WIMS-D Library Update

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

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WIMS-D LIBRARY UPDATE

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WIMS-D LIBRARY UPDATE

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FOREWORD

WIMS-D (Winfrith Improved Multigroup Scheme-D) is the name of a family of software packages for reactor lattice calculations and is one of the few reactor lattice codes in the public domain and available on non-commercial terms. WIMSD-5B has recently been released from the OECD Nuclear Energy Agency Data Bank, and features major improvements in machine portability, as well as incorporating a few minor corrections. This version supersedes WIMS-D/4, which was released by the Winfrith Technology Centre in the United Kingdom 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 multigroup constants library, which is based on very old data. The relatively good performance of WIMS-D is attributed to a series of empirical adjustments to the multigroup 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 with the support of the IAEA. This project consisted of voluntary contributions from a large number of participants. Several benchmarks for testing the library were identified and analysed, 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 the WLUP was organized as a coordinated research project (CRP) in order to speed up completion of the fully updated library. Research coordination meetings were held in Vienna in 1999 and 2001, and in San Carlos de Bariloche, Argentina, in 2000. Intensive work has been performed over the past years, and all of the objectives were achieved. The present publication refers to the results of the WLUP.

The final product includes:

(a) The WIMSD-IAEA-69 group library prepared from the selected evaluated data files;
(b) The WIMSD-IAEA-172 group library prepared from the selected evaluated data files;
(c) An IAEA technical report with detailed documentation;
(d) Data processing inputs for the NJOY evaluated nuclear data processing system and the WIMS-D library maintenance code WILLIE;
(e) Benchmark inputs models for WIMS;
(f) A 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 of the Division of Physical and Chemical Sciences.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

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] that 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 1960s.

The WIMSD-5B version of the code was released from Winfrith in 1998 [1.2] for distribution by the OECD Nuclear Energy Agency Data Bank. An important improvement of this version lies in the inclusion of the 1986 WIMS library. Halsall has summarized several compelling justifications for the modifications to 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 1960s. Since 1986 the WIMS nuclear data libraries have 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 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 multigroup nuclear data library in the WIMS-D format grew out of discussions between the participants, lecturers and directors of a Joint IAEA–Abdus Salam International Centre for Theoretical Physics (ICTP) Workshop on Reactor Physics Calculations for Applications in Nuclear Technology, held from 12 February to 16 March 1990.

Work on the WLUP started officially in the early 1990s [1.4–1.6], when the idea was promoted within the IAEA. The IAEA was responsible for the coordination, creation, formulation and execution of this project during 1990–1994 and through informal contacts in 1995–1996.

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 from 4 to 7 December 1989, and the International Nuclear Data Committee (INDC) endorsed the continuation of the WLUP in March 1993 to provide updated multigroup constants in the WIMS-D format for research and power thermal reactor applications. The WLUP was also recommended by specialists from developing countries at an IAEA–ICTP workshop (1994) and by the participants of the IAEA consultants meeting held in 1993 on the processing of nuclear data.

A. 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.

1.2.1. Need for a coordinated research project on the final stage of the WIMS-D Library Update Project

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 [1.7] to plan for the final stage of the WLUP. The final stage of the WLUP as a CRP began in December 1998, with the assignment of research contracts to participants. Research coordination meetings were held in Vienna in 1999 and 2001 and in San Carlos de Bariloche, Argentina, in 2000. This report refers to the results of the WLUP.

1.3. SUMMARY OF WORK

1.3.1. Work before the coordinated research project

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

(a) Stage 1: Benchmark definition.
(b) Stage 2: Data processing codes.
(c) Stage 3: Major reactor materials replacement.
(d) Stage 4: Actinides and fission products.
(e) Stage 5: Structural materials.
(f) Stage 6: Other moderators and missing materials.
(g) Stage 7: Final benchmarking and documentation.

1.3.1.1. Stage 1

Extensive work was performed to define the benchmarks [1.5, 1.8]. 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:

(a) 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.
(b) Optimized 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 finalized. Additional benchmarks were added later.

1.3.1.2. Stage 2

The objective was to check the definitions of the multigroup 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 that 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 did 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 multigroup constants for WIMS. Seven laboratories participated, each with their own code system. The overall conclusion was that none of the codes were adequate, and all required extensive updates to meet all the requirements for the preparation of multigroup constants for the WIMS-D library. At that same time, the NJOY-91 code system, which included the WIMSR module, was released. The decision was taken to adopt NJOY as the data processing system and to upgrade the WIMSR module as necessary because:

(a) NJOY is a state of the art data processing system.
(b) Extensions due to format changes in the evaluated nuclear data files are maintained by the author.
(c) NJOY is a widely used system — feedback from users helps the author to quickly eliminate possible errors in the code.
(d) 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 multigroup 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 intercomparison 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 the Korea Atomic Energy Research Institute, 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 NJOY97 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 to perform checking and data intercomparisons. 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 intercomparison task, the WILLIE code for WIMS-D library maintenance was developed, based on the WILIT2 code of Holubar of the OECD/NEA Data Bank (Package ID IAEA1243/01, http://www.nea.fr/html/dbprog). 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, and consistency checking.

1.3.1.3. Stage 3

The objective was to replace the main reactor materials in the existing WIMS-D library for testing purposes. These materials are hydrogen bound in water, oxygen, aluminium, U-235 and U-238. 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. Optimization of the data processing options was based on numerical benchmarks available in the literature, based mainly on ENDF/B-IV data, since ENDF/B-V was restricted and ENDF/B-VI did not exist at that time.

1.3.1.4. Stage 4

The objective was to replace the actinide and fission product cross-sections, fission product yields, and 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 multigroup 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 with 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 Section 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.

1.3.1.5. 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.

1.3.1.6. 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.

1.3.1.7. 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.

1.3.1.8. 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 coordinated research project

The main objective was to produce the following products:

(a) A fully updated WIMS-D library, compatible with the WIMSD-5B code;
(b) 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:

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

A secondary objective was to remove the restriction in the WIMS-D code that 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.

Summaries of the WLUP coordination meetings are given below.

1.3.2.1. First Research Coordination Meeting of the Final Stage of the WIMS-D Library Update Project

Twelve participants attended the First Research Coordination Meeting of the Final Stage of the WIMS-D Library Update Project, held on 15–18 February 1999 at the IAEA in Vienna [1.12]. 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 discussion about various important issues took place during this meeting. The topics were:

(a) Codes (WIMSD-5B, NJOY97).
(b) 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).
(c) 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).
(d) Benchmarks (collection of additional benchmarks, provision of spectra with benchmark output, WIMS input options, comparison with other codes).
(e) WIMS code upgrade (increasing the number of groups, isotope dependent fission spectra, number of resonance groups, treatment of the (n,2n) reaction products and capture branching ratios, increasing the limits on the number of fission products).

1.3.2.2. Second Research Coordination Meeting of the Final Stage of the WIMS-D Library Update Project

The purpose of the second meeting, held in San Carlos de Bariloche, Argentina, on 14–17 August 2000 [1.13], 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.

1.3.2.3. Final Research Coordination Meeting of the Final Stage of the WIMS-D Library Update Project

An intensive programme of work was successfully completed in the Final Research Coordination Meeting, held on 19–23 November 2001 at the IAEA in Vienna [1.14]. 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 IAEA 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 pressurized water reactor (PWR) design calculations. Problems were encountered and a last minute change of the selected data for U-235 was found to be necessary. All benchmarks were reanalysed 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 publicized and made available by the IAEA.

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, which includes libraries and documentation, to users in Member States. 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 THIS REPORT

This report summarizes the results of the CRP and presents the libraries produced for general use. The contents and details of production of each type of data included in the WIMSD libraries are described in Sections 2–11.

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

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

Section 14 contains the types, organization, index and results of the benchmarks implemented for testing the new WIMS-D 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 Section 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 the WLUP and all material related to the generation of libraries and benchmarks are available at http://www-nds.iaea.org/wimsd/. A CD-ROM with all this material and additional valuable information is available upon request.

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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 the 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, in which 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 Tables 6.1 and 6.2). Details of the resonance treatment and weighting spectra are given in Section 3 and Section 10, respectively.

2.1. TRANSPORT CROSS-SECTION

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

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

where

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

$\sigma_{sl,g}$ 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 a 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;

$\sigma_{sl,h\to g}$ is the P_1 scattering matrix element for scattering from group h into g;

J_h is the neutron current in group h (see Section 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]:

$$\sigma'_{s0g\to h} = \sigma_{s0,g\to h} + 2\sigma_{(n,2n),g\to h} + 3\sigma_{(n,3n),g\to h} \tag{2.5}$$

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):

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

2.4. OTHER PARAMETERS

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

(a) Resonance integrals (see Section 3).
(b) Potential cross-section σ_p (see Section 6).
(c) 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.
(d) Fission neutron production cross-section $(\nu\sigma_f)_g$.
(e) Fission cross-section $\sigma_{f,g}$.
(f) Fission product yields, burnup and decay chain data (see Sections 4–6, 8).
(g) Fission spectrum (see Section 10).
(h) P_1 scattering matrix $\sigma_{s1,g\to h}$ (see Section 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 (IR) 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 WIMS-D formatted libraries.

Assuming that the IR approximation is valid for all non-resonant nuclides, the resonance integrals can be tabulated as a function of temperature and a lumped parameter σ_0 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_0 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_0 depends on the formalism used to approximate the scattering kernel of the non-resonant materials. In the case of the IR approximation, the Goldstein–Cohen IR λ factors are needed to obtain the σ_0 value of the actual system. The background cross-section σ_b is used instead of the Bondarenko cross-section σ_0 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_0. As a consequence of this feature, the resonance tabulations and the λ values are interrelated 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 Neutron Resonance Spectrum Calculation (NRSC) code system, which was developed to estimate the Goldstein–Cohen λ factors following the WIMS-D conventions. The λ values included in 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 resonance data of WIMS-D formatted libraries.

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;
Σ_s^i is the macroscopic scattering cross-section of the ith nuclide in the mixture.

The slowing down operator for the ith nuclide is defined as:

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

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 Eq. (3.1) can be written as:

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

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;

$\sigma_0^i = \frac{N_i}{N_r}\sigma_p^i$ is the potential scattering cross-section of the ith nuclide per resonant atom;

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 IR 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_0 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 IR factor of nuclide i and the other symbols have the same meaning as before. Note that $\lambda_I = 1$ for the narrow resonance (NR) approximation, and $\lambda_I = 0$ for the wide resonance (WR) or infinite mass (IA) approximation. After introducing the IR approximation, Eq. (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 Eq. (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_0 is calculated with $\lambda_I = 1$ for all isotopes. Thus from Eq. (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_0 values. An important point to note is that the background cross-section σ_b is used instead of the Bondarenko σ_0 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 a heterogeneous medium is a more complicated problem than for a 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:

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

where Σ_t^k and 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:

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

where

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

$$\sigma_e = \frac{\Sigma_e}{N_r} \qquad (3.15)$$

are the heterogeneous Bondarenko (σ_0) and the microscopic escape cross-section (σ_e), respectively.

An equivalence theorem can be deduced by comparing Eqs (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 this report.

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

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

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:

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

which is exactly the inverse formula of the approximate expression in Eq. (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 WIMS-D formatted libraries. 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 Goldstein–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 Eq. (3.6) for a given resonant isotope, the shape of the resonance flux will be the same if the background cross-section σ_0 (or σ_b) is the same.

A good approximation for hydrogen is to take $\lambda = 1$, because all resonances can be considered narrow compared with the maximum energy loss from scattering on hydrogen atoms. The λ values can be obtained by comparing the exact solution of Eq. (3.4) for a mixture of the main resonant isotope U-238 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 resonant absorber and hydrogen (H), and solve Eq. (3.4) for a mixture in which hydrogen is replaced by a nuclide of interest (X). Values of $I_a(\sigma_b(\mathrm{H} + X))$ can be calculated in the resonance range and converted to the corresponding self-shielded cross-section $\sigma_a(\sigma_b(\mathrm{H} + X))$. If the IR approximation is valid, Eqs (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:

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

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

Adopting this expression and $\lambda_{\mathrm{H}} = 1$ gives the following:

$$\lambda_x = \frac{\sigma_b(\mathrm{H}) - \left(\frac{N_{\mathrm{H}}}{N_r}\right)_{\mathrm{H}+x}\sigma_{p\mathrm{H}} - \lambda_r\sigma_{pr}}{\left(\frac{N_x}{N_r}\right)_{\mathrm{H}+x}\sigma_{px}} \quad (3.19)$$

or by taking into account the relationship between σ_b and σ_0:

$$\lambda_x = \frac{\sigma_0(\mathrm{H}) - \left(\frac{N_{\mathrm{H}}}{N_r}\right)_{\mathrm{H}+x}\sigma_{p\mathrm{H}}}{\left(\frac{N_x}{N_r}\right)_{\mathrm{H}+x}\sigma_{px}} \quad (3.20)$$

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 Eqs (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 [3.5–3.7]. Computations of σ_a in several mixtures of the main resonant absorber U-238, hydrogen and different isotopes X were obtained in different runs of NRSC/RMET21. The 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 O-16, Al-27, Fe-56 and Zr-91. An estimate of λ for U-238 was derived from an additional calculation in which isotope X was a fictitious nuclide with A = 238 and the potential cross-section of U-238.

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) A typical value of the N_O/N_U ratio in UO_2 fuel was selected for oxygen.
(b) Selected values for aluminium, iron and zirconium correspond to cladding made from these elements, with the atom density ratios calculated from the following formula:

$$\frac{N_i}{N_u} = \frac{N_i^* V_{\text{clad}}}{N_u^* V_{\text{fuel}}} \tag{3.21}$$

where N_i^* is the atom density in the cladding for nuclide i, N_u^* is the atom density of U-238 in the fuel, and V_{clad} and V_{fuel} are the cladding and fuel volumes, respectively.
(c) The selected ratio N_H/N_U for all cases was 1.219, which corresponds to a typical LWR 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 (GOLDSTEIN–COHEN PARAMETER)

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 HYDROGEN, OXYGEN, ALUMINIUM, IRON, ZIRCONIUM AND URANIUM-238 (GOLDSTEIN–COHEN PARAMETER)

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

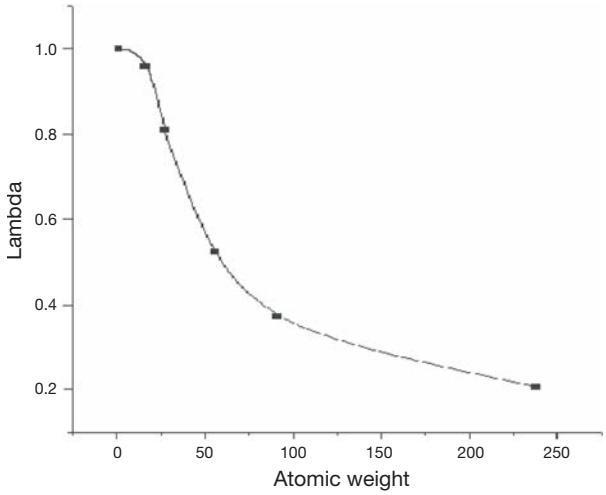

FIG. 3.1. One-group λ plotted against atomic weight.

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 these products have a significant impact on the nuclear properties of the core and must be treated explicitly. Others, although individually unimportant, 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 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. This section describes 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:

(a) Short lived nuclides are those which satisfy the condition:

$$\sigma_p H_p < 1.16 \times 10^{19}\ \varepsilon_1 \ln 2/\Phi$$

where σ_p is the capture cross-section in barns and H_p is the half-life in 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.

(b) Nearly stable nuclides are those which satisfy the condition:

$$\sigma_p H_p > 1.16 \times 10^{19} \ln 2/(\varepsilon_2\ \Phi)$$

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

(c) Highly absorbing fission products are those which satisfy the criterion:

$$\gamma_p \sigma_p > 1.16 \times 10^{19}\ 2\varepsilon_3/(\Phi T)$$

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 with the fission reactions during fuel irradiation. All nuclides that satisfy this criterion must be treated explicitly.

