0.1342	0.1522	0.959
jef22	0.99384(-.62)	1.535	0.1348	0.1503	0.972
aere_umb2	1.00000(~.25)	0.000	0.0000	0.0000	0.000
iaeagx	1.00315(0.31)	1.129	0.1005	0.1306	0.827
iaea	1.00152(0.15)	1.152	0.1009	0.1296	0.836
wdn29	1.00252(0.25)	1.133	0.1004	0.1328	0.828
endfb6gx	0.99648(-.35)	1.127	0.1002	0.1338	0.837
endfb6	0.99489(-.51)	1.148	0.1006	0.1330	0.845
jendl3gx	0.99912(-.09)	1.131	0.0996	0.1282	0.835
jendl3	0.99756(-.24)	1.152	0.1000	0.1275	0.843
jef22gx	0.99859(-.14)	1.123	0.1006	0.1301	0.836
jef22	0.99608(-.39)	1.147	0.1010	0.1282	0.845
bnl_umc1	1.00000(~.10)	0.000	0.0000	0.0000	0.000

iaeagx	0.99097(-.92)	0.880	0.0560	0.0695	0.746
iaea	0.99220(-.79)	0.878	0.0559	0.0685	0.746
wdn29	0.99269(-.74)	0.867	0.0558	0.0706	0.742
endfb6gx	0.98635(-1.4)	0.876	0.0557	0.0698	0.753
endfb6	0.98760(-1.3)	0.874	0.0556	0.0689	0.752
jendl3gx	0.99011(-1.0)	0.877	0.0557	0.0680	0.751
jendl3	0.99134(-.88)	0.875	0.0556	0.0672	0.750
jef22gx	0.98915(-1.1)	0.872	0.0560	0.0688	0.752
jef22	0.99016(-1.0)	0.871	0.0559	0.0672	0.752
bnl_umc2	1.00000(~.21)	0.000	0.0000	0.0000	0.000
iaeagx	0.99890(-.11)	1.679	0.1341	0.1393	1.010
iaea	0.99655(-.35)	1.705	0.1345	0.1384	1.020
wdn29	0.99580(-.42)	1.680	0.1341	0.1422	1.009
endfb6gx	0.99097(-.92)	1.677	0.1339	0.1429	1.022
endfb6	0.98877(-1.1)	1.702	0.1343	0.1422	1.032
jendl3gx	0.99398(-.61)	1.680	0.1333	0.1368	1.019
jendl3	0.99177(-.83)	1.704	0.1336	0.1362	1.028
jef22gx	0.99507(-.50)	1.669	0.1344	0.1390	1.019
jef22	0.99170(-.84)	1.696	0.1347	0.1369	1.029
bnl_umd1	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99841(-.16)	2.048	0.1518	0.1329	0.996
iaea	0.99712(-.29)	2.066	0.1518	0.1319	1.002
wdn29	0.99553(-.45)	2.040	0.1514	0.1356	0.992
endfb6gx	0.99000(-1.0)	2.045	0.1516	0.1361	1.007
endfb6	0.98886(-1.1)	2.061	0.1516	0.1353	1.013
jendl3gx	0.99384(-.62)	2.047	0.1508	0.1305	1.004
jendl3	0.99268(-.74)	2.063	0.1508	0.1297	1.009
jef22gx	0.99524(-.48)	2.034	0.1520	0.1325	1.003
jef22	0.99304(-.70)	2.054	0.1520	0.1304	1.010
bnl_umd2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99603(-.40)	1.571	0.1140	0.1103	0.862
iaea	0.99553(-.45)	1.582	0.1140	0.1092	0.867
wdn29	0.99342(-.66)	1.562	0.1138	0.1124	0.859
endfb6gx	0.98827(-1.2)	1.566	0.1137	0.1123	0.872
endfb6	0.98785(-1.2)	1.577	0.1137	0.1114	0.876
jendl3gx	0.99284(-.72)	1.569	0.1133	0.1082	0.869
jendl3	0.99238(-.77)	1.579	0.1133	0.1073	0.873
jef22gx	0.99311(-.70)	1.559	0.1142	0.1097	0.869
jef22	0.99200(-.81)	1.572	0.1141	0.1077	0.874
bnl_umd3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99255(-.75)	1.097	0.0778	0.0850	0.722
iaea	0.99308(-.70)	1.102	0.0778	0.0840	0.724
wdn29	0.99154(-.86)	1.087	0.0777	0.0864	0.719
endfb6gx	0.98624(-1.4)	1.093	0.0775	0.0860	0.729
endfb6	0.98679(-1.3)	1.097	0.0774	0.0851	0.731
jendl3gx	0.99103(-.91)	1.095	0.0773	0.0833	0.727
jendl3	0.99152(-.86)	1.099	0.0773	0.0825	0.729
jef22gx	0.99006(-1.0)	1.089	0.0779	0.0843	0.728
jef22	0.99033(-.98)	1.095	0.0778	0.0826	0.730
bnl_umd4	1.00000(~.23)	0.000	0.0000	0.0000	0.000
iaeagx	0.99543(-.46)	1.091	0.0773	0.0846	0.720
iaea	0.99597(-.40)	1.096	0.0773	0.0836	0.722
wdn29	0.99451(-.55)	1.081	0.0773	0.0860	0.717
endfb6gx	0.98916(-1.1)	1.087	0.0770	0.0855	0.727
endfb6	0.98971(-1.0)	1.091	0.0770	0.0846	0.729
jendl3gx	0.99392(-.61)	1.089	0.0769	0.0829	0.725
jendl3	0.99441(-.56)	1.093	0.0768	0.0820	0.727
jef22gx	0.99293(-.71)	1.082	0.0774	0.0838	0.726
jef22	0.99321(-.69)	1.088	0.0774	0.0822	0.728
bnl_umd5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99264(-.74)	0.860	0.0603	0.0714	0.649
iaea	0.99368(-.64)	0.863	0.0603	0.0704	0.650
wdn29	0.99316(-.69)	0.850	0.0603	0.0724	0.645

endfb6gx	0.98748(-1.3)	0.856	0.0600	0.0719	0.655
endfb6	0.98850(-1.2)	0.858	0.0600	0.0710	0.655
jendl3gx	0.99197(-.81)	0.858	0.0599	0.0698	0.653
jendl3	0.99294(-.71)	0.860	0.0599	0.0691	0.654
jef22gx	0.99031(-.98)	0.853	0.0604	0.0706	0.654
jef22	0.99122(-.89)	0.856	0.0603	0.0691	0.656
bnl_umd6	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99335(-.67)	0.986	0.0767	0.0904	0.686
iaea	0.99331(-.68)	0.997	0.0769	0.0894	0.690
wdn29	0.99221(-.79)	0.982	0.0767	0.0918	0.685
endfb6gx	0.98702(-1.3)	0.982	0.0765	0.0916	0.693
endfb6	0.98697(-1.3)	0.992	0.0766	0.0907	0.697
jendl3gx	0.99165(-.85)	0.985	0.0762	0.0885	0.691
jendl3	0.99154(-.86)	0.995	0.0764	0.0877	0.695
jef22gx	0.99020(-.99)	0.979	0.0768	0.0896	0.692
jef22	0.98986(-1.0)	0.991	0.0770	0.0879	0.697
bnl_umd7	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99321(-.69)	0.776	0.0603	0.0779	0.621
iaea	0.99367(-.64)	0.783	0.0604	0.0770	0.624
wdn29	0.99442(-.56)	0.771	0.0602	0.0790	0.620
endfb6gx	0.98807(-1.2)	0.773	0.0600	0.0787	0.627
endfb6	0.98851(-1.2)	0.779	0.0601	0.0778	0.630
jendl3gx	0.99220(-.79)	0.775	0.0598	0.0763	0.626
jendl3	0.99260(-.75)	0.781	0.0600	0.0756	0.628
jef22gx	0.99008(-1.0)	0.771	0.0604	0.0772	0.627
jef22	0.99036(-.98)	0.779	0.0605	0.0757	0.630
trx_um1	1.00000(~.30)	1.320(~1.6)	0.0987(~1.0)	0.0946(~4.3)	0.797(~1.0)
iaeagx	0.99523(-.48)	1.364(3.36)	0.0980(-.70)	0.0991(4.80)	0.797(0.00)
iaea	0.99515(-.49)	1.373(4.04)	0.0980(-.74)	0.0981(3.67)	0.800(0.41)
wdn29	0.99309(-.70)	1.355(2.67)	0.0979(-.82)	0.1009(6.68)	0.794(-.41)
endfb6gx	0.98798(-1.2)	1.360(3.02)	0.0977(-.99)	0.1007(6.42)	0.805(1.03)
endfb6	0.98795(-1.2)	1.368(3.62)	0.0976(-1.1)	0.0997(5.42)	0.808(1.41)
jendl3gx	0.99279(-.73)	1.363(3.23)	0.0974(-1.3)	0.0972(2.73)	0.803(0.75)
jendl3	0.99269(-.74)	1.370(3.80)	0.0974(-1.3)	0.0963(1.84)	0.806(1.10)
jef22gx	0.99251(-.76)	1.354(2.58)	0.0981(-.59)	0.0984(4.07)	0.803(0.82)
jef22	0.99196(-.81)	1.364(3.33)	0.0981(-.65)	0.0966(2.11)	0.807(1.28)
trx_um2	1.00000(~.10)	0.837(~1.9)	0.0614(~1.3)	0.0693(~5.1)	0.647(~.93)
iaeagx	0.99429(-.58)	0.860(2.74)	0.0602(-1.9)	0.0710(2.42)	0.644(-.42)
iaea	0.99531(-.47)	0.862(3.01)	0.0602(-1.9)	0.0700(1.05)	0.645(-.26)
wdn29	0.99482(-.52)	0.850(1.55)	0.0602(-1.9)	0.0721(3.98)	0.641(-.90)
endfb6gx	0.98913(-1.1)	0.856(2.26)	0.0600(-2.3)	0.0715(3.15)	0.650(0.48)
endfb6	0.99016(-1.0)	0.858(2.46)	0.0599(-2.4)	0.0706(1.90)	0.651(0.62)
jendl3gx	0.99364(-.64)	0.858(2.52)	0.0599(-2.5)	0.0695(0.27)	0.649(0.25)
jendl3	0.99461(-.54)	0.859(2.68)	0.0599(-2.5)	0.0687(-.87)	0.649(0.37)
jef22gx	0.99195(-.81)	0.853(1.91)	0.0603(-1.8)	0.0702(1.36)	0.650(0.45)
jef22	0.99289(-.72)	0.856(2.27)	0.0603(-1.8)	0.0688(-.79)	0.651(0.66)
hw_umc1	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00434(0.43)	2.042	0.1811	0.1598	0.882
iaea	1.00017(0.02)	2.099	0.1824	0.1595	0.897
wdn29	0.99553(-.45)	2.074	0.1811	0.1644	0.889
endfb6gx	0.99505(-.50)	2.039	0.1809	0.1655	0.893
endfb6	0.99103(-.91)	2.094	0.1822	0.1654	0.908
jendl3gx	0.99858(-.14)	2.046	0.1792	0.1572	0.891
jendl3	0.99453(-.55)	2.100	0.1804	0.1572	0.906
jef22gx	1.00015(0.01)	2.030	0.1811	0.1597	0.889
jef22	0.99492(-.51)	2.089	0.1824	0.1583	0.906
hw_umc2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00680(0.67)	1.704	0.1514	0.1455	0.801
iaea	1.00353(0.35)	1.750	0.1524	0.1450	0.814
wdn29	0.99971(-.03)	1.728	0.1513	0.1493	0.807
endfb6gx	0.99806(-.19)	1.701	0.1512	0.1501	0.811
endfb6	0.99489(-.51)	1.744	0.1521	0.1498	0.823
jendl3gx	1.00196(0.19)	1.707	0.1498	0.1430	0.809

jendl3	0.99876(-.12)	1.750	0.1508	0.1428	0.822
jef22gx	1.00272(0.27)	1.694	0.1515	0.1452	0.808
jef22	0.99856(-.14)	1.742	0.1524	0.1437	0.822
hw_umc3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00724(0.72)	1.459	0.1298	0.1345	0.740
iaea	1.00473(0.47)	1.497	0.1306	0.1338	0.751
wdn29	1.00208(0.21)	1.477	0.1296	0.1375	0.744
endfb6gx	0.99918(-.08)	1.455	0.1295	0.1382	0.748
endfb6	0.99672(-.33)	1.490	0.1303	0.1377	0.759
jendl3gx	1.00315(0.31)	1.461	0.1285	0.1321	0.747
jendl3	1.00067(0.07)	1.496	0.1292	0.1316	0.758
jef22gx	1.00328(0.33)	1.450	0.1299	0.1340	0.747
jef22	1.00001(0.00)	1.489	0.1306	0.1324	0.758
hw_umc4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00919(0.91)	1.144	0.1020	0.1193	0.659
iaea	1.00772(0.76)	1.172	0.1025	0.1185	0.668
wdn29	1.00802(0.79)	1.155	0.1017	0.1214	0.662
endfb6gx	1.00251(0.25)	1.139	0.1017	0.1221	0.666
endfb6	1.00105(0.10)	1.165	0.1022	0.1214	0.674
jendl3gx	1.00613(0.61)	1.145	0.1010	0.1171	0.665
jendl3	1.00465(0.46)	1.171	0.1015	0.1165	0.673
jef22gx	1.00539(0.53)	1.137	0.1020	0.1188	0.665
jef22	1.00330(0.33)	1.166	0.1025	0.1171	0.674
hw_umc5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00828(0.82)	0.952	0.0850	0.1102	0.608
iaea	1.00739(0.73)	0.974	0.0854	0.1093	0.615
wdn29	1.01092(1.07)	0.959	0.0846	0.1117	0.610
endfb6gx	1.00286(0.28)	0.947	0.0847	0.1124	0.614
endfb6	1.00197(0.20)	0.968	0.0850	0.1116	0.621
jendl3gx	1.00574(0.57)	0.953	0.0842	0.1081	0.613
jendl3	1.00487(0.48)	0.973	0.0845	0.1075	0.619
jef22gx	1.00449(0.45)	0.946	0.0851	0.1096	0.614
jef22	1.00301(0.30)	0.969	0.0854	0.1079	0.621
srl_um1	1.00000(~.29)	0.000	0.0000	0.0000	0.000
iaeagx	1.02730(2.62)	4.306	0.3575	0.1630	0.643
iaea	1.02479(2.39)	4.404	0.3591	0.1625	0.655
wdn29	1.01268(1.24)	4.415	0.3740	0.1685	0.647
endfb6gx	1.01469(1.44)	4.291	0.3575	0.1701	0.651
endfb6	1.01228(1.21)	4.382	0.3589	0.1698	0.662
jendl3gx	1.02076(2.01)	4.312	0.3518	0.1602	0.652
jendl3	1.01836(1.79)	4.400	0.3531	0.1601	0.663
jef22gx	1.02213(2.14)	4.275	0.3569	0.1629	0.648
jef22	1.01855(1.80)	4.377	0.3583	0.1613	0.660
srl_um2	1.00000(~.28)	0.000	0.0000	0.0000	0.000
iaeagx	1.01502(1.47)	3.021	0.2528	0.1398	0.524
iaea	1.01399(1.37)	3.085	0.2535	0.1391	0.532
wdn29	1.00616(0.61)	3.076	0.2627	0.1434	0.526
endfb6gx	1.00449(0.45)	3.003	0.2523	0.1448	0.529
endfb6	1.00347(0.34)	3.060	0.2528	0.1442	0.537
jendl3gx	1.01068(1.05)	3.025	0.2489	0.1373	0.530
jendl3	1.00962(0.95)	3.080	0.2495	0.1368	0.537
jef22gx	1.01065(1.05)	2.998	0.2524	0.1394	0.527
jef22	1.00888(0.88)	3.063	0.2529	0.1377	0.536
srl_um3	1.00000(~.28)	0.000	0.0000	0.0000	0.000
iaeagx	1.00134(0.13)	2.424	0.2033	0.1280	0.462
iaea	1.00113(0.11)	2.471	0.2036	0.1271	0.469
wdn29	0.99782(-.22)	2.455	0.2102	0.1304	0.463
endfb6gx	0.99277(-.73)	2.403	0.2026	0.1319	0.466
endfb6	0.99252(-.76)	2.446	0.2028	0.1312	0.472
jendl3gx	0.99826(-.17)	2.425	0.2003	0.1256	0.467
jendl3	0.99798(-.20)	2.466	0.2005	0.1250	0.473
jef22gx	0.99755(-.25)	2.405	0.2031	0.1275	0.465
jef22	0.99678(-.32)	2.453	0.2031	0.1257	0.472

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srl_um4    1.00000(~.33)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00436(0.43)  8.315        0.6708        0.2291        0.932
      iaea 1.00236(0.23)  8.455        0.6716        0.2291        0.945
     wdn29 0.98871(-1.1)  8.676        0.7226        0.2399        0.937
  endfb6gx 0.99231(-.78)  8.307        0.6732        0.2430        0.945
    endfb6 0.99084(-.93)  8.427        0.6733        0.2433        0.957
  jendl3gx 0.99350(-.66)  8.333        0.6591        0.2261        0.948
    jendl3 0.99214(-.80)  8.448        0.6590        0.2264        0.960
   jef22gx 0.99864(-.14)  8.256        0.6696        0.2303        0.938
     jef22 0.99512(-.49)  8.396        0.6696        0.2286        0.952

srl_um5    1.00000(~.31)  0.000        0.0000        0.0000        0.000
    iaeagx 1.01849(1.80)  5.260        0.4322        0.1919        0.721
      iaea 1.01748(1.70)  5.343        0.4320        0.1914        0.731
     wdn29 1.00520(0.52)  5.423        0.4602        0.1993        0.724
  endfb6gx 1.00707(0.70)  5.233        0.4323        0.2018        0.729
    endfb6 1.00641(0.63)  5.303        0.4317        0.2014        0.738
  jendl3gx 1.01030(1.01)  5.269        0.4250        0.1889        0.732
    jendl3 1.00970(0.96)  5.337        0.4243        0.1887        0.740
   jef22gx 1.01311(1.29)  5.216        0.4313        0.1923        0.725
     jef22 1.01093(1.08)  5.300        0.4305        0.1904        0.736

srl_um6    1.00000(~.30)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00579(0.57)  3.961        0.3278        0.1729        0.612
      iaea 1.00566(0.56)  4.018        0.3273        0.1722        0.620
     wdn29 0.99678(-.32)  4.053        0.3465        0.1783        0.613
  endfb6gx 0.99583(-.42)  3.928        0.3271        0.1807        0.617
    endfb6 0.99590(-.41)  3.976        0.3263        0.1801        0.624
  jendl3gx 0.99947(-.05)  3.966        0.3225        0.1700        0.620
    jendl3 0.99957(-.04)  4.012        0.3216        0.1695        0.627
   jef22gx 1.00097(0.10)  3.924        0.3270        0.1730        0.615
     jef22 0.99987(-.01)  3.985        0.3262        0.1710        0.624

srl_um7    1.00000(~.30)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99696(-.30)  3.226        0.2676        0.1608        0.544
      iaea 0.99734(-.27)  3.270        0.2670        0.1598        0.550
     wdn29 0.99323(-.68)  3.280        0.2811        0.1646        0.544
  endfb6gx 0.98884(-1.1)  3.189        0.2666        0.1672        0.547
    endfb6 0.98937(-1.1)  3.226        0.2656        0.1664        0.552
  jendl3gx 0.99203(-.81)  3.229        0.2634        0.1581        0.550
    jendl3 0.99254(-.75)  3.262        0.2623        0.1573        0.555
   jef22gx 0.99274(-.73)  3.193        0.2668        0.1605        0.547
     jef22 0.99230(-.78)  3.239        0.2658        0.1585        0.553
  ------------------------------------------------------------------------------
   Average         0.24         1.76          1.17          4.71          0.97
    iaeagx  -0.02(~0.72)  3.05(~0.31)  -1.29(~0.60)   3.61(~1.19) -0.21(~0.21)
      iaea  -0.15(~0.64)  3.52(~0.51)  -1.32(~0.58)   2.36(~1.31)  0.08(~0.34)
     wdn29  -0.09(~0.62)  2.11(~0.56)  -1.36(~0.54)   5.33(~1.35) -0.66(~0.24)
  endfb6gx  -0.68(~0.64)  2.64(~0.38)  -1.66(~0.67)   4.78(~1.64)  0.75(~0.27)
    endfb6  -0.80(~0.57)  3.04(~0.58)  -1.72(~0.66)   3.66(~1.76)  1.01(~0.39)
  jendl3gx  -0.43(~0.61)  2.87(~0.35)  -1.87(~0.59)   1.50(~1.23)  0.50(~0.25)
    jendl3  -0.55(~0.57)  3.24(~0.56)  -1.91(~0.58)   0.49(~1.35)  0.74(~0.37)
   jef22gx  -0.39(~0.67)  2.25(~0.34)  -1.19(~0.60)   2.71(~1.36)  0.63(~0.18)
     jef22  -0.61(~0.59)  2.80(~0.53)  -1.24(~0.59)   0.66(~1.45)  0.97(~0.31)
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 #
 # Uranium UO2 criticality benchmarks
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 SMRDIF - Compare lattice spectr.indices
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   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
bapl1      1.00000(~.10)  1.390(~.72)  0.0840(~2.4)  0.0780(~5.1)  0.000
    iaeagx 0.99910(-.09)  1.425(2.50)  0.0829(-1.3)  0.0770(-1.3)  0.811
      iaea 0.99964(-.04)  1.428(2.72)  0.0826(-1.6)  0.0762(-2.3)  0.813
     wdn29 0.99887(-.11)  1.414(1.76)  0.0827(-1.5)  0.0786(0.78)  0.808
  endfb6gx 0.99337(-.67)  1.418(2.00)  0.0826(-1.7)  0.0775(-.62)  0.818
    endfb6 0.99408(-.60)  1.419(2.09)  0.0823(-2.0)  0.0769(-1.4)  0.819
  jendl3gx 0.99861(-.14)  1.419(2.08)  0.0825(-1.7)  0.0754(-3.3)  0.816
    jendl3 0.99923(-.08)  1.420(2.16)  0.0823(-2.1)  0.0749(-4.0)  0.816
   jef22gx 0.99764(-.24)  1.411(1.52)  0.0830(-1.2)  0.0762(-2.4)  0.817
     jef22 0.99797(-.20)  1.415(1.78)  0.0827(-1.6)  0.0748(-4.1)  0.818

bapl2      1.00000(~.10)  1.120(~.89)  0.0680(~1.5)  0.0700(~5.7)  0.000
    iaeagx 0.99802(-.20)  1.188(6.06)  0.0676(-.53)  0.0664(-5.1)  0.740
      iaea 0.99899(-.10)  1.189(6.12)  0.0675(-.79)  0.0657(-6.2)  0.740
     wdn29 0.99820(-.18)  1.178(5.13)  0.0676(-.59)  0.0678(-3.2)  0.737
  endfb6gx 0.99302(-.70)  1.181(5.47)  0.0673(-1.0)  0.0667(-4.7)  0.746
    endfb6 0.99410(-.59)  1.181(5.43)  0.0671(-1.3)  0.0661(-5.6)  0.746
  jendl3gx 0.99812(-.19)  1.182(5.57)  0.0674(-.96)  0.0650(-7.1)  0.744
    jendl3 0.99912(-.09)  1.182(5.50)  0.0671(-1.3)  0.0645(-7.9)  0.744
   jef22gx 0.99674(-.33)  1.176(5.01)  0.0677(-.49)  0.0657(-6.2)  0.745
     jef22 0.99763(-.24)  1.177(5.12)  0.0675(-.78)  0.0644(-8.0)  0.746

bapl3      1.00000(~.10)  0.906(~1.1)  0.0520(~1.9)  0.0570(~5.3)  0.000
    iaeagx 0.99766(-.23)  0.936(3.28)  0.0520(-.02)  0.0547(-4.1)  0.662
      iaea 0.99900(-.10)  0.934(3.11)  0.0519(-.21)  0.0540(-5.3)  0.661
     wdn29 0.99868(-.13)  0.925(2.15)  0.0521(0.12)  0.0557(-2.2)  0.659
  endfb6gx 0.99364(-.64)  0.930(2.65)  0.0517(-.56)  0.0547(-4.0)  0.667
    endfb6 0.99504(-.50)  0.928(2.38)  0.0516(-.79)  0.0541(-5.1)  0.666
  jendl3gx 0.99835(-.17)  0.931(2.75)  0.0518(-.46)  0.0535(-6.2)  0.665
    jendl3 0.99969(-.03)  0.928(2.46)  0.0516(-.67)  0.0529(-7.1)  0.665
   jef22gx 0.99646(-.36)  0.926(2.23)  0.0520(0.04)  0.0540(-5.3)  0.667
     jef22 0.99786(-.21)  0.925(2.12)  0.0519(-.21)  0.0528(-7.4)  0.667

bapl4      1.00000(~.50)  0.000        0.0000        0.0710(~9.9)  0.000
    iaeagx 0.99136(-.87)  1.335        0.0786        0.0758(6.75)  0.794
      iaea 0.99203(-.81)  1.339        0.0784        0.0750(5.63)  0.795
     wdn29 0.99110(-.90)  1.326        0.0784        0.0773(8.92)  0.791
  endfb6gx 0.98571(-1.5)  1.329        0.0783        0.0763(7.45)  0.801
    endfb6 0.98655(-1.4)  1.330        0.0780        0.0756(6.51)  0.802
  jendl3gx 0.99095(-.92)  1.330        0.0783        0.0742(4.54)  0.798
    jendl3 0.99171(-.84)  1.331        0.0780        0.0736(3.72)  0.799
   jef22gx 0.98968(-1.0)  1.323        0.0787        0.0749(5.54)  0.800
     jef22 0.99020(-.99)  1.327        0.0784        0.0736(3.61)  0.801

bapl5      1.00000(~.50)  0.000        0.0000        0.0590(~ 10)  0.000
    iaeagx 0.99301(-.71)  1.067        0.0614        0.0633(7.27)  0.711
      iaea 0.99419(-.59)  1.068        0.0613        0.0625(5.97)  0.712
     wdn29 0.99350(-.66)  1.057        0.0614        0.0645(9.34)  0.709
  endfb6gx 0.98829(-1.2)  1.062        0.0611        0.0635(7.61)  0.717
    endfb6 0.98957(-1.1)  1.061        0.0610        0.0628(6.47)  0.717
  jendl3gx 0.99328(-.68)  1.063        0.0612        0.0619(4.97)  0.715
    jendl3 0.99447(-.56)  1.061        0.0610        0.0613(3.98)  0.715
   jef22gx 0.99149(-.86)  1.057        0.0615        0.0625(5.93)  0.717
     jef22 0.99265(-.74)  1.058        0.0613        0.0612(3.80)  0.717

bapl6      1.00000(~.50)  0.000        0.0000        0.0510(~7.8)  0.000
    iaeagx 0.99174(-.84)  0.893        0.0506        0.0549(7.61)  0.656
      iaea 0.99320(-.69)  0.891        0.0505        0.0542(6.18)  0.656
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wdn29	0.99297(-.71)	0.883	0.0507	0.0559(9.61)	0.654
endfb6gx	0.98776(-1.2)	0.888	0.0504	0.0549(7.71)	0.662
endfb6	0.98927(-1.1)	0.885	0.0502	0.0543(6.43)	0.661
jendl3gx	0.99242(-.77)	0.889	0.0504	0.0537(5.25)	0.660
jendl3	0.99386(-.62)	0.886	0.0503	0.0531(4.14)	0.659
jef22gx	0.99025(-.99)	0.884	0.0507	0.0542(6.20)	0.662
jef22	0.99175(-.83)	0.883	0.0505	0.0530(3.90)	0.662
naig_nca	1.00000(~.40)	0.000	0.0000	0.0000	0.000
iaeagx	1.00173(0.17)	1.073	0.0584	0.0434	0.461
iaea	1.00386(0.38)	1.070	0.0583	0.0428	0.461
wdn29	1.00142(0.14)	1.061	0.0582	0.0441	0.459
endfb6gx	0.99767(-.23)	1.065	0.0581	0.0433	0.465
endfb6	0.99980(-.02)	1.061	0.0580	0.0428	0.464
jendl3gx	1.00398(0.40)	1.067	0.0581	0.0424	0.463
jendl3	1.00592(0.59)	1.063	0.0580	0.0419	0.463
jef22gx	1.00194(0.19)	1.061	0.0584	0.0427	0.464
jef22	1.00450(0.45)	1.059	0.0583	0.0418	0.464
curl_zpr1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00499(0.49)	2.494	0.1574	0.0909	0.708
iaea	1.00410(0.41)	2.518	0.1572	0.0903	0.713
wdn29	0.99891(-.11)	2.498	0.1570	0.0931	0.708
endfb6gx	0.99613(-.39)	2.483	0.1570	0.0922	0.715
endfb6	0.99555(-.45)	2.503	0.1567	0.0918	0.720
jendl3gx	1.00399(0.40)	2.486	0.1564	0.0891	0.712
jendl3	1.00317(0.32)	2.505	0.1561	0.0887	0.717
jef22gx	1.00338(0.34)	2.472	0.1575	0.0899	0.712
jef22	1.00231(0.23)	2.497	0.1572	0.0887	0.718
curl_zpr2	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.98506(-1.5)	1.352	0.0819	0.0583	0.503
iaea	0.98628(-1.4)	1.359	0.0818	0.0576	0.505
wdn29	0.98229(-1.8)	1.347	0.0819	0.0593	0.502
endfb6gx	0.97923(-2.1)	1.344	0.0816	0.0585	0.507
endfb6	0.98051(-2.0)	1.349	0.0814	0.0580	0.508
jendl3gx	0.98657(-1.4)	1.346	0.0815	0.0570	0.506
jendl3	0.98762(-1.3)	1.351	0.0813	0.0565	0.507
jef22gx	0.98456(-1.6)	1.339	0.0820	0.0574	0.507
jef22	0.98605(-1.4)	1.347	0.0818	0.0564	0.508
curl_zpr3	1.00000(~.50)	0.000	0.0000	0.0460(~2.2)	0.000
iaeagx	0.99358(-.65)	0.967	0.0579	0.0455(-.98)	0.428
iaea	0.99539(-.46)	0.969	0.0578	0.0450(-2.2)	0.429
wdn29	0.99327(-.68)	0.959	0.0578	0.0463(0.59)	0.427
endfb6gx	0.98940(-1.1)	0.961	0.0575	0.0456(-.91)	0.431
endfb6	0.99121(-.89)	0.961	0.0575	0.0451(-2.0)	0.432
jendl3gx	0.99579(-.42)	0.963	0.0575	0.0445(-3.2)	0.430
jendl3	0.99743(-.26)	0.962	0.0574	0.0441(-4.2)	0.431
jef22gx	0.99298(-.71)	0.958	0.0579	0.0448(-2.5)	0.431
jef22	0.99522(-.48)	0.960	0.0578	0.0439(-4.5)	0.432
curl_zpr4	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99260(-.75)	0.773	0.0461	0.0392	0.389
iaea	0.99449(-.56)	0.772	0.0460	0.0387	0.389
wdn29	0.99402(-.60)	0.764	0.0460	0.0398	0.388
endfb6gx	0.98940(-1.1)	0.768	0.0458	0.0391	0.392
endfb6	0.99124(-.89)	0.766	0.0457	0.0386	0.392
jendl3gx	0.99494(-.51)	0.769	0.0458	0.0383	0.391
jendl3	0.99667(-.33)	0.767	0.0457	0.0379	0.391
jef22gx	0.99158(-.85)	0.766	0.0461	0.0386	0.393
jef22	0.99392(-.61)	0.766	0.0460	0.0378	0.393
baw_bay2a	1.00000(~.25)	2.280(~1.3)	0.0000	0.0000	0.000
iaeagx	1.01091(1.07)	2.343(2.78)	0.1350	0.0692	0.577
iaea	1.01175(1.15)	2.349(3.03)	0.1346	0.0685	0.578
wdn29	1.00640(0.63)	2.334(2.39)	0.1346	0.0707	0.575
endfb6gx	1.00312(0.31)	2.329(2.15)	0.1345	0.0698	0.581
endfb6	1.00410(0.41)	2.332(2.28)	0.1340	0.0693	0.582

jendl3gx	1.01147(1.13)	2.332(2.29)	0.1342	0.0678	0.580
jendl3	1.01219(1.20)	2.335(2.39)	0.1337	0.0673	0.580
jef22gx	1.01093(1.08)	2.319(1.73)	0.1350	0.0683	0.580
jef22	1.01187(1.17)	2.326(2.03)	0.1345	0.0672	0.581
baw_cx10	1.00000(~.13)	1.850(~1.1)	0.0000	0.0000	0.000
iaeagx	0.99088(-.92)	1.819(-1.7)	0.1019	0.0569	0.498
iaea	0.99242(-.77)	1.821(-1.6)	0.1016	0.0563	0.498
wdn29	0.98754(-1.3)	1.809(-2.2)	0.1017	0.0580	0.496
endfb6gx	0.98449(-1.6)	1.807(-2.3)	0.1014	0.0572	0.502
endfb6	0.98609(-1.4)	1.807(-2.3)	0.1011	0.0566	0.502
jendl3gx	0.99253(-.75)	1.810(-2.2)	0.1013	0.0557	0.500
jendl3	0.99386(-.62)	1.809(-2.2)	0.1010	0.0552	0.500
jef22gx	0.99145(-.87)	1.800(-2.7)	0.1019	0.0561	0.500
jef22	0.99330(-.68)	1.803(-2.6)	0.1016	0.0550	0.501
aerl_ocf1	1.00000(~.22)	1.350(~3.0)	0.0000	0.0430(~4.7)	0.000
iaeagx	0.99907(-.09)	1.434(6.26)	0.0785	0.0463(7.74)	0.431
iaea	1.00107(0.11)	1.434(6.21)	0.0783	0.0457(6.40)	0.431
wdn29	0.99718(-.28)	1.424(5.49)	0.0784	0.0472(9.67)	0.430
endfb6gx	0.99399(-.61)	1.424(5.50)	0.0781	0.0464(7.91)	0.434
endfb6	0.99600(-.40)	1.422(5.35)	0.0779	0.0459(6.70)	0.434
jendl3gx	1.00152(0.15)	1.427(5.68)	0.0780	0.0453(5.33)	0.433
jendl3	1.00326(0.32)	1.424(5.50)	0.0778	0.0448(4.28)	0.433
jef22gx	0.99994(-.01)	1.419(5.10)	0.0785	0.0456(6.02)	0.434
jef22	1.00241(0.24)	1.419(5.11)	0.0783	0.0447(3.93)	0.434
aerl_ocf2	1.00000(~.40)	1.050(~3.8)	0.0000	0.0330(~6.1)	0.000
iaeagx	0.99944(-.06)	1.089(3.72)	0.0584	0.0372(13)	0.375
iaea	1.00184(0.18)	1.086(3.40)	0.0583	0.0367(11)	0.375
wdn29	0.99910(-.09)	1.078(2.65)	0.0584	0.0378(15)	0.374
endfb6gx	0.99572(-.43)	1.081(2.93)	0.0581	0.0371(12)	0.378
endfb6	0.99809(-.19)	1.077(2.52)	0.0580	0.0366(11)	0.377
jendl3gx	1.00250(0.25)	1.083(3.12)	0.0581	0.0363(10)	0.377
jendl3	1.00463(0.46)	1.078(2.68)	0.0580	0.0359(8.82)	0.377
jef22gx	1.00029(0.03)	1.077(2.58)	0.0584	0.0366(11)	0.378
jef22	1.00328(0.33)	1.074(2.33)	0.0583	0.0358(8.39)	0.378
jaeritca1	1.00000(~.05)	0.000	0.0000	0.0000	0.000
iaeagx	0.99093(-.92)	1.978	0.1122	0.0594	0.495
iaea	0.99237(-.77)	1.981	0.1119	0.0587	0.496
wdn29	0.98688(-1.3)	1.969	0.1119	0.0605	0.494
endfb6gx	0.98405(-1.6)	1.965	0.1117	0.0597	0.499
endfb6	0.98557(-1.5)	1.966	0.1114	0.0591	0.500
jendl3gx	0.99248(-.76)	1.968	0.1115	0.0580	0.498
jendl3	0.99370(-.64)	1.969	0.1111	0.0576	0.498
jef22gx	0.99127(-.88)	1.957	0.1122	0.0585	0.498
jef22	0.99298(-.71)	1.962	0.1118	0.0574	0.499
jaeritca2	1.00000(~.05)	0.000	0.0000	0.0000	0.000
iaeagx	0.98892(-1.1)	1.771	0.0994	0.0543	0.465
iaea	0.99064(-.95)	1.772	0.0992	0.0537	0.465
wdn29	0.98557(-1.5)	1.761	0.0992	0.0553	0.463
endfb6gx	0.98267(-1.8)	1.759	0.0990	0.0546	0.469
endfb6	0.98444(-1.6)	1.758	0.0987	0.0540	0.469
jendl3gx	0.99089(-.92)	1.762	0.0988	0.0531	0.467
jendl3	0.99237(-.77)	1.761	0.0985	0.0527	0.467
jef22gx	0.98944(-1.1)	1.752	0.0994	0.0535	0.468
jef22	0.99152(-.86)	1.755	0.0991	0.0525	0.468
jaeritca3	1.00000(~.05)	0.000	0.0000	0.0000	0.000
iaeagx	0.98488(-1.5)	1.526	0.0846	0.0483	0.428
iaea	0.98697(-1.3)	1.525	0.0844	0.0477	0.428
wdn29	0.98243(-1.8)	1.515	0.0845	0.0491	0.426
endfb6gx	0.97950(-2.1)	1.515	0.0842	0.0484	0.431
endfb6	0.98159(-1.9)	1.513	0.0840	0.0479	0.431
jendl3gx	0.98736(-1.3)	1.518	0.0841	0.0472	0.430
jendl3	0.98916(-1.1)	1.515	0.0839	0.0467	0.430
jef22gx	0.98561(-1.5)	1.510	0.0846	0.0475	0.431

jef22	0.98815(-1.2)	1.510	0.0843	0.0465	0.431
jaeritca4	1.00000(~.33)	0.000	0.0000	0.0000	0.000
iaeagx	1.00870(0.86)	2.221	0.1308	0.0661	0.521
iaea	1.00950(0.94)	2.231	0.1305	0.0654	0.522
wdn29	1.00366(0.36)	2.216	0.1304	0.0675	0.520
endfb6gx	1.00090(0.09)	2.208	0.1303	0.0666	0.525
endfb6	1.00183(0.18)	2.214	0.1300	0.0661	0.526
jendl3gx	1.00968(0.95)	2.211	0.1299	0.0647	0.523
jendl3	1.01030(1.01)	2.217	0.1296	0.0642	0.525
jef22gx	1.00854(0.84)	2.200	0.1308	0.0652	0.524
jef22	1.00952(0.94)	2.210	0.1305	0.0641	0.525
jaeritca5	1.00000(~.19)	0.000	0.0000	0.0000	0.000
iaeagx	0.99402(-.60)	1.866	0.1084	0.0580	0.471
iaea	0.99534(-.47)	1.872	0.1082	0.0574	0.472
wdn29	0.99001(-1.0)	1.859	0.1081	0.0591	0.470
endfb6gx	0.98722(-1.3)	1.855	0.1079	0.0584	0.475
endfb6	0.98863(-1.2)	1.858	0.1077	0.0578	0.475
jendl3gx	0.99572(-.43)	1.858	0.1076	0.0568	0.473
jendl3	0.99683(-.32)	1.860	0.1074	0.0563	0.474
jef22gx	0.99424(-.58)	1.848	0.1083	0.0572	0.474
jef22	0.99589(-.41)	1.854	0.1081	0.0561	0.475
jaeritca6	1.00000(~.23)	0.000	0.0000	0.0000	0.000
iaeagx	0.99539(-.46)	1.436	0.0820	0.0474	0.408
iaea	0.99738(-.26)	1.437	0.0818	0.0468	0.408
wdn29	0.99320(-.69)	1.426	0.0818	0.0482	0.406
endfb6gx	0.99004(-1.0)	1.426	0.0816	0.0475	0.411
endfb6	0.99206(-.80)	1.425	0.0814	0.0469	0.411
jendl3gx	0.99794(-.21)	1.429	0.0814	0.0463	0.410
jendl3	0.99966(-.03)	1.428	0.0812	0.0458	0.410
jef22gx	0.99589(-.41)	1.421	0.0820	0.0466	0.410
jef22	0.99836(-.16)	1.423	0.0817	0.0457	0.411
jaeritca7	1.00000(~.40)	0.000	0.0000	0.0000	0.000
iaeagx	1.00025(0.02)	1.224	0.0693	0.0419	0.376
iaea	1.00251(0.25)	1.223	0.0692	0.0413	0.376
wdn29	0.99916(-.08)	1.213	0.0692	0.0426	0.374
endfb6gx	0.99572(-.43)	1.215	0.0689	0.0419	0.379
endfb6	0.99796(-.20)	1.213	0.0688	0.0414	0.378
jendl3gx	1.00314(0.31)	1.217	0.0689	0.0409	0.377
jendl3	1.00512(0.51)	1.215	0.0687	0.0405	0.377
jef22gx	1.00073(0.07)	1.211	0.0693	0.0412	0.378
jef22	1.00354(0.35)	1.211	0.0691	0.0404	0.378
wapd_crxa1	1.00000(~.14)	0.000	0.0000	0.0000	0.000
iaeagx	1.00542(0.54)	3.763	0.2130	0.0849	0.707
iaea	1.00431(0.43)	3.793	0.2122	0.0844	0.712
wdn29	0.99961(-.04)	3.779	0.2121	0.0871	0.709
endfb6gx	0.99733(-.27)	3.739	0.2124	0.0859	0.713
endfb6	0.99647(-.35)	3.765	0.2115	0.0855	0.718
jendl3gx	1.00477(0.47)	3.739	0.2113	0.0831	0.710
jendl3	1.00373(0.37)	3.765	0.2105	0.0829	0.714
jef22gx	1.00236(0.23)	3.732	0.2133	0.0838	0.711
jef22	1.00093(0.09)	3.763	0.2124	0.0828	0.716
wapd_crxa2	1.00000(~.14)	0.000	0.0000	0.0000	0.000
iaeagx	1.00198(0.20)	3.332	0.1852	0.0775	0.655
iaea	1.00143(0.14)	3.355	0.1845	0.0769	0.659
wdn29	0.99662(-.34)	3.342	0.1846	0.0794	0.656
endfb6gx	0.99439(-.57)	3.309	0.1846	0.0782	0.661
endfb6	0.99403(-.60)	3.329	0.1839	0.0778	0.664
jendl3gx	1.00189(0.19)	3.310	0.1838	0.0758	0.658
jendl3	1.00135(0.13)	3.329	0.1831	0.0755	0.661
jef22gx	0.99927(-.07)	3.303	0.1854	0.0764	0.659
jef22	0.99850(-.15)	3.327	0.1847	0.0754	0.663
wapd_crxa3	1.00000(~.13)	0.000	0.1580(~3.8)	0.0760(~2.6)	0.000

iaeagx	1.00363(0.36)	2.896	0.1577(-.20)	0.0693(-8.8)	0.601
iaea	1.00366(0.36)	2.911	0.1571(-.54)	0.0688(-9.5)	0.604
wdn29	0.99901(-.10)	2.899	0.1572(-.48)	0.0709(-6.7)	0.601
endfb6gx	0.99668(-.33)	2.875	0.1571(-.58)	0.0698(-8.1)	0.605
endfb6	0.99686(-.31)	2.888	0.1565(-.96)	0.0694(-8.7)	0.608
jendl3gx	1.00416(0.41)	2.877	0.1565(-.93)	0.0678(-11)	0.603
jendl3	1.00415(0.41)	2.889	0.1560(-1.3)	0.0674(-11)	0.605
jef22gx	1.00129(0.13)	2.870	0.1579(-.08)	0.0684(-10)	0.604
jef22	1.00121(0.12)	2.886	0.1573(-.44)	0.0673(-11)	0.607
wapd_crxa4	1.00000(~.12)	0.000	0.0000	0.0600(~8.3)	0.000
iaeagx	0.99920(-.08)	2.276	0.1200	0.0571(-4.9)	0.519
iaea	1.00008(0.01)	2.283	0.1196	0.0565(-5.9)	0.520
wdn29	0.99577(-.42)	2.272	0.1196	0.0582(-2.9)	0.518
endfb6gx	0.99341(-.67)	2.259	0.1194	0.0573(-4.5)	0.522
endfb6	0.99436(-.57)	2.263	0.1190	0.0567(-5.4)	0.523
jendl3gx	1.00072(0.07)	2.260	0.1191	0.0558(-7.1)	0.521
jendl3	1.00148(0.15)	2.264	0.1187	0.0553(-7.8)	0.521
jef22gx	0.99746(-.25)	2.255	0.1201	0.0562(-6.3)	0.522
jef22	0.99843(-.16)	2.262	0.1197	0.0552(-8.0)	0.523
wapd_crxa5	1.00000(~.15)	0.000	0.0000	0.0000	0.470(~2.1)
iaeagx	0.99253(-.75)	1.993	0.1033	0.0512	0.479(2.00)
iaea	0.99382(-.62)	1.996	0.1031	0.0506	0.480(2.15)
wdn29	0.98975(-1.0)	1.986	0.1031	0.0522	0.478(1.77)
endfb6gx	0.98739(-1.3)	1.977	0.1028	0.0513	0.483(2.70)
endfb6	0.98871(-1.1)	1.979	0.1025	0.0507	0.483(2.81)
jendl3gx	0.99455(-.55)	1.979	0.1026	0.0500	0.481(2.36)
jendl3	0.99568(-.43)	1.980	0.1023	0.0496	0.481(2.43)
jef22gx	0.99111(-.90)	1.974	0.1035	0.0504	0.482(2.60)
jef22	0.99259(-.75)	1.978	0.1032	0.0494	0.483(2.79)
wapd_crxa6	1.00000(~.14)	0.000	0.0000	0.0000	0.000
iaeagx	1.00665(0.66)	1.006	0.0492	0.0291	0.334
iaea	1.00868(0.86)	1.000	0.0491	0.0286	0.333
wdn29	1.00762(0.75)	0.994	0.0490	0.0295	0.332
endfb6gx	1.00432(0.43)	0.997	0.0488	0.0289	0.336
endfb6	1.00630(0.62)	0.990	0.0487	0.0285	0.335
jendl3gx	1.00990(0.98)	0.998	0.0488	0.0283	0.335
jendl3	1.01177(1.16)	0.991	0.0487	0.0280	0.334
jef22gx	1.00534(0.53)	0.996	0.0492	0.0286	0.336
jef22	1.00780(0.77)	0.990	0.0491	0.0279	0.336
aeewjuno	1.00000(~.24)	0.000	0.0000	0.0000	0.000
iaeagx	0.99157(-.85)	1.691	0.0916	0.0453	0.390
iaea	0.99358(-.65)	1.692	0.0913	0.0447	0.390
wdn29	0.98878(-1.1)	1.682	0.0914	0.0460	0.389
endfb6gx	0.98643(-1.4)	1.678	0.0911	0.0453	0.393
endfb6	0.98844(-1.2)	1.677	0.0909	0.0448	0.393
jendl3gx	0.99440(-.56)	1.681	0.0909	0.0442	0.392
jendl3	0.99611(-.39)	1.679	0.0907	0.0438	0.392
jef22gx	0.99127(-.88)	1.674	0.0916	0.0445	0.393
jef22	0.99369(-.64)	1.676	0.0914	0.0436	0.393
r1100h	1.00000(~.10)	0.000	0.0000	0.0928(~.97)	0.629(~.72)
iaeagx	1.00515(0.51)	4.000	0.2357	0.0877(-5.5)	0.647(2.94)
iaea	1.00185(0.18)	4.031	0.2350	0.0873(-5.9)	0.652(3.66)
wdn29	0.99442(-.56)	4.015	0.2342	0.0901(-2.9)	0.649(3.18)
endfb6gx	0.99531(-.47)	3.977	0.2352	0.0890(-4.1)	0.653(3.95)
endfb6	0.99221(-.79)	4.003	0.2345	0.0887(-4.4)	0.657(4.57)
jendl3gx	1.00410(0.41)	3.980	0.2338	0.0859(-7.5)	0.651(3.53)
jendl3	1.00067(0.07)	4.005	0.2331	0.0857(-7.6)	0.655(4.12)
jef22gx	1.00262(0.26)	3.967	0.2359	0.0866(-6.7)	0.651(3.50)
jef22	0.99901(-.10)	3.999	0.2352	0.0856(-7.8)	0.655(4.25)
r2100h	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00331(0.33)	1.436	0.0772	0.0394	0.352
iaea	1.00146(0.14)	1.436	0.0770	0.0389	0.352
wdn29	0.99807(-.19)	1.426	0.0770	0.0401	0.351

endfb6gx	0.99886(-.11)	1.425	0.0767	0.0393	0.355
endfb6	0.99694(-.31)	1.423	0.0765	0.0389	0.355
jendl3gx	1.00610(0.60)	1.427	0.0766	0.0384	0.354
jendl3	1.00372(0.37)	1.425	0.0764	0.0381	0.354
jef22gx	1.00282(0.28)	1.422	0.0772	0.0387	0.355
jef22	1.00130(0.13)	1.422	0.0770	0.0380	0.355
r3100h	1.00000(~.10)	0.000	0.0000	0.1113(~1.6)	0.725(~1.1)
iaeagx	1.00526(0.52)	5.088	0.3082	0.1038(-6.7)	0.751(3.46)
iaea	1.00161(0.16)	5.135	0.3072	0.1036(-7.0)	0.757(4.36)
wdn29	0.99416(-.59)	5.116	0.3056	0.1069(-4.0)	0.754(3.91)
endfb6gx	0.99442(-.56)	5.064	0.3079	0.1058(-5.0)	0.759(4.59)
endfb6	0.99113(-.90)	5.103	0.3068	0.1057(-5.0)	0.764(5.36)
jendl3gx	1.00302(0.30)	5.065	0.3056	0.1017(-8.6)	0.756(4.14)
jendl3	0.99942(-.06)	5.103	0.3045	0.1017(-8.6)	0.761(4.89)
jef22gx	1.00209(0.21)	5.049	0.3084	0.1026(-7.8)	0.755(4.02)
jef22	0.99798(-.20)	5.098	0.3074	0.1016(-8.7)	0.762(4.96)
bnluo2_1	1.00000(~.05)	2.920(~3.1)	0.0000	0.0650(~1.5)	0.000
iaeagx	0.99525(-.48)	2.970(1.73)	0.1685	0.0677(4.12)	0.545
iaea	0.99428(-.58)	3.007(2.97)	0.1683	0.0672(3.42)	0.550
wdn29	0.98872(-1.1)	2.994(2.52)	0.1682	0.0693(6.69)	0.547
endfb6gx	0.98807(-1.2)	2.950(1.01)	0.1679	0.0682(4.91)	0.549
endfb6	0.98724(-1.3)	2.982(2.13)	0.1677	0.0678(4.34)	0.554
jendl3gx	0.99587(-.41)	2.951(1.05)	0.1671	0.0662(1.88)	0.547
jendl3	0.99484(-.52)	2.983(2.16)	0.1669	0.0660(1.49)	0.552
jef22gx	0.99303(-.70)	2.945(0.85)	0.1687	0.0667(2.65)	0.548
jef22	0.99200(-.81)	2.982(2.12)	0.1685	0.0658(1.23)	0.553
bnluo2_2	1.00000(~.16)	2.410(~1.7)	0.0000	0.0560(~1.8)	0.000
iaeagx	0.98710(-1.3)	2.452(1.75)	0.1367	0.0587(4.89)	0.484
iaea	0.98698(-1.3)	2.477(2.78)	0.1365	0.0582(3.98)	0.488
wdn29	0.98180(-1.9)	2.465(2.28)	0.1364	0.0601(7.25)	0.486
endfb6gx	0.98084(-2.0)	2.434(1.00)	0.1361	0.0590(5.39)	0.488
endfb6	0.98080(-2.0)	2.456(1.91)	0.1359	0.0586(4.62)	0.491
jendl3gx	0.98852(-1.2)	2.436(1.07)	0.1356	0.0574(2.55)	0.486
jendl3	0.98825(-1.2)	2.457(1.96)	0.1354	0.0571(1.98)	0.489
jef22gx	0.98539(-1.5)	2.430(0.84)	0.1368	0.0579(3.32)	0.487
jef22	0.98533(-1.5)	2.456(1.90)	0.1366	0.0569(1.70)	0.491
bnluo2_3	1.00000(~.17)	0.000	0.0000	0.0480(~2.1)	0.000
iaeagx	0.98782(-1.2)	1.968	0.1078	0.0496(3.37)	0.425
iaea	0.98845(-1.2)	1.983	0.1076	0.0491(2.27)	0.427
wdn29	0.98407(-1.6)	1.972	0.1076	0.0506(5.46)	0.426
endfb6gx	0.98263(-1.8)	1.953	0.1072	0.0497(3.56)	0.428
endfb6	0.98330(-1.7)	1.965	0.1070	0.0492(2.60)	0.430
jendl3gx	0.99000(-1.0)	1.955	0.1069	0.0485(1.00)	0.427
jendl3	0.99045(-.97)	1.967	0.1067	0.0481(0.23)	0.429
jef22gx	0.98648(-1.4)	1.950	0.1079	0.0488(1.73)	0.428
jef22	0.98733(-1.3)	1.965	0.1076	0.0480(-.06)	0.430
bnluo2_4	1.00000(~.16)	1.410(~1.4)	0.0000	0.0370(~1.1)	0.000
iaeagx	0.98897(-1.1)	1.501(6.44)	0.0808	0.0403(8.92)	0.365
iaea	0.99025(-.99)	1.507(6.89)	0.0806	0.0398(7.59)	0.366
wdn29	0.98706(-1.3)	1.498(6.23)	0.0807	0.0410(11)	0.365
endfb6gx	0.98502(-1.5)	1.489(5.58)	0.0803	0.0402(8.78)	0.368
endfb6	0.98628(-1.4)	1.493(5.92)	0.0801	0.0398(7.59)	0.369
jendl3gx	0.99186(-.82)	1.490(5.70)	0.0802	0.0394(6.38)	0.366
jendl3	0.99293(-.71)	1.495(6.01)	0.0800	0.0390(5.38)	0.367
jef22gx	0.98786(-1.2)	1.487(5.44)	0.0808	0.0396(7.14)	0.368
jef22	0.98951(-1.1)	1.494(5.93)	0.0807	0.0389(5.03)	0.369
bnluo2_5	1.00000(~.14)	0.000	0.0000	0.0310(~ 19)	0.000
iaeagx	0.98495(-1.5)	1.124	0.0597	0.0326(5.10)	0.315
iaea	0.98657(-1.4)	1.125	0.0595	0.0321(3.68)	0.315
wdn29	0.98489(-1.5)	1.117	0.0596	0.0331(6.87)	0.314
endfb6gx	0.98212(-1.8)	1.114	0.0593	0.0325(4.68)	0.317
endfb6	0.98370(-1.7)	1.114	0.0592	0.0321(3.42)	0.317
jendl3gx	0.98823(-1.2)	1.116	0.0593	0.0318(2.61)	0.316

jendl3	0.98967(-1.0)	1.115	0.0591	0.0315(1.52)	0.316
jef22gx	0.98371(-1.7)	1.113	0.0597	0.0320(3.32)	0.317
jef22	0.98580(-1.5)	1.114	0.0596	0.0314(1.19)	0.318
anl_zpr7a1	1.00000(~.05)	0.000	0.0000	0.0000	0.000
iaeagx	1.00430(0.43)	8.707	0.5534	0.1439	1.027
iaea	1.00112(0.11)	8.792	0.5519	0.1441	1.037
wdn29	0.99498(-.51)	8.758	0.5480	0.1491	1.034
endfb6gx	0.99169(-.84)	8.690	0.5548	0.1481	1.041
endfb6	0.98936(-1.1)	8.757	0.5528	0.1486	1.050
jendl3gx	0.99954(-.05)	8.681	0.5481	0.1414	1.037
jendl3	0.99689(-.31)	8.747	0.5462	0.1419	1.046
jef22gx	1.00185(0.18)	8.645	0.5535	0.1429	1.033
jef22	0.99801(-.20)	8.731	0.5516	0.1422	1.043
anl_zpr7a2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99746(-.25)	4.995	0.2991	0.1027	0.743
iaea	0.99628(-.37)	5.027	0.2980	0.1022	0.747
wdn29	0.98820(-1.2)	5.008	0.2964	0.1056	0.744
endfb6gx	0.98607(-1.4)	4.971	0.2988	0.1046	0.751
endfb6	0.98529(-1.5)	4.995	0.2976	0.1043	0.754
jendl3gx	0.99565(-.44)	4.974	0.2966	0.1006	0.748
jendl3	0.99455(-.55)	4.997	0.2955	0.1004	0.751
jef22gx	0.99613(-.39)	4.950	0.2990	0.1016	0.746
jef22	0.99466(-.54)	4.984	0.2978	0.1004	0.751
anl_zpr7a3	1.00000(~.26)	0.000	0.0000	0.0000	0.000
iaeagx	0.99228(-.78)	3.969	0.2315	0.0873	0.644
iaea	0.99245(-.76)	3.980	0.2307	0.0867	0.646
wdn29	0.98443(-1.6)	3.964	0.2299	0.0895	0.643
endfb6gx	0.98192(-1.9)	3.946	0.2311	0.0887	0.650
endfb6	0.98234(-1.8)	3.952	0.2302	0.0882	0.652
jendl3gx	0.99166(-.84)	3.951	0.2298	0.0855	0.648
jendl3	0.99176(-.83)	3.956	0.2289	0.0851	0.649
jef22gx	0.99154(-.86)	3.931	0.2315	0.0863	0.647
jef22	0.99158(-.85)	3.944	0.2306	0.0850	0.649
anl_zpr7a4	1.00000(~.10)	4.120(~.73)	0.0000	0.0000	0.000
iaeagx	1.00044(0.04)	4.344(5.43)	0.2534	0.0883	0.683
iaea	0.99873(-.13)	4.392(6.60)	0.2528	0.0880	0.689
wdn29	0.99224(-.79)	4.378(6.26)	0.2522	0.0908	0.687
endfb6gx	0.99128(-.88)	4.318(4.80)	0.2529	0.0895	0.689
endfb6	0.98986(-1.0)	4.360(5.82)	0.2522	0.0893	0.695
jendl3gx	0.99942(-.06)	4.318(4.80)	0.2512	0.0865	0.686
jendl3	0.99778(-.22)	4.359(5.81)	0.2506	0.0864	0.692
jef22gx	0.99749(-.25)	4.309(4.59)	0.2537	0.0872	0.687
jef22	0.99548(-.46)	4.358(5.78)	0.2530	0.0862	0.693
anl_zpr7a5	1.00000(~.26)	0.000	0.0000	0.0000	0.000
iaeagx	0.98654(-1.4)	2.874	0.1608	0.0680	0.527
iaea	0.98768(-1.3)	2.877	0.1604	0.0673	0.528
wdn29	0.98048(-2.0)	2.864	0.1602	0.0694	0.525
endfb6gx	0.97802(-2.3)	2.855	0.1603	0.0686	0.531
endfb6	0.97928(-2.1)	2.855	0.1598	0.0681	0.532
jendl3gx	0.98752(-1.3)	2.859	0.1597	0.0665	0.530
jendl3	0.98844(-1.2)	2.859	0.1593	0.0660	0.530
jef22gx	0.98664(-1.4)	2.844	0.1608	0.0670	0.530
jef22	0.98793(-1.2)	2.849	0.1603	0.0659	0.531
npy_nora1	1.00000(~.49)	0.000	0.0000	0.0620(~4.8)	0.000
iaeagx	1.00400(0.40)	2.673	0.1555	0.0612(-1.2)	0.447
iaea	1.00419(0.42)	2.699	0.1552	0.0607(-2.1)	0.450
wdn29	0.99714(-.29)	2.685	0.1547	0.0625(0.85)	0.448
endfb6gx	0.99639(-.36)	2.655	0.1549	0.0617(-.52)	0.451
endfb6	0.99669(-.33)	2.677	0.1546	0.0612(-1.3)	0.454
jendl3gx	1.00539(0.53)	2.658	0.1542	0.0598(-3.5)	0.449
jendl3	1.00536(0.53)	2.680	0.1539	0.0595(-4.0)	0.452
jef22gx	1.00291(0.29)	2.649	0.1556	0.0603(-2.8)	0.449
jef22	1.00325(0.32)	2.676	0.1553	0.0593(-4.3)	0.453