(d) Highly absorbing capture products are those which satisfy the criterion:

$$\gamma_p \sigma_p \sigma_c > (1.16 \times 10^{19})^2\ 6\varepsilon_4/(\Phi T)^2$$

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.

The 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:

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

The specified criteria reduce to:

(i) $\sigma_p H_p < 1600$ (in barn·days);
(ii) $\sigma_p H_p > 4 \times 10^8$ (in barn·days);
(iii) $\gamma_p \sigma_p > 0.12$ (in barns);
(iv) $\gamma_p \sigma_p \sigma_c > 400$ (in $barns^2$).

Additionally, a qualitative criterion was 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 $\gamma_p \sigma_p > 10^{-8}$ b, $\varepsilon_3 = 4 \times 10^{-12}$: 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.

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 700 K 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. A WLUP averaging spectrum was used to produce the multigroup 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 the 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:

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

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

where

y^k is the cumulative fission product yield of the pseudo fission product for the fissile nuclide k;
y_l^k is the cumulative fission product yield of the nuclide l for the fissile nuclide k;
$ó_x^k$ is the group cross-section x of the pseudo fission product for the fissile nuclide k;
$ó_{x,l}$ is the group cross-section x of the constituent nuclide l;
x is the 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 Fig. 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 U-235, U-238 and Pu-239 in the ratio of w^k = 54%, 8% and 38%, respectively:

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

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

where

y is the cumulative fission product yield of the average pseudo fission product;
$ó_x$ is the group cross-section x of the average pseudo fission product;
w^k is the 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

TABLE 4.1. EXPLICITLY REPRESENTED FISSION PRODUCTS

No.	Nuclide	WIMS ID	Resonance tables	Number of temperatures	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	Caesium-133
20	55-Cs-134	4134	0	1	Caesium-134
21	55-Cs-137	4137	0	1	Caesium-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	Caesium-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
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	—

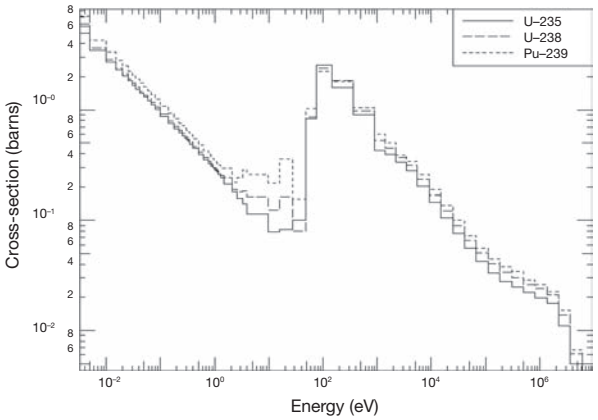

FIG. 4.1. Absorption cross-section of the pseudo fission product for different fissile nuclides.

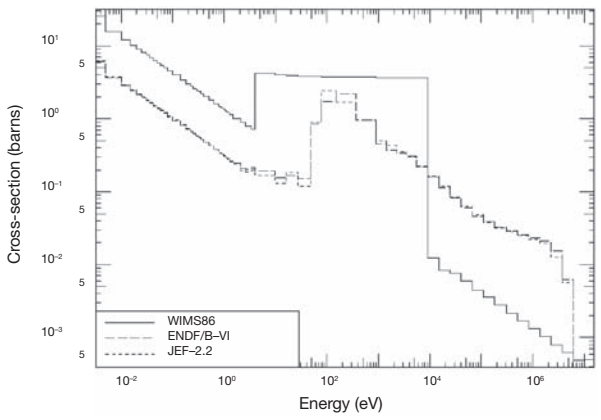

FIG. 4.2. Absorption cross-section of the average pseudo fission product in different libraries.

shown in Fig. 4.2, along with the data from the original WIMS-D library. Although the WIMS-D 1986 (WIMS86) 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 Fig. 4.3.

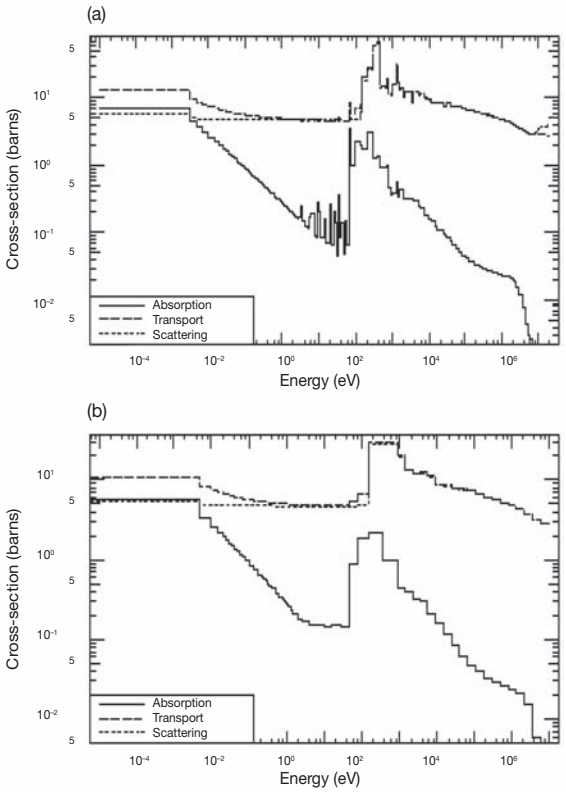

FIG. 4.3. Pseudo fission product cross-section data. (a) WIMSD-IAEA-172 group; (b) WIMSD-IAEA-69 group.

REFERENCES TO SECTION 4

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

[4.2] DUNFORD, C.L., ENDF Utility Codes Release 6.12 Manual, Brookhaven Natl Lab., Upton, NY (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, Radiation Safety Information Computational Center, Oak Ridge, TN (1998).

[4.4] TRKOV, A., LOPEZ ALDAMA, D., "Definition of the pseudo fission product data for reactor calculations", Nuclear Energy in Central Europe '99 (Proc. Int. Conf. Portorož, Slovenia, 1999), Jožef Stefan Institute, Ljubljana (1999) 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:

$$W^i_{\text{fiss}} = E^i_r + Q^i_c + W^i_n \tag{5.1}$$

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;
W^i_r is the kinetic 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:

$$W^i_n = \frac{\sum_g E^g_a \sigma^g_{f,i} \Phi^g}{\sum_g \sigma^g_{f,i} \Phi^g} \tag{5.2}$$

where

$\sigma^g_{f,i}$ is the microscopic fission cross-section of the fissionable nuclide i in energy group g;
Φ^g is the neutron spectrum;
E^g_a 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 and 2.8615 MeV, respectively), to give the average energy in a Maxwellian fission spectrum at a temperature corresponding to 1.4 MeV:

$$E^g_a = \frac{\int_g E\sqrt{E}\exp(-E/T)\mathrm{d}E}{\int_g \sqrt{E}\exp(-E/T)\mathrm{d}E} \tag{5.3}$$

The additional energy released due to gamma activation is calculated from:

$$Q_c = (\bar{\nu} - 1)Q \tag{5.4}$$

where $(\bar{\nu} - 1)$ 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 LWR 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 the 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[a]	W_{fiss} (J/mole)
90-Th-232	2232	1.8670E-11
91-Pa-233[b]	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[b]	1939	1.9600E-11

TABLE 5.1. ENERGY RELEASE PER FISSION FOR FISSIONABLE ACTINIDES (cont.)

Nuclide	MAT[a]	W_{fiss} (J/mole)
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-Am-242m	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

[a] MAT: WIMS-D identification number.
[b] Fission product data not available.

REFERENCES TO SECTION 5

[5.1] PERŠIČ, A., TRKOV, A., "The energy released by neutron capture in thermal reactors", Nuclear Energy in Central Europe '99 (Proc. Int. Conf. Portorož, Slovenia, 1999), Jožef Stefan Institute, Ljubljana (1999) 83–90.

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6. LIST OF MATERIALS

The essential information about materials included in the WIMSD-IAEA libraries is summarized in this section. 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 the P_1 scattering matrix has been prepared. Other kinds of data, such as detailed information about dosimetry materials and burnup chains, are given in Sections 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:

(a) Material: Material identification. Atomic number (Z), chemical symbol, mass number (A) or other information that identifies the material.
(b) 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.
(c) At. wt: Atomic weight (amu).
(d) 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.
(e) T: Temperatures at which thermal data are given (K).
(f) 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.
(g) 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 cannot 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 WIMS-D libraries 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, for which 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.
(h) Description: Brief description of the material, thermal scattering law (if not 'free gas') and weighting spectrum (if not the standard PWR spectrum), dosimetry reaction (note: (n,g) stands for radiative capture; other reactions are self-explanatory).
(i) 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 the 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–H_2O	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–D_2O	3002	2.0141	0	296 350 400 450 500 600	M	inf. dil.	Deuterium bound in D_2O 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.	Beryllium	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
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

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
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

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
67-Ho-165	165	164.93	0	293 700 1100	B/FP	2.0E5	Holmium-165	ENDF/B-VI.8

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
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	Caesium-133	ENDF/B-VI.8
55-Cs-134	4134	133.907	0	700	FP	5.0E5	Caesium-134	ENDF/B-VI.8
55-Cs-137	4137	136.907	0	700	FP	5.0E4	Caesium-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	Caesium-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 FP	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 FP U-232(n,2n)U-231	n.a.

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
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

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
95-Am-242	1952	242.059	0	293 700 1100	FP	5.0E6	Americium-242 (non-fissile FP)	FOND-2.2
95-Am-242m	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.
R*v*	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

TABLE 6.1. GENERAL INFORMATION ON MATERIALS (cont.)

Material	ID	At. wt	NF	T	Typ	XS0	Description	Data source
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
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

HWR: heavy water reactor.
n.a.: Not applicable.

6.2. DETAILED INFORMATION FOR RESONANCE MATERIALS

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

(a) Material: Material identification. Atomic number (Z), chemical symbol, mass number (A).
(b) ID_r: WIMS-D identification number for resonance data (real).
(c) 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.
(d) T_{res}: List of temperatures in the resonance range (K).
(e) PotXS: Potential cross-section (barns).
(f) $XS0_{res}$: List of background cross-section values σ_0 for resonance tabulation (barns).

6.3. DETAILED INFORMATION FOR MATERIALS WITH P_1 SCATTERING MATRICES

Table 6.3 shows the general information for materials with the P_1 matrix data. These data are given in the same order in which they are stored in the WIMSD-IAEA libraries. 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 P_1 matrices, and the data are given at only one temperature. The following information is presented:

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	1E10, 2.E4, 3600, 1000, 260, 140, 64, 52, 28, 10
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

TABLE 6.2. RESONANCE DATA (cont.)

Material	ID_r	NF	T_{res}	PotXS	$XS0_{res}$
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	1E10, 2E4, 3600, 1000, 260, 140, 64, 52, 28, 10
92-U-233	9233.0	3	293 600 900 1100	12.2989	1E10, 2E4, 3600, 1000, 260, 140, 64, 52, 28, 10
92-U-234	234.0	2	293 700 1100	12.6113	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 5E3, 1E3
92-U-235	2235.0	3	293 600 900 1100	11.6070	1E10, 3E4, 8000, 4500, 2800, 1800, 1200, 800, 500, 200
92-U-236	236.0	2	293 700 1100	11.2615	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 5E3, 1E3
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	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 5E3, 1E3
94-Pu-240	1240.0	2	293 600 900 1100	9.2474	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 5E3, 2E3, 1E3, 5E2
94-Pu-241	1241.0	3	293 600 900 1100	12.0	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 5E3, 3E3, 1E3, 5E2
94-Pu-242	242.0[a]	2	293 700 1100	10.5	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 8E3, 5E3, 1E3, 5E2
94-Pu-242	1242.0[b]	2	293 700 1100	10.5	1E10, 5E5, 3E5, 1E5, 5E4, 1E4, 8E3, 5E3, 1E3, 5E2

[a] High self-shielding (high concentration).
[b] Low self-shielding (low concentration).

TABLE 6.3. MATERIALS WITH P_1 MATRICES

Order	Material	ID	Tp1	Description	Data source
1	1-H–H_2O	3001	296	Hydrogen bound in water PWR spectrum	ENDF/B-VI.8
2	1-D–D_2O	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

(a) Order: Consecutive number of the P_1 matrix in the library.
(b) Material: Material identification.
Atomic number (Z), chemical symbol, associated compound.
(c) ID: WIMS-D identification number.
(d) Tp1: Temperature for the P_1 matrix (K).
(e) Description: Brief description of the material.
(f) Data source: Source of evaluated data for the final WIMSD-IAEA libraries.

REFERENCES TO SECTION 6

[6.1] ROSE, P.F. (Ed.), ENDF/B-VI Summary Documentation, Rep. BNL NCS-17541 (ENDF-201), Brookhaven Natl Lab., Upton, NY (1991). Data Library ENDF/B-VI, update 2001, by the US Natl Nuclear Data Center on behalf of the Cross-section Evaluation Working Group. Data received on tape (or retrieved online) from the IAEA Nuclear Data Section, Rep. IAEA-NDS-100, Rev. 11, 2001. ENDF/B-VI, Release 8, the US Evaluated Nuclear Data Library for Neutron Reaction Data by the US National Nuclear Data Center — 1990, includes revisions up to Nov. 2001 — Summary of contents, LEMMEL, H.D., McLAUGHLIN, P.K., PRONYAEV, V.G.

[6.2] JENDL-3.2, The Japanese Evaluated Nuclear Data Library, by the JAERI Nuclear Data Center and the Japanese Nuclear Data Committee. Data available from the IAEA (Rep. IAEA-NDS-110, Rev. 5, 1994).

[6.3] JEF-2.2, Nuclear Energy Agency Data Bank, Joint Evaluated File Version 2 (1992). See NORDBORG, C., SALVATORES, M., "Status of the JEF evaluated data library", Int. Conf. on Nuclear Data for Science and Technology, Gatlinburg, TN, 1994, Proc. Amer. Nucl. Soc. (1994) 580. Data available from IAEA-NDS (Rep. IAEA-NDS-120, Rev. 3, 1996).

[6.4] CENDL (Versions 2.2 and 3), Chinese Nuclear Data Centre, A Brief Description of the Second Version of the Chinese Evaluated Nuclear Data Library CENDL-2, Communication of Nuclear Data Progress No. 6, Rep. INDC(CPR)-25, Beijing, 1991. Data library CENDL-2.1, including 1995 updates, distributed by IAEA Nuclear Data Section. Summary documentation by LIANG QICHANG, LEMMEL, H.D. (Eds), Rep. IAEA-NDS-61, Rev. 3, 1996.

[6.5] KOSCHEEV, V.N., NIKOLAEV, M.N., KORCHAGINA, Z.A., SAVOSKINA, G.V., The FOND-2.2 Evaluated Neutron Data Library, Rep. INDC(CCP)-429, IAEA, Vienna (2001) 57–93, http://www-nds.iaea.org/indc_sel.html#ccp

7. DOSIMETRY DATA

Dosimetry data are included in WIMS-D libraries as special materials in order to perform reaction rate calculations using the WIMS-D lattice code. A total of 15 dosimetry materials are contained in the WIMS86 library [7.1], including eight dosimetry reactions, two damage cross-sections and five 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 WLUP. 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. The POINT2000 [7.3] library is the pointwise 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 ENDF/B-VI Rev. 7 were processed with the NJOY code system [7.4] to generate a pointwise 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 libraries 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. The WIMSIE code was developed to perform WIMS-D formatting and to 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 pointwise dosimetry files from the JENDL/D-99 library were not linearly interpolable over the resonance range (the 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 pointwise cross-section data (MF = 3) of the evaluated source file. SIGMA1 Doppler broadened the cross-section to 300 K, and GROUPIE converted the multigroup 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 multigroup 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 performed 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 in 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 the IAEA Nuclear Data Section, and they are included on the WLUP CD-ROM.