npy_nora2	1.00000(~.32)	1.524(~1.0)	0.0000	0.0000	0.000
iaeagx	1.00364(0.36)	1.566(2.78)	0.0884	0.0411	0.328
iaea	1.00533(0.53)	1.574(3.25)	0.0883	0.0406	0.329
wdn29	1.00111(0.11)	1.563(2.57)	0.0881	0.0418	0.327
endfb6gx	0.99894(-.11)	1.554(1.98)	0.0880	0.0411	0.330
endfb6	1.00061(0.06)	1.559(2.33)	0.0878	0.0407	0.331
jendl3gx	1.00681(0.67)	1.557(2.19)	0.0877	0.0401	0.329
jendl3	1.00818(0.81)	1.562(2.49)	0.0876	0.0397	0.330
jef22gx	1.00332(0.33)	1.552(1.81)	0.0885	0.0404	0.330
jef22	1.00548(0.54)	1.559(2.33)	0.0883	0.0396	0.331
npy_nora3	1.00000(~.26)	1.065(~1.2)	0.0000	0.0000	0.000
iaeagx	0.99850(-.15)	1.130(6.07)	0.0632	0.0327	0.277
iaea	1.00055(0.05)	1.131(6.20)	0.0631	0.0322	0.277
wdn29	0.99846(-.15)	1.122(5.39)	0.0629	0.0332	0.276
endfb6gx	0.99526(-.48)	1.120(5.20)	0.0628	0.0326	0.279
endfb6	0.99726(-.27)	1.121(5.22)	0.0627	0.0322	0.279
jendl3gx	1.00211(0.21)	1.123(5.43)	0.0627	0.0319	0.278
jendl3	1.00388(0.39)	1.123(5.41)	0.0626	0.0316	0.278
jef22gx	0.99798(-.20)	1.119(5.07)	0.0632	0.0321	0.279
jef22	1.00064(0.06)	1.121(5.27)	0.0631	0.0315	0.280
wapd_crxb1	1.00000(~.10)	0.000	0.0000	0.0780(~6.4)	0.000
iaeagx	1.00508(0.50)	4.337	0.2382	0.0732(-6.2)	0.563
iaea	1.00442(0.44)	4.373	0.2375	0.0727(-6.8)	0.567
wdn29	0.99639(-.36)	4.365	0.2368	0.0751(-3.8)	0.565
endfb6gx	0.99599(-.40)	4.306	0.2376	0.0739(-5.2)	0.567
endfb6	0.99551(-.45)	4.337	0.2368	0.0736(-5.7)	0.571
jendl3gx	1.00512(0.51)	4.308	0.2361	0.0716(-8.2)	0.565
jendl3	1.00436(0.43)	4.338	0.2354	0.0713(-8.6)	0.569
jef22gx	1.00320(0.32)	4.298	0.2384	0.0721(-7.6)	0.565
jef22	1.00243(0.24)	4.335	0.2376	0.0711(-8.8)	0.570
wapd_crxb2	1.00000(~.12)	0.000	0.0000	0.0000	0.408(~4.9)
iaeagx	0.99726(-.27)	2.555	0.1313	0.0481	0.404(-1.1)
iaea	0.99864(-.14)	2.562	0.1310	0.0475	0.405(-.86)
wdn29	0.99251(-.76)	2.554	0.1309	0.0490	0.403(-1.2)
endfb6gx	0.99119(-.89)	2.534	0.1307	0.0482	0.406(-.42)
endfb6	0.99258(-.75)	2.538	0.1303	0.0477	0.407(-.22)
jendl3gx	0.99969(-.03)	2.537	0.1303	0.0469	0.405(-.76)
jendl3	1.00079(0.08)	2.541	0.1300	0.0465	0.406(-.56)
jef22gx	0.99686(-.31)	2.529	0.1313	0.0472	0.406(-.59)
jef22	0.99852(-.15)	2.537	0.1310	0.0464	0.407(-.32)
sckvenus1	1.00000(~.48)	0.000	0.0000	0.0000	0.000
iaeagx	0.99155(-.86)	3.616	0.1968	0.0621	0.461
iaea	0.99201(-.81)	3.638	0.1962	0.0615	0.463
wdn29	0.98355(-1.7)	3.629	0.1955	0.0635	0.462
endfb6gx	0.98310(-1.7)	3.588	0.1962	0.0626	0.464
endfb6	0.98366(-1.7)	3.607	0.1955	0.0621	0.467
jendl3gx	0.99279(-.73)	3.592	0.1951	0.0607	0.463
jendl3	0.99299(-.71)	3.610	0.1945	0.0603	0.465
jef22gx	0.99077(-.94)	3.582	0.1969	0.0611	0.463
jef22	0.99132(-.88)	3.605	0.1963	0.0601	0.465
sckvenus2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99049(-.96)	1.471	0.0743	0.0302	0.269
iaea	0.99312(-.69)	1.466	0.0741	0.0298	0.269
wdn29	0.98943(-1.1)	1.459	0.0741	0.0306	0.268
endfb6gx	0.98704(-1.3)	1.458	0.0738	0.0301	0.271
endfb6	0.98961(-1.1)	1.452	0.0737	0.0297	0.270
jendl3gx	0.99471(-.53)	1.461	0.0737	0.0295	0.270
jendl3	0.99697(-.30)	1.454	0.0736	0.0291	0.269
jef22gx	0.99111(-.90)	1.455	0.0743	0.0296	0.271
jef22	0.99443(-.56)	1.452	0.0741	0.0290	0.270
baw_bay2b1	1.00000(~.33)	5.080(~6.1)	0.0000	0.0000	0.000
iaeagx	0.98931(-1.1)	4.999(-1.6)	0.2884	0.0814	0.561

iaea	0.98839(-1.2)	5.048(-.62)	0.2880	0.0810	0.566
wdn29	0.97834(-2.2)	5.039(-.81)	0.2866	0.0836	0.565
endfb6gx	0.97865(-2.2)	4.967(-2.2)	0.2880	0.0826	0.567
endfb6	0.97796(-2.3)	5.009(-1.4)	0.2874	0.0822	0.571
jendl3gx	0.98885(-1.1)	4.970(-2.2)	0.2857	0.0797	0.564
jendl3	0.98780(-1.2)	5.012(-1.3)	0.2852	0.0795	0.569
jef22gx	0.98754(-1.3)	4.956(-2.4)	0.2886	0.0803	0.564
jef22	0.98648(-1.4)	5.007(-1.4)	0.2881	0.0793	0.569
baw_bay2b2	1.00000(~.12)	4.120(~7.5)	0.0000	0.0000	0.000
iaeagx	0.99274(-.73)	4.224(2.52)	0.2398	0.0720	0.505
iaea	0.99246(-.76)	4.261(3.41)	0.2394	0.0715	0.508
wdn29	0.98303(-1.7)	4.250(3.15)	0.2382	0.0738	0.507
endfb6gx	0.98304(-1.7)	4.195(1.82)	0.2392	0.0728	0.509
endfb6	0.98293(-1.8)	4.226(2.58)	0.2387	0.0724	0.513
jendl3gx	0.99310(-.70)	4.199(1.92)	0.2376	0.0704	0.507
jendl3	0.99263(-.74)	4.230(2.66)	0.2371	0.0701	0.511
jef22gx	0.99148(-.86)	4.186(1.59)	0.2398	0.0709	0.507
jef22	0.99116(-.89)	4.224(2.52)	0.2394	0.0699	0.511
wapd_crxc	1.00000(~.24)	0.000	0.2510(~8.0)	0.0700(~7.1)	0.000
iaeagx	0.99764(-.24)	4.693	0.2516(0.24)	0.0653(-6.8)	0.493
iaea	0.99686(-.31)	4.740	0.2509(-.05)	0.0648(-7.4)	0.497
wdn29	0.98774(-1.2)	4.736	0.2498(-.47)	0.0670(-4.2)	0.496
endfb6gx	0.98861(-1.2)	4.656	0.2509(-.03)	0.0658(-5.9)	0.497
endfb6	0.98797(-1.2)	4.698	0.2501(-.35)	0.0655(-6.4)	0.501
jendl3gx	0.99810(-.19)	4.658	0.2492(-.70)	0.0639(-8.8)	0.495
jendl3	0.99714(-.29)	4.699	0.2485(-1.0)	0.0636(-9.1)	0.499
jef22gx	0.99629(-.37)	4.649	0.2517(0.29)	0.0642(-8.2)	0.495
jef22	0.99549(-.45)	4.697	0.2509(-.02)	0.0634(-9.4)	0.500
anl_zpr7b1	1.00000(~.20)	0.000	0.0000	0.0000	0.000
iaeagx	1.00286(0.28)	5.751	0.3163	0.0728	0.499
iaea	1.00183(0.18)	5.813	0.3157	0.0723	0.504
wdn29	0.99071(-.94)	5.814	0.3146	0.0748	0.503
endfb6gx	0.99194(-.82)	5.709	0.3158	0.0737	0.503
endfb6	0.99111(-.90)	5.764	0.3151	0.0734	0.508
jendl3gx	1.00290(0.29)	5.713	0.3131	0.0712	0.501
jendl3	1.00167(0.17)	5.767	0.3125	0.0710	0.506
jef22gx	1.00166(0.16)	5.699	0.3164	0.0717	0.501
jef22	1.00057(0.06)	5.762	0.3157	0.0707	0.506
anl_zpr7b2	1.00000(~.53)	0.000	0.2430(~ 21)	0.0650(~9.2)	0.000
iaeagx	1.00214(0.21)	4.414	0.2361(-2.9)	0.0598(-8.1)	0.422
iaea	1.00250(0.25)	4.444	0.2356(-3.0)	0.0592(-8.9)	0.425
wdn29	0.99277(-.73)	4.439	0.2346(-3.5)	0.0612(-5.9)	0.424
endfb6gx	0.99289(-.72)	4.378	0.2354(-3.1)	0.0603(-7.2)	0.425
endfb6	0.99334(-.67)	4.404	0.2349(-3.3)	0.0598(-8.0)	0.428
jendl3gx	1.00351(0.35)	4.384	0.2338(-3.8)	0.0584(-10)	0.424
jendl3	1.00355(0.35)	4.409	0.2334(-4.0)	0.0581(-11)	0.426
jef22gx	1.00176(0.17)	4.371	0.2361(-2.8)	0.0588(-9.6)	0.424
jef22	1.00224(0.22)	4.403	0.2356(-3.0)	0.0579(-11)	0.427
wapd_crxd1	1.00000(~.49)	0.000	0.0000	0.0000	0.000
iaeagx	1.00069(0.07)	5.018	0.2677	0.0586	0.393
iaea	1.00087(0.09)	5.059	0.2671	0.0581	0.396
wdn29	0.99010(-1.0)	5.059	0.2658	0.0600	0.395
endfb6gx	0.99083(-.93)	4.977	0.2671	0.0591	0.396
endfb6	0.99110(-.90)	5.012	0.2664	0.0587	0.398
jendl3gx	1.00218(0.22)	4.983	0.2650	0.0573	0.394
jendl3	1.00202(0.20)	5.018	0.2643	0.0569	0.397
jef22gx	1.00063(0.06)	4.969	0.2677	0.0576	0.394
jef22	1.00096(0.09)	5.011	0.2670	0.0567	0.397
wapd_crxd2	1.00000(~.36)	0.000	0.0000	0.0000	0.000
iaeagx	1.00970(0.96)	3.947	0.2057	0.0485	0.337
iaea	1.01075(1.06)	3.971	0.2053	0.0480	0.338
wdn29	1.00159(0.16)	3.967	0.2046	0.0496	0.338
endfb6gx	1.00146(0.14)	3.913	0.2050	0.0488	0.339

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    endfb6 1.00254(0.25)  3.933        0.2045        0.0484        0.341
  jendl3gx 1.01227(1.20)  3.920        0.2037        0.0474        0.338
    jendl3 1.01291(1.27)  3.938        0.2033        0.0470        0.340
   jef22gx 1.01028(1.01)  3.907        0.2057        0.0477        0.338
     jef22 1.01164(1.14)  3.932        0.2052        0.0469        0.340

wapd_crxd3 1.00000(~.21)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00197(0.20)  1.688        0.0832        0.0250        0.200
      iaea 1.00493(0.49)  1.682        0.0830        0.0246        0.199
     wdn29 1.00112(0.11)  1.676        0.0827        0.0253        0.199
  endfb6gx 0.99866(-.13)  1.671        0.0827        0.0249        0.201
    endfb6 1.00153(0.15)  1.665        0.0825        0.0245        0.200
  jendl3gx 1.00700(0.69)  1.676        0.0825        0.0244        0.200
    jendl3 1.00949(0.94)  1.668        0.0823        0.0241        0.200
   jef22gx 1.00359(0.36)  1.669        0.0832        0.0245        0.201
     jef22 1.00735(0.73)  1.665        0.0830        0.0239        0.200
  ------------------------------------------------------------------------------
   Average         0.29         3.05          9.24          7.00         2.75
    iaeagx  -0.29(~0.68)  3.20(~2.50)  -0.77(~1.05)   0.40(~6.41)  1.83(~1.76)
      iaea  -0.23(~0.64)  3.63(~2.41)  -1.04(~1.02)  -0.61(~6.16)  2.33(~2.00)
     wdn29  -0.74(~0.69)  3.00(~2.35)  -1.07(~1.17)   2.53(~6.32)  1.93(~1.94)
  endfb6gx  -0.97(~0.67)  2.50(~2.47)  -1.17(~1.01)   0.89(~6.11)  2.71(~1.93)
    endfb6  -0.89(~0.68)  2.82(~2.37)  -1.46(~0.98)   0.03(~5.88)  3.13(~2.14)
  jendl3gx  -0.17(~0.66)  2.62(~2.48)  -1.42(~1.12)  -1.81(~6.23)  2.32(~1.89)
    jendl3  -0.12(~0.65)  2.91(~2.38)  -1.71(~1.09)  -2.52(~6.01)  2.72(~2.09)
   jef22gx  -0.38(~0.67)  2.22(~2.47)  -0.72(~1.07)  -1.04(~6.27)  2.38(~1.79)
     jef22  -0.30(~0.66)  2.69(~2.39)  -1.01(~1.04)  -2.76(~5.97)  2.92(~2.03)
 #
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#
# WWER criticality benchmarks
# ---------------------------


SMRDIF - Compare lattice spectr.indices
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  LATTICE      K-eff       Rho28         Del25          Del28         ConvR
 ========================================================================
 p2w1b0t1 1.00000(~.50)  0.000        0.0000         0.0000        0.000
   iaeagx 0.98804(-1.2)  1.487        0.0806         0.0636        0.689
     iaea 0.98949(-1.1)  1.490        0.0803         0.0629        0.691
    wdn29 0.98587(-1.4)  1.482        0.0804         0.0646        0.688
 endfb6gx 0.98201(-1.8)  1.479        0.0802         0.0641        0.695
   endfb6 0.98360(-1.7)  1.480        0.0799         0.0635        0.696
 jendl3gx 0.98640(-1.4)  1.481        0.0803         0.0619        0.693
   jendl3 0.98781(-1.2)  1.482        0.0800         0.0615        0.694
  jef22gx 0.98616(-1.4)  1.474        0.0807         0.0627        0.694
    jef22 0.98754(-1.3)  1.477        0.0804         0.0615        0.696

 p2w1b4t1 1.00000(~.60)  0.000        0.0000         0.0000        0.000
   iaeagx 0.98644(-1.4)  1.580        0.0858         0.0664        0.713
     iaea 0.98746(-1.3)  1.583        0.0855         0.0657        0.714
    wdn29 0.98575(-1.5)  1.573        0.0855         0.0674        0.711
 endfb6gx 0.98102(-2.0)  1.570        0.0854         0.0668        0.719
   endfb6 0.98220(-1.8)  1.572        0.0851         0.0663        0.719
 jendl3gx 0.98456(-1.6)  1.573        0.0854         0.0646        0.716
   jendl3 0.98565(-1.5)  1.574        0.0851         0.0641        0.717
  jef22gx 0.98434(-1.6)  1.565        0.0859         0.0654        0.718
    jef22 0.98518(-1.5)  1.569        0.0856         0.0642        0.719

 p3w1b0t1 1.00000(~.50)  0.000        0.0000         0.0000        0.000
   iaeagx 0.99639(-.36)  0.962        0.0492         0.0437        0.556
     iaea 0.99849(-.15)  0.959        0.0491         0.0432        0.555
    wdn29 0.99652(-.35)  0.953        0.0493         0.0444        0.554
 endfb6gx 0.99250(-.76)  0.955        0.0490         0.0438        0.560
   endfb6 0.99462(-.54)  0.952        0.0488         0.0432        0.559
 jendl3gx 0.99661(-.34)  0.957        0.0491         0.0426        0.559
   jendl3 0.99860(-.14)  0.953        0.0489         0.0421        0.558
  jef22gx 0.99491(-.51)  0.952        0.0493         0.0430        0.560
    jef22 0.99719(-.28)  0.950        0.0492         0.0421        0.560

 p2w2b0t1 1.00000(~.50)  0.000        0.0000         0.0000        0.000
   iaeagx 0.99918(-.08)  2.943        0.1558         0.0560        0.452
     iaea 1.00110(0.11)  2.954        0.1553         0.0554        0.454
    wdn29 0.99342(-.66)  2.950        0.1551         0.0569        0.453
 endfb6gx 0.99062(-.95)  2.921        0.1552         0.0565        0.456
   endfb6 0.99265(-.74)  2.930        0.1547         0.0560        0.457
 jendl3gx 0.99914(-.09)  2.928        0.1547         0.0545        0.454
   jendl3 1.00078(0.08)  2.936        0.1542         0.0541        0.456
  jef22gx 0.99914(-.09)  2.913        0.1558         0.0550        0.454
    jef22 1.00120(0.12)  2.925        0.1553         0.0541        0.456

 p2w2b0t2 1.00000(~.60)  0.000        0.0000         0.0000        0.000
   iaeagx 0.99474(-.53)  3.035        0.1606         0.0573        0.465
     iaea 0.99656(-.35)  3.047        0.1602         0.0567        0.467
    wdn29 0.98910(-1.1)  3.045        0.1597         0.0582        0.465
 endfb6gx 0.98585(-1.4)  3.011        0.1601         0.0579        0.469
   endfb6 0.98778(-1.2)  3.020        0.1596         0.0574        0.470
 jendl3gx 0.99464(-.54)  3.019        0.1596         0.0558        0.467
   jendl3 0.99617(-.38)  3.027        0.1591         0.0554        0.468
  jef22gx 0.99458(-.55)  3.006        0.1608         0.0563        0.467
    jef22 0.99651(-.35)  3.019        0.1603         0.0554        0.469

 p2w2b0t3 1.00000(~.60)  0.000        0.0000         0.0000        0.000
   iaeagx 0.99335(-.67)  3.160        0.1677         0.0591        0.480
     iaea 0.99506(-.50)  3.174        0.1672         0.0585        0.481
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wdn29	0.98759(-1.3)	3.173	0.1663	0.0601	0.481
endfb6gx	0.98404(-1.6)	3.134	0.1672	0.0598	0.484
endfb6	0.98588(-1.4)	3.144	0.1667	0.0593	0.485
jendl3gx	0.99307(-.70)	3.143	0.1665	0.0576	0.482
jendl3	0.99450(-.55)	3.153	0.1660	0.0572	0.483
jef22gx	0.99313(-.69)	3.130	0.1677	0.0581	0.482
jef22	0.99491(-.51)	3.145	0.1672	0.0571	0.484
p2w2b5t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00477(0.47)	3.177	0.1686	0.0586	0.475
iaea	1.00621(0.62)	3.190	0.1681	0.0580	0.477
wdn29	1.00034(0.03)	3.181	0.1678	0.0596	0.475
endfb6gx	0.99682(-.32)	3.153	0.1680	0.0591	0.479
endfb6	0.99839(-.16)	3.162	0.1674	0.0586	0.480
jendl3gx	1.00442(0.44)	3.160	0.1674	0.0570	0.477
jendl3	1.00569(0.56)	3.168	0.1669	0.0566	0.479
jef22gx	1.00436(0.43)	3.145	0.1686	0.0576	0.477
jef22	1.00587(0.58)	3.158	0.1681	0.0566	0.479
p2w2b5t2	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00018(0.02)	3.270	0.1734	0.0599	0.488
iaea	1.00155(0.15)	3.283	0.1730	0.0593	0.489
wdn29	0.99587(-.41)	3.277	0.1722	0.0608	0.488
endfb6gx	0.99187(-.82)	3.243	0.1729	0.0605	0.492
endfb6	0.99336(-.67)	3.253	0.1724	0.0600	0.493
jendl3gx	0.99980(-.02)	3.251	0.1722	0.0583	0.490
jendl3	1.00098(0.10)	3.260	0.1717	0.0579	0.491
jef22gx	0.99966(-.03)	3.238	0.1735	0.0589	0.490
jef22	1.00106(0.10)	3.253	0.1730	0.0579	0.492
p2w2b5t3	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00026(0.02)	3.395	0.1804	0.0616	0.502
iaea	1.00150(0.15)	3.409	0.1799	0.0610	0.504
wdn29	0.99581(-.42)	3.405	0.1788	0.0626	0.503
endfb6gx	0.99151(-.86)	3.366	0.1799	0.0622	0.507
endfb6	0.99289(-.72)	3.377	0.1794	0.0617	0.508
jendl3gx	0.99968(-.03)	3.375	0.1791	0.0599	0.504
jendl3	1.00075(0.07)	3.386	0.1786	0.0595	0.506
jef22gx	0.99968(-.03)	3.363	0.1805	0.0606	0.504
jef22	1.00093(0.09)	3.379	0.1799	0.0596	0.507
p2w2b6t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00213(0.21)	3.286	0.1745	0.0599	0.486
iaea	1.00338(0.34)	3.299	0.1740	0.0593	0.487
wdn29	0.99827(-.17)	3.289	0.1736	0.0609	0.486
endfb6gx	0.99444(-.56)	3.261	0.1739	0.0604	0.489
endfb6	0.99581(-.42)	3.270	0.1734	0.0599	0.491
jendl3gx	1.00165(0.16)	3.267	0.1733	0.0583	0.488
jendl3	1.00276(0.27)	3.276	0.1727	0.0579	0.489
jef22gx	1.00160(0.16)	3.252	0.1745	0.0589	0.488
jef22	1.00287(0.29)	3.266	0.1740	0.0579	0.490
p2w2b6t2	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00373(0.37)	3.375	0.1792	0.0610	0.498
iaea	1.00487(0.48)	3.389	0.1787	0.0604	0.500
wdn29	1.00000	3.381	0.1779	0.0620	0.498
endfb6gx	0.99566(-.44)	3.348	0.1786	0.0616	0.502
endfb6	0.99694(-.31)	3.358	0.1781	0.0611	0.503
jendl3gx	1.00316(0.31)	3.355	0.1779	0.0594	0.500
jendl3	1.00418(0.42)	3.365	0.1773	0.0590	0.501
jef22gx	1.00305(0.30)	3.343	0.1793	0.0600	0.500
jef22	1.00418(0.42)	3.358	0.1787	0.0590	0.502
p2w2b6t3	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	1.00066(0.06)	3.502	0.1863	0.0628	0.512
iaea	1.00171(0.17)	3.518	0.1858	0.0622	0.514
wdn29	0.99677(-.32)	3.511	0.1846	0.0638	0.513
endfb6gx	0.99215(-.79)	3.473	0.1858	0.0634	0.517
endfb6	0.99334(-.67)	3.484	0.1852	0.0629	0.518

jendl3gx	0.99993(-.01)	3.481	0.1849	0.0611	0.515
jendl3	1.00085(0.08)	3.493	0.1843	0.0607	0.516
jef22gx	0.99995(-.01)	3.469	0.1864	0.0617	0.515
jef22	1.00096(0.09)	3.486	0.1858	0.0607	0.517
p2w2b7t1	1.00000(~.60)	0.000	0.0000	0.0000	0.000
iaeagx	1.00556(0.55)	3.368	0.1790	0.0608	0.493
iaea	1.00663(0.66)	3.381	0.1785	0.0602	0.495
wdn29	1.00215(0.21)	3.370	0.1780	0.0618	0.493
endfb6gx	0.99805(-.20)	3.342	0.1784	0.0613	0.497
endfb6	0.99926(-.07)	3.352	0.1778	0.0608	0.499
jendl3gx	1.00491(0.49)	3.348	0.1777	0.0591	0.496
jendl3	1.00589(0.58)	3.357	0.1771	0.0587	0.497
jef22gx	1.00491(0.49)	3.333	0.1790	0.0598	0.495
jef22	1.00594(0.59)	3.347	0.1784	0.0588	0.498
p1w2b0t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99137(-.87)	5.194	0.2973	0.0868	0.645
iaea	0.99104(-.91)	5.239	0.2961	0.0863	0.651
wdn29	0.97999(-2.1)	5.245	0.2947	0.0887	0.650
endfb6gx	0.97928(-2.1)	5.165	0.2971	0.0886	0.652
endfb6	0.97933(-2.1)	5.203	0.2957	0.0883	0.656
jendl3gx	0.98728(-1.3)	5.173	0.2951	0.0845	0.650
jendl3	0.98694(-1.3)	5.211	0.2938	0.0843	0.654
jef22gx	0.98976(-1.0)	5.147	0.2974	0.0855	0.648
jef22	0.98914(-1.1)	5.194	0.2961	0.0845	0.654
p1w2b0t2	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.98365(-1.7)	5.380	0.3076	0.0889	0.664
iaea	0.98321(-1.7)	5.428	0.3064	0.0885	0.669
wdn29	0.97213(-2.9)	5.437	0.3042	0.0909	0.669
endfb6gx	0.97135(-3.0)	5.347	0.3074	0.0908	0.670
endfb6	0.97130(-3.0)	5.388	0.3061	0.0905	0.675
jendl3gx	0.97944(-2.1)	5.358	0.3052	0.0865	0.668
jendl3	0.97899(-2.2)	5.398	0.3039	0.0864	0.673
jef22gx	0.98195(-1.9)	5.335	0.3078	0.0875	0.667
jef22	0.98120(-1.9)	5.385	0.3065	0.0866	0.673
p1w2b0t3	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.98075(-2.0)	5.628	0.3222	0.0915	0.686
iaea	0.98013(-2.0)	5.680	0.3209	0.0911	0.692
wdn29	0.96889(-3.3)	5.691	0.3180	0.0936	0.692
endfb6gx	0.96817(-3.3)	5.592	0.3221	0.0935	0.693
endfb6	0.96797(-3.4)	5.635	0.3207	0.0933	0.698
jendl3gx	0.97627(-2.5)	5.604	0.3196	0.0891	0.690
jendl3	0.97567(-2.5)	5.647	0.3183	0.0890	0.696
jef22gx	0.97899(-2.2)	5.582	0.3223	0.0902	0.688
jef22	0.97803(-2.3)	5.635	0.3210	0.0892	0.695
p1w2b2t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99618(-.38)	5.249	0.3006	0.0871	0.650
iaea	0.99575(-.43)	5.295	0.2994	0.0867	0.655
wdn29	0.98511(-1.5)	5.299	0.2980	0.0890	0.655
endfb6gx	0.98424(-1.6)	5.220	0.3004	0.0889	0.656
endfb6	0.98420(-1.6)	5.258	0.2991	0.0886	0.661
jendl3gx	0.99205(-.80)	5.228	0.2984	0.0848	0.654
jendl3	0.99163(-.85)	5.266	0.2971	0.0846	0.659
jef22gx	0.99454(-.55)	5.202	0.3007	0.0858	0.652
jef22	0.99382(-.62)	5.250	0.2994	0.0848	0.658
p1w2b3t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99372(-.63)	5.277	0.3022	0.0874	0.652
iaea	0.99329(-.68)	5.323	0.3010	0.0870	0.657
wdn29	0.98274(-1.8)	5.327	0.2995	0.0893	0.657
endfb6gx	0.98183(-1.9)	5.247	0.3020	0.0892	0.658
endfb6	0.98178(-1.9)	5.286	0.3007	0.0889	0.663
jendl3gx	0.98959(-1.1)	5.255	0.3000	0.0851	0.656
jendl3	0.98917(-1.1)	5.294	0.2986	0.0850	0.661
jef22gx	0.99208(-.80)	5.230	0.3023	0.0861	0.655

jef22	0.99135(-.88)	5.278	0.3010	0.0852	0.660
p3w2b0t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99705(-.30)	1.836	0.0920	0.0377	0.340
iaea	1.00012(0.01)	1.833	0.0917	0.0372	0.340
wdn29	0.99515(-.49)	1.828	0.0917	0.0382	0.339
endfb6gx	0.99156(-.85)	1.820	0.0915	0.0378	0.342
endfb6	0.99463(-.54)	1.817	0.0912	0.0374	0.342
jendl3gx	0.99948(-.05)	1.825	0.0914	0.0368	0.342
jendl3	1.00215(0.21)	1.821	0.0911	0.0364	0.341
jef22gx	0.99804(-.20)	1.815	0.0920	0.0370	0.342
jef22	1.00159(0.16)	1.814	0.0916	0.0363	0.342
p3w2b5t1	1.00000(~.60)	0.000	0.0000	0.0000	0.000
iaeagx	1.00680(0.67)	2.073	0.1042	0.0409	0.366
iaea	1.00907(0.89)	2.070	0.1039	0.0404	0.366
wdn29	1.00642(0.63)	2.061	0.1037	0.0415	0.364
endfb6gx	1.00185(0.18)	2.055	0.1037	0.0410	0.368
endfb6	1.00413(0.41)	2.051	0.1033	0.0405	0.368
jendl3gx	1.00844(0.83)	2.059	0.1035	0.0398	0.367
jendl3	1.01050(1.03)	2.055	0.1032	0.0394	0.367
jef22gx	1.00682(0.67)	2.050	0.1042	0.0402	0.368
jef22	1.00943(0.93)	2.049	0.1038	0.0393	0.368
p4w2b0t1	1.00000(~.70)	0.000	0.0000	0.0000	0.000
iaeagx	1.00104(0.10)	1.082	0.0521	0.0245	0.257
iaea	1.00441(0.44)	1.074	0.0520	0.0241	0.256
wdn29	1.00189(0.19)	1.070	0.0520	0.0248	0.256
endfb6gx	0.99828(-.17)	1.072	0.0518	0.0244	0.259
endfb6	1.00157(0.16)	1.064	0.0516	0.0240	0.258
jendl3gx	1.00486(0.48)	1.075	0.0518	0.0238	0.258
jendl3	1.00783(0.77)	1.066	0.0516	0.0236	0.257
jef22gx	1.00205(0.20)	1.070	0.0521	0.0240	0.259
jef22	1.00617(0.61)	1.063	0.0520	0.0235	0.258
p2w3b0t1	1.00000(~.60)	0.000	0.0000	0.0000	0.000
iaeagx	0.99359(-.65)	3.548	0.1863	0.0548	0.415
iaea	0.99546(-.46)	3.564	0.1856	0.0542	0.416
wdn29	0.98686(-1.3)	3.563	0.1848	0.0557	0.416
endfb6gx	0.98436(-1.6)	3.520	0.1857	0.0554	0.418
endfb6	0.98633(-1.4)	3.533	0.1850	0.0549	0.419
jendl3gx	0.99382(-.62)	3.529	0.1849	0.0534	0.417
jendl3	0.99534(-.47)	3.541	0.1842	0.0530	0.418
jef22gx	0.99394(-.61)	3.511	0.1862	0.0538	0.416
jef22	0.99596(-.41)	3.529	0.1855	0.0529	0.418
p2w3b1t1	1.00000(~.70)	0.000	0.0000	0.0000	0.000
iaeagx	1.00056(0.05)	3.583	0.1882	0.0550	0.417
iaea	1.00234(0.23)	3.600	0.1875	0.0544	0.419
wdn29	0.99399(-.61)	3.598	0.1867	0.0559	0.419
endfb6gx	0.99141(-.87)	3.556	0.1876	0.0555	0.421
endfb6	0.99330(-.68)	3.569	0.1869	0.0551	0.422
jendl3gx	1.00074(0.07)	3.564	0.1868	0.0536	0.419
jendl3	1.00220(0.22)	3.576	0.1861	0.0532	0.421
jef22gx	1.00084(0.08)	3.546	0.1882	0.0540	0.419
jef22	1.00276(0.27)	3.564	0.1875	0.0531	0.421
p2w3b7t1	1.00000(~.80)	0.000	0.0000	0.0000	0.000
iaeagx	1.01235(1.21)	3.989	0.2102	0.0584	0.448
iaea	1.01344(1.32)	4.008	0.2095	0.0579	0.450
wdn29	1.00743(0.73)	4.000	0.2084	0.0595	0.449
endfb6gx	1.00398(0.40)	3.957	0.2096	0.0590	0.451
endfb6	1.00520(0.52)	3.972	0.2088	0.0585	0.453
jendl3gx	1.01202(1.18)	3.964	0.2085	0.0569	0.450
jendl3	1.01295(1.27)	3.979	0.2078	0.0565	0.451
jef22gx	1.01210(1.19)	3.947	0.2102	0.0575	0.449
jef22	1.01322(1.30)	3.967	0.2094	0.0565	0.452
p3w3b0t1	1.00000(~.50)	0.000	0.0000	0.0000	0.000

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   iaeagx 0.99085(-.93)  2.191        0.1088        0.0368        0.307
     iaea 0.99401(-.60)  2.191        0.1085        0.0363        0.307
    wdn29 0.98849(-1.2)  2.186        0.1084        0.0373        0.307
 endfb6gx 0.98494(-1.5)  2.173        0.1083        0.0369        0.309
   endfb6 0.98807(-1.2)  2.170        0.1080        0.0365        0.309
 jendl3gx 0.99364(-.64)  2.178        0.1081        0.0359        0.308
   jendl3 0.99633(-.37)  2.175        0.1078        0.0355        0.308
  jef22gx 0.99236(-.77)  2.167        0.1088        0.0361        0.309
    jef22 0.99600(-.40)  2.168        0.1085        0.0354        0.309
 ------------------------------------------------------------------------------
  Average         0.56         0.00          0.00          0.00          0.00
   iaeagx  -0.32(~0.74)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
     iaea  -0.18(~0.79)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
    wdn29  -0.84(~0.97)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
 endfb6gx  -1.16(~0.89)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
   endfb6  -1.01(~0.95)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
 jendl3gx  -0.39(~0.88)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
   jendl3  -0.28(~0.93)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
  jef22gx  -0.38(~0.79)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
    jef22  -0.24(~0.86)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
#
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 #
 # LWR MOX criticality benchmarks
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 SMRDIF - Compare lattice spectr.indices
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   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
ge_pu1     1.00000(~.50)  0.000        0.0000         0.0000        0.000
    iaeagx 0.99833(-.17)  4.035        0.2330         1.1456        9.187
      iaea 0.99964(-.04)  4.050        0.2316         1.1367        9.227
     wdn29 0.99819(-.18)  3.933        0.2287         1.1406        9.020
  endfb6gx 1.00028(0.03)  4.001        0.2314         1.1557        9.245
    endfb6 1.00183(0.18)  4.011        0.2300         1.1493        9.278
  jendl3gx 1.00427(0.42)  3.999        0.2313         1.1103        9.203
    jendl3 1.00565(0.56)  4.009        0.2299         1.1054        9.235
   jef22gx 1.00279(0.28)  3.989        0.2328         1.1264        9.219
     jef22 1.00385(0.38)  4.006        0.2314         1.1102        9.263

ge_pu2     1.00000(~.30)  0.000        0.0000         0.0000        0.000
    iaeagx 0.99933(-.07)  2.769        0.1534         0.8655        7.279
      iaea 1.00146(0.14)  2.773        0.1527         0.8568        7.293
     wdn29 0.99782(-.22)  2.695        0.1511         0.8612        7.148
  endfb6gx 1.00164(0.16)  2.744        0.1522         0.8692        7.320
    endfb6 1.00389(0.39)  2.746        0.1516         0.8622        7.331
  jendl3gx 1.00680(0.67)  2.744        0.1523         0.8394        7.291
    jendl3 1.00885(0.87)  2.745        0.1517         0.8337        7.301
   jef22gx 1.00441(0.44)  2.737        0.1533         0.8505        7.310
     jef22 1.00656(0.65)  2.744        0.1526         0.8361        7.328

ge_pu3     1.00000(~.10)  0.000        0.0000         0.0000        0.000
    iaeagx 1.00238(0.24)  1.587        0.0837         0.5552        5.262
      iaea 1.00540(0.54)  1.584        0.0835         0.5484        5.258
     wdn29 0.99963(-.04)  1.543        0.0829         0.5533        5.180
  endfb6gx 1.00571(0.57)  1.573        0.0830         0.5543        5.290
    endfb6 1.00877(0.87)  1.568        0.0828         0.5484        5.284
  jendl3gx 1.01139(1.12)  1.573        0.0832         0.5390        5.274
    jendl3 1.01420(1.39)  1.568        0.0830         0.5340        5.266
   jef22gx 1.00797(0.79)  1.570        0.0838         0.5452        5.293
     jef22 1.01136(1.12)  1.567        0.0835         0.5345        5.290

ge_pu4     1.00000(~.10)  0.000        0.0000         0.0000        0.000
    iaeagx 1.00165(0.16)  1.161        0.0600         0.4326        4.474
      iaea 1.00492(0.49)  1.155        0.0600         0.4270        4.464
     wdn29 0.99835(-.17)  1.128        0.0597         0.4320        4.412
  endfb6gx 1.00559(0.55)  1.150        0.0595         0.4306        4.498
    endfb6 1.00886(0.87)  1.143        0.0594         0.4257        4.487
  jendl3gx 1.01102(1.08)  1.150        0.0597         0.4203        4.486
    jendl3 1.01406(1.38)  1.144        0.0596         0.4160        4.474
   jef22gx 1.00713(0.70)  1.148        0.0601         0.4248        4.504
     jef22 1.01088(1.07)  1.144        0.0600         0.4161        4.496

ge_pu5     1.00000(~.10)  0.000        0.0000         0.0000        0.000
    iaeagx 1.00260(0.26)  0.891        0.0456         0.3538        3.959
      iaea 1.00581(0.58)  0.885        0.0455         0.3491        3.947
     wdn29 0.99886(-.11)  0.865        0.0454         0.3540        3.911
  endfb6gx 1.00697(0.69)  0.883        0.0452         0.3515        3.981
    endfb6 1.01017(1.00)  0.876        0.0451         0.3473        3.969
  jendl3gx 1.01181(1.16)  0.883        0.0454         0.3440        3.971
    jendl3 1.01485(1.45)  0.876        0.0453         0.3403        3.958
   jef22gx 1.00760(0.75)  0.882        0.0457         0.3475        3.989
     jef22 1.01134(1.11)  0.876        0.0456         0.3402        3.979

ge_pu6     1.00000(~.10)  0.000        0.0000         0.0000        0.000
    iaeagx 1.00372(0.37)  0.834        0.0426         0.3370        3.847
      iaea 1.00686(0.68)  0.827        0.0425         0.3325        3.835
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wdn29	0.99991(-.01)	0.809	0.0424	0.3374	3.802
endfb6gx	1.00818(0.81)	0.825	0.0422	0.3346	3.869
endfb6	1.01132(1.11)	0.818	0.0421	0.3306	3.856
jendl3gx	1.01282(1.26)	0.826	0.0423	0.3278	3.860
jendl3	1.01581(1.54)	0.819	0.0423	0.3242	3.846
jef22gx	1.00852(0.84)	0.825	0.0426	0.3311	3.877
jef22	1.01218(1.20)	0.819	0.0426	0.3241	3.866
wcrx_pu1	1.00000(~.34)	0.000	0.0000	0.0000	0.000
iaeagx	0.99705(-.30)	5.332	0.3169	0.4885	3.323
iaea	0.99829(-.17)	5.362	0.3153	0.4846	3.343
wdn29	0.99602(-.40)	5.215	0.3102	0.4880	3.270
endfb6gx	0.99765(-.24)	5.284	0.3149	0.4930	3.344
endfb6	0.99912(-.09)	5.307	0.3133	0.4901	3.361
jendl3gx	1.00338(0.34)	5.284	0.3142	0.4740	3.330
jendl3	1.00459(0.45)	5.306	0.3126	0.4719	3.346
jef22gx	1.00157(0.16)	5.266	0.3163	0.4795	3.331
jef22	1.00270(0.27)	5.299	0.3147	0.4727	3.353
wcrx_pu2	1.00000(~.27)	0.000	0.0000	0.0000	0.000
iaeagx	0.99303(-.70)	3.692	0.2128	0.3801	2.645
iaea	0.99503(-.50)	3.708	0.2120	0.3763	2.656
wdn29	0.99132(-.88)	3.606	0.2090	0.3789	2.601
endfb6gx	0.99423(-.58)	3.658	0.2113	0.3820	2.660
endfb6	0.99634(-.37)	3.670	0.2105	0.3789	2.669
jendl3gx	1.00084(0.08)	3.659	0.2111	0.3690	2.650
jendl3	1.00264(0.26)	3.670	0.2103	0.3665	2.658
jef22gx	0.99828(-.17)	3.648	0.2125	0.3729	2.654
jef22	1.00041(0.04)	3.666	0.2118	0.3668	2.666
wcrx_pu3	1.00000(~.31)	0.000	0.0000	0.0000	0.000
iaeagx	1.00217(0.22)	1.461	0.0787	0.1858	1.532
iaea	1.00511(0.51)	1.460	0.0786	0.1835	1.532
wdn29	1.00211(0.21)	1.423	0.0782	0.1853	1.510
endfb6gx	1.00537(0.53)	1.446	0.0781	0.1850	1.540
endfb6	1.00834(0.82)	1.444	0.0780	0.1830	1.539
jendl3gx	1.01052(1.04)	1.448	0.0782	0.1805	1.536
jendl3	1.01327(1.30)	1.445	0.0781	0.1788	1.534
jef22gx	1.00769(0.76)	1.445	0.0788	0.1822	1.541
jef22	1.01116(1.10)	1.444	0.0787	0.1787	1.541
wcrx_pu4	1.00000(~.20)	0.000	0.0000	0.0000	0.000
iaeagx	1.00118(0.12)	1.195	0.0640	0.1611	1.382
iaea	1.00418(0.42)	1.192	0.0640	0.1591	1.381
wdn29	1.00094(0.09)	1.163	0.0638	0.1609	1.363
endfb6gx	1.00470(0.47)	1.183	0.0635	0.1603	1.389
endfb6	1.00771(0.76)	1.179	0.0635	0.1585	1.388
jendl3gx	1.00953(0.94)	1.184	0.0636	0.1567	1.386
jendl3	1.01235(1.21)	1.180	0.0636	0.1551	1.383
jef22gx	1.00631(0.63)	1.182	0.0641	0.1581	1.391
jef22	1.00990(0.98)	1.180	0.0641	0.1550	1.390
wcrx_pu5	1.00000(~.08)	0.000	0.0000	0.0000	0.000
iaeagx	0.99676(-.33)	0.786	0.0429	0.1307	1.143
iaea	0.99960(-.04)	0.782	0.0429	0.1291	1.141
wdn29	0.99575(-.43)	0.763	0.0427	0.1307	1.130
endfb6gx	1.00104(0.10)	0.778	0.0426	0.1297	1.150
endfb6	1.00386(0.38)	0.773	0.0425	0.1283	1.147
jendl3gx	1.00557(0.55)	0.779	0.0427	0.1274	1.147
jendl3	1.00825(0.81)	0.774	0.0426	0.1261	1.144
jef22gx	1.00046(0.04)	0.779	0.0430	0.1285	1.153
jef22	1.00389(0.39)	0.775	0.0430	0.1260	1.151
wcrx_pu6	1.00000(~.35)	0.000	0.0000	0.0000	0.000
iaeagx	0.99465(-.54)	13.612	0.7302	1.0100	5.992
iaea	0.99665(-.34)	13.672	0.7251	1.0015	6.032
wdn29	0.99643(-.36)	13.322	0.7126	1.0086	5.907
endfb6gx	0.99712(-.29)	13.434	0.7246	1.0140	6.019
endfb6	0.99933(-.07)	13.481	0.7194	1.0069	6.055

jendl3gx	1.00350(0.35)	13.437	0.7224	0.9788	5.993
jendl3	1.00544(0.54)	13.480	0.7171	0.9733	6.027
jef22gx	1.00076(0.07)	13.388	0.7268	0.9857	5.986
jef22	1.00304(0.30)	13.456	0.7215	0.9710	6.030
jtca_pu1	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.98402(-1.6)	2.271	0.1025	0.2223	1.996
iaea	0.98791(-1.2)	2.254	0.1022	0.2193	1.987
wdn29	0.98638(-1.4)	2.200	0.1017	0.2208	1.954
endfb6gx	0.98784(-1.2)	2.242	0.1016	0.2210	2.002
endfb6	0.99176(-.83)	2.224	0.1012	0.2183	1.992
jendl3gx	0.99344(-.66)	2.244	0.1017	0.2154	1.996
jendl3	0.99723(-.28)	2.225	0.1014	0.2130	1.985
jef22gx	0.99154(-.86)	2.240	0.1025	0.2175	2.002
jef22	0.99605(-.40)	2.224	0.1021	0.2129	1.994
jtca_pu2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.98605(-1.4)	1.857	0.0826	0.1881	1.770
iaea	0.99004(-1.0)	1.840	0.0824	0.1854	1.761
wdn29	0.98773(-1.2)	1.798	0.0821	0.1869	1.735
endfb6gx	0.99017(-1.0)	1.834	0.0818	0.1867	1.776
endfb6	0.99417(-.59)	1.816	0.0816	0.1842	1.765
jendl3gx	0.99566(-.44)	1.835	0.0820	0.1823	1.770
jendl3	0.99951(-.05)	1.817	0.0817	0.1802	1.760
jef22gx	0.99336(-.67)	1.833	0.0826	0.1840	1.777
jef22	0.99807(-.19)	1.817	0.0824	0.1801	1.768
jtca_pu3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99001(-1.0)	1.343	0.0587	0.1447	1.478
iaea	0.99397(-.61)	1.327	0.0586	0.1426	1.469
wdn29	0.99060(-.95)	1.298	0.0585	0.1442	1.452
endfb6gx	0.99450(-.55)	1.326	0.0581	0.1433	1.483
endfb6	0.99845(-.16)	1.309	0.0580	0.1415	1.474
jendl3gx	0.99956(-.04)	1.327	0.0582	0.1404	1.479
jendl3	1.00333(0.33)	1.310	0.0581	0.1387	1.469
jef22gx	0.99665(-.34)	1.326	0.0587	0.1417	1.486
jef22	1.00139(0.14)	1.311	0.0586	0.1386	1.477
jtca_pu4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99285(-.72)	1.067	0.0463	0.1217	1.316
iaea	0.99657(-.34)	1.052	0.0462	0.1200	1.308
wdn29	0.99273(-.73)	1.031	0.0462	0.1216	1.295
endfb6gx	0.99747(-.25)	1.054	0.0458	0.1205	1.322
endfb6	1.00117(0.12)	1.039	0.0457	0.1189	1.313
jendl3gx	1.00196(0.19)	1.055	0.0459	0.1182	1.319
jendl3	1.00552(0.55)	1.039	0.0459	0.1169	1.309
jef22gx	0.99863(-.14)	1.054	0.0463	0.1193	1.325
jef22	1.00314(0.31)	1.040	0.0462	0.1167	1.316
bnw_pua1	1.00000(~.12)	0.000	0.0000	0.0000	0.000
iaeagx	0.99120(-.89)	3.888	0.2247	0.3946	2.733
iaea	0.99290(-.72)	3.911	0.2239	0.3909	2.747
wdn29	0.98931(-1.1)	3.804	0.2206	0.3935	2.690
endfb6gx	0.99228(-.78)	3.852	0.2232	0.3968	2.749
endfb6	0.99410(-.59)	3.871	0.2223	0.3938	2.761
jendl3gx	0.99882(-.12)	3.853	0.2229	0.3830	2.737
jendl3	1.00033(0.03)	3.870	0.2221	0.3807	2.749
jef22gx	0.99635(-.37)	3.842	0.2245	0.3871	2.741
jef22	0.99816(-.18)	3.866	0.2236	0.3810	2.757
bnw_pua2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00613(0.61)	2.276	0.1273	0.2657	1.966
iaea	1.00889(0.88)	2.281	0.1270	0.2627	1.970
wdn29	1.00424(0.42)	2.221	0.1256	0.2647	1.935
endfb6gx	1.00854(0.84)	2.255	0.1263	0.2657	1.976
endfb6	1.01132(1.11)	2.258	0.1260	0.2631	1.979
jendl3gx	1.01542(1.51)	2.256	0.1263	0.2581	1.970
jendl3	1.01787(1.74)	2.258	0.1261	0.2560	1.972
jef22gx	1.01197(1.17)	2.251	0.1272	0.2605	1.975

jef22	1.01515(1.48)	2.257	0.1270	0.2558	1.980
bnw_pua3	1.00000(~.11)	0.000	0.0000	0.0000	0.000
iaeagx	1.00820(0.81)	1.617	0.0892	0.2065	1.616
iaea	1.01135(1.12)	1.617	0.0891	0.2040	1.616
wdn29	1.00633(0.63)	1.576	0.0883	0.2058	1.592
endfb6gx	1.01142(1.12)	1.602	0.0885	0.2058	1.625
endfb6	1.01456(1.42)	1.600	0.0884	0.2036	1.624
jendl3gx	1.01805(1.76)	1.603	0.0886	0.2007	1.620
jendl3	1.02088(2.02)	1.600	0.0885	0.1988	1.619
jef22gx	1.01403(1.37)	1.600	0.0892	0.2024	1.626
jef22	1.01778(1.73)	1.600	0.0891	0.1987	1.627
bnw_pua4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00631(0.63)	1.317	0.0722	0.1785	1.449
iaea	1.00957(0.94)	1.314	0.0721	0.1763	1.448
wdn29	1.00449(0.45)	1.281	0.0716	0.1781	1.429
endfb6gx	1.00995(0.98)	1.304	0.0716	0.1777	1.457
endfb6	1.01318(1.29)	1.300	0.0715	0.1758	1.456
jendl3gx	1.01625(1.59)	1.305	0.0717	0.1736	1.453
jendl3	1.01920(1.87)	1.301	0.0717	0.1719	1.451
jef22gx	1.01189(1.17)	1.303	0.0723	0.1751	1.459
jef22	1.01582(1.54)	1.301	0.0722	0.1718	1.458
bnw_pua5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00223(0.22)	0.975	0.0533	0.1470	1.253
iaea	1.00299(0.30)	0.971	0.0533	0.1453	1.252
wdn29	0.99823(-.18)	0.948	0.0529	0.1470	1.238
endfb6gx	1.00634(0.63)	0.965	0.0528	0.1461	1.261
endfb6	1.00706(0.70)	0.961	0.0528	0.1446	1.259
jendl3gx	1.01182(1.16)	0.966	0.0529	0.1431	1.258
jendl3	1.01233(1.21)	0.961	0.0529	0.1418	1.255
jef22gx	1.00697(0.69)	0.965	0.0534	0.1443	1.263
jef22	1.00846(0.83)	0.962	0.0533	0.1417	1.262
bnw_pua6	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00948(0.93)	0.937	0.0512	0.1434	1.232
iaea	1.01257(1.23)	0.933	0.0512	0.1416	1.229
wdn29	1.00796(0.79)	0.911	0.0509	0.1433	1.217
endfb6gx	1.01366(1.34)	0.928	0.0508	0.1425	1.239
endfb6	1.01674(1.63)	0.923	0.0507	0.1409	1.236
jendl3gx	1.01895(1.84)	0.929	0.0509	0.1396	1.236
jendl3	1.02182(2.11)	0.924	0.0509	0.1382	1.233
jef22gx	1.01402(1.37)	0.928	0.0513	0.1408	1.241
jef22	1.01781(1.73)	0.924	0.0512	0.1381	1.240
bnw_pua7	1.00000(~.50)	0.000	0.0000	0.0000	0.000
iaeagx	0.99245(-.76)	0.704	0.0386	0.1252	1.094
iaea	0.99497(-.51)	0.700	0.0385	0.1237	1.092
wdn29	0.99211(-.80)	0.684	0.0383	0.1253	1.083
endfb6gx	0.99672(-.33)	0.697	0.0382	0.1243	1.101
endfb6	0.99924(-.08)	0.692	0.0382	0.1229	1.099
jendl3gx	1.00060(0.06)	0.698	0.0383	0.1222	1.098
jendl3	1.00302(0.30)	0.693	0.0383	0.1209	1.095
jef22gx	0.99542(-.46)	0.697	0.0387	0.1232	1.104
jef22	0.99838(-.16)	0.694	0.0386	0.1208	1.102
bnw_pua8	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.98417(-1.6)	0.698	0.0383	0.1251	1.091
iaea	0.98671(-1.4)	0.695	0.0383	0.1236	1.089
wdn29	0.98385(-1.7)	0.679	0.0381	0.1252	1.080
endfb6gx	0.98842(-1.2)	0.692	0.0380	0.1242	1.098
endfb6	0.99093(-.92)	0.687	0.0379	0.1228	1.095
jendl3gx	0.99229(-.78)	0.692	0.0381	0.1221	1.095
jendl3	0.99474(-.53)	0.688	0.0380	0.1208	1.092
jef22gx	0.98713(-1.3)	0.692	0.0384	0.1231	1.101
jef22	0.99011(-1.0)	0.689	0.0383	0.1207	1.099
bnw_pub1	1.00000(~.10)	0.000	0.0000	0.0000	0.000

iaeagx	1.00618(0.61)	2.168	0.1194	0.2522	1.912
iaea	1.00879(0.87)	2.173	0.1192	0.2493	1.916
wdn29	1.00558(0.55)	2.115	0.1181	0.2512	1.882
endfb6gx	1.00884(0.87)	2.147	0.1185	0.2520	1.922
endfb6	1.01149(1.13)	2.149	0.1183	0.2495	1.925
jendl3gx	1.01480(1.45)	2.148	0.1185	0.2449	1.916
jendl3	1.01717(1.67)	2.150	0.1183	0.2428	1.918
jef22gx	1.01207(1.18)	2.142	0.1194	0.2473	1.921
jef22	1.01506(1.47)	2.149	0.1191	0.2428	1.926
bnw_pub2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00737(0.73)	1.540	0.0837	0.1959	1.575
iaea	1.01038(1.02)	1.539	0.0836	0.1935	1.575
wdn29	1.00650(0.64)	1.500	0.0830	0.1953	1.552
endfb6gx	1.01070(1.05)	1.525	0.0830	0.1952	1.583
endfb6	1.01373(1.34)	1.523	0.0829	0.1931	1.583
jendl3gx	1.01651(1.61)	1.526	0.0831	0.1904	1.579
jendl3	1.01926(1.87)	1.524	0.0830	0.1886	1.578
jef22gx	1.01311(1.29)	1.523	0.0837	0.1921	1.584
jef22	1.01668(1.63)	1.523	0.0836	0.1884	1.585
bnw_pub3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00958(0.94)	1.253	0.0677	0.1692	1.414
iaea	1.01267(1.24)	1.250	0.0677	0.1671	1.413
wdn29	1.00863(0.85)	1.219	0.0673	0.1688	1.395
endfb6gx	1.01329(1.30)	1.240	0.0672	0.1683	1.422
endfb6	1.01638(1.60)	1.237	0.0671	0.1664	1.420
jendl3gx	1.01876(1.82)	1.242	0.0673	0.1645	1.418
jendl3	1.02163(2.09)	1.237	0.0672	0.1629	1.416
jef22gx	1.01498(1.46)	1.239	0.0678	0.1659	1.424
jef22	1.01870(1.82)	1.237	0.0677	0.1627	1.423
bnw_pub4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00370(0.37)	0.928	0.0500	0.1396	1.227
iaea	1.00666(0.66)	0.924	0.0500	0.1378	1.225
wdn29	1.00289(0.29)	0.902	0.0498	0.1395	1.212
endfb6gx	1.00778(0.77)	0.919	0.0496	0.1386	1.234
endfb6	1.01074(1.06)	0.914	0.0496	0.1371	1.232
jendl3gx	1.01246(1.22)	0.920	0.0497	0.1359	1.231
jendl3	1.01524(1.49)	0.915	0.0497	0.1345	1.228
jef22gx	1.00816(0.81)	0.919	0.0501	0.1371	1.237
jef22	1.01175(1.15)	0.916	0.0501	0.1344	1.235
bnw_pub5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00996(0.98)	0.893	0.0481	0.1362	1.206
iaea	1.01285(1.26)	0.889	0.0481	0.1345	1.204
wdn29	1.00924(0.91)	0.868	0.0479	0.1362	1.192
endfb6gx	1.01410(1.38)	0.884	0.0477	0.1353	1.213
endfb6	1.01699(1.66)	0.879	0.0477	0.1338	1.211
jendl3gx	1.01860(1.81)	0.885	0.0478	0.1327	1.210
jendl3	1.02133(2.07)	0.880	0.0478	0.1313	1.207
jef22gx	1.01423(1.39)	0.884	0.0482	0.1338	1.216
jef22	1.01772(1.73)	0.880	0.0481	0.1312	1.214
bnw_puc1	1.00000(~.12)	0.000	0.0000	0.0000	0.000
iaeagx	0.99709(-.29)	3.544	0.2000	0.3580	2.585
iaea	0.99846(-.15)	3.565	0.1993	0.3547	2.599
wdn29	0.99874(-.13)	3.465	0.1971	0.3565	2.543
endfb6gx	0.99880(-.12)	3.509	0.1985	0.3595	2.599
endfb6	1.00033(0.03)	3.526	0.1978	0.3568	2.611
jendl3gx	1.00342(0.34)	3.510	0.1983	0.3473	2.589
jendl3	1.00478(0.47)	3.527	0.1977	0.3451	2.601
jef22gx	1.00262(0.26)	3.499	0.1997	0.3513	2.592
jef22	1.00399(0.40)	3.521	0.1990	0.3456	2.608
bnw_puc2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00241(0.24)	2.075	0.1134	0.2410	1.865
iaea	1.00490(0.49)	2.080	0.1132	0.2382	1.868
wdn29	1.00280(0.28)	2.024	0.1123	0.2401	1.836

endfb6gx	1.00500(0.50)	2.054	0.1125	0.2407	1.874
endfb6	1.00755(0.75)	2.057	0.1123	0.2383	1.877
jendl3gx	1.01027(1.01)	2.056	0.1125	0.2340	1.868
jendl3	1.01260(1.24)	2.058	0.1124	0.2320	1.870
jef22gx	1.00820(0.81)	2.050	0.1133	0.2364	1.873
jef22	1.01103(1.08)	2.056	0.1132	0.2320	1.878
bnw_puc3	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00920(0.91)	1.474	0.0795	0.1869	1.539
iaea	1.01208(1.19)	1.473	0.0794	0.1846	1.539
wdn29	1.00916(0.90)	1.436	0.0790	0.1864	1.517
endfb6gx	1.01244(1.22)	1.459	0.0788	0.1861	1.547
endfb6	1.01534(1.50)	1.457	0.0787	0.1841	1.546
jendl3gx	1.01754(1.71)	1.460	0.0789	0.1816	1.543
jendl3	1.02023(1.96)	1.458	0.0788	0.1798	1.542
jef22gx	1.01472(1.44)	1.457	0.0795	0.1833	1.548
jef22	1.01811(1.76)	1.457	0.0794	0.1797	1.549
bnw_puc4	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00470(0.47)	1.201	0.0644	0.1619	1.385
iaea	1.00767(0.76)	1.199	0.0644	0.1598	1.384
wdn29	1.00448(0.44)	1.169	0.0641	0.1616	1.367
endfb6gx	1.00823(0.81)	1.189	0.0639	0.1610	1.393
endfb6	1.01121(1.10)	1.185	0.0639	0.1592	1.391
jendl3gx	1.01305(1.28)	1.190	0.0640	0.1574	1.389
jendl3	1.01585(1.55)	1.186	0.0640	0.1558	1.387
jef22gx	1.00984(0.97)	1.188	0.0645	0.1588	1.395
jef22	1.01339(1.31)	1.186	0.0644	0.1557	1.394
bnw_puc5	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	0.99430(-.57)	0.892	0.0477	0.1339	1.206
iaea	0.99714(-.29)	0.888	0.0477	0.1323	1.204
wdn29	0.99415(-.59)	0.867	0.0476	0.1340	1.192
endfb6gx	0.99811(-.19)	0.883	0.0473	0.1330	1.213
endfb6	1.00097(0.10)	0.878	0.0473	0.1315	1.211
jendl3gx	1.00219(0.22)	0.884	0.0474	0.1304	1.210
jendl3	1.00490(0.49)	0.879	0.0474	0.1291	1.207
jef22gx	0.99844(-.16)	0.883	0.0478	0.1316	1.215
jef22	1.00184(0.18)	0.880	0.0477	0.1290	1.214
bnw_puc6	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.01032(1.02)	0.856	0.0458	0.1304	1.185
iaea	1.01304(1.28)	0.852	0.0458	0.1287	1.183
wdn29	1.01033(1.02)	0.832	0.0457	0.1305	1.171
endfb6gx	1.01425(1.39)	0.847	0.0454	0.1294	1.192
endfb6	1.01698(1.65)	0.843	0.0454	0.1280	1.190
jendl3gx	1.01803(1.75)	0.849	0.0455	0.1270	1.189
jendl3	1.02065(2.00)	0.844	0.0455	0.1256	1.186
jef22gx	1.01421(1.39)	0.848	0.0459	0.1281	1.195
jef22	1.01743(1.70)	0.844	0.0458	0.1255	1.193
bnw_pud1	1.00000(~.20)	0.000	0.0000	0.0000	0.000
iaeagx	0.99728(-.27)	6.478	0.3579	0.6094	3.816
iaea	0.99885(-.12)	6.527	0.3565	0.6041	3.845
wdn29	0.99956(-.04)	6.333	0.3512	0.6065	3.750
endfb6gx	0.99930(-.07)	6.403	0.3551	0.6115	3.833
endfb6	1.00097(0.10)	6.444	0.3536	0.6071	3.859
jendl3gx	1.00482(0.48)	6.404	0.3543	0.5906	3.817
jendl3	1.00644(0.64)	6.441	0.3528	0.5871	3.841
jef22gx	1.00385(0.38)	6.384	0.3568	0.5962	3.818
jef22	1.00555(0.55)	6.435	0.3553	0.5871	3.849
bnw_pud2	1.00000(~.10)	0.000	0.0000	0.0000	0.000
iaeagx	1.00493(0.49)	5.054	0.2747	0.5162	3.267
iaea	1.00705(0.70)	5.084	0.2737	0.5110	3.286
wdn29	1.00675(0.67)	4.932	0.2700	0.5129	3.206
endfb6gx	1.00747(0.74)	4.995	0.2724	0.5166	3.281
endfb6	1.00966(0.95)	5.020	0.2715	0.5123	3.297
jendl3gx	1.01341(1.31)	4.997	0.2720	0.5003	3.267