REFERENCES TO SECTION 7

[7.1] HALSALL, M.J., TAUBMAN, C.J., The '1986' WIMS Nuclear Data Library, Rep. AEEW-R2133, United Kingdom Atomic Energy Authority, Winfrith (1986).

TABLE 7.1. DOSIMETRY MATERIALS

Dosimetry reaction	Source of evaluated data	File name	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"
Inverse lethargy interval						4000	Wlup1u"L"
Const. = 1 absorber						3000	Wlup1a"L"

Note: Presence of suffix L denotes 172 energy group structure, otherwise a 69 energy group structure is implied.

[7.2] KOBAYASHI, K., et al., JENDL Dosimetry File (JENDL/D-99), Rep. JAERI 1344, Japan Atomic Energy Research Institute, Tokai-mura (2002).
[7.3] CULLEN, D.E., POINT2000: A Temperature Dependent ENDF/D-VI, Release 7 Cross Section Library, Rep. UCRL-ID-127776, Rev.1, Lawrence Livermore Natl Lab., CA (2000).
[7.4] 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, Radiation Safety Information Computational Center, Oak Ridge, TN (1998).
[7.5] CULLEN, D.E., PREPRO2000: 2000 ENDF/B Pre-processing Codes, Rep. IAEA-NDS-39, Rev. 10, 1, IAEA, Vienna (2000).

8. BURNUP DATA

8.1. ACTINIDE CHAIN

Figure 8.1 depicts the actinide burnup and decay transitions implemented in the WIMSD-IAEA libraries.

Numbered items in Fig. 8.1 are:

(1) Direct capture in Cm-243 yields Cm-244.
(2) Direct capture in Cm-242 yields Cm-243.
(3) Beta decay of Am-242 yields Cm-242. The branching ratio (B_{Cm2} = 82.7%) is accounted for by an effective (reduced) yield for production of Am-242, which is treated as a fission product (i.e. has no fission cross-section). The positron emission branch that produces Pu-242 is ignored.
(4) Am-242m decays by isomeric transition to Am-242. Unfortunately, the concept of a reduced Am-242 concentration cannot be implemented for production by isomeric transition decay of Am-242m because such a yield by decay cannot be specified in the WIMS-D libraries. See the discussion on Am-242 production by capture in Am-241.
(5) Capture in Am-241 results in Am-242m 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 bapl2 (Bettis Atomic Power Laboratory) 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 Am-242 is produced from capture in Am-241. Since only one nuclide can be specified as the capture product (Am-242m under the previous item), Am-242 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 bapl2 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 Am-242 is given by:

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

Fission in Am-241 is predominantly a threshold reaction with a small subthreshold contribution, and Am-241 fission is not an important contributor to reactivity. The fission cross-section of Am-241 in the WIMS-D libraries is forced to be proportional to the absorption cross-section (normalized to conserve the selected c/f ratio) in order to make the yield of Am-242g exact. Thus the effective reduced Am-242 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) Am-241 decays by alpha emission to Np-237.
(8) Cm-244 decays by alpha emission to Pu-240.
(9) Cm-243 decays by alpha emission to Pu-239.
(10) Cm-242 decays by alpha emission to Pu-238.
(11) Pu-241 decays by beta emission to Am-241.
(12) Capture in Np-239: resulting Np-240 is assumed to decay instantly by beta emission to Pu-240.
(13) Np-239 decays by beta emission to Pu-239.
(14) Capture in Np-237: resulting Np-238 is assumed to decay instantly by beta emission to Pu-238.
(15) Pu-238 decays by alpha emission to U-234.
(16) Capture in U-238: resulting U-239 is assumed to decay instantly by beta emission to Np-239.
(17) Production of U-237 from the (n,2n) reaction of U-238: a pseudo fission product (ID = 4927) is defined, which decays instantly into U-237. The yield is equal to the ratio of (n,2n)/(n,f) reactions of U-238, 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 U-237.
(18) Capture product of Pa-233 is assumed to decay instantly to U-234.
(19) U-237 decays by beta emission to Np-237.
(20) Capture chain from U-232 to U-238 is represented explicitly.
(21) Production of U-232 from the (n,2n) reaction in U-233 is represented by a pseudo fission product (ID = 4927), which decays instantly to U-232. The yield is equal to the ratio of (n,2n)/(n,f) reactions.

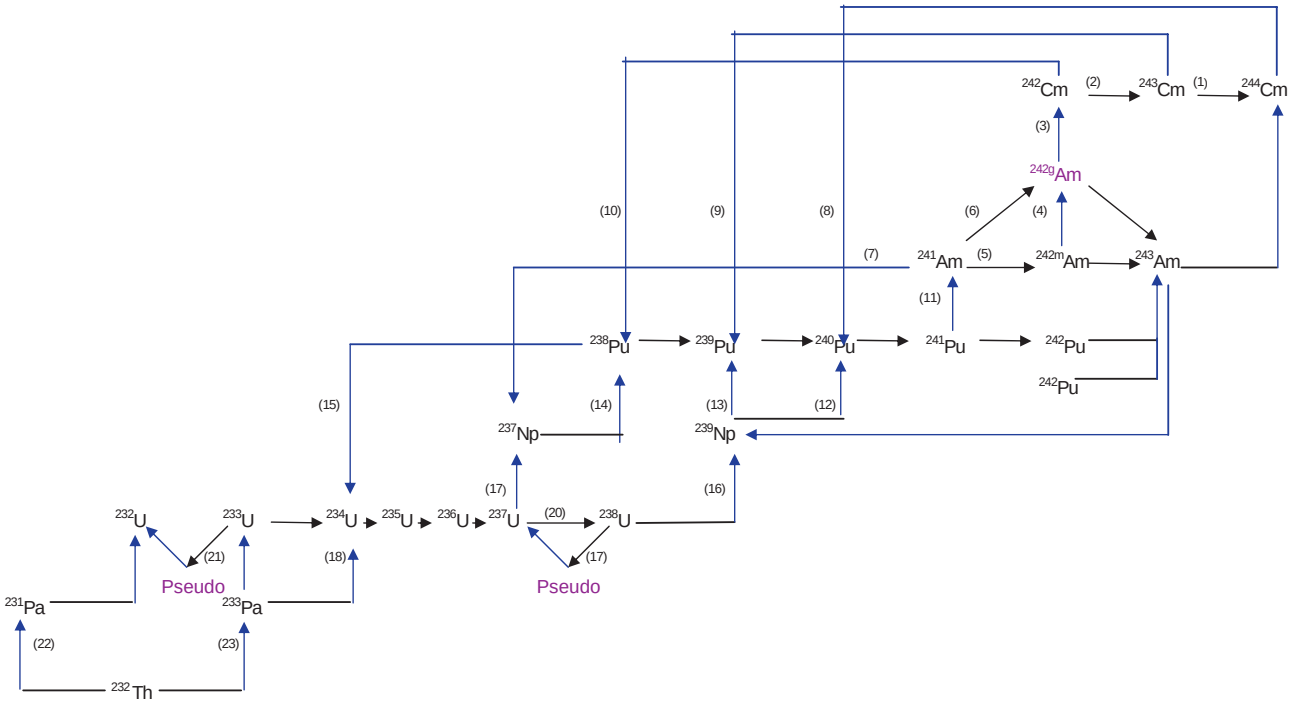

FIG. 8.1. Actinide chain.

(22) Production of U-232, involves the introduction of fission product Pa-231 (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 Th-232, and the capture product of Pa-231 is assumed to decay instantly to U-232.

(23) Capture product of Th-232 is assumed to decay instantly to Pa-233.

8.2. FISSION PRODUCT YIELDS AND DECAY DATA

Within the scope of the 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 rest of this section.

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

8.2.1. Format considerations

The ENDF-6 format [8.2] for fission product yields contains the parameter FPS as the '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 the 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 these kinds of formatting inconsistency.

8.2.2. Fission product yield 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 (e.g. 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-point averaging function was defined in AVRFPY according to the following conditions:

(a) The 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). The upper boundary of the thermal group is at 0.55 eV, which is approximately the cadmium cut-off energy; the upper boundary of the epithermal group is at 1 keV; the upper boundary of the fast group is at 10 MeV.
(b) The integral of the thermal spectrum is defined such that the spectral ratio (i.e. the 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.
(c) 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.
(d) The spectrum at 0.55 eV assumes a $1/E$ 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 (LWRs) 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 1–2%, 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.

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:

(a) Isotope: Material identification of the form: atomic number (Z), chemical symbol, mass number (A).
(b) MAT: WIMS-D identification number.
(c) HL: Decay constant (s^{-1}).
(d) DP: Decay product and WIMS-D identification number.
(e) CP: Capture product and WIMS-D identification number.
(f) BR: Branching ratio for the capture product formation.

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES

MAT	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

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES (cont.)

FP	Th-232	U-232	U-233	U-234	U-235	U-236
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

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES (cont.)

FP	U-237	U-238	Pu-238	Pu-239	Pu-240	Pu-241
4133	5.4541E-02	6.7293E-02	5.8731E-02	7.0145E02	6.8519E02	6.7260E02
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

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES (cont.)

FP	Pu-242	Am-241	Am-242m	Am-243	Cm-242	Cm-243
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

TABLE 8.1. FISSION PRODUCT YIELDS FOR FISSILE ACTINIDES (cont.)

FP	Pu-242	Am-241	Am-242m	Am-243	Cm-242	Cm-243
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	FP	Cm-244
4083	1.5996E-03	5147	1.5271E-02
4095	3.0264E-02	5148	5.9100E-07
4099	5.1176E-02	4148	1.3800E-06
4101	6.2015E-02	5149	2.0910E-02
5103	6.7017E-02	6147	0.0000E+00
4106	5.8890E-02	6148	0.0000E+00
4103	3.5144E-08	4149	2.2352E-08
4105	6.4092E-02	4150	1.5129E-04
5105	0.0000E+00	4151	1.4904E-02
4107	5.2012E-02	4152	1.1923E-02
4108	4.3007E-02	5151	3.7253E-09
4109	3.4011E-02	5152	4.2934E-08
4113	8.3642E-03	4153	9.0419E-03
4115	3.2379E-03	4154	8.3300E-06
4125	1.7943E-03	4155	5.2683E-03
5127	8.1743E-04	2154	9.2892E-09
4127	3.8534E-03	2155	1.6158E-07
6135	4.4201E-02	2156	3.6666E-03
4131	2.3891E-02	2157	2.5765E-03
5134	4.8740E-02	2158	1.7837E-03
4135	1.2202E-02	160	5.4656E-06
4136	6.2433E-02	161	4.6575E-04
4133	3.9817E-02	162	2.7072E-04
4134	2.7930E-05	163	1.6845E-04
5135	3.4881E-04	164	9.9071E-05
4137	6.7576E-02	165	5.6641E-05
4143	4.7835E-02	2166	1.3112E-05
4145	3.7848E-02	2167	2.4940E-08
4147	1.3543E-02	4902	8.5929E-01

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	—	

TABLE 8.2. BURNUP AND DECAY DATA (cont.)

Isotope	MAT	HL	DP	CP	BR
60-Nd-145	4145	—	Stable	—	
61-Pm-147	4147	8.373E-09	Sm-147 (6147)	Pm-148m (4148)	1.0[a]
61-Pm-147	5147	8.373E-09	Sm-147 (6147)	Pm-148 (5148)	1.0[a]
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[b]
63-Eu-151	5151	—	Stable	Eu-152 (5152)	1.0
63-Eu-152	5152	1.648E-09	[c]	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[d]	—	—	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)	—	

[a] Pm-147 + n → Pm-148m Mat 4147
→ Pm-148 Mat 5147.

[b] Sm-152 + n → [Sm-153] → Eu-153.

[c] Eu-152 decays into void (ignore 72.08% Sm-152 and 27.92% Gd-152).

[d] Pu-242 data produced by Pu-241 (n,γ) reaction at low concentration.

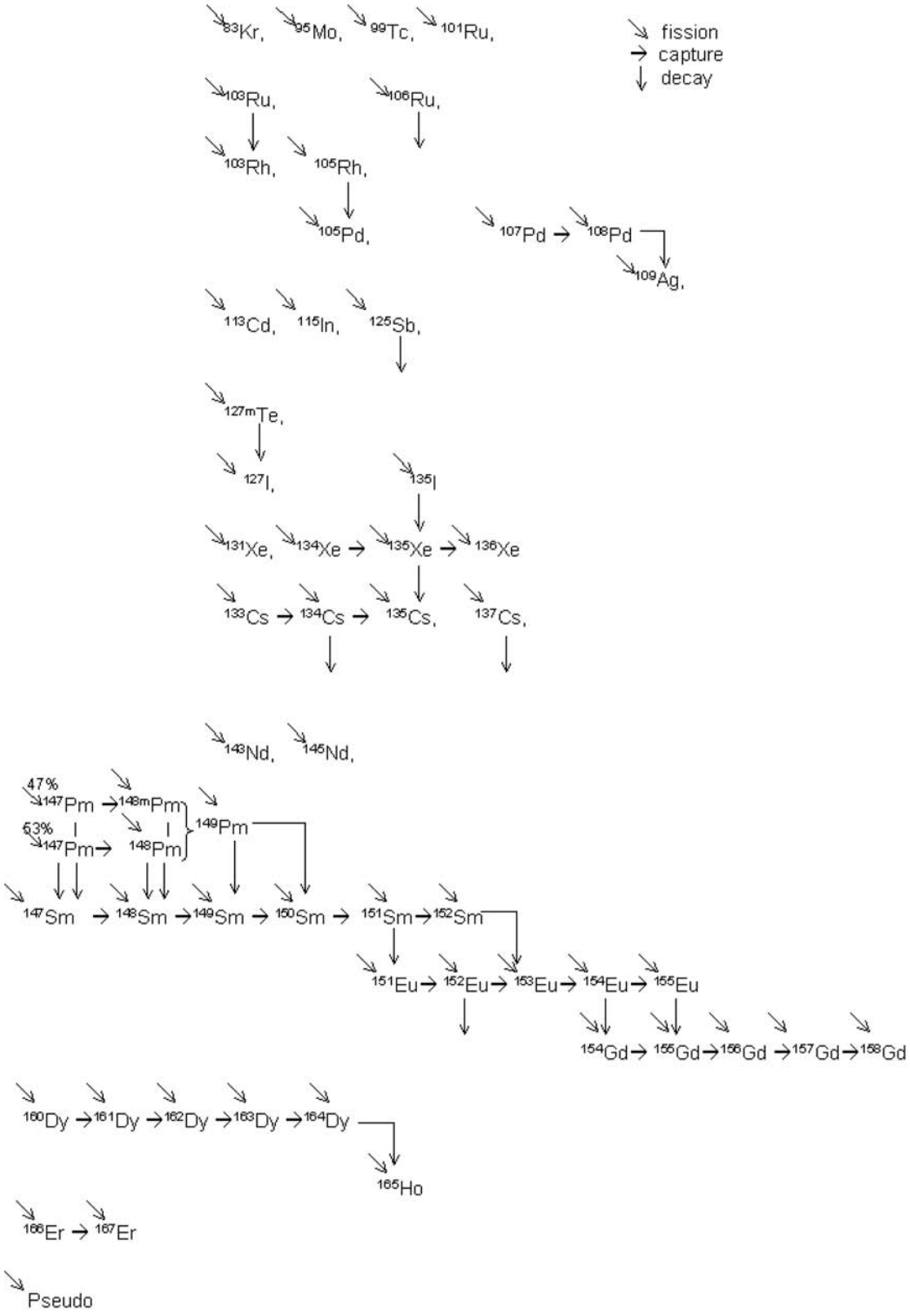

FIG. 8.2. Fission product chains.