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    jendl3 1.01548(1.51)  5.019        0.2711        0.4967        3.282
   jef22gx 1.01190(1.17)  4.984        0.2741        0.5049        3.271
     jef22 1.01431(1.40)  5.016        0.2731        0.4965        3.292

bnw_pud3   1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00491(0.49)  3.669        0.1959        0.4135        2.664
      iaea 1.00764(0.76)  3.683        0.1954        0.4089        2.674
     wdn29 1.00621(0.62)  3.574        0.1931        0.4104        2.613
  endfb6gx 1.00806(0.80)  3.627        0.1943        0.4127        2.675
    endfb6 1.01082(1.06)  3.638        0.1937        0.4088        2.683
  jendl3gx 1.01434(1.40)  3.630        0.1942        0.4010        2.665
    jendl3 1.01690(1.65)  3.638        0.1936        0.3976        2.672
   jef22gx 1.01218(1.20)  3.621        0.1957        0.4044        2.671
     jef22 1.01541(1.51)  3.637        0.1951        0.3973        2.682

bnw_pud4   1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00286(0.28)  1.344        0.0701        0.2110        1.471
      iaea 1.00618(0.61)  1.340        0.0699        0.2085        1.469
     wdn29 1.00339(0.34)  1.304        0.0696        0.2099        1.447
  endfb6gx 1.00760(0.75)  1.329        0.0694        0.2094        1.478
    endfb6 1.01089(1.07)  1.324        0.0693        0.2071        1.475
  jendl3gx 1.01283(1.26)  1.331        0.0695        0.2052        1.474
    jendl3 1.01592(1.55)  1.324        0.0694        0.2033        1.471
   jef22gx 1.00877(0.87)  1.330        0.0702        0.2068        1.481
     jef22 1.01291(1.27)  1.326        0.0700        0.2031        1.479

bnw_pud5   1.00000(~.10)  0.000        0.0000        0.0000        0.000
    iaeagx 0.99287(-.72)  0.952        0.0499        0.1807        1.245
      iaea 0.99560(-.44)  0.949        0.0498        0.1786        1.243
     wdn29 0.99450(-.55)  0.924        0.0496        0.1801        1.228
  endfb6gx 0.99762(-.24)  0.942        0.0495        0.1791        1.252
    endfb6 1.00034(0.03)  0.937        0.0494        0.1772        1.250
  jendl3gx 1.00129(0.13)  0.943        0.0496        0.1761        1.248
    jendl3 1.00395(0.39)  0.938        0.0495        0.1744        1.246
   jef22gx 0.99678(-.32)  0.943        0.0500        0.1775        1.255
     jef22 1.00011(0.01)  0.941        0.0499        0.1743        1.254
  ------------------------------------------------------------------------------
   Average         0.19         0.00          0.00          0.00          0.00
    iaeagx   0.00(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
      iaea   0.27(~0.71)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
     wdn29  -0.05(~0.68)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
  endfb6gx   0.33(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
    endfb6   0.60(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
  jendl3gx   0.85(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
    jendl3   1.09(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
   jef22gx   0.53(~0.71)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
     jef22   0.83(~0.72)  0.00(~0.00)   0.00(~0.00)   0.00(~0.00)  0.00(~0.00)
 #
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 #
 # Intermediate spectrum criticality benchmarks
 # -------------------------------------------


 SMRDIF - Compare lattice spectr.indices
 =======================================

   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
hiss1      1.00000(~.10)  0.000        0.0000         0.0000         0.000
    iaeagx 1.03211(3.06) 99.999       10.0000         0.0004         0.054
      iaea 1.02373(2.29) 99.999       10.0000         0.0005         0.054
     wdn29 0.99415(-.59) 99.999       10.0000         0.0004         0.057
  endfb6gx 1.01165(1.14) 99.999       10.0000         0.0004         0.054
    endfb6 1.00388(0.39) 99.999       10.0000         0.0005         0.054
  jendl3gx 1.02263(2.19) 99.999       10.0000         0.0004         0.055
    jendl3 1.01442(1.41) 99.999       10.0000         0.0004         0.054
   jef22gx 1.03135(2.99) 99.999       10.0000         0.0004         0.054
     jef22 1.02313(2.23) 99.999       10.0000         0.0004         0.054

hiss2      1.00000(~.10)  0.000        0.0000         0.0000         0.000
    iaeagx 1.01626(1.59)  0.000        0.0000         0.0000         0.000
      iaea 1.01701(1.66)  0.000        0.0000         0.0000         0.000
     wdn29 1.04455(4.17)  0.000        0.0000         0.0000         0.000
  endfb6gx 1.01093(1.08)  0.000        0.0000         0.0000         0.000
    endfb6 1.01177(1.16)  0.000        0.0000         0.0000         0.000
  jendl3gx 1.01346(1.32)  0.000        0.0000         0.0000         0.000
    jendl3 1.01452(1.42)  0.000        0.0000         0.0000         0.000
   jef22gx 0.99653(-.35)  0.000        0.0000         0.0000         0.000
     jef22 0.99755(-.25)  0.000        0.0000         0.0000         0.000
  ------------------------------------------------------------------------------
   Average         0.10         0.00           0.00           0.00          0.00
    iaeagx   2.32(~0.74)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
      iaea   1.97(~0.32)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
     wdn29   1.79(~2.38)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
  endfb6gx   1.11(~0.03)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
    endfb6   0.77(~0.39)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
  jendl3gx   1.75(~0.43)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
    jendl3   1.42(~0.00)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
   jef22gx   1.32(~1.67)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
     jef22   0.99(~1.24)  0.00(~0.00)    0.00(~0.00)    0.00(~0.00)   0.00(~0.00)
 #
```

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 #
 # BNL-Th2-U3-H2O criticality benchmarks
 # -------------------------------------


 SMRDIF - Compare lattice spectr.indices
 =======================================

   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
BNL_THH2O1 1.00000(~.76)  1.380(~3.0)  0.0000        0.0000        0.000
    iaeagx 1.01428(1.40)  1.111( -20)  0.5678        0.0181        0.594
      iaea 1.01595(1.56)  1.116( -19)  0.5649        0.0181        0.596
     wdn29 0.99282(-.73)  1.214( -12)  0.5892        0.0172        0.619
  endfb6gx 0.99636(-.37)  1.208( -12)  0.5704        0.0176        0.626
    endfb6 0.99808(-.19)  1.211( -12)  0.5674        0.0175        0.628
  jendl3gx 1.01464(1.43)  1.136( -18)  0.5839        0.0174        0.593
    jendl3 1.01607(1.57)  1.139( -17)  0.5815        0.0174        0.595
   jef22gx 0.99452(-.55)  1.171( -15)  0.5770        0.0168        0.610
     jef22 0.99625(-.38)  1.176( -15)  0.5739        0.0166        0.613

BNL_THH2O2 1.00000(~.45)  0.928(~4.1)  0.0000        0.0000        0.000
    iaeagx 1.00879(0.87)  0.780( -16)  0.4106        0.0149        0.560
      iaea 1.01060(1.04)  0.784( -16)  0.4079        0.0149        0.562
     wdn29 0.99203(-.81)  0.846(-8.8)  0.4245        0.0142        0.579
  endfb6gx 0.99483(-.52)  0.845(-8.9)  0.4119        0.0144        0.585
    endfb6 0.99664(-.34)  0.848(-8.6)  0.4092        0.0143        0.587
  jendl3gx 1.01099(1.08)  0.795( -14)  0.4217        0.0143        0.559
    jendl3 1.01250(1.23)  0.798( -14)  0.4194        0.0143        0.561
   jef22gx 0.99304(-.70)  0.819( -12)  0.4167        0.0137        0.573
     jef22 0.99510(-.49)  0.824( -11)  0.4140        0.0136        0.576

BNL_THH2O3 1.00000(~.65)  0.754(~3.2)  0.0000        0.0000        0.000
    iaeagx 1.00896(0.88)  0.626( -17)  0.3345        0.0131        0.543
      iaea 1.01085(1.07)  0.629( -17)  0.3321        0.0130        0.545
     wdn29 0.99440(-.56)  0.677( -10)  0.3453        0.0124        0.559
  endfb6gx 0.99717(-.28)  0.677( -10)  0.3355        0.0126        0.563
    endfb6 0.99904(-.10)  0.680(-9.8)  0.3330        0.0125        0.565
  jendl3gx 1.01200(1.18)  0.638( -15)  0.3435        0.0126        0.541
    jendl3 1.01359(1.33)  0.640( -15)  0.3413        0.0125        0.543
   jef22gx 0.99569(-.43)  0.656( -13)  0.3394        0.0120        0.554
     jef22 0.99796(-.20)  0.660( -12)  0.3369        0.0118        0.556

BNL_THH2O4 1.00000(~.49)  0.607(~4.3)  0.0000        0.0000        0.000
    iaeagx 1.00782(0.77)  0.490( -19)  0.2658        0.0112        0.526
      iaea 1.00978(0.96)  0.493( -19)  0.2636        0.0112        0.528
     wdn29 0.99523(-.48)  0.529( -13)  0.2739        0.0106        0.540
  endfb6gx 0.99824(-.18)  0.530( -13)  0.2664        0.0108        0.543
    endfb6 1.00016(0.01)  0.532( -12)  0.2642        0.0107        0.545
  jendl3gx 1.01161(1.14)  0.499( -18)  0.2727        0.0108        0.525
    jendl3 1.01324(1.30)  0.501( -17)  0.2709        0.0108        0.526
   jef22gx 0.99717(-.28)  0.513( -15)  0.2695        0.0103        0.536
     jef22 0.99962(-.04)  0.516( -15)  0.2673        0.0101        0.538

BNL_THH2O5 1.00000(~.24)  0.435(~3.0)  0.0000        0.0000        0.000
    iaeagx 1.00610(0.60)  0.364( -16)  0.2007        0.0093        0.510
      iaea 1.00809(0.80)  0.367( -16)  0.1989        0.0092        0.511
     wdn29 0.99530(-.47)  0.393(-9.7)  0.2066        0.0088        0.521
  endfb6gx 0.99884(-.12)  0.393(-9.6)  0.2011        0.0089        0.523
    endfb6 1.00078(0.08)  0.395(-9.1)  0.1992        0.0088        0.525
  jendl3gx 1.01044(1.03)  0.371( -15)  0.2059        0.0089        0.508
    jendl3 1.01211(1.19)  0.372( -14)  0.2042        0.0089        0.510
   jef22gx 0.99821(-.18)  0.381( -12)  0.2035        0.0084        0.517
     jef22 1.00080(0.08)  0.384( -12)  0.2016        0.0083        0.519

BNL_THH2O6 1.00000(~.29)  0.000        0.0000        0.0000        0.000
    iaeagx 1.00598(0.59)  0.267        0.1493        0.0076        0.496
      iaea 1.00781(0.77)  0.269        0.1479        0.0076        0.497
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     wdn29 0.99647(-.35)  0.287        0.1535        0.0072        0.505
   endfb6gx 1.00069(0.07)  0.288        0.1495        0.0073        0.506
     endfb6 1.00247(0.25)  0.290        0.1480        0.0072        0.507
   jendl3gx 1.01035(1.02)  0.271        0.1530        0.0073        0.494
     jendl3 1.01193(1.17)  0.273        0.1517        0.0073        0.495
    jef22gx 1.00027(0.03)  0.279        0.1513        0.0069        0.502
      jef22 1.00279(0.28)  0.281        0.1498        0.0068        0.504

BNL_THH2O7 1.00000(~.06)  0.218(~3.7)  0.0000        0.0000        0.000
    iaeagx 1.00372(0.37)  0.184( -16)  0.1043        0.0062        0.483
      iaea 1.00496(0.49)  0.185( -15)  0.1032        0.0061        0.484
     wdn29 0.99585(-.42)  0.198(-9.3)  0.1071        0.0059        0.491
   endfb6gx 1.00020(0.02)  0.198(-9.3)  0.1043        0.0059        0.491
     endfb6 1.00139(0.14)  0.199(-8.6)  0.1032        0.0058        0.492
   jendl3gx 1.00716(0.71)  0.186( -14)  0.1068        0.0059        0.482
     jendl3 1.00828(0.82)  0.188( -14)  0.1058        0.0059        0.483
    jef22gx 0.99938(-.06)  0.192( -12)  0.1057        0.0056        0.489
      jef22 1.00115(0.11)  0.194( -11)  0.1045        0.0055        0.490

BNL_THH2O8 1.00000(~.10)  0.170(~4.1)  0.0000        0.0000        0.000
    iaeagx 1.00119(0.12)  0.148( -13)  0.0851        0.0056        0.478
      iaea 1.00159(0.16)  0.150( -12)  0.0842        0.0056        0.479
     wdn29 0.99517(-.49)  0.160(-5.8)  0.0872        0.0054        0.485
   endfb6gx 0.99827(-.17)  0.160(-5.9)  0.0851        0.0054        0.484
     endfb6 0.99868(-.13)  0.161(-5.1)  0.0842        0.0053        0.485
   jendl3gx 1.00336(0.33)  0.151( -11)  0.0871        0.0054        0.476
     jendl3 1.00377(0.37)  0.152( -11)  0.0863        0.0054        0.477
    jef22gx 0.99692(-.31)  0.155(-8.7)  0.0862        0.0051        0.483
      jef22 0.99747(-.25)  0.157(-7.6)  0.0852        0.0050        0.484
   ------------------------------------------------------------------------------
    Average         0.45         3.66          0.00          0.00          0.00
     iaeagx   0.70(~0.36)-16.67(~2.15)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
       iaea   0.86(~0.39)-16.09(~2.33)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
      wdn29  -0.54(~0.14) -9.83(~2.13)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
    endfb6gx  -0.19(~0.18) -9.87(~2.14)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
      endfb6  -0.04(~0.18) -9.41(~2.31)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
    jendl3gx   0.99(~0.31)-15.14(~2.04)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
      jendl3   1.12(~0.34)-14.70(~2.19)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
     jef22gx  -0.31(~0.23)-12.64(~2.12)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
       jef22  -0.11(~0.25)-12.01(~2.29)   0.00(~0.00)   0.00(~0.00)   0.00(~0.00)
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 #
 # BNL-Th2-U3-D2O criticality benchmarks
 # -------------------------------------


 SMRDIF - Compare lattice spectr.indices
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LATTICE	K-eff	Rho28	Del25	Del28	ConvR
BNL-TD2O-1	1.00000(~.22)	5.190(~ 10)	0.0000	0.0117(~6.8)	0.000
iaeagx	1.01759(1.71)	4.097(-21)	1.7365	0.0119(1.54)	0.794
iaea	1.02095(2.03)	4.045(-22)	1.7218	0.0118(1.20)	0.790
wdn29	0.97869(-2.2)	4.541(-13)	1.8249	0.0114(-2.8)	0.840
endfb6gx	0.98414(-1.6)	4.507(-13)	1.7591	0.0117(-.09)	0.863
endfb6	0.98793(-1.2)	4.443(-14)	1.7433	0.0116(-.51)	0.859
jendl3gx	1.01409(1.38)	4.244(-18)	1.8059	0.0112(-3.9)	0.795
jendl3	1.01776(1.73)	4.187(-19)	1.7920	0.0112(-4.2)	0.790
jef22gx	1.00387(0.38)	4.289(-17)	1.7769	0.0108(-8.0)	0.815
jef22	1.00709(0.70)	4.237(-18)	1.7606	0.0106(-9.4)	0.812
BNL-TD2O-2	1.00000(~.28)	0.780(~4.1)	0.0000	0.0056(~ 13)	0.000
iaeagx	0.98972(-1.0)	0.742(-4.9)	0.3881	0.0051(-8.6)	0.557
iaea	0.99056(-.96)	0.737(-5.5)	0.3843	0.0051(-8.9)	0.557
wdn29	0.97504(-2.6)	0.796(2.04)	0.4044	0.0048(-14)	0.571
endfb6gx	0.97797(-2.3)	0.803(2.94)	0.3896	0.0049(-12)	0.580
endfb6	0.97887(-2.2)	0.798(2.24)	0.3856	0.0049(-13)	0.580
jendl3gx	0.99475(-.53)	0.758(-2.8)	0.4003	0.0049(-13)	0.555
jendl3	0.99554(-.45)	0.753(-3.5)	0.3968	0.0049(-13)	0.555
jef22gx	0.99001(-1.0)	0.767(-1.7)	0.3948	0.0046(-18)	0.565
jef22	0.99121(-.89)	0.763(-2.2)	0.3909	0.0045(-19)	0.565
BNL-TD2O-3	1.00000(~.40)	0.559(~3.2)	0.0000	0.0047(~ 15)	0.000
iaeagx	0.99067(-.95)	0.527(-5.8)	0.2832	0.0044(-6.6)	0.531
iaea	0.99117(-.89)	0.525(-6.2)	0.2805	0.0044(-7.0)	0.531
wdn29	0.97673(-2.4)	0.565(1.04)	0.2954	0.0041(-12)	0.542
endfb6gx	0.98161(-1.9)	0.569(1.84)	0.2840	0.0042(-11)	0.549
endfb6	0.98214(-1.8)	0.566(1.32)	0.2812	0.0042(-11)	0.549
jendl3gx	0.99598(-.40)	0.538(-3.8)	0.2919	0.0042(-11)	0.529
jendl3	0.99640(-.36)	0.535(-4.3)	0.2894	0.0042(-11)	0.529
jef22gx	0.99260(-.75)	0.544(-2.7)	0.2878	0.0039(-17)	0.538
jef22	0.99345(-.66)	0.542(-3.1)	0.2850	0.0039(-18)	0.538
BNL-TD2O-4	1.00000(~.27)	0.297(~3.7)	0.0000	0.0000	0.000
iaeagx	0.98616(-1.4)	0.287(-3.2)	0.1605	0.0035	0.498
iaea	0.98612(-1.4)	0.287(-3.3)	0.1590	0.0035	0.499
wdn29	0.97105(-3.0)	0.309(4.11)	0.1679	0.0033	0.506
endfb6gx	0.98065(-2.0)	0.310(4.44)	0.1607	0.0034	0.509
endfb6	0.98061(-2.0)	0.310(4.28)	0.1592	0.0034	0.510
jendl3gx	0.99117(-.89)	0.293(-1.3)	0.1653	0.0034	0.497
jendl3	0.99104(-.91)	0.292(-1.5)	0.1639	0.0034	0.497
jef22gx	0.98985(-1.0)	0.296(-.20)	0.1629	0.0032	0.503
jef22	0.99014(-1.0)	0.296(-.24)	0.1613	0.0031	0.504
BNL-TD2O-5	1.00000(~.75)	0.234(~3.4)	0.0000	0.0000	0.000
iaeagx	0.99404(-.60)	0.221(-5.5)	0.1251	0.0033	0.488
iaea	0.99378(-.63)	0.221(-5.3)	0.1240	0.0033	0.489
wdn29	0.97776(-2.3)	0.238(1.92)	0.1311	0.0031	0.496
endfb6gx	0.98956(-1.1)	0.239(1.97)	0.1253	0.0031	0.498
endfb6	0.98929(-1.1)	0.239(1.97)	0.1241	0.0031	0.498
jendl3gx	0.99863(-.14)	0.225(-3.7)	0.1288	0.0032	0.487
jendl3	0.99829(-.17)	0.225(-3.7)	0.1278	0.0032	0.487
jef22gx	0.99796(-.20)	0.228(-2.6)	0.1269	0.0029	0.493
jef22	0.99800(-.20)	0.228(-2.4)	0.1257	0.0029	0.494
BNL-TD2O-6	1.00000(~.59)	0.166(~3.6)	0.0000	0.0000	0.000
iaeagx	0.98794(-1.2)	0.155(-6.6)	0.0888	0.0031	0.479
iaea	0.98739(-1.3)	0.156(-6.2)	0.0880	0.0031	0.479

```
     wdn29 0.96971(-3.2)  0.168(1.33)  0.0932        0.0029        0.485
  endfb6gx 0.98464(-1.6)  0.167(0.72)  0.0888        0.0029        0.486
    endfb6 0.98407(-1.6)  0.168(1.02)  0.0880        0.0029        0.486
  jendl3gx 0.99187(-.82)  0.158(-4.8)  0.0913        0.0030        0.477
    jendl3 0.99121(-.89)  0.158(-4.6)  0.0906        0.0030        0.477
   jef22gx 0.99200(-.81)  0.160(-3.6)  0.0899        0.0027        0.483
     jef22 0.99170(-.84)  0.161(-3.2)  0.0891        0.0027        0.483

BNL-TD2O-7 1.00000(~.99)  0.104(~4.8)  0.0000        0.0000        0.000
    iaeagx 1.00971(0.96)  0.107(2.60)  0.0616        0.0029        0.471
      iaea 1.00888(0.88)  0.108(3.46)  0.0611        0.0029        0.472
     wdn29 0.98960(-1.1)  0.117(  12)  0.0648        0.0027        0.477
  endfb6gx 1.00715(0.71)  0.115(  11)  0.0616        0.0027        0.476
    endfb6 1.00632(0.63)  0.116(  11)  0.0611        0.0027        0.477
  jendl3gx 1.01272(1.25)  0.109(4.62)  0.0634        0.0028        0.470
    jendl3 1.01181(1.16)  0.109(5.29)  0.0629        0.0028        0.470
   jef22gx 1.01338(1.31)  0.110(6.15)  0.0623        0.0026        0.475
     jef22 1.01274(1.25)  0.111(7.02)  0.0618        0.0026        0.476

BNL-TD2O-8 1.00000(~.68)  0.089(~5.6)  0.0000        0.0000        0.000
    iaeagx 1.01247(1.22)  0.075( -15)  0.0433        0.0028        0.466
      iaea 1.01141(1.12)  0.076( -14)  0.0430        0.0028        0.467
     wdn29 0.99076(-.94)  0.083(-6.6)  0.0456        0.0027        0.471
  endfb6gx 1.01050(1.03)  0.081(-8.9)  0.0433        0.0026        0.470
    endfb6 1.00943(0.93)  0.082(-7.8)  0.0430        0.0026        0.471
  jendl3gx 1.01458(1.43)  0.077( -14)  0.0446        0.0027        0.465
    jendl3 1.01345(1.32)  0.078( -13)  0.0442        0.0027        0.465
   jef22gx 1.01576(1.54)  0.078( -12)  0.0438        0.0025        0.470
     jef22 1.01481(1.45)  0.079( -11)  0.0435        0.0025        0.471
  ------------------------------------------------------------------------------
   Average         0.58         5.35          0.00         11.90         0.00
    iaeagx  -0.17(~1.17) -7.48(~6.91)   0.00(~0.00)  -4.54(~4.38)  0.00(~0.00)
      iaea  -0.14(~1.21) -7.42(~7.14)   0.00(~0.00)  -4.92(~4.39)  0.00(~0.00)
     wdn29  -2.21(~0.77)  0.43(~6.83)   0.00(~0.00)  -9.63(~4.87)  0.00(~0.00)
  endfb6gx  -1.08(~1.18)  0.07(~7.09)   0.00(~0.00)  -7.68(~5.42)  0.00(~0.00)
    endfb6  -1.05(~1.11)  0.00(~7.30)   0.00(~0.00)  -8.09(~5.39)  0.00(~0.00)
  jendl3gx   0.16(~0.95) -5.47(~6.74)   0.00(~0.00)  -9.40(~3.97)  0.00(~0.00)
    jendl3   0.18(~0.99) -5.53(~6.94)   0.00(~0.00)  -9.62(~3.94)  0.00(~0.00)
   jef22gx  -0.07(~0.97) -4.26(~6.81)   0.00(~0.00) -14.34(~4.52)  0.00(~0.00)
     jef22  -0.02(~0.94) -4.17(~7.04)   0.00(~0.00) -15.58(~4.42)  0.00(~0.00)
 #
```

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#
# Uranium D2O criticality benchmarks
# ----------------------------------


D2OSMR - Summarize WLUP D2O Benchmarks
======================================

  LATTICE      K-eff         Del         ConvR          CuA          LuR
=============================================================================
ZED2T1D2O 1.00000(0.25) 0.0511( 1.5) 1.4138( 0.3)  1.140(1.00)  1.206(0.40)
   iaeagx 1.00721(0.72) 0.0528( 3.3) 1.4186( 0.3)  1.146(0.86)  1.219(1.10)
     iaea 1.00528(0.53) 0.0526( 3.0) 1.4238( 0.7)  1.146(0.85)  1.221(1.27)
    wdn29 1.00313(0.31) 0.0531( 4.0) 1.4223( 0.6)  1.146(1.33)  1.203(-.24)
 endfb6gx 1.00296(0.30) 0.0531( 3.9) 1.4183( 0.3)  1.146(0.84)  1.222(1.30)
   endfb6 1.00116(0.12) 0.0530( 3.7) 1.4231( 0.7)  1.146(0.81)  1.224(1.47)
 jendl3gx 1.00435(0.43) 0.0516( 1.0) 1.4214( 0.5)  1.146(0.84)  1.221(1.21)
   jendl3 1.00254(0.25) 0.0516( 0.9) 1.4261( 0.9)  1.146(0.83)  1.223(1.39)
  jef22gx 1.00717(0.71) 0.0518( 1.3) 1.4171( 0.2)  1.146(0.82)  1.197(-.75)
    jef22 1.00492(0.49) 0.0514( 0.5) 1.4224( 0.6)  1.146(0.81)  1.200(-.46)

ZED2T1Air 1.00000(0.25) 0.0583( 1.5) 1.3765( 0.3)  1.146(1.00)  1.223(0.40)
   iaeagx 1.01076(1.07) 0.0602( 3.2) 1.3706(-0.4)  1.147(0.60)  1.238(1.24)
     iaea 1.00841(0.83) 0.0600( 3.0) 1.3765( 0.0)  1.147(0.54)  1.241(1.47)
    wdn29 1.00609(0.61) 0.0610( 4.6) 1.3726(-0.3)  1.145(0.40)  1.227(0.33)
 endfb6gx 1.00637(0.63) 0.0607( 4.2) 1.3713(-0.4)  1.147(0.75)  1.241(1.45)
   endfb6 1.00419(0.42) 0.0607( 4.1) 1.3768( 0.0)  1.146(0.68)  1.244(1.69)
 jendl3gx 1.00839(0.83) 0.0591( 1.4) 1.3720(-0.3)  1.147(0.67)  1.240(1.36)
   jendl3 1.00621(0.62) 0.0591( 1.4) 1.3773( 0.1)  1.146(0.60)  1.243(1.61)
  jef22gx 1.01125(1.11) 0.0592( 1.5) 1.3677(-0.6)  1.147(0.65)  1.217(-.53)
    jef22 1.00860(0.85) 0.0589( 1.0) 1.3739(-0.2)  1.146(0.58)  1.221(-.18)

ZED2T2p24 1.00000(0.25) 0.0580( 1.5) 0.9258( 0.6)
   iaeagx 1.00043(0.04) 0.0537(-7.4) 0.8999(-2.8)
     iaea 0.99859(-.14) 0.0535(-7.8) 0.9017(-2.6)
    wdn29 0.99723(-.28) 0.0541(-6.7) 0.9036(-2.4)
 endfb6gx 0.99522(-.48) 0.0541(-6.8) 0.9064(-2.1)
   endfb6 0.99364(-.64) 0.0539(-7.1) 0.9082(-1.9)
 jendl3gx 0.99719(-.28) 0.0524(-9.7) 0.9073(-2.0)
   jendl3 0.99558(-.44) 0.0523(-9.9) 0.9091(-1.8)
  jef22gx 0.99916(-.08) 0.0527(-9.2) 0.9082(-1.9)
    jef22 0.99702(-.30) 0.0522(****) 0.9101(-1.7)

ZED2T2p40 1.00000(0.25) 0.0547( 1.5) 0.7663( 0.6)
   iaeagx 1.00823(0.82) 0.0493(-9.9) 0.7280(-5.0)
     iaea 1.00693(0.69) 0.0491(****) 0.7288(-4.9)
    wdn29 1.00362(0.36) 0.0497(-9.1) 0.7372(-3.8)
 endfb6gx 1.00445(0.44) 0.0496(-9.4) 0.7333(-4.3)
   endfb6 1.00321(0.32) 0.0494(-9.7) 0.7341(-4.2)
 jendl3gx 1.00426(0.42) 0.0484(****) 0.7356(-4.0)
   jendl3 1.00304(0.30) 0.0482(****) 0.7372(-3.8)
  jef22gx 1.00626(0.62) 0.0484(****) 0.7379(-3.7)
    jef22 1.00467(0.47) 0.0481(****) 0.7395(-3.5)

ZED2T3p24 1.00000(0.25)
   iaeagx 1.00580(0.58)
     iaea 1.00427(0.43)
    wdn29 1.00074(0.07)
 endfb6gx 1.00152(0.15)
   endfb6 1.00012(0.01)
 jendl3gx 1.00262(0.26)
   jendl3 1.00121(0.12)
  jef22gx 1.00462(0.46)
    jef22 1.00283(0.28)

ZED2T4D22 1.00000(0.25) 0.0071(10.0)
   iaeagx 1.00017(0.02) 0.0087(23.2)
     iaea 0.99982(-.02) 0.0087(23.2)
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    wdn29 0.99578(-.42) 0.0081(14.6)
 endfb6gx 0.99062(-.95) 0.0083(17.9)
   endfb6 0.99030(-.98) 0.0083(17.9)
 jendl3gx 1.00141(0.14) 0.0084(18.7)
   jendl3 1.00111(0.11) 0.0084(18.9)
  jef22gx 0.99793(-.21) 0.0079(11.2)
    jef22 0.99748(-.25) 0.0078(10.3)

ZED2T4A22 1.00000(0.25) 0.0069(10.0)
   iaeagx 1.00360(0.36) 0.0098(41.4)
     iaea 1.00317(0.32) 0.0098(41.5)
    wdn29 0.99939(-.06) 0.0091(31.7)
 endfb6gx 0.99375(-.63) 0.0094(35.5)
   endfb6 0.99334(-.67) 0.0094(35.6)
 jendl3gx 1.00524(0.52) 0.0095(36.8)
   jendl3 1.00487(0.49) 0.0095(37.0)
  jef22gx 1.00173(0.17) 0.0089(28.1)
    jef22 1.00117(0.12) 0.0088(27.2)

ZED2T4D28 1.00000(0.25) 0.0061(10.0)
   iaeagx 0.99885(-.12) 0.0085(38.1)
     iaea 0.99849(-.15) 0.0085(38.2)
    wdn29 0.99592(-.41) 0.0078(28.2)
 endfb6gx 0.99206(-.80) 0.0081(31.9)
   endfb6 0.99167(-.84) 0.0081(31.9)
 jendl3gx 0.99995(-.01) 0.0082(33.5)
   jendl3 0.99960(-.04) 0.0082(33.6)
  jef22gx 0.99680(-.32) 0.0076(24.7)
    jef22 0.99635(-.37) 0.0076(23.8)

ZED2T4A28 1.00000(0.25) 0.0069(10.0)
   iaeagx 1.00001(0.00) 0.0095(37.4)
     iaea 0.99959(-.04) 0.0095(37.6)
    wdn29 0.99699(-.30) 0.0088(27.7)
 endfb6gx 0.99329(-.68) 0.0090(31.3)
   endfb6 0.99286(-.72) 0.0090(31.3)
 jendl3gx 1.00158(0.16) 0.0092(33.2)
   jendl3 1.00119(0.12) 0.0092(33.4)
  jef22gx 0.99844(-.16) 0.0086(24.5)
    jef22 0.99788(-.21) 0.0085(23.7)

 DCAT1D22 1.00000(0.25)
   iaeagx 1.00081(0.08)
     iaea 1.00074(0.07)
    wdn29 1.00060(0.06)
 endfb6gx 1.00033(0.03)
   endfb6 1.00028(0.03)
 jendl3gx 1.00082(0.08)
   jendl3 1.00077(0.08)
  jef22gx 1.00104(0.10)
    jef22 1.00096(0.10)

 DCAT1A22 1.00000(0.25)
   iaeagx 1.00027(0.03)
     iaea 0.99994(-.01)
    wdn29 0.99960(-.04)
 endfb6gx 0.99974(-.03)
   endfb6 0.99944(-.06)
 jendl3gx 1.00026(0.03)
   jendl3 0.99996(0.00)
  jef22gx 1.00055(0.06)
    jef22 1.00020(0.02)

 DCAT1H22 1.00000(0.25)
   iaeagx 1.00109(0.11)
     iaea 1.00113(0.11)
    wdn29 1.00126(0.13)
 endfb6gx 1.00069(0.07)
   endfb6 1.00074(0.07)
```

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 jendl3gx 1.00118(0.12)
   jendl3 1.00124(0.12)
  jef22gx 1.00130(0.13)
    jef22 1.00134(0.13)

 DCAT1D25 1.00000(0.25)
   iaeagx 1.00104(0.10)
     iaea 1.00085(0.09)
    wdn29 1.00038(0.04)
 endfb6gx 1.00060(0.06)
   endfb6 1.00043(0.04)
 jendl3gx 1.00100(0.10)
   jendl3 1.00083(0.08)
  jef22gx 1.00129(0.13)
    jef22 1.00110(0.11)

 DCAT1A25 1.00000(0.25)
   iaeagx 1.00114(0.11)
     iaea 1.00086(0.09)
    wdn29 1.00041(0.04)
 endfb6gx 1.00067(0.07)
   endfb6 1.00041(0.04)
 jendl3gx 1.00114(0.11)
   jendl3 1.00088(0.09)
  jef22gx 1.00144(0.14)
    jef22 1.00115(0.12)

 DCAT1H25 1.00000(0.25)
   iaeagx 1.00160(0.16)
     iaea 1.00169(0.17)
    wdn29 1.00176(0.18)
 endfb6gx 1.00122(0.12)
   endfb6 1.00130(0.13)
 jendl3gx 1.00167(0.17)
   jendl3 1.00172(0.17)
  jef22gx 1.00180(0.18)
    jef22 1.00183(0.18)
================================================================================
Average          (0.24)       ( 5.8)       ( 0.5)       (1.00)       (0.40)
   iaeagx    0.27(0.44)   16.2(25.7)   -2.0( 2.9)   0.73(0.74)   1.17(1.17)
     iaea    0.20(0.35)   16.1(25.8)   -1.7( 2.8)   0.69(0.71)   1.37(1.37)
    wdn29    0.02(0.28)   11.9(19.2)   -1.5( 2.3)   0.87(0.98)   0.05(0.29)
 endfb6gx   -0.11(0.47)   13.6(21.6)   -1.6( 2.4)   0.79(0.79)   1.38(1.38)
   endfb6   -0.18(0.47)   13.5(21.7)   -1.4( 2.3)   0.74(0.74)   1.58(1.58)
 jendl3gx    0.21(0.33)   12.9(22.8)   -1.4( 2.3)   0.76(0.76)   1.29(1.29)
   jendl3    0.14(0.27)   12.9(22.9)   -1.2( 2.1)   0.71(0.72)   1.50(1.50)
  jef22gx    0.20(0.42)    8.8(17.1)   -1.5( 2.1)   0.73(0.74)  -0.64(0.65)
    jef22    0.12(0.34)    8.1(16.7)   -1.2( 2.0)   0.70(0.70)  -0.32(0.35)
#
```

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#
# Uranium D2O burnup benchmark
# ----------------------------


D2OE3B comparison AVERAGE VALUES (Ni/Nj%)(delta%)
================================================

      BUP N25/N28     N26/N28     N49/N28     N40/N49     N41/N49     N42/N4
=============================================================================
EXP  3250 0.438( 2.0) 0.044( 2.0) 0.178( 2.0) 16.50( 2.0) 2.240( 2.0) 0.220(  2.0)
   iaeagx 0.436(-0.6) 0.043(-1.1) 0.173(-2.8) 17.09( 3.6) 2.406( 7.4) 0.225(  2.2)
     iaea 0.436(-0.5) 0.043(-1.1) 0.173(-2.7) 17.25( 4.5) 2.394( 6.9) 0.225(  2.1)
    wdn29 0.435(-0.7) 0.043(-3.1) 0.176(-1.1) 17.37( 5.3) 2.300( 2.7) 0.215( -2.1)
 endfb6gx 0.436(-0.4) 0.044(-0.8) 0.174(-2.1) 16.95( 2.8) 2.376( 6.1) 0.222(  0.8)
   endfb6 0.436(-0.4) 0.044(-0.7) 0.175(-2.0) 17.12( 3.7) 2.365( 5.6) 0.221(  0.7)
 jendl3gx 0.434(-0.8) 0.043(-1.1) 0.175(-1.4) 16.99( 3.0) 2.364( 5.5) 0.221(  0.4)
   jendl3 0.435(-0.8) 0.043(-1.0) 0.176(-1.3) 17.15( 4.0) 2.353( 5.1) 0.221(  0.4)
  jef22gx 0.436(-0.4) 0.043(-1.3) 0.175(-1.8) 16.90( 2.5) 2.353( 5.1) 0.221(  0.3)
    jef22 0.436(-0.4) 0.043(-1.2) 0.175(-1.6) 17.07( 3.5) 2.342( 4.6) 0.220(  0.2)

EXP  6500 0.247( 2.0) 0.074( 2.0) 0.242( 2.0) 34.30( 2.0) 6.290( 2.0) 1.580(  2.0)
   iaeagx 0.259( 4.8) 0.070(-5.9) 0.236(-2.4) 33.85(-1.3) 6.477( 3.0) 1.424( -9.9)
     iaea 0.259( 5.1) 0.070(-6.0) 0.236(-2.4) 34.15(-0.4) 6.472( 2.9) 1.428( -9.6)
    wdn29 0.258( 4.4) 0.068(-7.9) 0.241(-0.6) 34.58( 0.8) 6.268(-0.3) 1.380(-12.6)
 endfb6gx 0.260( 5.3) 0.070(-5.7) 0.238(-1.6) 33.55(-2.2) 6.377( 1.4) 1.393(-11.8)
   endfb6 0.261( 5.5) 0.070(-5.7) 0.238(-1.6) 33.85(-1.3) 6.375( 1.4) 1.398(-11.5)
 jendl3gx 0.257( 4.2) 0.070(-6.0) 0.240(-1.0) 33.70(-1.8) 6.422( 2.1) 1.413(-10.6)
   jendl3 0.258( 4.4) 0.070(-6.0) 0.240(-1.0) 34.01(-0.9) 6.420( 2.1) 1.419(-10.2)
  jef22gx 0.260( 5.4) 0.069(-6.2) 0.239(-1.2) 33.48(-2.4) 6.305( 0.2) 1.388(-12.2)
    jef22 0.261( 5.6) 0.069(-6.2) 0.239(-1.2) 33.79(-1.5) 6.302( 0.2) 1.391(-11.9)

EXP 10800 0.122( 2.0) 0.089( 2.0) 0.267( 2.0) 53.60( 2.0)11.140( 2.0) 5.110(  2.0)
   iaeagx 0.123( 1.2) 0.089( 0.0) 0.262(-2.0) 55.33( 3.2)12.013( 7.8) 5.209(  1.9)
     iaea 0.124( 1.8) 0.089(-0.2) 0.262(-2.1) 55.79( 4.1)12.034( 8.0) 5.242(  2.6)
    wdn29 0.123( 0.4) 0.087(-2.3) 0.267(-0.1) 56.79( 5.9)11.743( 5.4) 5.102( -0.2)
 endfb6gx 0.125( 2.3) 0.089( 0.3) 0.264(-1.0) 54.84( 2.3)11.838( 6.3) 5.078( -0.6)
   endfb6 0.125( 2.9) 0.089( 0.2) 0.264(-1.1) 55.32( 3.2)11.864( 6.5) 5.114(  0.1)
 jendl3gx 0.122( 0.1) 0.089(-0.2) 0.266(-0.5) 55.09( 2.8)11.972( 7.5) 5.208(  1.9)
   jendl3 0.123( 0.6) 0.089(-0.3) 0.265(-0.6) 55.56( 3.7)12.000( 7.7) 5.254(  2.8)
  jef22gx 0.125( 2.6) 0.089(-0.3) 0.265(-0.7) 54.74( 2.1)11.680( 4.8) 5.057( -1.0)
    jef22 0.126( 3.1) 0.089(-0.4) 0.265(-0.7) 55.22( 3.0)11.705( 5.1) 5.088( -0.4)
=============================================================================
Average        ( 2.0)      ( 2.0)      ( 2.0)      ( 2.0)      ( 2.0)      (  2.0)
   iaeagx  1.62( 1.5) -3.72( 2.5) -3.58( 2.2)  1.95( 1.8)  6.18( 1.6) -1.89(  4.6)
     iaea  1.83( 1.6) -3.74( 2.4) -3.50( 2.1)  2.84( 1.8)  6.09( 1.6) -1.58(  4.6)
    wdn29  1.25( 1.5) -5.71( 2.3) -1.86( 2.4)  4.18( 1.9)  2.82( 1.8) -4.81(  4.6)
 endfb6gx  2.05( 1.6) -3.40( 2.5) -2.78( 2.3)  1.04( 1.8)  4.62( 1.7) -3.96(  4.5)
   endfb6  2.26( 1.7) -3.41( 2.4) -2.73( 2.2)  1.97( 1.8)  4.58( 1.7) -3.60(  4.5)
 jendl3gx  1.06( 1.5) -3.76( 2.4) -2.20( 2.3)  1.46( 1.8)  5.25( 1.6) -2.60(  4.6)
   jendl3  1.27( 1.5) -3.78( 2.4) -2.15( 2.2)  2.38( 1.8)  5.22( 1.7) -2.13(  4.7)
  jef22gx  2.13( 1.6) -3.92( 2.4) -2.43( 2.3)  0.83( 1.8)  3.42( 1.7) -4.38(  4.4)
    jef22  2.33( 1.7) -3.93( 2.4) -2.33( 2.2)  1.77( 1.8)  3.36( 1.6) -4.09(  4.5)
#
```

```
#
# NEA/CRP Burnup Credit Criticality Benchmarks
# Part-1B: Isotopic composition prediction
# ----------------------------------------


WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Measured values)
************************************
Burnup =    27.35 GWd/tU
k-inf  =  0.96623
************************

Reference  results                  : BUCR1BM.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22

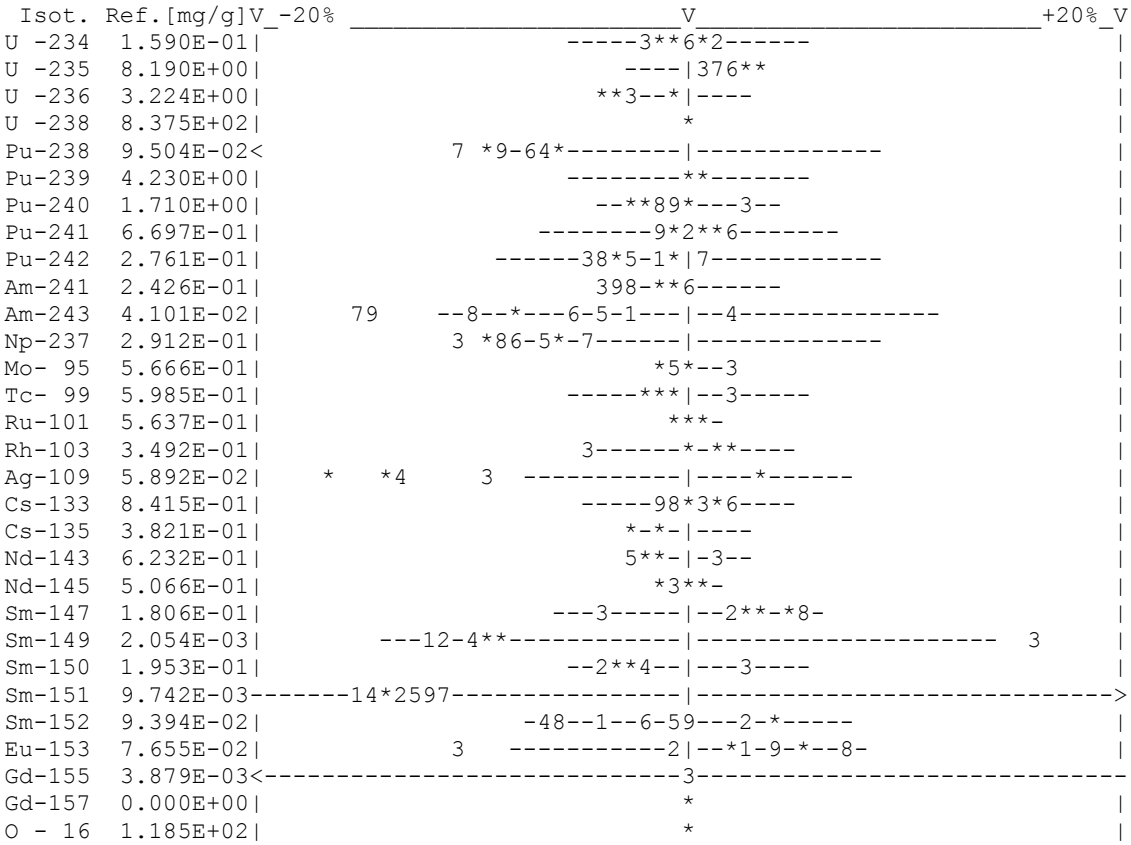
 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.600E-01|                        3**6*2                        |
U -235  8.470E+00|                      3 *** |                         |
U -236  3.140E+00|                           **3 45                     |
U -238  8.425E+02|                           *|                         |
Pu-238  1.012E-01<    75296 *8               |                          |
Pu-239  4.264E+00|                      2**   |                          |
Pu-240  1.719E+00|                      * *9* | 3                        |
Pu-241  6.812E-01|                    9*2**6  |                          |
Pu-242  2.886E-01|               3**  *6 7     |                          |
Am-241  0.000E+00|                           *                          |
Am-243  0.000E+00|                           *                          |
Np-237  2.680E-01|                      3 4186|5* 7                      |
Mo- 95  0.000E+00|                           *                          |
Tc- 99  0.000E+00|                           *                          |
Ru-101  0.000E+00|                           *                          |
Rh-103  0.000E+00|                           *                          |
Ag-109  0.000E+00|                           *                          |
Cs-133  8.500E-01|                        98**6                         |
Cs-135  3.600E-01|                           |    * *4                  |
Nd-143  6.130E-01|                         **    3                      |
Nd-145  5.100E-01|                        *31*                          |
Sm-147  0.000E+00|                           *                          |
Sm-149  2.900E-03<3                          |                          |
Sm-150  2.070E-01|              2***4     3    |                          |
Sm-151  0.000E+00|                           *                          |
Sm-152  8.700E-02|                           |48   1 6  59   2 37       |
Eu-153  7.900E-02|         3             2   *1|9*  8                     |
Gd-155  0.000E+00|                           *                          |
Gd-157  0.000E+00|                           *                          |
O - 16  0.000E+00|                           *                          |


WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Average results)
```

```
************************************
Burnup =    27.35 GWd/tU
k-inf  =  0.96623
************************
```