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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: U-235, U-238 and Pu-239 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. 9.1.

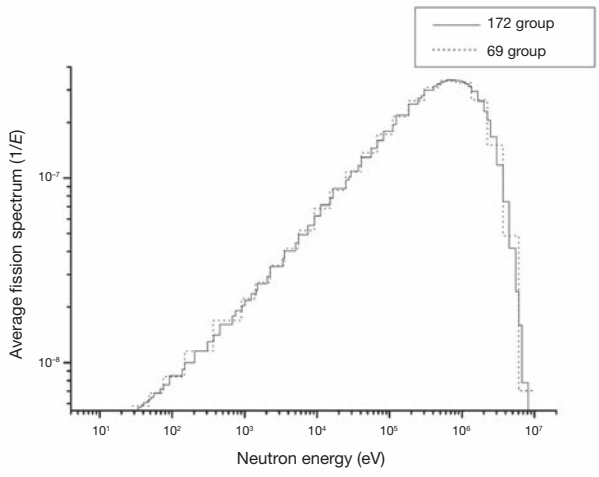

FIG. 9.1. Average fission spectra for the 69 and 172 group libraries.

TABLE 9.1. AVERAGE FISSION SPECTRUM FOR THE 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 THE 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

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 the 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 was generated with the MCNP code for HWRs, and was used for deuterium data only.

Another special spectrum was generated for the thorium fuel cycle, which is used to average Th-232, Pa-232 and U-233 data only. These spectra are discussed in Section 10.1.

In the formalism of multigroup libraries, a neutron current spectrum is necessary in order to obtain the 'transport correction' from P_1 cross-section data. The correction is made by weighting P_1 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 multigroup neutron current spectra for the deuterium and 172 group libraries were generated by solving the B_1 equations for typical LWR and HWR systems. These spectra are shown in Figs 10.1–10.3.

10.1. NEUTRON FLUX SPECTRA

Standard WIMS libraries would appear to be oriented to LWRs, since their P_0 and P_1 neutron spectra are typical of LWRs. 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 uranium systems, such effects can be significant, depending on the type of cells analysed, temperature of the different component materials and number of energy groups of the WIMS libraries.

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 HWRs and Th–U-233 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.

10.2. NEUTRON CURRENT SPECTRA

The multigroup WIMS-D libraries include transport corrected total cross-sections as generated from P_1 multigroup 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 B_1 equations are solved to generate current spectra for typical systems using the neutron multigroup transport calculation program CONDOR [10.3]. The shapes of the current spectra for HWRs differ significantly from the LWR spectra. These differences are

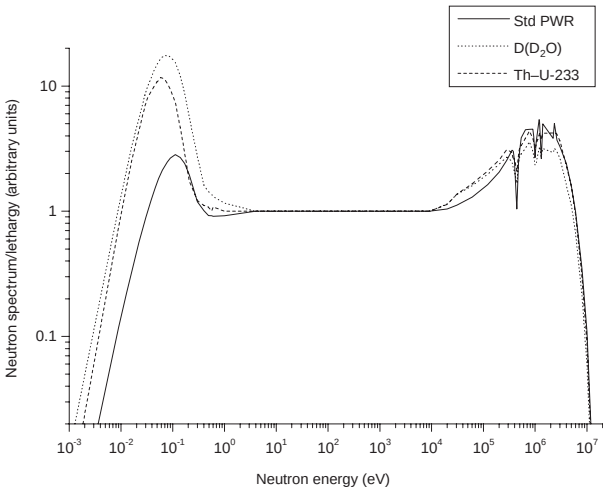

FIG. 10.1. Neutron flux spectra.

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	

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 homogenized 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 B_1 method is normally used in multigroup form to obtain the leakage spectrum and define the flux and current spectrum [10.4]. The current spectrum calculated by means of the B_1 method can be used to obtain the transport correction for the multigroup cross-section library so long as:

(a) The number of groups adopted for the B_1 calculation is large enough compared with the number of groups of the final library to give sufficient energy resolution;
(b) The P_1 cross-sections for all the important isotopes are used to solve the B_1 equations for a particular lattice.

Hence the WIMS-D code is unsuitable for this purpose, because of the restriction to 69 energy groups and because the P_1 cross-sections are only available for hydrogen, deuterium, carbon and oxygen. 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 P_1 cross-sections. This code has been used with a 190 group library to obtain the B_1 current spectra for two typical lattices.

10.2.2. Calculations

The two referenced lattices modelled with CONDOR to give a B_1 option leakage spectrum were:

(a) LWR pin cell benchmark — Rowlands [10.5, 10.6];
(b) Typical CANDU–HWR lattice, CANDU–ZED2 [10.7].

Calculations were performed with a 190 energy group library.

10.2.3. Results

A program has been written to process the B_1 current spectra output from CONDOR (normalization and group averaging over the WIMSD-IAEA-69 standard groups and 172 groups, and formatting 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 — J is the neutron current scaled by the neutron energy E ($J \times E$) as a function of E (eV).

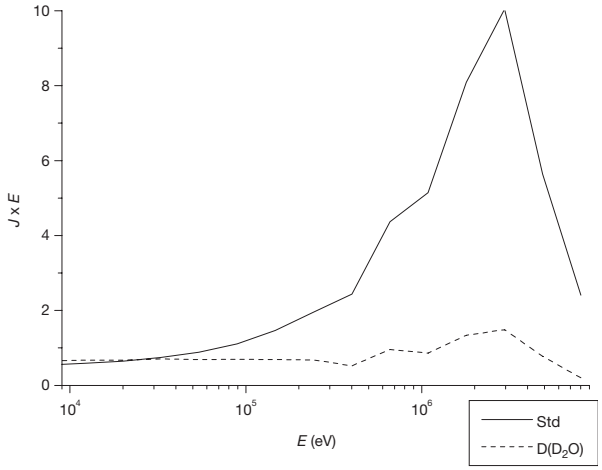

FIG. 10.2. $J \times E$ for 69 group libraries.

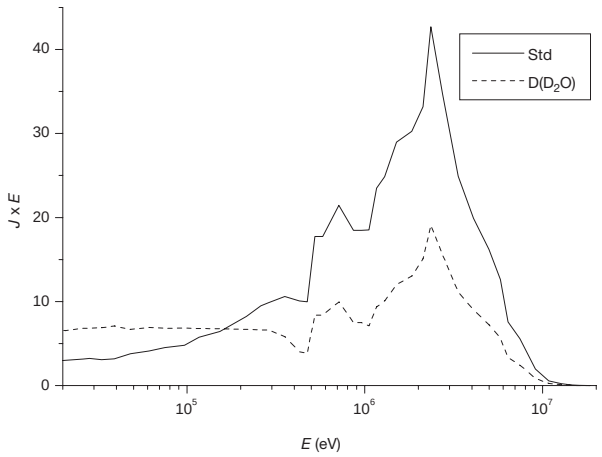

FIG. 10.3. $J \times E$ for 172 group libraries.

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11. ENERGY STRUCTURE

11.1. 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 to 4 eV. Table 11.1 lists the energy limits of the groups (E_{max}).

TABLE 11.1. 69 ENERGY GROUP STRUCTURE

Fast groups		Resonance groups		Thermal groups	
Group	E_{max} (eV)	Group	E_{max} (eV)	Group	E_{max} (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

11.2. 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 4 eV. Table 11.2 lists the energy limits of the groups (E_{max}).

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

TABLE 11.2. 172 ENERGY GROUP STRUCTURE

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

TABLE 11.2. 172 ENERGY GROUP STRUCTURE (cont.)

Fast groups		Resonance groups		Thermal groups			
Group	E_{max} (eV)	Group	E_{max} (eV)	Group	E_{max} (eV)	Group	E_{max} (eV)
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 THE 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 as follows:

(a) The upper limit is extended from 69 to 200 energy groups;
(b) The upper energy of the first fast group is extended from 10 to 20 MeV;
(c) The number of allowed resonance groups is extended from 13 to 55;
(d) The number of allowed resonant isotopes is increased to 30;
(e) The maximum number of nuclides in the library is increased to 300;
(f) The maximum number of burnable nuclides in the WIMS-D input is increased to 60;
(g) A modification to handle WIMS-D libraries with an extended format that includes multiple product nuclei reactions.

12.1. PURPOSE OF THE 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, library dependent arrays also exist with dimensions depending on the number of fast, resonance and thermal groups. 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 has been added that offers the introduction of multiple product nuclei in the burnup chains. The 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 the 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 ≥ 100 000 is defined as virtual, and represents a copy of the isotope with ID $- N \times 100\,000$ (N = 1...9) labelled 'base'. This approach is illustrated in Fig. 12.1 with one base (Am-241) and two virtual isotopes (IDs 109 241 and 209 241). The base isotope in Fig. 12.1 leads to plutonium, while the virtual isotopes allow for buildup of americium and curium.

During the burnup chain execution, the isotope with ID ≥ 100 000 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 isotopes if the data for the latter are missing in the library: if the library capture cross-sections of the virtual isotope are less than 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

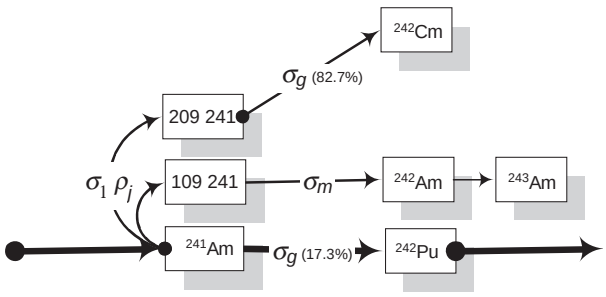

FIG. 12.1. Base isotope Am-241, virtual 109 241 and 209 241.

procedure for reaction rate 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 is not equivalent to the WIMS/ABBN library — the latter has two additional features improving the results for reactor systems with plutonium:

(a) Resonance self-shielding of Pu-242 in the thermal energy region is treated more accurately by redefining a number of thermal groups as resonance groups;
(b) The fission spectrum of Pu-239 is given more weight.

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

(i) 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;
(ii) A small correction in the HFS subroutine to avoid precision problems with thin annuli (i.e. all local variables expressed in double precision);
(iii) A change of the default value of the 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 THE CODE EXTENSIONS

The basic assumption underlying the work on the WIMSD-5B code extensions has been to leave untouched the original version distributed by the OECD/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 73–80. This division of 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**, with **xxxx** denoting the card number in the **namedeck**. The third member of the code package is the auxiliary Fortran program **upd**, which 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 73–80.

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 OEDC/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) and 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 resonant 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 reallocation 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	Identifier	Subroutine
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	Identifier	Module/deck	Identifier
prelud	**up2**	**chain12**	**up2d**
chain2	**up2a**	**wimsdl**	**up3**
chain5	**up2b**	**prelud**	**up4**
chain8	**up2c**		

— **up2:** Updates 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 unifies 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:** Increases 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 an informative printout.
- An additional check: If the first entry on the STORE card exceeds the available memory, the code stops with an informative error message.
- **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 use of parameter (**ll** = 500) to define size.

TABLE 12.3. CHANGES INTRODUCED TO MODIFY THE MAXIMUM NUMBER OF LIBRARY GROUPS, IDENT **up6**

Module/deck	Subroutines	Total number of groups	Number of resonance groups	Dynamic dimension
prelud	**nuprel, prelud**	+	+	+
chain1	**datag**	+		
chain2	**ichn02, two**			+
chain3	**ichn03, three, resalt, dasqhe**		+	+
chain4	**difenr**	+		
chain5	**ichn05, five**	+		+

- **chain14:** A minor correction has been made to the format of the printout of the final k_∞, where only two digits had been foreseen for the number of library groups.

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 the ICAR option.

The last modification consisted of the allocation of three new arrays in the memory: **xxfs**, **idno** and **rnuf**. While these arrays had not been included previously in the general WIMS treatment of the COMMON block, they had originally been introduced into the labelled COMMON block with fixed dimensions that were determined by the number of resonant isotopes and resonance groups adjusted to the British 86 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:
  - The 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 ≥ 100 000 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.
  - The 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 a '.0' suffix.
  - Mandatory specification of a small but non-zero concentration for resonant isotopes, with the suffix differing from '.0' and part of the burnup process (i.e. with zero concentration at the start of the burnup calculations).

12.3. TESTING THE EXTENDED VERSION OF THE CODE

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

(a) The WIMS86 library delivered to the OECD/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.
(b) The 69 group library based on ENDF/B-VI, and developed through an IAEA CRP.
(c) The 172 group library based on ENDF/B-VI, and developed through an IAEA CRP.
(d) The 69 group library based on ENDF/B-VI, with additional isotopes according to the extended convention of Jerdev.
(e) The 69 group library based on FOND22.

(f) The 69 group library based on FOND22, with additional isotopes according to the extended convention of Jerdev.

Switching between 69 and 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 is 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 (a value of 92 should be satisfactory for currently 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 1 000 000). A suitable informative message has been coded into the program.

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 indexes 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 it 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. the main transport routine using DSN or PERSEUS) and/or the third level (i.e. solution accounting for the leakage). However, an important point to note is that the first level was successfully achieved in all cases of multigroup 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.

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 200 000	store 600 000
test12	4157 (Gd-157)	2157
test13	9056 (stainless steel)	follow composition of stainless steel

REFERENCES TO SECTION 12

[12.1] ASKEW, J.R., FAYERS, F.J., KEMSHELL, P.B., A general description of the lattice code WIMS, J. Br. Nucl. Energy Soc. **5** (1966) 564.

[12.2] WIMS-D5, OECD/NEA Data Bank Documentation, Package ID No. 1507/02 (1998), http://www.nea.fr/html/dbprog

[12.3] FINK, J., Modifications Made to WIMSD5B Source, Rep. NT/FN/01/003, Nucleoeléctrica Argentina (2001).

[12.4] MOHR, P.J., TAYLOR, B.N., CODATA recommended values of the fundamental physical constants: 1998, J. Phys. Chem. Ref. Data **28** (1999) 1713–1852.

13. PROCESSING OPTIONS FOR EVALUATED NUCLEAR DATA

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

(a) The NJOY Nuclear Data Processing System (Version 99.65) to generate multigroup constants for WIMS-D from the evaluated nuclear data files;
(b) The AVRFPY code to process fission product yield and decay data;
(c) The WILLIE code to manage the WIMS-D libraries;
(d) The NRSC system of codes to calculate the Goldstein–Cohen parameters;
(e) The ENDF preprocessing codes for dosimetry cross-sections;
(f) WIMSIE to convert PrePro output for dosimetry reactions into WIMS-D format;
(g) XnWlup for interactive visualization of the cross-sections in the WIMS-D libraries.

There also exist a number of additional utility codes for performing minor data manipulation, postprocessing 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 the 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: A 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 resonant 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 the 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. The 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. A free gas model is used for all materials except the main moderators: hydrogen in H_2O, hydrogen in ZrH, deuterium in D_2O, beryllium and carbon — thermal-scattering law data are taken from the corresponding evaluated data file for these materials.
  • TOL: An angular distribution tolerance criterion of 0.1% is used for all materials.
  • NBIN: The number of equi-probable angles is 12 for all materials.
  • EMAX: The maximum energy for thermal treatment is set to 4.0 eV, which is the boundary condition for the thermal range in the WIMS-D libraries.
— GROUPR: Group averaged data preparation.
  • IGN: The 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 Section 11.

- IWT: The weighting spectrum parameter is 1 for all cases read in pointwise form from input (spectra are shown in Section 10), and have a $1/E$ 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 Section 3); the NR approximation is used above this energy.

NJOY input instructions for the flux calculator require the following parameters:

- EHI: The upper energy limit to which the flux calculation is applied (in eV).
- SIGPOT: The potential cross-section of the resonant absorber (in barns).
- NFLMAX: The maximum number of points at which the neutron spectrum is generated with the flux calculator.
- LORD: Legendre order of 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 in Section 6.