Reference results : BUCR1BA.REF

```
Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22
```



```
WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Measured values)
************************************
Burnup =    37.12 GWd/tU
k-inf  =  0.87923
************************

Reference  results                  : BUCR1BM.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.400E-01|               3     ** *12|                           |
U -235  5.170E+00|               3 76 **8    |                           |
U -236  3.530E+00|                           ** 3 *                      |
U -238  8.327E+02|                           *                           |
Pu-238  1.893E-01<        *2964*             |                           |
Pu-239  4.357E+00|                     32**   |                           |
Pu-240  2.239E+00|                      **8*  | 3                         |
Pu-241  9.028E-01|                    9***6   |                           |
Pu-242  5.761E-01|                  3**  * 6 7 |                           |
Am-241  0.000E+00|                           *                           |
Am-243  0.000E+00|                           *                           |
Np-237  3.560E-01|                           |    34186   5*  7            |
Mo- 95  0.000E+00|                           *                           |
Tc- 99  0.000E+00|                           *                           |
Ru-101  0.000E+00|                           *                           |
Rh-103  0.000E+00|                           *                           |
Ag-109  0.000E+00|                           *                           |
Cs-133  1.090E+00|                        9 8*3*6                        |
Cs-135  4.000E-01|                          3* **                        |
Nd-143  7.160E-01|                         **|      3                    |
Nd-145  6.530E-01|                       45 3**                          |
Sm-147  0.000E+00|                           *                           |
Sm-149  3.000E-03<   3                     |                           |
Sm-150  2.710E-01|                     2176* *|      3                    |
Sm-151  0.000E+00|                           *                           |
Sm-152  1.040E-01|                           |       4 8   1  6    5 9   2 >
Eu-153  1.090E-01|                     3     |       2  1*  * 9  8        |
Gd-155  0.000E+00|                           *                           |
Gd-157  0.000E+00|                           *                           |
O - 16  0.000E+00|                           *                           |
```

```
WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Average results)
************************************
Burnup =    37.12 GWd/tU
k-inf  =  0.87923
**********************

Reference  results                  : BUCR1BA.REF

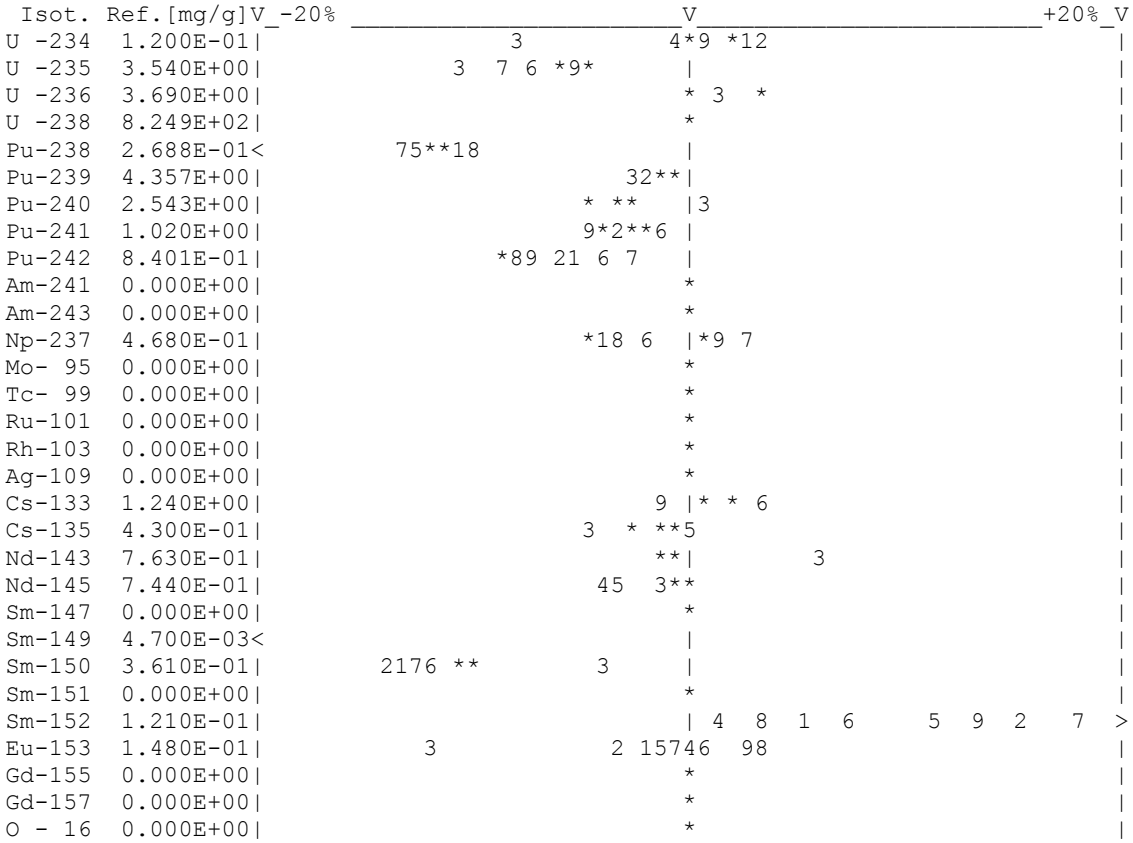
Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.363E-01|                 ----3----**|6*2--------                |
U -235  4.879E+00|                   --------3|-76-**---                  |
U -236  3.633E+00|                       6*-3-*----                        |
U -238  8.304E+02|                            *                            |
Pu-238  1.835E-01<            *2964*----------|-----------                |
Pu-239  4.314E+00|                   -------32**--------                   |
Pu-240  2.189E+00|                      ----**8*----3                      |
Pu-241  8.859E-01|                   -------9***6-------                   |
Pu-242  5.593E-01|                 ------**9-126--7---------               |
Am-241  3.119E-01|                       398-2**6-----                      |
Am-243  1.137E-01|          *  -8-----2-*-1-5--|4---------------           |
Np-237  4.183E-01|           3*8 6--*9-7------|-------------              |
Mo- 95  7.333E-01|                         *5*--  3                         |
Tc- 99  7.745E-01|                        ---******---3                     |
Ru-101  7.611E-01|                           ****                           |
Rh-103  4.436E-01|                     --3-----*-**4----                    |
Ag-109  8.570E-02|            *    *----3-----|----------- *                |
Cs-133  1.085E+00|                      -----9-8**-6---                     |
Cs-135  4.148E-01|                       398-**|-----                       |
Nd-143  7.292E-01|                       --**--|----3-                      |
Nd-145  6.454E-01|                         45-**7                           |
Sm-147  2.010E-01|                 -----3------|--2-*-1-*8--               |
Sm-149  2.208E-03|       ---12--46*9-----------|--------------------3--     |
Sm-150  2.738E-01|                   --2-*-6**--|----3------                |
Sm-151  1.092E-02----1-4*-2579-----------------|----------------------------->
Sm-152  1.195E-01|               4-8--1--6---5|9--2--7-3-----              |
Eu-153  1.139E-01|                3-----------|-2--*7-469--8               |
Gd-155  6.676E-03<-----------------------------3-----------------------------
Gd-157  0.000E+00|                            *                             |
O - 16  1.185E+02|                            *                             |
```

```
WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Measured values)
************************************
Burnup =    44.34 GWd/tU
k-inf  =  0.82582
************************

Reference  results                  : BUCR1BM.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22
```



```
WEDB1B - Isotopic composition comparison
************************************
 OECD/NEA Burnup Credit Calculational
 Criticality Benchmark Phase 1B
 (Average results)
************************************
Burnup =    44.34 GWd/tU
k-inf  =  0.82582
**********************

Reference  results                  : BUCR1BA.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22

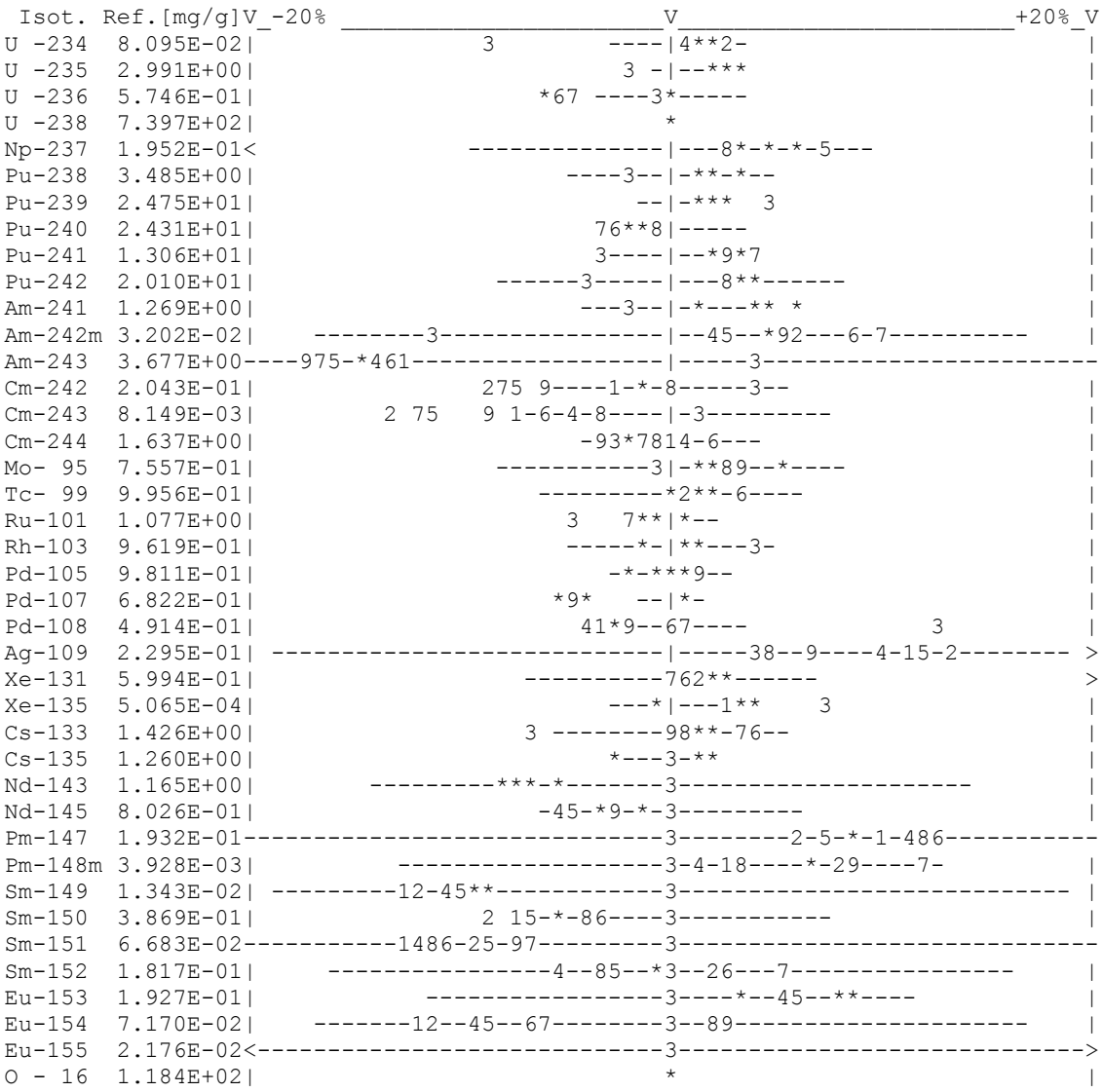
 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.215E-01|               3----------4*9-*12----------             |
U -235  3.201E+00|                ---------3--7-6--*-*-----               |
U -236  3.769E+00|                        **-3|*---                       |
U -238  8.274E+02|                           **                          |
Pu-238  2.572E-01<            *29*18----------|----------                 |
Pu-239  4.303E+00|                 --------32**-----------                |
Pu-240  2.437E+00|                    -------*|**----3-                   |
Pu-241  9.892E-01|                   -------9*2**6--------                |
Pu-242  7.985E-01|                  --------*5*--*--6-7--------           |
Am-241  3.403E-01|                      --398-2**6-------                 |
Am-243  1.917E-01|             -9*-------6213--54---------------          |
Np-237  5.005E-01|            *18-6--5*-7------|--------------            |
Mo- 95  8.440E-01|                          -1***--  3                    |
Tc- 99  8.958E-01|                        -----**4*----3                  |
Ru-101  9.021E-01|                           --*****-                     |
Rh-103  4.989E-01|                      ----3---*-*2*4---                 |
Ag-109  1.053E-01|                 *------**---3|-----------     76        |
Cs-133  1.244E+00|                     ------9-|*-*-6---                  |
Cs-135  4.318E-01|                      3-*-***|-------                   |
Nd-143  7.748E-01|                      --**8--|-----3-                   |
Nd-145  7.339E-01|                         *--3**                        |
Sm-147  2.070E-01|               ------3-------|--2-7*--16*---            |
Sm-149  2.336E-03|      ---12---6**-9----------|------------------3----   |
Sm-150  3.311E-01|                  ---2-*-659*--|-----3-------             |
Sm-151  1.171E-02---1-4682-*-9-----------------|----------------------------->
Sm-152  1.355E-01|              -4-8--1--6-----5-9--2--7--3----             |
Eu-153  1.397E-01|                ---3---------|---21-5746---98            |
Gd-155  8.849E-03<-----------------------------3-------------------------------
Gd-157  0.000E+00|                             *                          |
O - 16  1.185E+02|                             *                          |
#
```

```
#
# NEA/CRP Plutonium Recycling Benchmarks
# --------------------------------------

WEDB1B - Isotopic composition comparison
************************************************************
Physics of Plutonium Recycling
Benchmark A - Highly degraded Plutonium
Nuclide Densities of Actinides and Fission Products, 1/(b cm)
************************************************************
Burnup =    50.00 GWd/tU
k-inf  =  0.93978
************************

Reference  results                  : purecya.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22
```



```
WEDB1B - Isotopic composition comparison
************************************************************
Physics of Plutonium Recycling
Benchmark B - Normal PWR recycled Plutonium
Nuclide Densities of Actinides and Fission Products, 1/(b cm)
************************************************************
Burnup =    50.00 GWd/tU
k-inf  =  0.91357
************************

Reference  results                  : purecyb.REF

Legend: --- Uncertainty
        *   Multiple points
        1      iaeagx
        2        iaea
        3       wdn29
        4    endfb6gx
        5      endfb6
        6    jendl3gx
        7      jendl3
        8     jef22gx
        9       jef22

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.904E-02<----------------------------|----------------5*8*-1--------
U -235  7.984E-01|                           --|3-  * 5*1                    |
U -236  2.499E-01|                      ** ----*-3--                         |
U -238  8.000E+02|                           *                               |
Np-237  1.476E-01|            -----------------|----------8*1*4*-            |
Pu-238  8.054E-01<             ----------------|-*2-9-6*-8------              |
Pu-239  1.208E+01|                        ---3|---76**4                     |
Pu-240  9.957E+00|                        76*1*8---     3                     |
Pu-241  6.240E+00|                         3--|-9*1*4                       |
Pu-242  3.921E+00|   3              -4-8--16--|5-9--2--7-                    |
Am-241  4.351E-01|                     --3---|---98-   21*6                 |
Am-242m 9.080E-03----------------------------3|-------*--*54-----76----------
Am-243  1.125E+00|         97     --25-8----6-1|4-------------                3
Cm-242  1.320E-01|          27*      -------1*4|-----3----                    |
Cm-243  5.519E-03<5--9-------16--4-8-----------|-3-------------------------- |
Cm-244  7.072E-019   7  2  5           ----3--8|----16-- 4                    |
Mo- 95  7.384E-01|                   ---------3|--1*-*--*-                    |
Tc- 99  9.775E-01|                      ------***-*----                       |
Ru-101  1.067E+00|                     3   **-98-                            |
Rh-103  8.478E-01|                      9*--2*|-----3                        |
Pd-105  9.674E-01|                       * *-4**--                           |
Pd-107  6.705E-01|                    *3**  ---*---                          |
Pd-108  4.886E-01|                   **9  67---|---               3          |
Ag-109  2.130E-01|  --------------------------|-8--93----4152-------------6 >
Xe-131  5.689E-01|                   ---------*|**8-------                   >
Xe-135  3.119E-04|                        -----98---**4   3                  |
Cs-133  1.392E+00|                   3   ----98*-*7-6-                       |
Cs-135  8.780E-01|                         --983---7*                        |
Nd-143  1.046E+00|          -------*1**--------3-------------------          |
Nd-145  7.757E-01|                   45-1*967--3---------                     |
Pm-147  1.848E-01----------------------------2-*79-1-4-*----------------------
Pm-148m 2.815E-03|                   --4-18--*-*9--7------                    |
Sm-149  5.213E-03|           ----*----**-*-----3-----------------            |
Sm-150  4.057E-01|              2  1 * *68-----3--------                     |
Sm-151  3.142E-02--------------------1--4682--5*9-----------------------------
Sm-152  1.796E-01|     ---------4-8--1--5-69---*----7-------------------     |
Eu-153  2.041E-01|              --------------*1--*--76*-----                 |
Eu-154  7.634E-02<  ----------------------------3-------9--8----------------  |
Eu-155  1.877E-02----------21-**---------------3----------------------------->
O - 16  1.184E+02|                           *                               |
#
```

```
 #
 # WLUP SUPPLEMENTARY BENCHMARK SEQUENCE
 # -------------------------------------
 #
 # U-H2O-Be criticality benchmarks
 # -------------------------------


 SMRDIF - Compare lattice spectr.indices
 =======================================

   LATTICE      K-eff       Rho28         Del25          Del28         ConvR
  ========================================================================
ber-tubes  1.68681(~.03)  8.545(~.11)  0.0528(~.19)  0.0001        0.011
    iaeagx 1.67563(-.40)  7.674( -10)  0.0540(2.27)  0.0001(  40)  0.010( -10)
      iaea 1.67952(-.26)  7.648( -10)  0.0539(2.03)  0.0001(  30)  0.010( -11)
     wdn29 1.69435(0.26)  8.092(-5.3)  0.0535(1.34)  0.0001(  40)  0.010(-6.4)
  endfb6gx 1.67115(-.56)  7.564( -11)  0.0536(1.42)  0.0001(  30)  0.010( -11)
    endfb6 1.67514(-.41)  7.538( -12)  0.0534(1.17)  0.0001(  30)  0.010( -11)
  jendl3gx 1.62073(-2.5)  7.562( -12)  0.0536(1.55)  0.0001(  30)  0.010( -11)
    jendl3 1.62188(-2.4)  7.538( -12)  0.0535(1.29)  0.0001(  30)  0.010( -11)
   jef22gx 1.57721(-4.3)  7.561( -12)  0.0541(2.42)  0.0001(  30)  0.010( -11)
     jef22 1.57554(-4.3)  7.539( -12)  0.0540(2.18)  0.0001(  30)  0.010( -11)

ber-hom    1.00036(~.06) 13.150(~.01)  0.0699(~.14)  0.0001        0.016
    iaeagx 1.00257(0.22) 13.400(1.90)  0.0663(-5.2)  0.0001( -10)  0.016(2.50)
      iaea 1.00495(0.45) 13.399(1.89)  0.0662(-5.3)  0.0001(0.00)  0.016(2.50)
     wdn29 1.01217(1.16) 13.142(-.06)  0.0668(-4.5)  0.0001(0.00)  0.016(0.62)
  endfb6gx 1.00023(-.01) 13.217(0.51)  0.0656(-6.1)  0.0001( -10)  0.016(2.50)
    endfb6 1.00267(0.23) 13.215(0.50)  0.0656(-6.2)  0.0001( -10)  0.016(2.50)
  jendl3gx 0.95908(-4.4) 13.198(0.37)  0.0658(-5.9)  0.0001( -10)  0.016(1.87)
    jendl3 0.95971(-4.3) 13.196(0.35)  0.0657(-6.0)  0.0001( -10)  0.016(1.87)
   jef22gx 0.92338(-8.7) 13.215(0.49)  0.0662(-5.3)  0.0001( -10)  0.016(2.50)
     jef22 0.92204(-8.8) 13.213(0.48)  0.0661(-5.4)  0.0001( -10)  0.016(2.50)
  ------------------------------------------------------------------------------
   Average         0.05         0.07          0.17          0.00         0.00
    iaeagx  -0.09(~0.31) -4.14(~6.05)  -1.45(~3.73)  15.00(~****) -3.75(~6.25)
      iaea   0.10(~0.36) -4.30(~6.19)  -1.63(~3.65)  15.00(~****) -4.20(~6.70)
     wdn29   0.71(~0.45) -2.68(~2.62)  -1.57(~2.91)  20.00(~****) -2.87(~3.49)
  endfb6gx  -0.29(~0.27) -5.49(~5.99)  -2.35(~3.77)  10.00(~****) -4.20(~6.70)
    endfb6  -0.09(~0.32) -5.64(~6.14)  -2.52(~3.69)  10.00(~****) -4.20(~6.70)
  jendl3gx  -3.43(~0.96) -5.57(~5.93)  -2.19(~3.75)  10.00(~****) -4.52(~6.39)
    jendl3  -3.37(~0.95) -5.71(~6.06)  -2.37(~3.66)  10.00(~****) -4.52(~6.39)
   jef22gx  -6.47(~2.21) -5.51(~6.01)  -1.42(~3.84)  10.00(~****) -4.20(~6.70)
     jef22  -6.59(~2.26) -5.65(~6.13)  -1.60(~3.78)  10.00(~****) -4.20(~6.70)
 #
```

```
#
# DOPPLER REACT.COEF.benchmark
# ----------------------------


DOPPLER comparison COEFF.OF REACTIVITY (pcm/K)
==================================================

    E(wt%) DOPPLER COEF.(pcm/K)-DIF(%)
==================================================
REF 0.711 -5.97(  0.00)
   iaeagx -5.21( 14.52)
     iaea -5.21( 14.66)
    wdn29 -5.21( 17.07)
 endfb6gx -5.21( 15.67)
   endfb6 -5.21( 15.75)
 jendl3gx -5.21( 15.11)
   jendl3 -5.21( 15.34)
  jef22gx -5.21( 14.77)
    jef22 -5.21( 15.20)

REF 1.600 -3.71(  0.00)
   iaeagx -3.36( 10.30)
     iaea -3.36( 10.83)
    wdn29 -3.36( 14.79)
 endfb6gx -3.36( 11.40)
   endfb6 -3.36( 11.72)
 jendl3gx -3.36( 10.80)
   jendl3 -3.36( 11.15)
  jef22gx -3.36( 10.36)
    jef22 -3.36( 10.96)

REF 2.400 -3.03(  0.00)
   iaeagx -2.67( 13.55)
     iaea -2.67( 14.41)
    wdn29 -2.67( 19.10)
 endfb6gx -2.67( 14.48)
   endfb6 -2.67( 15.26)
 jendl3gx -2.67( 13.99)
   jendl3 -2.67( 14.75)
  jef22gx -2.67( 13.51)
    jef22 -2.67( 14.48)

REF 3.100 -2.71(  0.00)
   iaeagx -2.73( -0.72)
     iaea -2.73(  0.32)
    wdn29 -2.73(  4.59)
 endfb6gx -2.73(  0.15)
   endfb6 -2.73(  0.98)
 jendl3gx -2.73( -0.31)
   jendl3 -2.73(  0.61)
  jef22gx -2.73( -0.72)
    jef22 -2.73(  0.33)

REF 3.900 -2.58(  0.00)
   iaeagx -2.36(  9.40)
     iaea -2.36( 10.62)
    wdn29 -2.36( 14.96)
 endfb6gx -2.36( 10.30)
   endfb6 -2.36( 11.46)
 jendl3gx -2.36(  9.89)
   jendl3 -2.36( 11.06)
  jef22gx -2.36(  9.35)
    jef22 -2.36( 10.74)
==================================================
Average         (  0.00)
   iaeagx  9.41( 10.86)
     iaea 10.17( 11.43)
```

```
    wdn29 14.10( 14.97)
 endfb6gx 10.40( 11.76)
   endfb6 11.03( 12.25)
 jendl3gx  9.90( 11.30)
   jendl3 10.58( 11.83)
  jef22gx  9.45( 10.92)
    jef22 10.34( 11.63)
#
```

```
 #
 # RTC React.Coeffic. benchmark
 # ---------------------------


 RTC-DIFFS.BETWEEN CALCULATION AND MEASUREMENTS
 ==============================================

     Case   D-ALPHA(pcm/C)
 ==============================================
NORA-1.66
    iaeagx         (-1.250653)
      iaea         (-1.401038)
     wdn29         (-0.561798)
  endfb6gx         (-1.814348)
    endfb6         (-1.987484)
  jendl3gx         (-1.225787)
    jendl3         (-1.354147)
   jef22gx         (-1.504252)
     jef22         (-1.670597)

NORA-3.03
    iaeagx         (-1.602761)
      iaea         (-1.762049)
     wdn29         (-0.690088)
  endfb6gx         (-2.326895)
    endfb6         (-2.500093)
  jendl3gx         (-1.435546)
    jendl3         (-1.639569)
   jef22gx         (-1.643239)
     jef22         (-1.890936)

   KRITZ1
    iaeagx         (-0.788418)
      iaea         (-0.876929)
     wdn29         (-0.278048)
  endfb6gx         (-1.701533)
    endfb6         (-1.754198)
  jendl3gx         (-1.085884)
    jendl3         (-1.134869)
   jef22gx         (-0.843161)
     jef22         (-1.000329)

  KRITZ21
    iaeagx         (-0.635759)
      iaea         (-0.734485)
     wdn29         (-0.914746)
  endfb6gx         (-1.583842)
    endfb6         (-1.639089)
  jendl3gx         (-1.126898)
    jendl3         (-1.186082)
   jef22gx         (-0.778777)
     jef22         (-0.942225)


KRITZ213
    iaeagx         (-1.563324)
      iaea         (-1.734971)
     wdn29         (-2.046583)
  endfb6gx         (-2.712262)
    endfb6         (-2.865223)
  jendl3gx         (-1.877188)
    jendl3         (-2.056946)
   jef22gx         (-1.593725)
     jef22         (-1.808080)
```

```
KRITZ219
    iaeagx          (-2.042563)
      iaea          (-2.093482)
     wdn29          (-1.807170)
  endfb6gx          (-2.368689)
    endfb6          (-2.413569)
  jendl3gx          (-2.218374)
    jendl3          (-2.264208)
   jef22gx          (-2.168168)
     jef22          (-2.246067)

    VVER1
    iaeagx          (-8.308042)
      iaea          (-8.435917)
     wdn29          (-8.726958)
  endfb6gx          (-8.966033)
    endfb6          (-9.054797)
  jendl3gx          (-8.701528)
    jendl3          (-8.799491)
   jef22gx          (-8.473359)
     jef22          (-8.649285)

    VVER2
    iaeagx          (-5.169262)
      iaea          (-5.346289)
     wdn29          (-5.219774)
  endfb6gx          (-5.920580)
    endfb6          (-6.083958)
  jendl3gx          (-5.359175)
    jendl3          (-5.533841)
   jef22gx          (-5.320021)
     jef22          (-5.553422)

    VVER3
    iaeagx          (-4.695835)
      iaea          (-4.766273)
     wdn29          (-4.648499)
  endfb6gx          (-5.501630)
    endfb6          (-5.557629)
  jendl3gx          (-4.895978)
    jendl3          (-4.962101)
   jef22gx          (-4.852720)
     jef22          (-4.966087)

    VVER4
    iaeagx          (-2.306124)
      iaea          (-2.392866)
     wdn29          (-2.232279)
  endfb6gx          (-3.099670)
    endfb6          (-3.162388)
  jendl3gx          (-2.524608)
    jendl3          (-2.588628)
   jef22gx          (-2.469742)
     jef22          (-2.598583)
 ================================================
 Average            ( 0.000000)
    iaeagx-2.836274( 3.672720)
      iaea-2.954430( 3.767753)
     wdn29-2.712594( 3.730385)
  endfb6gx-3.599548( 4.270785)
    endfb6-3.701843( 4.357649)
  jendl3gx-3.045097( 3.863146)
    jendl3-3.151988( 3.949078)
   jef22gx-2.964716( 3.785106)
     jef22-3.132561( 3.919621)
```

```
# Uranium D2O Gd exper. benchmarks
 # ---------------------------------


 Thermal Neutron Flux Distribution
 Ai:Annulus i;Mj:Moderator (j:cm)

 Case  COO  A1    DIF.%  A2    DIF.% A3NG  DIF.% A3WG  DIF.%  M11  DIF.%  M16  DIF.%  M22  DIF.%
 ================================================================================================
 Gd:NO  H2O 0.30(  33.3) 0.32(  31.3) 0.55(  18.2)             1.10(  9.1) 1.40(  7.1) 1.50(  6.7)
    iaeagx  0.23( -30.0) 0.24( -35.2) 0.43( -28.1)             1.08( -2.2) 1.42(  1.2) 1.54(  2.8)
      iaea  0.23( -28.1) 0.24( -34.0) 0.43( -27.6)             1.08( -2.2) 1.41(  1.0) 1.54(  2.7)
     wdn29  0.24( -25.4) 0.25( -29.4) 0.44( -24.7)             1.07( -2.4) 1.40( -0.1) 1.52(  1.4)
  endfb6gx  0.23( -31.2) 0.23( -36.2) 0.43( -28.6)             1.08( -2.2) 1.42(  1.2) 1.54(  2.9)
    endfb6  0.23( -30.2) 0.24( -35.4) 0.43( -28.2)             1.08( -2.2) 1.42(  1.1) 1.54(  2.8)
  jendl3gx  0.23( -29.2) 0.24( -35.2) 0.43( -28.4)             1.08( -2.2) 1.41(  1.0) 1.54(  2.6)
    jendl3  0.23( -29.4) 0.24( -34.9) 0.43( -28.1)             1.08( -2.2) 1.41(  0.9) 1.54(  2.5)
   jef22gx  0.23( -31.6) 0.23( -36.8) 0.43( -29.3)             1.08( -2.2) 1.41(  0.9) 1.54(  2.5)
     jef22  0.23( -30.3) 0.24( -35.9) 0.43( -28.8)             1.08( -2.3) 1.41(  0.8) 1.54(  2.4)

 Gd:NO  AIR 0.38(  26.3) 0.55(  18.2) 0.75(  13.3)             1.20(  8.3) 2.05(  4.9) 2.30(  4.3)
    iaeagx  0.40(   5.7) 0.48( -14.8) 0.68( -10.9)             1.21(  0.9) 2.13(  3.6) 2.47(  6.8)
      iaea  0.40(   5.9) 0.48( -14.6) 0.68( -10.7)             1.21(  0.8) 2.13(  3.6) 2.47(  6.8)
     wdn29  0.41(   6.6) 0.48( -14.2) 0.68( -10.9)             1.21(  0.8) 2.09(  1.7) 2.41(  4.6)
  endfb6gx  0.40(   5.1) 0.48( -15.4) 0.68( -11.1)             1.21(  0.9) 2.13(  3.6) 2.47(  6.9)
    endfb6  0.40(   5.3) 0.48( -15.1) 0.68( -10.9)             1.21(  0.8) 2.13(  3.6) 2.47(  6.8)
  jendl3gx  0.40(   5.1) 0.48( -15.4) 0.67( -11.2)             1.21(  1.0) 2.12(  3.5) 2.46(  6.6)
    jendl3  0.40(   5.3) 0.48( -15.2) 0.68( -11.0)             1.21(  0.9) 2.12(  3.4) 2.46(  6.6)
   jef22gx  0.40(   5.0) 0.48( -15.5) 0.67( -11.2)             1.21(  0.9) 2.13(  3.7) 2.47(  6.9)
     jef22  0.40(   5.2) 0.48( -15.3) 0.68( -11.0)             1.21(  0.9) 2.13(  3.6) 2.47(  6.9)

 Gd:YES H2O 0.15( 100.0) 0.17(  88.2)            0.06(250.0) 1.18( 12.7) 1.68(  8.9) 1.87(  8.0)
    iaeagx  0.22(  32.2) 0.11( -49.2)            0.07( 10.9) 1.13( -4.7) 1.70(  1.3) 1.89(  1.2)
      iaea  0.22(  33.1) 0.12( -47.3)            0.07( 12.0) 1.13( -4.8) 1.70(  1.2) 1.89(  1.1)
     wdn29  0.23(  33.7) 0.12( -44.8)            0.07( 13.8) 1.13( -4.8) 1.68(  0.0) 1.87( -0.3)
  endfb6gx  0.22(  31.6) 0.11( -50.5)            0.07( 10.6) 1.13( -4.7) 1.70(  1.3) 1.89(  1.2)
    endfb6  0.22(  32.4) 0.11( -48.7)            0.07( 11.8) 1.13( -4.7) 1.70(  1.2) 1.89(  1.1)
  jendl3gx  0.22(  32.3) 0.11( -49.0)            0.07( 10.9) 1.13( -4.7) 1.70(  1.1) 1.89(  0.9)
    jendl3  0.22(  33.0) 0.12( -47.4)            0.07( 12.0) 1.13( -4.7) 1.70(  1.0) 1.89(  0.8)
   jef22gx  0.22(  31.9) 0.11( -50.0)            0.07( 10.5) 1.13( -4.8) 1.70(  1.0) 1.89(  0.9)
     jef22  0.22(  32.7) 0.11( -48.0)            0.07( 11.7) 1.13( -4.8) 1.70(  0.9) 1.88(  0.8)
 ================================================================================================
```

```
 Therm.Flux Distr.AIR coolant-cluster without poison
Average

R(cm)     FLUX   DIF.%

Processed Benchmark analysis reports :
   iaeagx                    1 case  : E2T2.lis
     iaea                    1 case  : E2T2.lis
 endfb6gx                    1 case  : E2T2.lis
   endfb6                    1 case  : E2T2.lis
 jendl3gx                    1 case  : E2T2.lis
   jendl3                    1 case  : E2T2.lis
  jef22gx                    1 case  : E2T2.lis
    jef22                    1 case  : E2T2.lis
=======================
  3.83      0.38(  26.32)
   iaeagx   0.40(   5.72)
     iaea   0.40(   5.91)
    wdn29
 endfb6gx   0.40(   5.10)
   endfb6   0.40(   5.31)
 jendl3gx   0.40(   5.08)
   jendl3   0.40(   5.28)
  jef22gx   0.40(   4.96)
    jef22   0.40(   5.16)


Therm.Flux Distr.12 poisoned fuel pins on 3rd.layer
Average

R(cm)     FLUX   DIF.%

Processed Benchmark analysis reports :
   iaeagx                    1 case  : E2T2.lis
     iaea                    1 case  : E2T2.lis
 endfb6gx                    1 case  : E2T2.lis
   endfb6                    1 case  : E2T2.lis
 jendl3gx                    1 case  : E2T2.lis
   jendl3                    1 case  : E2T2.lis
  jef22gx                    1 case  : E2T2.lis
    jef22                    1 case  : E2T2.lis
=======================
  3.83      0.15(  66.67)
   iaeagx   0.22(  32.22)
     iaea   0.22(  33.08)
    wdn29
 endfb6gx   0.22(  31.60)
   endfb6   0.22(  32.37)
 jendl3gx   0.22(  32.32)
   jendl3   0.22(  33.04)
  jef22gx   0.22(  31.85)
    jef22   0.22(  32.75)


Therm.Flux Distr.-Average Dy-reaction rate on pins
Average

Case      Dy-RR  DIF.%

Processed Benchmark analysis reports :
   iaeagx                    1 case  : E2T2.lis
     iaea                    1 case  : E2T2.lis
 endfb6gx                    1 case  : E2T2.lis
   endfb6                    1 case  : E2T2.lis
 jendl3gx                    1 case  : E2T2.lis
   jendl3                    1 case  : E2T2.lis
  jef22gx                    1 case  : E2T2.lis
    jef22                    1 case  : E2T2.lis
=======================
```

```
Gd:NO      0.922(  3.471)
   iaeagx  0.916( -0.642)
     iaea  0.916( -0.656)
    wdn29
 endfb6gx  0.915( -0.719)
   endfb6  0.915( -0.735)
 jendl3gx  0.916( -0.705)
   jendl3  0.915( -0.720)
  jef22gx  0.916( -0.687)
    jef22  0.916( -0.701)
```

```
#
# MTR - OWR burnup benchmark
# --------------------------

MTR-OWR comparison AVERAGE VALUES (W%U235)(DIFF.)
=================================================

      CYC W%U235
=============================================
E-CYCLE 1  91.7( 2.0)
   iaeagx  91.5(-0.2)
     iaea  91.5(-0.2)
    wdn29  91.5(-0.2)
 endfb6gx  91.5(-0.2)
   endfb6  91.5(-0.2)
 jendl3gx  91.5(-0.2)
   jendl3  91.5(-0.2)
  jef22gx  91.5(-0.2)
    jef22  91.5(-0.2)

E-CYCLE 2  89.9( 2.0)
   iaeagx  89.4(-0.5)
     iaea  89.4(-0.5)
    wdn29  89.4(-0.5)
 endfb6gx  89.4(-0.5)
   endfb6  89.4(-0.5)
 jendl3gx  89.4(-0.5)
   jendl3  89.4(-0.5)
  jef22gx  89.4(-0.5)
    jef22  89.4(-0.5)

E-CYCLE 3  88.4( 2.0)
   iaeagx  87.6(-0.8)
     iaea  87.6(-0.8)
    wdn29  87.6(-0.8)
 endfb6gx  87.6(-0.8)
   endfb6  87.6(-0.8)
 jendl3gx  87.6(-0.8)
   jendl3  87.6(-0.8)
  jef22gx  87.6(-0.8)
    jef22  87.6(-0.8)

E-CYCLE 4  87.1( 2.0)
   iaeagx  86.0(-1.1)
     iaea  86.0(-1.1)
    wdn29  86.0(-1.1)
 endfb6gx  86.0(-1.1)
   endfb6  86.0(-1.1)
 jendl3gx  86.0(-1.1)
   jendl3  86.0(-1.1)
  jef22gx  86.1(-1.0)
    jef22  86.1(-1.0)

E-CYCLE 5  85.9( 2.0)
   iaeagx  84.6(-1.3)
     iaea  84.6(-1.3)
    wdn29  84.6(-1.3)
 endfb6gx  84.6(-1.3)
   endfb6  84.6(-1.3)
 jendl3gx  84.6(-1.3)
   jendl3  84.6(-1.3)
  jef22gx  84.6(-1.3)
    jef22  84.6(-1.3)
```

```
E-CYCLE 6  82.8( 2.0)
   iaeagx  81.0(-1.8)
     iaea  81.0(-1.8)
    wdn29  81.0(-1.8)
 endfb6gx  81.0(-1.8)
   endfb6  81.0(-1.8)
 jendl3gx  81.0(-1.8)
   jendl3  81.0(-1.8)
  jef22gx  81.0(-1.8)
    jef22  81.0(-1.8)

E-CYCLE 7  80.6( 2.0)
   iaeagx  78.5(-2.1)
     iaea  78.5(-2.1)
    wdn29  78.5(-2.1)
 endfb6gx  78.5(-2.1)
   endfb6  78.5(-2.1)
 jendl3gx  78.5(-2.1)
   jendl3  78.5(-2.1)
  jef22gx  78.5(-2.1)
    jef22  78.5(-2.1)

E-CYCLE 8  79.1( 2.0)
   iaeagx  76.7(-2.4)
     iaea  76.7(-2.4)
    wdn29  76.7(-2.4)
 endfb6gx  76.7(-2.4)
   endfb6  76.7(-2.4)
 jendl3gx  76.7(-2.4)
   jendl3  76.7(-2.4)
  jef22gx  76.7(-2.4)
    jef22  76.7(-2.4)

E-CYCLE 9  77.1( 2.0)
   iaeagx  74.4(-2.7)
     iaea  74.4(-2.7)
    wdn29  74.3(-2.8)
 endfb6gx  74.3(-2.8)
   endfb6  74.3(-2.8)
 jendl3gx  74.4(-2.7)
   jendl3  74.4(-2.7)
  jef22gx  74.4(-2.7)
    jef22  74.4(-2.7)

E-CYCLE10  75.3( 2.0)
   iaeagx  72.2(-3.1)
     iaea  72.2(-3.1)
    wdn29  72.2(-3.1)
 endfb6gx  72.2(-3.1)
   endfb6  72.2(-3.1)
 jendl3gx  72.2(-3.1)
   jendl3  72.2(-3.1)
  jef22gx  72.2(-3.1)
    jef22  72.2(-3.1)

E-CYCLE11  72.9( 2.0)
   iaeagx  69.4(-3.5)
     iaea  69.4(-3.5)
    wdn29  69.4(-3.5)
 endfb6gx  69.4(-3.5)
   endfb6  69.4(-3.5)
 jendl3gx  69.4(-3.5)
   jendl3  69.4(-3.5)
  jef22gx  69.4(-3.5)
    jef22  69.4(-3.5)
```

```
E-CYCLE12  69.5( 2.0)
   iaeagx  65.5(-4.0)
     iaea  65.5(-4.0)
    wdn29  65.4(-4.1)
 endfb6gx  65.4(-4.1)
   endfb6  65.4(-4.1)
 jendl3gx  65.5(-4.0)
   jendl3  65.5(-4.0)
  jef22gx  65.5(-4.0)
    jef22  65.5(-4.0)

E-CYCLE13  67.1( 2.0)
   iaeagx  62.8(-4.3)
     iaea  62.8(-4.3)
    wdn29  62.7(-4.4)
 endfb6gx  62.7(-4.4)
   endfb6  62.7(-4.4)
 jendl3gx  62.7(-4.4)
   jendl3  62.7(-4.4)
  jef22gx  62.8(-4.3)
    jef22  62.8(-4.3)

E-CYCLE14  65.7( 2.0)
   iaeagx  61.0(-4.7)
     iaea  61.0(-4.7)
    wdn29  60.9(-4.8)
 endfb6gx  61.0(-4.7)
   endfb6  61.0(-4.7)
 jendl3gx  61.0(-4.7)
   jendl3  61.0(-4.7)
  jef22gx  61.0(-4.7)
    jef22  61.0(-4.7)

E-CYCLE15  63.7( 2.0)
   iaeagx  58.7(-5.0)
     iaea  58.7(-5.0)
    wdn29  58.6(-5.1)
 endfb6gx  58.7(-5.0)
   endfb6  58.7(-5.0)
 jendl3gx  58.7(-5.0)
   jendl3  58.7(-5.0)
  jef22gx  58.7(-5.0)
    jef22  58.7(-5.0)

E-CYCLE16  60.4( 2.0)
   iaeagx  54.9(-5.5)
     iaea  54.9(-5.5)
    wdn29  54.8(-5.6)
 endfb6gx  54.8(-5.6)
   endfb6  54.8(-5.6)
 jendl3gx  54.8(-5.6)
   jendl3  54.8(-5.6)
  jef22gx  54.9(-5.5)
    jef22  54.9(-5.5)

E-CYCLE17  58.4( 2.0)
   iaeagx  52.5(-5.9)
     iaea  52.5(-5.9)
    wdn29  52.4(-6.0)
 endfb6gx  52.5(-5.9)
   endfb6  52.5(-5.9)
 jendl3gx  52.5(-5.9)
   jendl3  52.5(-5.9)
  jef22gx  52.6(-5.8)
    jef22  52.6(-5.8)
==========================================
```

```
Average
   iaeagx
     iaea
    wdn29
 endfb6gx
   endfb6
 jendl3gx
   jendl3
  jef22gx
    jef22
```