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

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

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

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

— Reference background cross-section (SGREF): The WIMS-D library format only allows self-shielding in the resonance energy range for the resonant isotopes that 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 a 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): The potential cross-section is calculated from the atomic radius in ENDF file MF = 2 and is constant for isotopes with tabulated resonance integrals; the 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 in Section 6.

The rest of the parameters are discussed in other sections.

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 recognizes the special input delimiter strings.

— Multigroup constants for updating a 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 multigroup constants in a WIMS-D library.

— A batch procedure (**bnchall**) is available to execute all benchmark test cases.

TABLE 13.1. FLUX CALCULATOR PARAMETERS

Isotope	EHI (eV)	SIGPOT (b)	Isotope	EHI (eV)	SIGPOT (b)	Isotope	EHI (eV)	SIGPOT (b)
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			

— 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

13.3.1. Fission cross-section of americium-241

The fission channel in Am-241 has a threshold, and therefore the capture to fission ratio is strongly spectrum dependent. This ratio may reach a value of 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 Am-241 in a WIMS-D library with branching to Am-242g and Am-242m cannot be represented accurately because WIMS-D libraries allow only a single capture product to be specified. Americium-242m is considered more important from the reactivity point of view, and therefore this branch is treated explicitly. However, Am-242g is important in the formation of Cm-242 by decay, leading on to Pu-238. Americium-242g production can only be dealt with in WIMS-D by treating this nuclide as a fission product of Am-241 with a yield equal to the capture to fission ratio.

Spectrum dependence of the effective Am-242g 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 Am-241 is not an important contributor to reactivity. With the fission cross-section forced to be proportional to capture, Am-242g production via an artificial fission product is exact.

FIDLAM was written by Trkov (and included on the WLUP CD-ROM) to adjust the Am-241 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.

13.3.2. Pseudo fission products to simulate (n,2n) reaction for uranium-238, uranium-233, americium-242 and protactinium-231

The approach used in the WIMKAL-88 library was adopted to model (n,2n) production from U-238, U-233 and Am-242 [13.2]. This model introduces a pseudo fission product with a fission yield that is the ratio of the (n,2n) and fission cross-sections of the parent nuclide. The pseudo fission product has zero absorption cross-section and decays instantaneously into the product of the (n,2n) reaction. 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 in Section 8).

REFERENCES TO SECTION 13

[13.1] 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-480, Version 99.56, Radiation Safety Information Computational Center, Oak Ridge, TN (1998).

[13.2] KIM, J.D., WIMKAL-88. The 1988 Version of the WIMS-KAERI Library, Summary Report, Rep. IAEA-NDS-92, Rev. 0, OECD/NEA Data Bank, Package ID No. NEA-1518 (1990).

14. BENCHMARKS

Descriptions of the organization, name conventions, contents and documentation of WLUP benchmarks are given in this section. Benchmark 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 is given. Finally, benchmark results for the final WLUP libraries (69 and 172 groups) are presented. Appendix I describes the QVALUE program for calculation of the lattice slowing down density. Appendix II lists the main parameters of the criticality benchmarks, while Appendix III contains a list of the WLUP library materials included in the inputs of benchmarks, ordered by temperature, component and material. Appendices IV and V provide specifications of the standard and supplementary benchmarks.

14.1. OBJECTIVES OF THE WLUP BENCHMARKS

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

(a) To test the performance of new WIMS-D libraries generated by the WLUP;
(b) To compare the results obtained with libraries generated from different basic nuclear data;
(c) To detect discrepant trends in the results for the main materials.

Discrepancies between measured and calculated integral parameters occur not only 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 measured parameters due to uncertainties in geometry, material composition, statistical uncertainties in the measurements and other simplifying assumptions.

Special care is required when interpreting 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; however, 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**, which calls the WIMS-D program with the appropriate WIMS-D input files and WIMS-D library, analyses the result with special auxiliary programs and reference experimental results files, and writes a summary file of results with per cent 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 the **bnchall.bat** file and the **readme** file included on the 'programs' subdirectory for the 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 the batch procedure program **bnchall.bat** and writes a file summarizing the results obtained using several different WIMS-D libraries.

The QVALUE program 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:

(a) Criticality experimental benchmarks (main parameter compared: k_{eff}).
(b) 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:

(c) Temperature coefficient benchmarks;
(d) 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 material; 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[1] 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:	High 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

[1] WWER and VVER are abbreviations for the same type of reactor; for historical reasons associated with the adoption of different file labelling, both forms are used throughout the text.

Summary of benchmark groups according to classification by fuel and coolant:

FUE-CO (keyword)	Number of benchmarks	Number of 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 Appendix IV.

Main sources of experimental results and references:

The bulk of information on the UME-LW, UO2-LW and MOX-LW benchmarks was retrieved from Ref. [14.1] and from original publications referenced in this work.

Experimental results for UO2-LB (WWER lattices) were extracted from the final reports of the Temporary International Collective (TIC) for joint research into the physics of WWER type reactors [14.2].

U-MI and Pu-MI benchmarks (uranium and plutonium intermediate spectrum for critical homogeneous systems): Ref. [14.3] is the main reference.

The main data source for the Th3-LW and Th3-HW benchmarks is Ref. [14.4].

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

Some of the benchmark groups have been collected together and published as Ref. [14.6].

A more detailed list of references of WLUP benchmarks is included in Appendix 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 & 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, 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.

SCK–BN	Studiecentrum 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	SCK–BN
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 per cent of fissile material (U-233, U-235, Pu-239, Pu-241) in heavy metal (thorium 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 ten character 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 subset 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 below in the tables labelled (1) to (9), ordered by name, enrichment, number of cases, WIMS input name (.win) and short name. 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	U-235 (wt%)	Number of 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

(2) UO2-LW (CRITUO2)

Benchmark identification	U-235 (wt%)	Number of 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	U-235 (wt%)	Number of 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	U-235 (wt%)	Number of 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	U-235 (wt%)	Number of cases	.win	Short name
5.01) U-MI-AEEW-HECTOR	92.3	1	hiss	hiss1

(5.2) Pu-MI (CRITISP)

Benchmark identification	U-235 (wt%)	Number of cases	.win	Short name
5.02) Pu-MI-AEEW-HECTOR	0.0	1	hiss	hiss2

(6) Th3-LW (BNLTH2O)

Benchmark identification	U-235 (wt%)	Number of cases	.win	Short name
6.01) Th3-LW-BNL-BNLea	97.0	8	bnlth2o	bnl_thh2o1-8

(7) Th3-HW (BNLTD2O)

Benchmark identification	U-235 (wt%)	Number of cases	.win	Short name
6.01) Th3-HW-BNL-BNLea	97.0	8	bnltd2o	bnl_thd2o1-8

(8) UO2-HW (CRITD2O)

Benchmark identification	U-235 (wt%)	Number of 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	U-235 (wt%)	Number of 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.

(a) 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).
(b) OECD/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).
(c) 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}).
  (i) MARIA tubular fuel with beryllium moderator benchmark. Beryllium moderated 80% enriched uranium–aluminium tubular fuel. Multiplication factor (K) comparison with results obtained with the MCNP code using a 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).
  (i) OWR-MTR experimental and numerical burnup benchmark. H_2O moderated 94% enriched uranium–aluminium fuel plates. Analysis of spent U-235 isotope as a function of burnup, and numerical comparison of isotopic concentration of actinides at end of cycle (MTRBURN).

(ii) 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) 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).
   (i) DOPPLER numerical benchmark. H_2O moderated uranium oxide lattices. Reactivity temperature coefficient compared with results obtained with the MCNP code and a standard library based on ENDF/B-VI (DOPPLER).
   (ii) RTC experimental benchmarks. H_2O moderated mixed oxide lattices. Reactivity temperature coefficient differences between calculated and experimental values obtained from measured buckling of four 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).
   (i) DCA experimental benchmark with gadolinium 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 the DCA facility. Comparison of measured and calculated thermal flux spatial distribution (D2OGD).

(e) Whole core benchmarks (parameters compared: several full core parameters).
   (i) TRIGA-IJS benchmark.

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

14.9. BENCHMARK RESULTS FOR THE FINAL WLUP LIBRARIES

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

Sections 14.9.1–14.9.10 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 the k_{eff} vs. q values 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 the k_{eff} vs. q values for the standard criticality benchmarks, different groups indexed in Section 14.5 and 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 the WLUP CD-ROM.

14.9.1. H_2O moderated uranium metal lattices

(a) Enrichment A (<2 wt% U-235)

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 (Table 14.1 and Fig. 14.1). The criticality condition is predicted to within 1% for most cases.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	EXPerror	Name
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

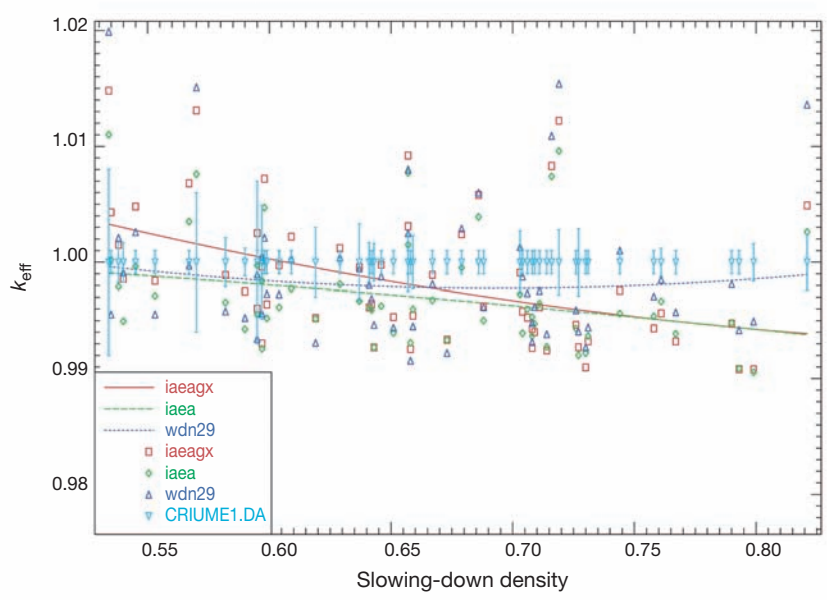

FIG. 14.1. H_2O moderated uranium metal lattices k_{eff} vs. q. Enrichment A (<2 wt% U-235). Standard criticality benchmarks.

(b) Enrichment B (>2 and <4 wt% U-235)

There are only seven cases of uranium metal lattices with enrichment between 2% and 4%, and they are all Savannah River Laboratory assemblies. q values range from 0.32 to 0.56, implying harder spectra than the low enrichment cases A (Table 14.2 and Fig. 14.2). 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 uranium metal lattices: trx_um1 and trx_um2. Definitions of the parameters are given in the description of the

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

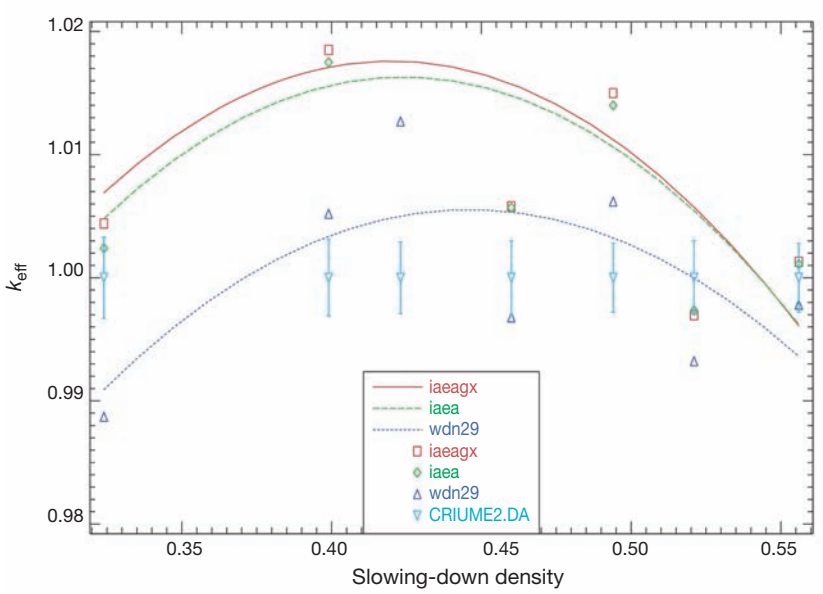

FIG. 14.2. H_2O moderated uranium metal lattices k_{eff} vs. q. Enrichment B (>2 and <4 wt% U-235). Standard criticality benchmarks.

TABLE 14.3. SPECTRAL INDEX RESULTS FOR H_2O MODERATED URANIUM METAL CRITICAL LATTICES[a]

Lattice	Rho28	Del25	Del28	ConvR
trx_um1 exp	1.320 (~1.6)	0.0987 (~1.0)	0.0946 (~4.3)	0.797 (~1.0)
IAEA-172	1.364 (3.36)	0.0980 (–0.70)	0.0991 (4.80)	0.797 (0.00)
IAEA-69	1.373 (4.04)	0.0980 (–0.74)	0.0981 (3.67)	0.800 (0.41)
WIMS86	1.355 (2.67)	0.0979 (–0.82)	0.1009 (6.68)	0.794 (–0.41)
trx_um2 exp	0.837 (~1.9)	0.0614 (~1.3)	0.0693 (~5.1)	0.647 (~0.93)
IAEA-172	0.860 (2.74)	0.0602 (–1.9)	0.0710 (2.42)	0.644 (–0.42)
IAEA-69	0.862 (3.01)	0.0602 (–1.9)	0.0700 (1.05)	0.645 (–0.26)
WIMS86	0.850 (1.55)	0.0602 (–1.9)	0.0721 (3.98)	0.641 (–0.90)

[a] Values within brackets are experimental errors (first line only) and per cent difference from experimental values for calculations with different libraries.

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 values are larger than experimental values by 2–4% and calculated Del25 values are smaller than experimental values by 0.7–1.9%.

14.9.2. H_2O moderated uranium oxide critical lattices

(a) Enrichment A (<2 wt% U-235)

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 (Table 14.4 and Fig. 14.3). The criticality condition is slightly underpredicted for cases bapl1–3, while the uncertainties in cases bapl4–6 are much larger and the discrepancies between measurements and calculations are comparatively high (which may indicate possible problems with the last three integral measurements).