MTR-OWR comparison Atomic Densities for Actinides

NAME	AT.DENS.(EOCycle17)	CALC.-REF.
U234	1.12E-05	(0.00E+00)
iaeagx	1.07E-05	(-4.79E-07)
iaea	1.07E-05	(-4.77E-07)
wdn29	1.07E-05	(-4.77E-07)
endfb6gx	1.07E-05	(-5.46E-07)
endfb6	1.07E-05	(-5.44E-07)
jendl3gx	1.07E-05	(-4.76E-07)
jendl3	1.07E-05	(-4.74E-07)
jef22gx	1.07E-05	(-5.43E-07)
jef22	1.07E-05	(-5.41E-07)
U235	9.28E-04	(0.00E+00)
iaeagx	9.14E-04	(-1.45E-05)
iaea	9.14E-04	(-1.45E-05)
wdn29	9.12E-04	(-1.63E-05)
endfb6gx	9.12E-04	(-1.59E-05)
endfb6	9.12E-04	(-1.59E-05)
jendl3gx	9.13E-04	(-1.51E-05)
jendl3	9.13E-04	(-1.52E-05)
jef22gx	9.14E-04	(-1.43E-05)
jef22	9.14E-04	(-1.43E-05)
U236	1.02E-04	(0.00E+00)
iaeagx	1.11E-04	(8.55E-06)
iaea	1.11E-04	(8.56E-06)
wdn29	1.10E-04	(7.66E-06)
endfb6gx	1.12E-04	(1.00E-05)
endfb6	1.12E-04	(1.01E-05)
jendl3gx	1.10E-04	(8.41E-06)
jendl3	1.10E-04	(8.41E-06)
jef22gx	1.10E-04	(8.46E-06)
jef22	1.10E-04	(8.46E-06)
U238	1.04E-04	(0.00E+00)
iaeagx	1.02E-04	(-2.15E-06)
iaea	1.02E-04	(-2.14E-06)
wdn29	1.02E-04	(-2.12E-06)
endfb6gx	1.02E-04	(-2.15E-06)
endfb6	1.02E-04	(-2.14E-06)
jendl3gx	1.02E-04	(-2.14E-06)
jendl3	1.02E-04	(-2.13E-06)
jef22gx	1.02E-04	(-2.13E-06)
jef22	1.02E-04	(-2.13E-06)
Np237	1.07E-06	(0.00E+00)
iaeagx	1.95E-06	(8.82E-07)
iaea	1.96E-06	(8.90E-07)
wdn29	1.81E-06	(7.38E-07)
endfb6gx	1.94E-06	(8.70E-07)
endfb6	1.95E-06	(8.78E-07)
jendl3gx	1.96E-06	(8.88E-07)
jendl3	1.97E-06	(8.96E-07)
jef22gx	1.95E-06	(8.81E-07)
jef22	1.96E-06	(8.90E-07)
Pu238	6.03E-08	(0.00E+00)
iaeagx	1.58E-07	(9.73E-08)
iaea	1.58E-07	(9.73E-08)
wdn29	1.44E-07	(8.37E-08)
endfb6gx	1.56E-07	(9.61E-08)
endfb6	1.56E-07	(9.61E-08)
jendl3gx	1.48E-07	(8.79E-08)
jendl3	1.48E-07	(8.78E-08)

```
   jef22gx  1.58E-07( 9.73E-08)
     jef22  1.58E-07( 9.72E-08)

Pu239       4.51E-07( 0.00E+00)
    iaeagx  1.73E-06( 1.28E-06)
      iaea  1.72E-06( 1.27E-06)
     wdn29  1.73E-06( 1.28E-06)
  endfb6gx  1.73E-06( 1.28E-06)
    endfb6  1.72E-06( 1.27E-06)
  jendl3gx  1.72E-06( 1.27E-06)
    jendl3  1.72E-06( 1.27E-06)
   jef22gx  1.72E-06( 1.27E-06)
     jef22  1.71E-06( 1.26E-06)

Pu240       7.46E-08( 0.00E+00)
    iaeagx  3.06E-07( 2.31E-07)
      iaea  3.07E-07( 2.33E-07)
     wdn29  3.10E-07( 2.36E-07)
  endfb6gx  3.04E-07( 2.29E-07)
    endfb6  3.05E-07( 2.31E-07)
  jendl3gx  3.06E-07( 2.32E-07)
    jendl3  3.08E-07( 2.33E-07)
   jef22gx  3.04E-07( 2.29E-07)
     jef22  3.05E-07( 2.31E-07)

Pu241       1.23E-08( 0.00E+00)
    iaeagx  9.64E-08( 8.41E-08)
      iaea  9.54E-08( 8.31E-08)
     wdn29  9.06E-08( 7.83E-08)
  endfb6gx  9.62E-08( 8.39E-08)
    endfb6  9.52E-08( 8.29E-08)
  jendl3gx  9.36E-08( 8.13E-08)
    jendl3  9.26E-08( 8.03E-08)
   jef22gx  9.51E-08( 8.28E-08)
     jef22  9.40E-08( 8.17E-08)

Pu242       1.51E-09( 0.00E+00)
    iaeagx  1.08E-08( 9.33E-09)
      iaea  1.08E-08( 9.28E-09)
     wdn29  9.96E-09( 8.45E-09)
  endfb6gx  1.06E-08( 9.13E-09)
    endfb6  1.06E-08( 9.07E-09)
  jendl3gx  1.03E-08( 8.83E-09)
    jendl3  1.03E-08( 8.78E-09)
   jef22gx  1.06E-08( 9.04E-09)
     jef22  1.05E-08( 8.97E-09)

Am241       1.54E-09( 0.00E+00)
    iaeagx  3.79E-09( 2.25E-09)
      iaea  3.75E-09( 2.21E-09)
     wdn29  3.47E-09( 1.93E-09)
  endfb6gx  3.78E-09( 2.24E-09)
    endfb6  3.74E-09( 2.20E-09)
  jendl3gx  3.68E-09( 2.14E-09)
    jendl3  3.64E-09( 2.10E-09)
   jef22gx  3.70E-09( 2.16E-09)
     jef22  3.66E-09( 2.12E-09)

Am242       0.00E+00( 0.00E+00)
    iaeagx  2.40E-12( 2.40E-12)
      iaea  1.59E-12( 1.59E-12)
     wdn29  0.00E+00( 0.00E+00)
  endfb6gx  2.41E-12( 2.41E-12)
    endfb6  1.59E-12( 1.59E-12)
  jendl3gx  2.27E-12( 2.27E-12)
    jendl3  1.50E-12( 1.50E-12)
   jef22gx  2.40E-12( 2.40E-12)
     jef22  1.62E-12( 1.62E-12)
```

```
Am242m      3.51E-12( 0.00E+00)
    iaeagx  3.27E-11( 2.92E-11)
      iaea  3.24E-11( 2.89E-11)
     wdn29  3.07E-11( 2.72E-11)
  endfb6gx  3.34E-11( 2.99E-11)
    endfb6  3.31E-11( 2.96E-11)
  jendl3gx  3.27E-11( 2.92E-11)
    jendl3  3.24E-11( 2.89E-11)
   jef22gx  3.19E-11( 2.84E-11)
     jef22  3.16E-11( 2.81E-11)

Am243       3.12E-11( 0.00E+00)
    iaeagx  3.29E-10( 2.98E-10)
      iaea  2.96E-10( 2.65E-10)
     wdn29  2.91E-10( 2.60E-10)
  endfb6gx  3.43E-10( 3.11E-10)
    endfb6  3.05E-10( 2.74E-10)
  jendl3gx  2.96E-10( 2.65E-10)
    jendl3  2.51E-10( 2.20E-10)
   jef22gx  3.05E-10( 2.74E-10)
     jef22  2.76E-10( 2.45E-10)

Cm242       2.36E-12( 0.00E+00)
    iaeagx  3.09E-10( 3.06E-10)
      iaea  2.06E-10( 2.03E-10)
     wdn29  0.00E+00( 0.00E+00)
  endfb6gx  3.09E-10( 3.07E-10)
    endfb6  2.06E-10( 2.04E-10)
  jendl3gx  2.92E-10( 2.89E-10)
    jendl3  1.94E-10( 1.92E-10)
   jef22gx  3.09E-10( 3.07E-10)
     jef22  2.10E-10( 2.08E-10)

Cm243       1.31E-13( 0.00E+00)
    iaeagx  1.37E-12( 1.24E-12)
      iaea  9.22E-13( 7.91E-13)
     wdn29  0.00E+00( 0.00E+00)
  endfb6gx  1.43E-12( 1.30E-12)
    endfb6  9.62E-13( 8.31E-13)
  jendl3gx  1.29E-12( 1.16E-12)
    jendl3  8.69E-13( 7.38E-13)
   jef22gx  1.47E-12( 1.34E-12)
     jef22  1.01E-12( 8.77E-13)

□□□□□□      0.00E+00( 0.00E+00)
    iaeagx  0.00E+00( 0.00E+00)
      iaea  0.00E+00( 0.00E+00)
     wdn29  0.00E+00( 0.00E+00)
  endfb6gx  0.00E+00( 0.00E+00)
    endfb6  0.00E+00( 0.00E+00)
  jendl3gx  0.00E+00( 0.00E+00)
    jendl3  0.00E+00( 0.00E+00)
   jef22gx  0.00E+00( 0.00E+00)
     jef22  0.00E+00( 0.00E+00)
 ============================================
 Average
    iaeagx
      iaea
     wdn29
  endfb6gx
    endfb6
  jendl3gx
    jendl3
   jef22gx
     jef22
 #
```

```
#
# PWR - Th burnup benchmark
# -------------------------

PWR THORIUM PIN CELL BURNUP BENCHMARK
=================================================

B(MWd/kgHM) Kinfinity   diff(%)
=================================================
     0.000  1.23782E+00 (   0.0 )
   iaeagx   1.26170E+00 (   1.93)
     iaea   1.25947E+00 (   1.75)
    wdn29   1.24242E+00 (   0.37)
 endfb6gx   1.23580E+00 (  -0.16)
   endfb6   1.23381E+00 (  -0.32)
 jendl3gx   1.25979E+00 (   1.78)
   jendl3   1.25755E+00 (   1.59)
  jef22gx   1.25199E+00 (   1.14)
    jef22   1.24966E+00 (   0.96)

     0.114  1.20071E+00 (   0.0 )
   iaeagx   1.22350E+00 (   1.90)
     iaea   1.22134E+00 (   1.72)
    wdn29   1.20543E+00 (   0.39)
 endfb6gx   1.19858E+00 (  -0.18)
   endfb6   1.19665E+00 (  -0.34)
 jendl3gx   1.22162E+00 (   1.74)
   jendl3   1.21945E+00 (   1.56)
  jef22gx   1.21422E+00 (   1.13)
    jef22   1.21194E+00 (   0.94)

     5.835  1.14828E+00 (   0.0 )
   iaeagx   1.16746E+00 (   1.67)
     iaea   1.16595E+00 (   1.54)
    wdn29   1.15385E+00 (   0.49)
 endfb6gx   1.14567E+00 (  -0.23)
   endfb6   1.14430E+00 (  -0.35)
 jendl3gx   1.16661E+00 (   1.60)
   jendl3   1.16508E+00 (   1.46)
  jef22gx   1.15918E+00 (   0.95)
    jef22   1.15743E+00 (   0.80)

    10.411  1.12108E+00 (   0.0 )
   iaeagx   1.13880E+00 (   1.58)
     iaea   1.13735E+00 (   1.45)
    wdn29   1.12833E+00 (   0.65)
 endfb6gx   1.11948E+00 (  -0.14)
   endfb6   1.11815E+00 (  -0.26)
 jendl3gx   1.13850E+00 (   1.55)
   jendl3   1.13705E+00 (   1.42)
  jef22gx   1.13157E+00 (   0.94)
    jef22   1.12988E+00 (   0.78)

    19.563  1.07245E+00 (   0.0 )
   iaeagx   1.08818E+00 (   1.47)
     iaea   1.08649E+00 (   1.31)
    wdn29   1.08311E+00 (   0.99)
 endfb6gx   1.07327E+00 (   0.08)
   endfb6   1.07165E+00 (  -0.08)
 jendl3gx   1.08847E+00 (   1.49)
   jendl3   1.08678E+00 (   1.34)
  jef22gx   1.08324E+00 (   1.01)
    jef22   1.08127E+00 (   0.82)
```

```
   31.004  1.02014E+00 (   0.0 )
   iaeagx   1.03256E+00 (   1.22)
     iaea   1.03035E+00 (   1.00)
    wdn29   1.03282E+00 (   1.24)
 endfb6gx   1.02252E+00 (   0.23)
   endfb6   1.02025E+00 (   0.01)
 jendl3gx   1.03317E+00 (   1.28)
   jendl3   1.03097E+00 (   1.06)
  jef22gx   1.03043E+00 (   1.01)
    jef22   1.02788E+00 (   0.76)

    40.156  9.81900E-01 (   0.0 )
   iaeagx   9.92041E-01 (   1.03)
     iaea   9.89308E-01 (   0.75)
    wdn29   9.95062E-01 (   1.34)
 endfb6gx   9.85545E-01 (   0.37)
   endfb6   9.82697E-01 (   0.08)
 jendl3gx   9.92725E-01 (   1.10)
   jendl3   9.90056E-01 (   0.83)
  jef22gx   9.91923E-01 (   1.02)
    jef22   9.88849E-01 (   0.71)

    49.308  9.46360E-01 (   0.0 )
   iaeagx   9.54803E-01 (   0.89)
     iaea   9.51825E-01 (   0.58)
    wdn29   9.59549E-01 (   1.39)
 endfb6gx   9.51536E-01 (   0.55)
   endfb6   9.48446E-01 (   0.22)
 jendl3gx   9.55459E-01 (   0.96)
   jendl3   9.52569E-01 (   0.66)
  jef22gx   9.56388E-01 (   1.06)
    jef22   9.53097E-01 (   0.71)

    51.596  9.38170E-01 (   0.0 )
   iaeagx   9.46051E-01 (   0.84)
     iaea   9.42990E-01 (   0.51)
    wdn29   9.51022E-01 (   1.37)
 endfb6gx   9.43560E-01 (   0.57)
   endfb6   9.40354E-01 (   0.23)
 jendl3gx   9.46670E-01 (   0.91)
   jendl3   9.43717E-01 (   0.59)
  jef22gx   9.48011E-01 (   1.05)
    jef22   9.44650E-01 (   0.69)

    60.749  9.07010E-01 (   0.0 )
   iaeagx   9.13638E-01 (   0.73)
     iaea   9.10319E-01 (   0.36)
    wdn29   9.19086E-01 (   1.33)
 endfb6gx   9.13923E-01 (   0.76)
   endfb6   9.10352E-01 (   0.37)
 jendl3gx   9.14105E-01 (   0.78)
   jendl3   9.10926E-01 (   0.43)
  jef22gx   9.16884E-01 (   1.09)
    jef22   9.13304E-01 (   0.69)

    72.189  8.73480E-01 (   0.0 )
   iaeagx   8.79392E-01 (   0.68)
     iaea   8.75685E-01 (   0.25)
    wdn29   8.84679E-01 (   1.28)
 endfb6gx   8.82358E-01 (   1.02)
   endfb6   8.78322E-01 (   0.55)
 jendl3gx   8.79630E-01 (   0.70)
   jendl3   8.76073E-01 (   0.30)
  jef22gx   8.83759E-01 (   1.18)
    jef22   8.79850E-01 (   0.73)
================================================
```

```
Average
   iaeagx
     iaea
    wdn29
 endfb6gx
   endfb6
 jendl3gx
   jendl3
  jef22gx
    jef22
#
```

PWR THORIUM PIN CELL BURNUP BENCHMARK

ISOTOPE	AtomDens.	diff(%)
Th-232	1.53769E-02	(0.0)
iaeagx	1.53852E-02	(0.05)
iaea	1.53849E-02	(0.05)
wdn29	1.53567E-02	(-0.13)
endfb6gx	1.53555E-02	(-0.14)
endfb6	1.53555E-02	(-0.14)
jendl3gx	1.53803E-02	(0.02)
jendl3	1.53805E-02	(0.02)
jef22gx	1.53708E-02	(-0.04)
jef22	1.53700E-02	(-0.05)
Pa-231	1.70440E-06	(0.0)
iaeagx	1.48709E-06	(-12.75)
iaea	1.48931E-06	(-12.62)
wdn29	0.00000E+00	(-100.00)
endfb6gx	1.51823E-06	(-10.92)
endfb6	1.52091E-06	(-10.77)
jendl3gx	1.43192E-06	(-15.99)
jendl3	1.43595E-06	(-15.75)
jef22gx	1.42763E-06	(-16.24)
jef22	1.41521E-06	(-16.97)
Pa-233	1.95229E-05	(0.0)
iaeagx	1.96248E-05	(0.52)
iaea	1.96312E-05	(0.55)
wdn29	2.06048E-05	(5.54)
endfb6gx	2.01310E-05	(3.11)
endfb6	2.01322E-05	(3.12)
jendl3gx	1.98034E-05	(1.44)
jendl3	1.98023E-05	(1.43)
jef22gx	1.99126E-05	(2.00)
jef22	1.99338E-05	(2.10)
U -232	1.56006E-06	(0.0)
iaeagx	1.61893E-06	(3.77)
iaea	1.60552E-06	(2.91)
wdn29	0.00000E+00	(-100.00)
endfb6gx	1.49556E-06	(-4.13)
endfb6	1.48249E-06	(-4.97)
jendl3gx	1.56705E-06	(0.45)
jendl3	1.55672E-06	(-0.21)
jef22gx	1.33811E-06	(-14.23)
jef22	1.30524E-06	(-16.33)
U -233	2.74202E-04	(0.0)
iaeagx	2.67501E-04	(-2.44)
iaea	2.67774E-04	(-2.34)
wdn29	2.74672E-04	(0.17)
endfb6gx	2.82825E-04	(3.14)
endfb6	2.82876E-04	(3.16)
jendl3gx	2.66193E-04	(-2.92)
jendl3	2.66156E-04	(-2.93)
jef22gx	2.76500E-04	(0.84)
jef22	2.76938E-04	(1.00)
U -234	5.15172E-05	(0.0)
iaeagx	5.21255E-05	(1.18)
iaea	5.16550E-05	(0.27)
wdn29	5.80601E-05	(12.70)
endfb6gx	5.29279E-05	(2.74)
endfb6	5.25525E-05	(2.01)

```
jendl3gx   5.28711E-05 (   2.63)
  jendl3   5.24177E-05 (   1.75)
 jef22gx   5.17610E-05 (   0.47)
   jef22   5.14724E-05 (  -0.09)

   U -235  1.78104E-04 (   0.0 )
  iaeagx   1.69067E-04 (  -5.07)
    iaea   1.68952E-04 (  -5.14)
   wdn29   1.67198E-04 (  -6.12)
endfb6gx   1.74742E-04 (  -1.89)
  endfb6   1.74528E-04 (  -2.01)
jendl3gx   1.68242E-04 (  -5.54)
  jendl3   1.68101E-04 (  -5.62)
 jef22gx   1.73262E-04 (  -2.72)
   jef22   1.73076E-04 (  -2.82)

   U -236  1.39420E-04 (   0.0 )
  iaeagx   1.41012E-04 (   1.14)
    iaea   1.40331E-04 (   0.65)
   wdn29   1.44256E-04 (   3.47)
endfb6gx   1.46834E-04 (   5.32)
  endfb6   1.46179E-04 (   4.85)
jendl3gx   1.40214E-04 (   0.57)
  jendl3   1.39586E-04 (   0.12)
 jef22gx   1.40437E-04 (   0.73)
   jef22   1.39809E-04 (   0.28)

   U -238  3.88419E-03 (   0.0 )
  iaeagx   3.90033E-03 (   0.42)
    iaea   3.89988E-03 (   0.40)
   wdn29   3.90093E-03 (   0.43)
endfb6gx   3.90155E-03 (   0.45)
  endfb6   3.90118E-03 (   0.44)
jendl3gx   3.89985E-03 (   0.40)
  jendl3   3.89934E-03 (   0.39)
 jef22gx   3.90303E-03 (   0.49)
   jef22   3.90285E-03 (   0.48)

   Np-237  1.82660E-05 (   0.0 )
  iaeagx   1.68435E-05 (  -7.79)
    iaea   1.78868E-05 (  -2.08)
   wdn29   1.59988E-05 ( -12.41)
endfb6gx   1.67566E-05 (  -8.26)
  endfb6   1.77747E-05 (  -2.69)
jendl3gx   1.70453E-05 (  -6.68)
  jendl3   1.80642E-05 (  -1.10)
 jef22gx   1.70086E-05 (  -6.88)
   jef22   1.80211E-05 (  -1.34)

   Np-239  7.61806E-07 (   0.0 )
  iaeagx   7.43598E-07 (  -2.39)
    iaea   7.41678E-07 (  -2.64)
   wdn29   7.30504E-07 (  -4.11)
endfb6gx   7.31696E-07 (  -3.95)
  endfb6   7.29725E-07 (  -4.21)
jendl3gx   7.47040E-07 (  -1.94)
  jendl3   7.45150E-07 (  -2.19)
 jef22gx   7.31643E-07 (  -3.96)
   jef22   7.29604E-07 (  -4.23)

   Pu-238  8.90932E-06 (   0.0 )
  iaeagx   8.52642E-06 (  -4.30)
    iaea   8.87454E-06 (  -0.39)
   wdn29   7.55844E-06 ( -15.16)
endfb6gx   8.37641E-06 (  -5.98)
  endfb6   8.71580E-06 (  -2.17)
jendl3gx   8.39271E-06 (  -5.80)
  jendl3   8.71876E-06 (  -2.14)
 jef22gx   8.56009E-06 (  -3.92)
```

```
    jef22   8.90209E-06 (  -0.08)

    Pu-239  5.37090E-05 (   0.0 )
   iaeagx   4.96907E-05 (  -7.48)
     iaea   4.98763E-05 (  -7.14)
    wdn29   4.90640E-05 (  -8.65)
 endfb6gx   5.07085E-05 (  -5.59)
   endfb6   5.08510E-05 (  -5.32)
 jendl3gx   4.95316E-05 (  -7.78)
   jendl3   4.96948E-05 (  -7.47)
  jef22gx   4.99922E-05 (  -6.92)
    jef22   5.01434E-05 (  -6.64)

    Pu-240  1.82233E-05 (   0.0 )
   iaeagx   1.75409E-05 (  -3.74)
     iaea   1.76464E-05 (  -3.17)
    wdn29   1.90920E-05 (   4.77)
 endfb6gx   1.76971E-05 (  -2.89)
   endfb6   1.77920E-05 (  -2.37)
 jendl3gx   1.79807E-05 (  -1.33)
   jendl3   1.80873E-05 (  -0.75)
  jef22gx   1.78621E-05 (  -1.98)
    jef22   1.79585E-05 (  -1.45)

    Pu-241  1.90707E-05 (   0.0 )
   iaeagx   1.81808E-05 (  -4.67)
     iaea   1.81703E-05 (  -4.72)
    wdn29   1.81217E-05 (  -4.98)
 endfb6gx   1.85142E-05 (  -2.92)
   endfb6   1.84937E-05 (  -3.03)
 jendl3gx   1.82395E-05 (  -4.36)
   jendl3   1.82291E-05 (  -4.41)
  jef22gx   1.80217E-05 (  -5.50)
    jef22   1.80028E-05 (  -5.60)

    Pu-242  9.96772E-06 (   0.0 )
   iaeagx   1.00383E-05 (   0.71)
     iaea   1.01991E-05 (   2.32)
    wdn29   0.00000E+00 (-100.00)
 endfb6gx   9.38217E-06 (  -5.87)
   endfb6   9.57290E-06 (  -3.96)
 jendl3gx   9.97154E-06 (   0.04)
   jendl3   1.03444E-05 (   3.78)
  jef22gx   9.62651E-06 (  -3.42)
    jef22   9.76718E-06 (  -2.01)
================================================
Average
   iaeagx
     iaea
    wdn29
 endfb6gx
   endfb6
 jendl3gx
   jendl3
  jef22gx
    jef22
#
```

Contents of CD-ROM

The CD-ROM is an image of the contents of the web-site and is organized for viewing with the html browser by clicking on the "index.htm" file in the main directory. Additional features of the package are described below.

Library updating procedure
If a user would like to generate his own libraries, it is recommended to prepare the following directory structure on hard disc:

```
[WLUP]___________ [INPUTS]
             |__ [PROGRAMS]
             |__ [WIMSLIB]
             |__ [DOSMAT]
```

The following files from the [DOWNLOADS] directory on the CD-ROM need to be loaded to the [PROGRAMS] subdirectory on hard disc:

DCKSPL.FOR	Fortran source code for operating on "SRC" files.
FOR.SRC	Merged auxiliary Fortran programs.
BAT.SRC	Merged DOS batch procedures.

Compile and link DCKSPL.FOR and run it on FOR.SRC and BAT.SRC, specifying extensions FOR and BAT for the expanded files, respectively. Input instructions for DCKSPL are included as comment on the Fortran source file. Prepare the executables for all WLUP codes on the [PROGRAMS] subdirectory. Note that readme.for and readme.bat are just text files. You might need to revise and set up the SETWLUP.BAT procedure according to your local computer environment. The Fortran codes and batch procedures are heavily commented for the users' convenience.

The following files from the [DOWNLOADS] directory on the CD-ROM need to be loaded to the [INPUTS] subdirectory on hard disc:

DOP.SRC	Doppler benchmark inputs.
MISCINP.ZIP	Miscellaneous input files.
NJI.SRC	NJOY inputs.
REF.SRC	Reference results for the benchmark test cases.
WGX.SRC	172-group benchmark inputs for the WIMSD-5B code.
WIN.SRC	69-group benchmark inputs for the WIMSD-5B code.
W86.SRC	69-group benchmark inputs for the WIMSD-5B code using the original "1986" WIMS-D library.
WLI.SRC	Inputs for the WILLIE code.
actlst.dat	List of fissile actinides.
fplstall.dat	Full list of fission product nuclides.
fplstexp.dat	List of explicitly treated fission product nuclides.
egb172.dat	Energy-group boundaries of the 172-group structure.
brond2nt.dat	BROND-2 cross section library
cendl2nt.dat	CENDL-2 cross section library
endfb6dy.dat	ENDF/B-VI Rel.8 decay data library.
endfb6fp.dat	ENDF/B-VI Rel.8 fission product yield data library.
endfb6nt.dat	ENDF/B-VI Rel.8 cross section data library.
endfb6sl.dat	ENDF/B-VI Rel.8 scattering law data library.
fond22nt.dat	FOND-2.2 cross section data library.

iaeady.dat	Adopted IAEA decay data library.
iaeafp.dat	Adopted IAEA fission product yield data library.
iaeant.dat	Adopted IAEA cross section data library.
iaeasl.dat	Adopted IAEA scattering law data library.
jef22dy.dat	JEF-2.2 decay data library.
jef22fp.dat	JEF-2.2 fission product yield data library.
jef22nt.dat	JEF-2.2 cross section data library.
jef22sl.dat	JEF-2.2 scattering law data library.
jeff30nt.dat	JEFF-3.0 cross section data library.
jeff3tdy.dat	JEFF-3.0 decay data library.
jen33nt.dat	JENDL-3.3 cross section data library.
jendl3dy.dat	JENDL-3.2 decay data library.
jendl3fp.dat	JENDL-3.2 fission product yield data library.
jendl3nt.dat	JENDL-3.2 cross section data library.

Split all 'name'.SRC files with the DCKSPL code, using 'name' as the extension. Unzip the MISCINP.ZIP file into the same directory.

A number of evaluated nuclear data libraries listed above are included on the CD-ROM for convenience and are not available in the on-line version from the web.

The following file from the [DOWNLOADS] directory on the CD-ROM need to be loaded to the [DOSMAT] subdirectory on hard disc:
DOSMAT.ZIP Compressed cross-section data for dosimetry reactions.

Unzip the dosimetry cross-section data into the same directory. If you need to generate the dosimetry files from new evaluated data, read carefully the readmedm.txt file on the [DOSMAT] subdirectory and check the wlupdosm.bat on the [PROGRAMS] subdirectory.

The procedure for generating an updated WIMS-D library is described in the rundos.txt file on the [DOWNLOADS] directory on CD-ROM.

Additional program packages

XnWlup	Software to plot cross-sections data from WIMS-D Library. (see readme file provided with the package).
NRSC	NRSC Package, for detailed resonance spectrum and λ factor calculations (see readme file provided with the package).
TRIGLAV	Package, for whole core benchmark calculations (see documentation provided with the package).

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