(b) Enrichment B (>2 and <4 wt% U-235)

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. (Table 14.5 and Fig. 14.4) 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.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

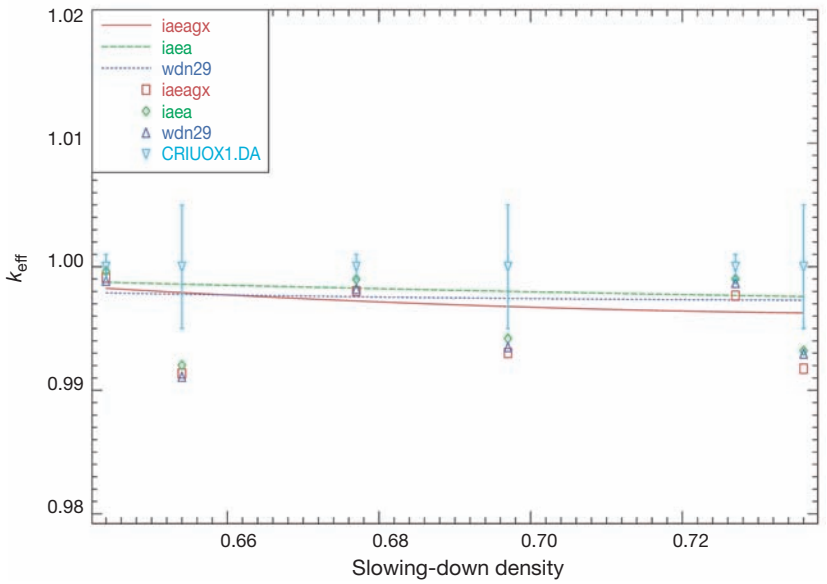

FIG. 14.3. H_2O moderated UO_2 lattices k_{eff} vs. q. Enrichment A (<2 wt% U-235). Standard criticality benchmarks.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

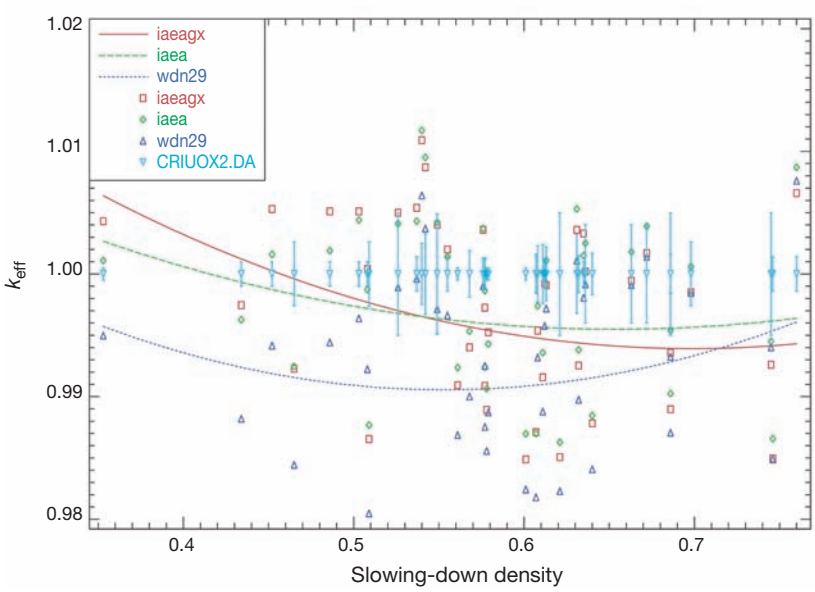

FIG. 14.4. H_2O moderated UO_2 lattices k_{eff} vs. q. Enrichment B (>2 and <4 wt% U-235). Standard criticality benchmarks.

(c) Enrichment C (>4 and <6 wt% U-235)

Uranium oxide lattices with enrichment >4% include ten cases, with q values ranging from 0.45 to 0.65 (Table 14.6 and Fig. 14.5). The 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 values are within the uncertainties of the experimental values for all libraries, while calculated Rho28 values are slightly higher than the experimental values and close to the experimental uncertainty of 3%.

14.9.3. WWER type UO_2–H_2O critical lattices

(a) Enrichment A (<2 wt% U-235)

Only three WWER lattices with enrichment <2% are included, and their q values are 0.63, 0.67 and 0.71 (Table 14.8 and Fig. 14.6). Criticality is significantly underpredicted with all libraries, which is not

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

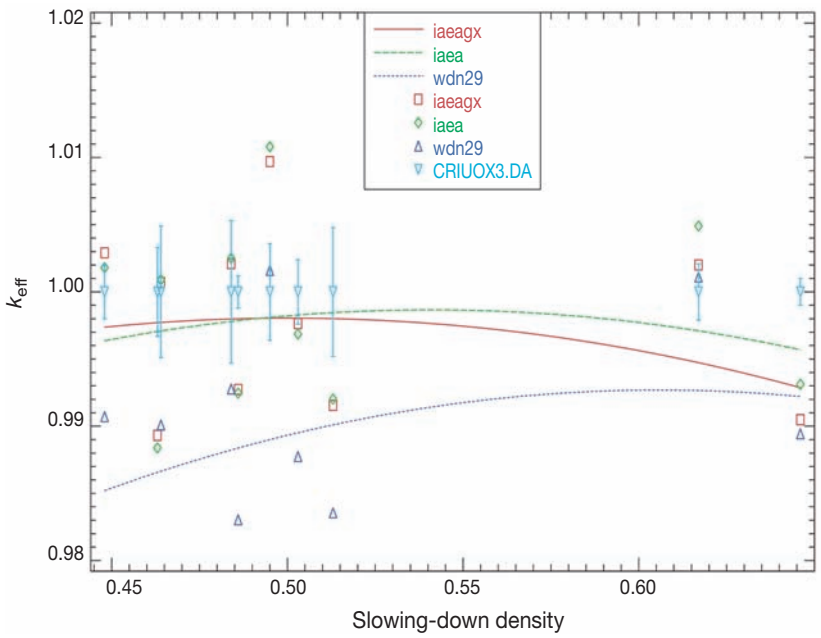

FIG. 14.5. H_2O moderated UO_2 lattices k_{eff} vs. q. Enrichment C (>4 and <6 wt% U-235). Standard criticality benchmarks.

TABLE 14.7. SPECTRAL INDEX RESULTS FOR H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES: AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES[a]

	Rho28		Del25		Del28		ConvR	
	E (%)	SD	*E* (%)	SD	*E* (%)	SD	*E* (%)	SD
Exp	3.05		9.24		7.00		2.75	
IAEA-172	3.50	2.50	–0.77	1.05	0.40	6.41	1.83	1.76
IAEA-69	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

[a] *E* (%) are experimental errors in the first line of data, while per cent difference of the calculated values from the experimental data are given on the other lines; SD are per cent standard deviations of these differences, and measure the spread of results.

TABLE 14.8. k_{eff} vs. q VALUE FOR WWER H_2O MODERATED URANIUM DIOXIDE CRITICAL LATTICES — ENRICHMENT A (<2 wt% URANIUM-235)

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

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% U-235)

WWER lattices with enrichment between 2% and 4% include 18 cases, with q values ranging from 0.43 to 0.66 (Table 14.9 and Fig. 14.7). The criticality condition is predicted within 1% for all lattices, except for six hard spectrum cases with low q values. The IAEA libraries perform significantly better.

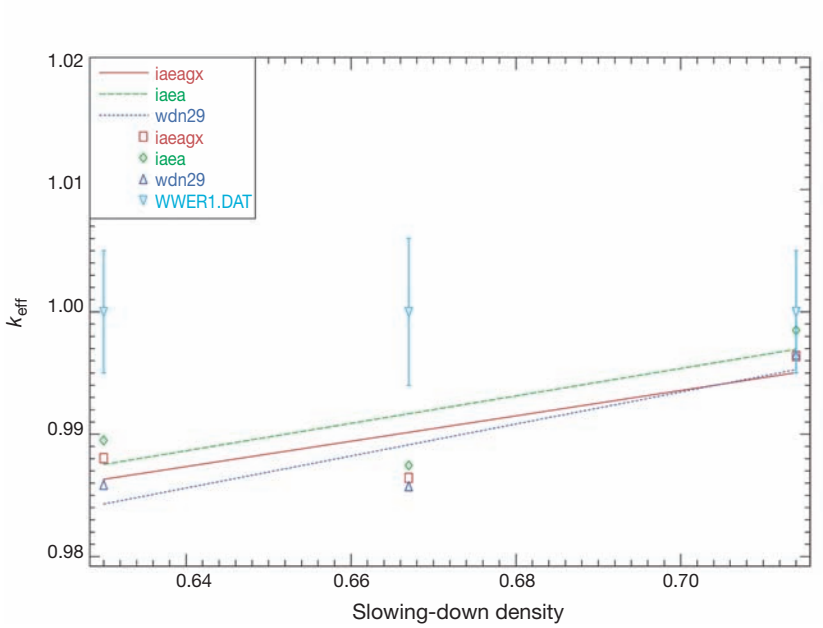

FIG. 14.6. H_2O moderated WWER UO_2 lattices k_{eff} vs. q. Enrichment A (<2 wt% U-235). Standard criticality benchmarks.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

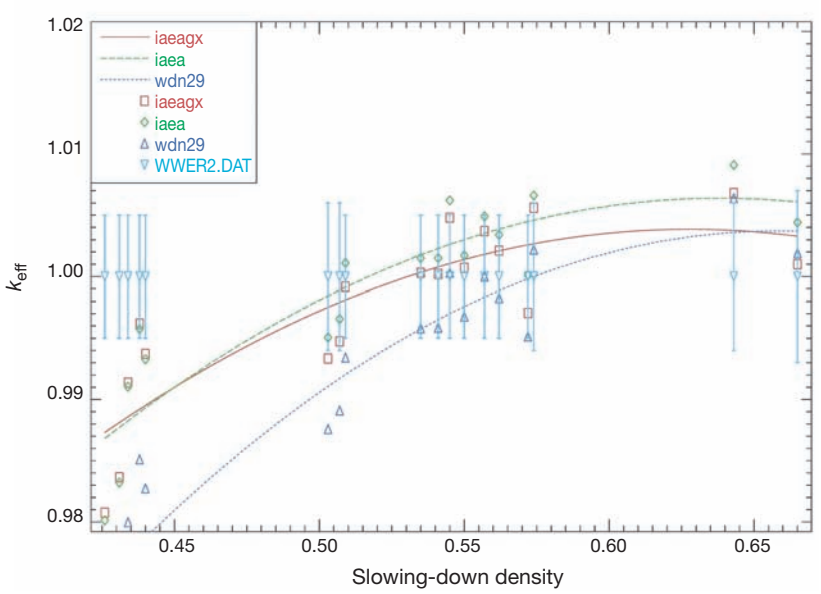

FIG. 14.7. H_2O moderated WWER UO_2 lattices k_{eff} vs. q. Enrichment B (>2 and <4 wt% U-235). Standard criticality benchmarks.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

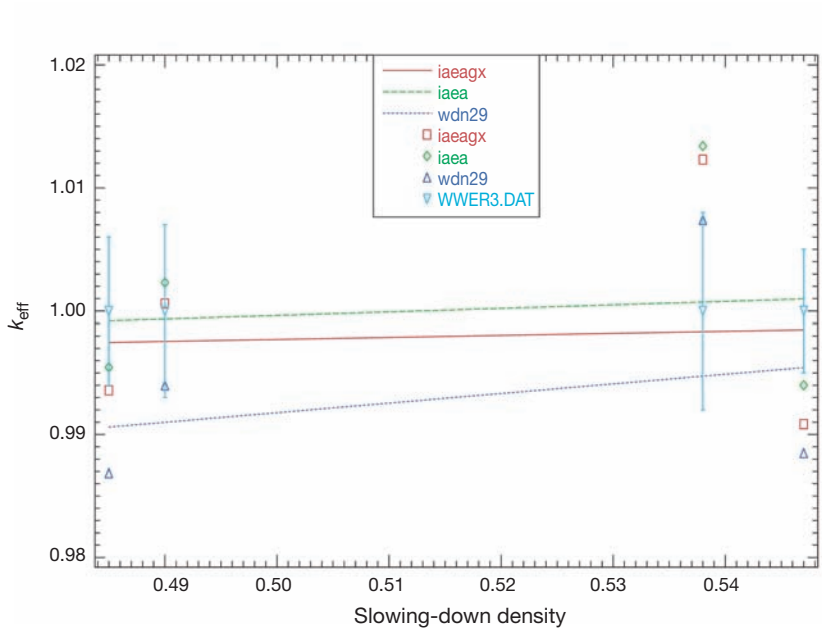

FIG. 14.8. H_2O moderated WWER UO_2 lattices k_{eff} vs. q. Enrichment C (>4 and <6 wt% U-235). Standard criticality benchmarks.

(c) Enrichment C (>4 and <6 wt% U-235)

WWER lattices with enrichment >2% are represented by four cases, with q values ranging from 0.49 to 0.55 (Table 14.10 and Fig. 14.8). 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)

Mixed oxide lattices with fissile metal content <2% include six cases, with q values ranging from 0.56 to 0.77 (Table 14.11 and Fig. 14.9). Results with all libraries are quite good, and the old WIMS86 library exhibits excellent agreement with measurements, which might be fortuitous due to the relatively small number of cases.

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

Mixed oxide lattices with fissile metal content >2% encompass 34 cases, with q values ranging from 0.47 to 0.87 (Table 14.12 and Fig. 14.10). The criticality condition is predicted within 1% for the majority of cases with all libraries. All values of k_{eff} generated by the WIMSD-IAEA-69 library are slightly higher than the corresponding values obtained with the WIMSD-IAEA-172 and WIMS86 libraries.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

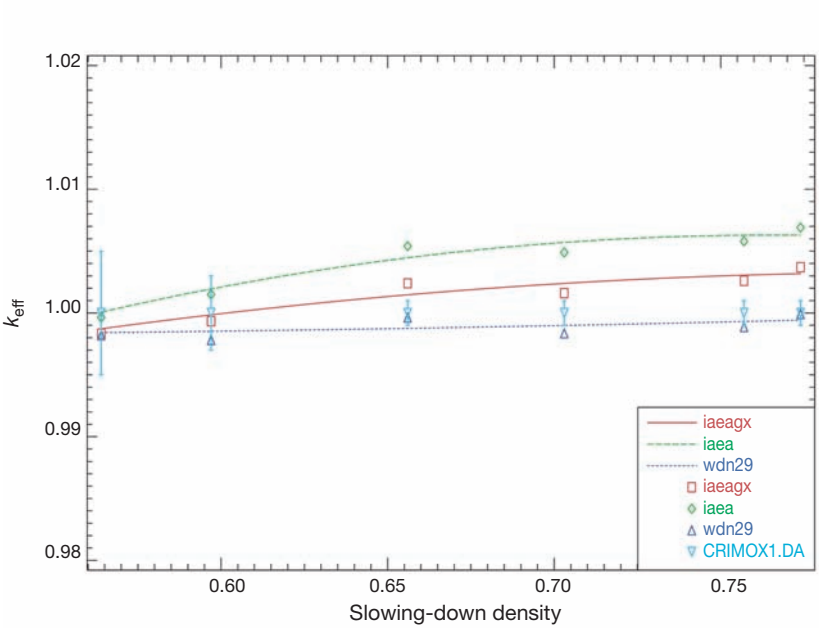

FIG. 14.9. H_2O moderated MOX lattices k_{eff} vs. q. Enrichment A (<2 wt% fissile metal). Standard criticality benchmarks.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

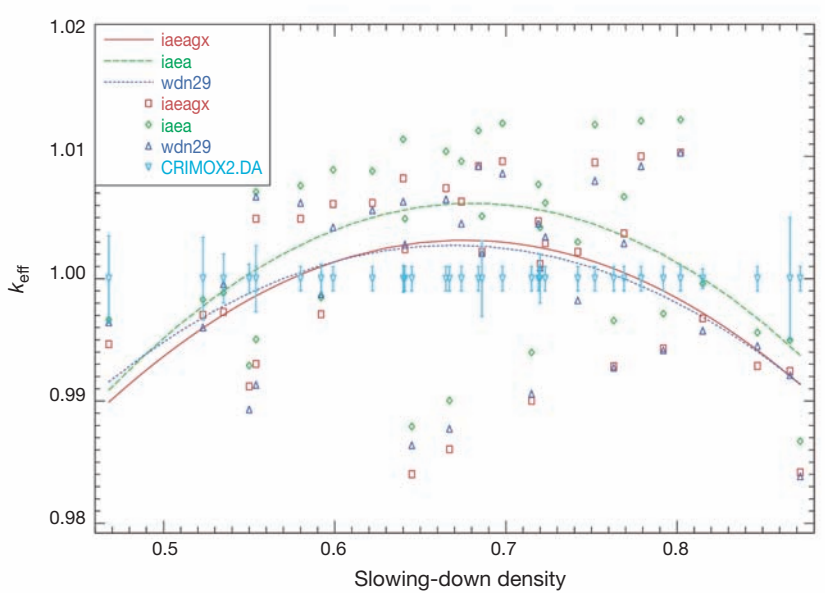

FIG. 14.10. H_2O moderated MOX lattices k_{eff} vs. q. Enrichment B (>2 wt% fissile metal). Standard criticality benchmarks.

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	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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 (U-235 mixture) and HISS2 (plutonium mixture) (Table 14.13). The predicted criticality with the IAEA libraries is too high, which is a feature of the basic evaluated data as verified by benchmark 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 is not valid for the analysis of intermediate spectrum lattices.

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

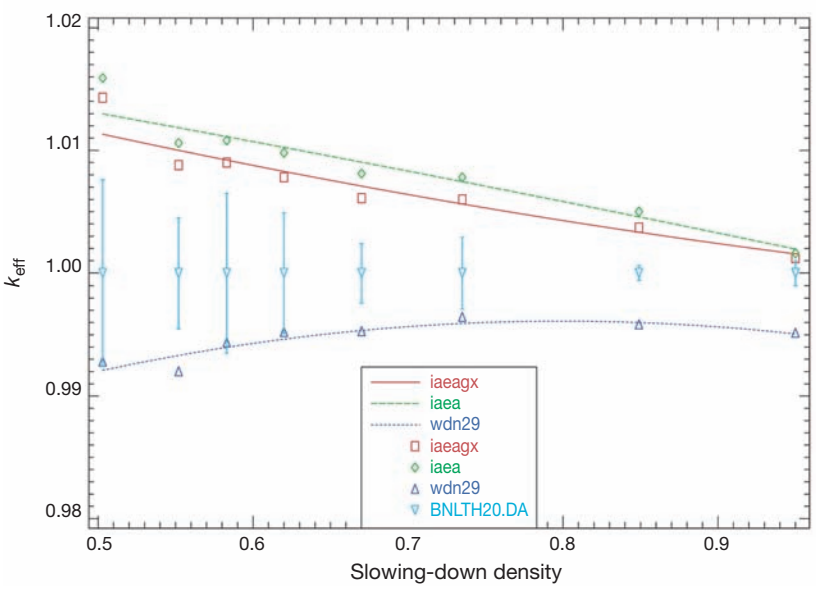

FIG. 14.11. H_2O moderated ThO_2–$^{233}UO_2$ lattices k_{eff} vs. q. Standard criticality benchmarks.

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

Light water moderated Th–U-233 benchmarks consist of eight cases, with q values ranging from 0.50 to 0.95 (Table 14.14 and Fig. 14.11). The 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.

(a) 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 calculation and experimental values for the IAEA libraries and WIMS86. On average the calculated values are significantly smaller than the experimental data.

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

Heavy water moderated Th–U-233 benchmarks consist of eight cases, with q values ranging from 0.35 to 0.86 (Table 14.16 and Fig. 14.12). Fairly large discrepancies are observed between measurements and calculations, with the IAEA libraries appearing to perform better.

TABLE 14.15. SPECTRAL INDEX RESULTS FOR H_2O MODERATED $^{233}UO_2$–ThO_2 CRITICAL LATTICES: AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES [a]

	Rho28	
	E (%)	SD
Exp	3.66	
IAEA-172	–16.67	2.15
IAEA-69	–16.09	2.33
WIMS86	–9.83	2.13

[a] E (%) are experimental errors in the first line of data, while per cent difference of the calculated values from experimental data are given on the other lines; SD are per cent standard deviations of these differences, and measure the spread of results.

(a) 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 14.16. k_{eff} vs. q VALUE FOR D_2O MODERATED $^{233}UO_2$–ThO_2 CRITICAL LATTICES

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

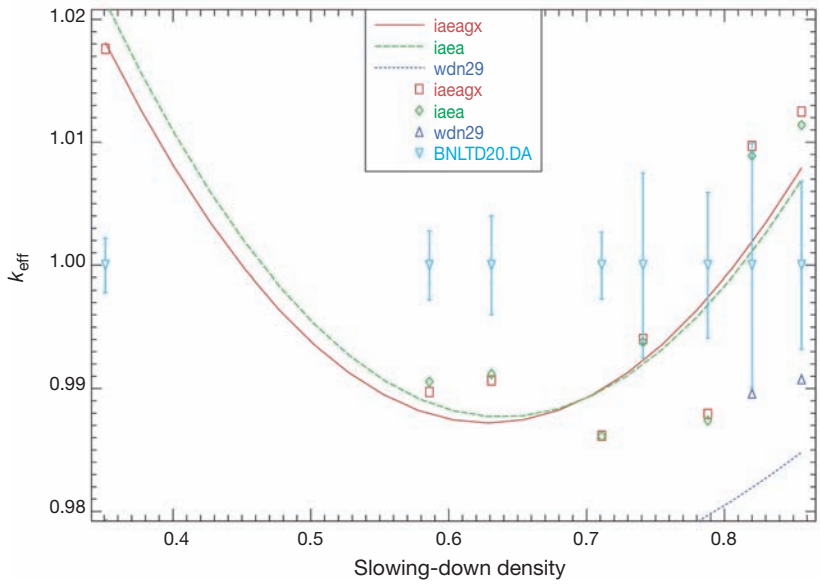

FIG. 14.12. D_2O moderated ThO_2–$^{233}UO_2$ lattices k_{eff} vs. q. Standard criticality benchmarks.

TABLE 14.17. SPECTRAL INDEX RESULTS FOR D_2O MODERATED $^{233}UO_2$–ThO_2 CRITICAL LATTICES: AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES[a]

	Rho28		Del28	
	E (%)	SD	E (%)	SD
Exp	5.35		11.90	
IAEA-172	–7.48	6.91	–4.54	4.38
IAEA-69	–7.42	7.14	–4.92	4.39
WIMS86	0.42	6.83	–9.63	4.87

[a] E (%) are experimental errors in the first line of data, while per cent difference of the calculated values from experimental data are given on the other lines; SD are per cent standard deviations of these differences, and measure the spread of results.

14.9.8. D_2O moderated UO_2 critical lattices

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 (Table 14.18 and Fig. 14.13). The data derived with the old WIMS86 library are marginally better in well moderated lattices.

(a) 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,

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

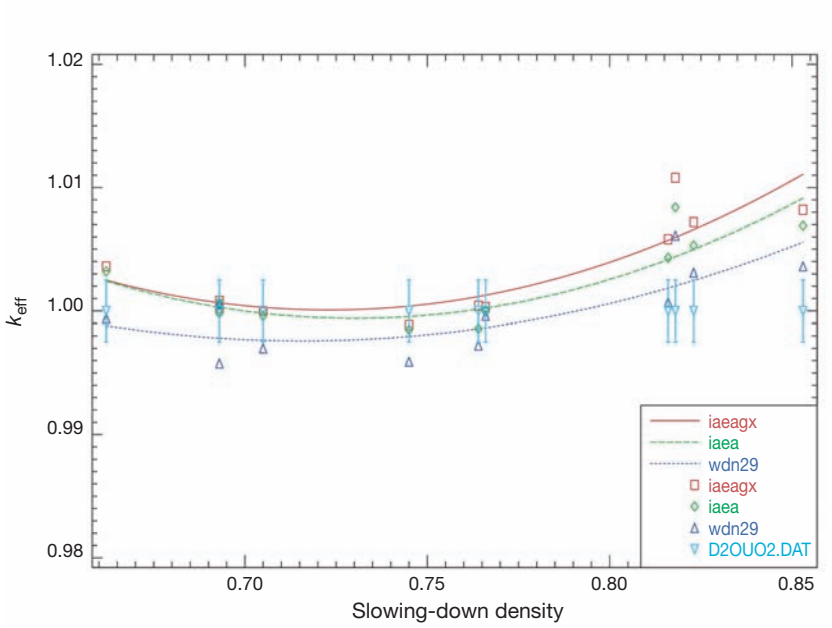

FIG. 14.13. D_2O moderated UO_2 lattices k_{eff} vs. q. Standard criticality benchmarks.

TABLE 14.19. SPECTRAL INDEX RESULTS FOR D_2O MODERATED UO_2 CRITICAL LATTICES: AVERAGE DIFFERENCES WITH EXPERIMENTAL VALUES[a]

	Del		ConvR		CuA		LuR	
	E (%)	SD	E (%)	SD	E (%)	SD	E (%)	SD
Exp	5.8		0.5		1.00		0.40	
IAEA-172	16.2	25.7	–2.0	2.9	0.73	0.74	1.17	1.17
IAEA-69	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

[a] *E* (%) are experimental errors in the first line of data, while per cent difference of the calculated values from experimental data are given on the other lines; SD are per cent standard deviations of these differences, and measure the spread of results.

CuA is within the experimental errors and LuR is slightly overestimated by the IAEA libraries only.

Definitions of spectral parameters in Table 14.19:

Del is the fast fission reaction ratio: (U-238 fission/U-235 fission).
ConvR is the relative conversion ratio: (U-238 capture/U-235 fission fuel)/(U-238 capture/U-235 fission Maxwellian).
CuA is the Cu-63 absorption rate distribution.
LuR is the 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

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 (Table 14.20 and Fig. 14.14).

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

Per cent differences calculation–experiment of isotopic concentration ratios for the bundle average of three burnup steps (3250, 6500 and 10 800 MW·d/t) are shown in Figs 14.15–14.17. The symbols represent:

N35/N38 = N(U-235)/N(U-238);
N36/N38 = N(U-236)/N(U-238);
N49/N38 = N(Pu-239)/N(U-238);
N40/N49 = N(Pu-240)/N(Pu-239);
N41/N49 = N(Pu-241)/N(Pu-239);
N42/N49 = N(Pu-242)/N(Pu-239).

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

q	IAEA-172	IAEA-69	WIMS86	EXPk_{eff}	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

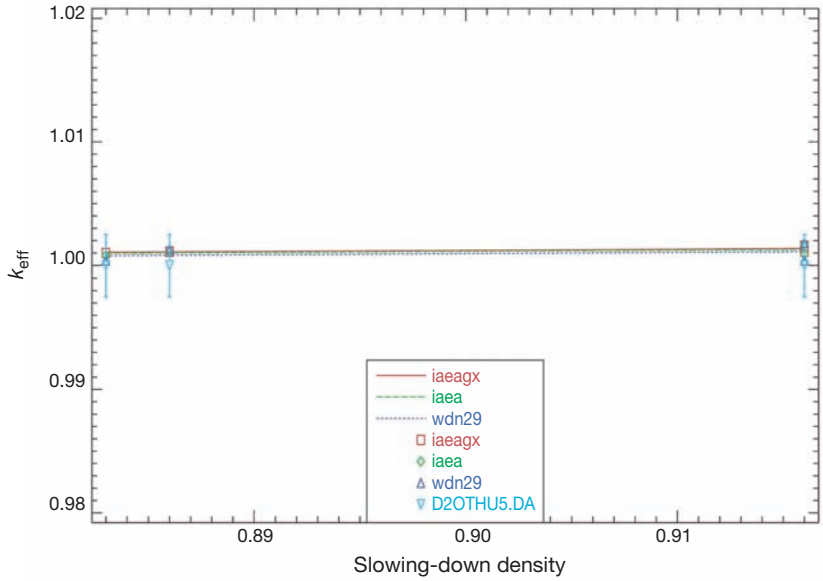

FIG. 14.14. D_2O moderated ThO_2–$^{235}UO_2$ lattices k_{eff} vs. q. Standard criticality benchmarks.

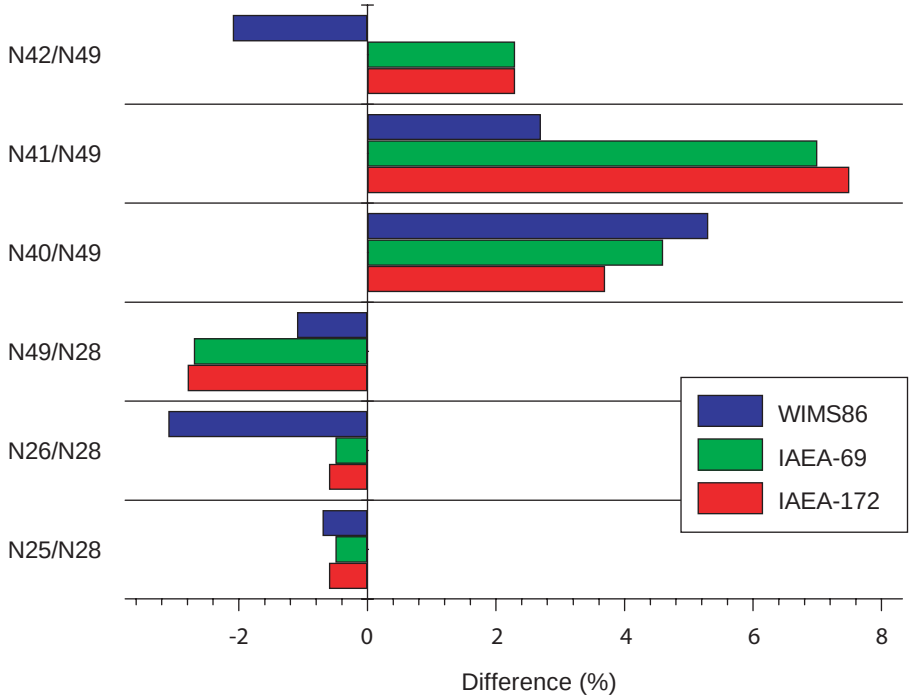

FIG. 14.15. NPD D_2O moderated uranium oxide lattice: isotopic composition rates. Burnup: 3250 MW·d/t U.

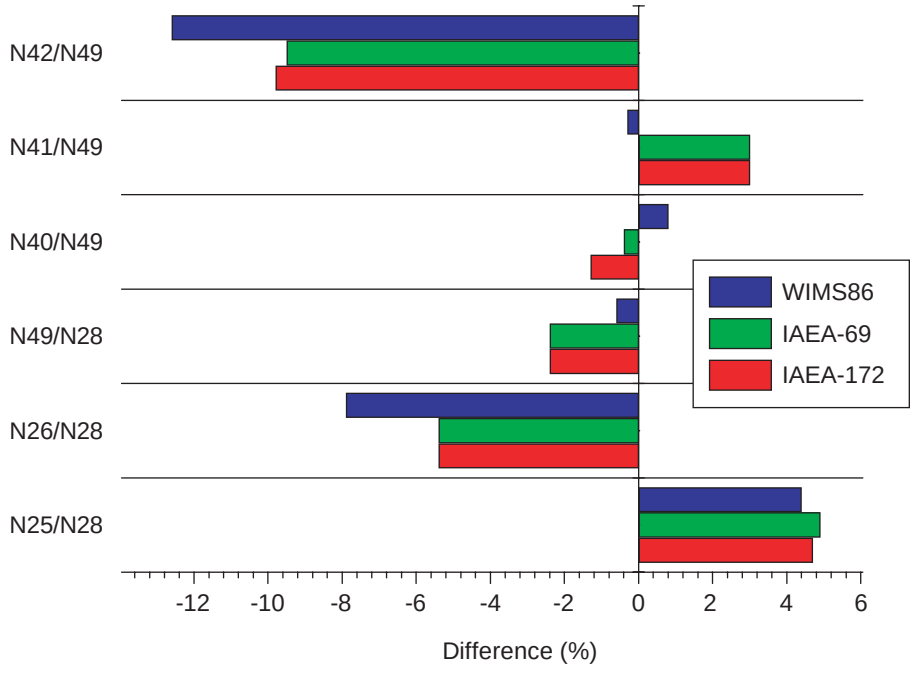

FIG. 14.16. NPD D_2O moderated uranium oxide lattice: isotopic composition rates. Burnup: 6500 MW·d/t U.

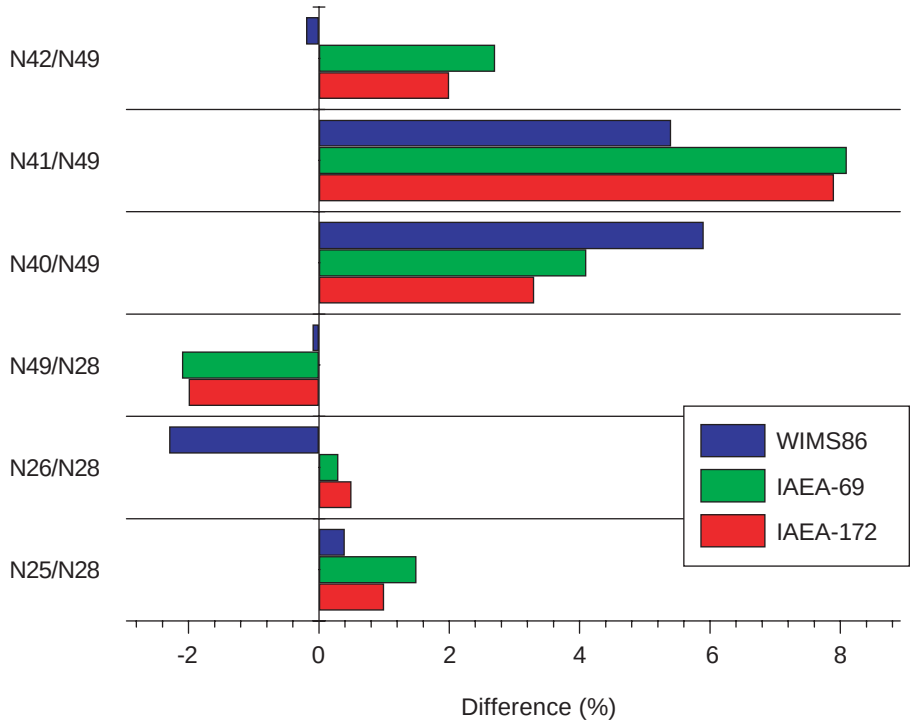

FIG. 14.17. NPD D_2O moderated uranium oxide lattice: isotopic composition rates. Burnup: 10 800 MW·d/t U.

The largest differences of between 3% and 7% for the IAEA libraries occur for the plutonium ratios, and are smaller for the intermediate burnup case. Differences for the uranium ratios are less than 1% at low burnup, but increase to 5% for N(U-236)/N(U-238) at intermediate burnup. There is an important improvement in the ratio prediction for N(U-236)/N(U-238) with the IAEA libraries compared with WIMS86.

(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.

Per cent differences from the reference average isotopic concentrations were calculated from the measured data and values determined from the WIMS-D libraries. Data for three burnup steps are available: 27.35, 37.12 and 44.34 GW·d/t U (see Figs 14.18–14.20).

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 with 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.

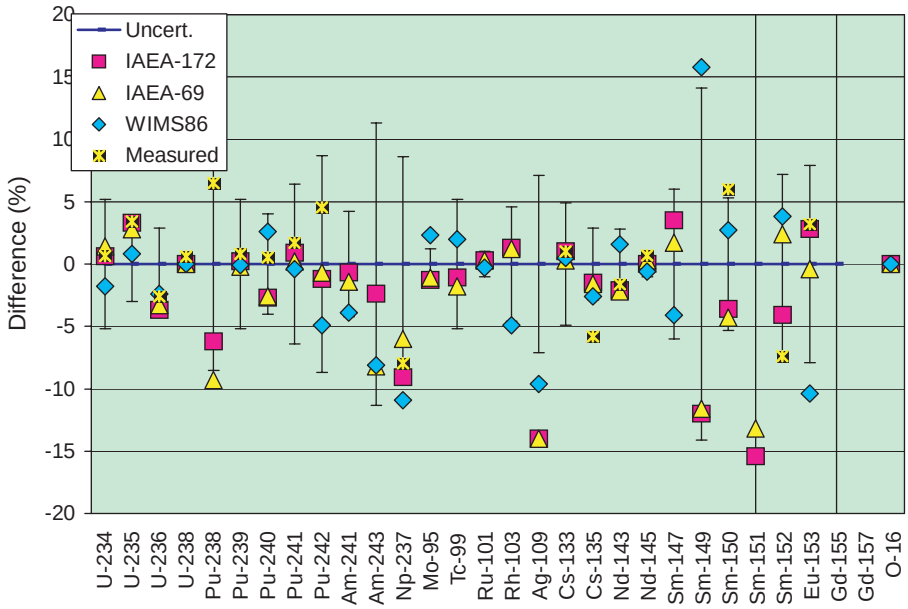

FIG. 14.18. OECD/NEA burnup credit calculational criticality benchmark: isotopic composition comparison. Burnup: 27.35 GW·d/t U.

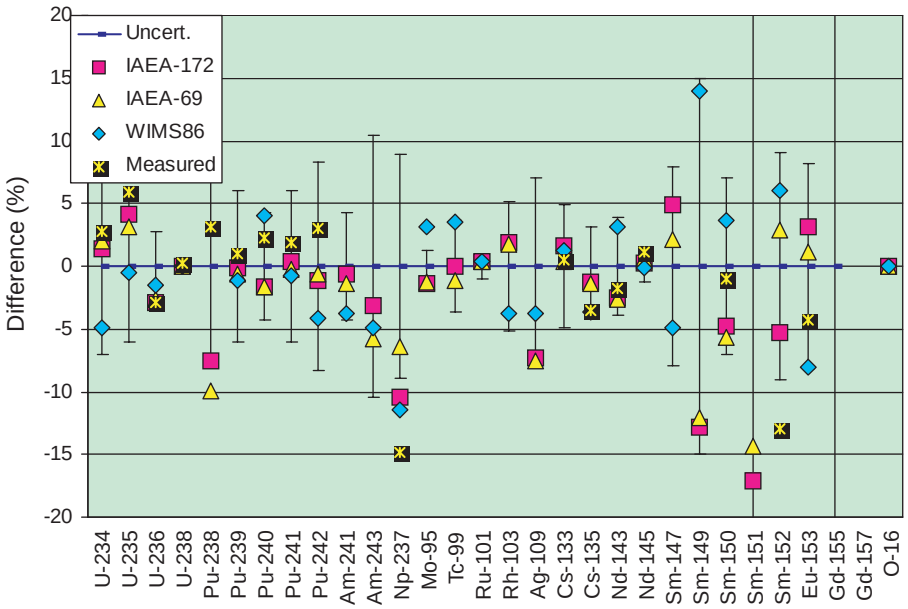

FIG. 14.19. OECD/NEA burnup credit calculational criticality benchmark: isotopic composition comparison. Burnup: 37.12 GW·d/t U.

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 those 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 average value; unfortunately, no measurement is available.

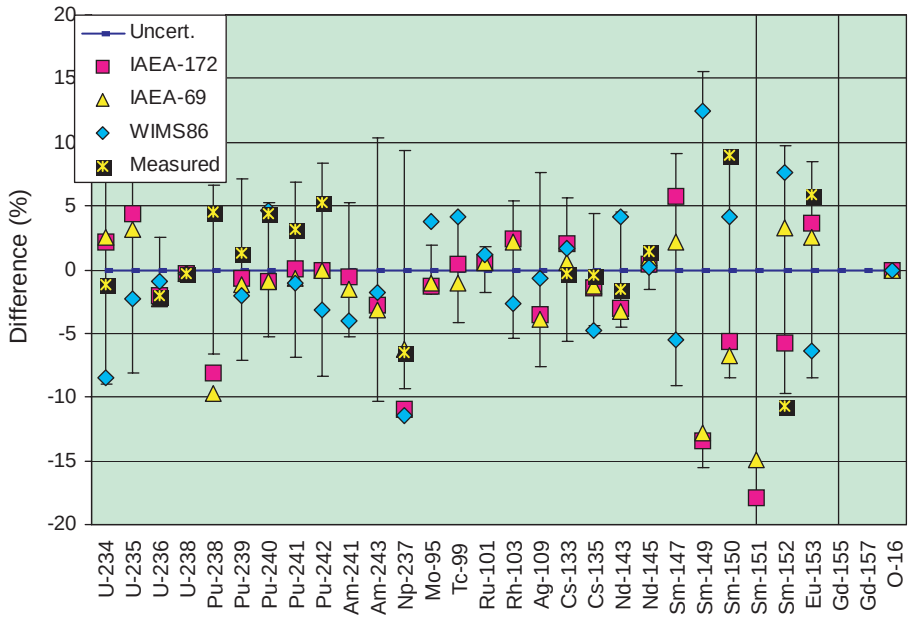

FIG. 14.20. OECD/NEA burnup credit calculational criticality benchmark: isotopic composition comparison. Burnup: 44.34 GW·d/t U.

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 IAEA libraries lie close to the edge of the uncertainty interval, but on opposite sides of the reference average values. Measured values are 40–100% 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. The 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 WIMSD-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 LWR lattices with uranium oxide fuel. They provide considerable improvements in predictions of the concentrations of some fission products, and major improvements in predictions of the actinide concentrations.

(c) OECD/NEA coordinated research project 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 ten 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.

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 plutonium isotopes, except Pu-239, for which similar arguments apply as cited for U-235.

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

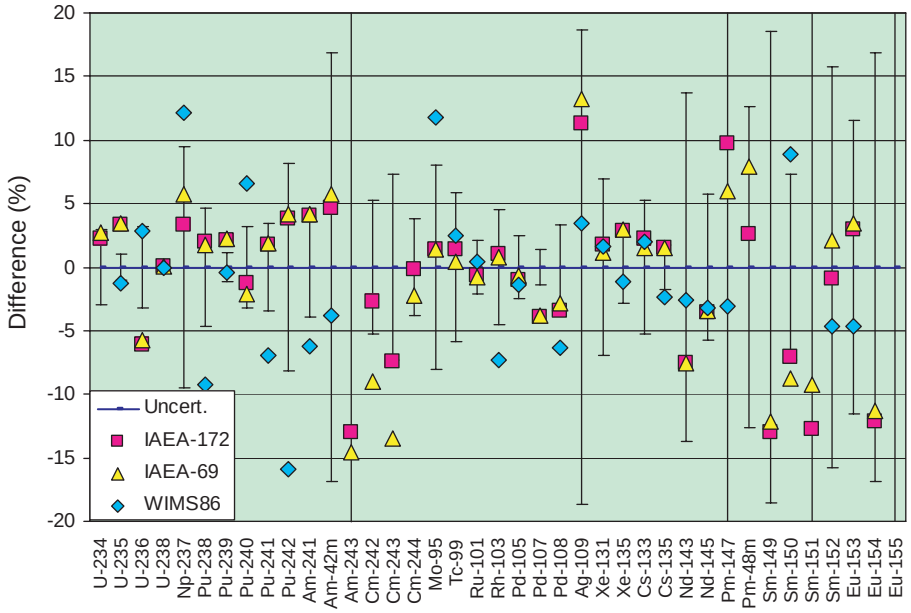

FIG. 14.21. OECD/NEA CRP plutonium recycling benchmark: isotopic composition comparison. Benchmark A: highly degraded plutonium. Burnup: 50 GW·d/t U.

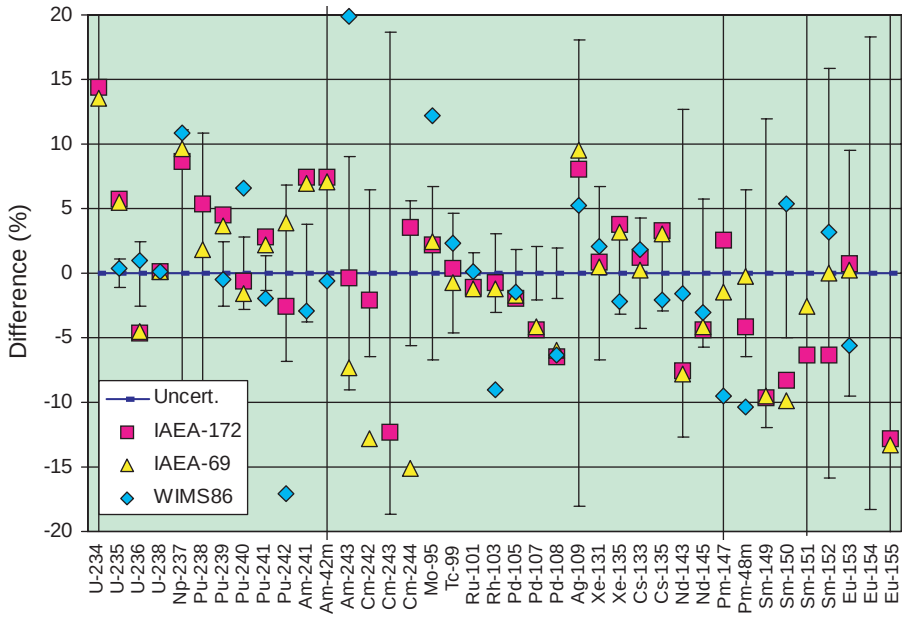

FIG. 14.22. OECD/NEA CRP plutonium recycling benchmark: isotopic composition comparison. Benchmark B: normal PWR recycled plutonium. Burnup: 50 GW·d/t U.

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.

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15. CONCLUSIONS AND RECOMMENDATIONS

15.1. OVERALL CONCLUSIONS

The primary objective of the 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 the WLUP and adopted to assess the WIMS-D libraries include more that 200 cases for over ten 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 successfully made to the WIMSD-5B code for use with the 172 group library. A set of programs and batch files was 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 include the following:

(a) Precise definitions of the constants in the WIMS-D libraries have been prepared, which facilitates a better understanding of the physics and methods adopted 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 utilize 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 improvement in several aspects compared with the last non-commercial WIMS86 library. These improvements are summarized below:

Number and types of material:

	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 group:

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

Burnup chains:

- Special treatment for U-232 and U-237 production;
- Special treatment of capture and decay of americium isotopes.

Cross-sections and related parameters:

- Self-shielding of scattering cross-sections with typical dilutions;
- Goldstein–Cohen factors recalculated, 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 the Doppler effect;
- Background cross-sections revised for better interpolation between tabulated values.

15.2. POSSIBLE FUTURE DEVELOPMENTS

Possible future developments are to:

- Develop a web page for the WIMSD-IAEA library that provides feedback from users;
- Develop scripts and programs to run under UNIX;
- Extend burnup schemes in the libraries;
- Include JENDL 3.3 based libraries;
- Include CENDL 3 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 the 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:

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

where

ϕ_s 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);

$\nu_g\Sigma_{fg}$ 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:

(a) Calculating the q value for each WLUP benchmark lattice processing WIMS-D outputs for one library;

(b) Preparing 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.

I.1. INPUT FILES

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

(b) SMRLIB.LST: The calculated k_{eff} values of the 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 (one record for each library in Fortran format A10, F8.5), preceded by a record that identifies the name of the benchmark (format: A10).

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

I.2. 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: EXPk_{eff} (=1.0) and EXPerror (absolute)

extracted from the SMRLIB.LST file, for plotting experimental error bars.

Steps for graphing k_{eff} vs. q:

(a) 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);
(b) Run **smrlib.exe** for including results of all libraries;
(c) Edit QVALUE.INP for adjusting to the actual case;
(d) Run **qvalue.exe**;
(e) Sort **benchY.dat** QVALUE output files;
(f) Enter the desired graph program and import each **benchY.dat** file as source of data.

Examples of graphs obtained from benchmark calculations with WLUP WIMS-D libraries and QVALUE results are included in Section 14.

Appendix II

WLUP CRITICALITY BENCHMARKS INDEX OF CASES

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

II.1 TITLES OF ITEMS INCLUDED IN THE LIST

General parameters:

ENRu5: Enrichment on U-235 (wt%).
Q-VAL: *q* value for the case (the method of calculation is explained in Appendix I).
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/subcritical experiments; STANDARD: first benchmarks adopted for WLUP; CANDU: benchmarks related to CANDU type clusters of rods).

Special parameters:

Bcon: Boron concentration (g/L of boric acid (H_3BO_3) 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

1) UME-LW (CRITUME) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
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
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

1) UME-LW (CRITUME) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
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	

2) UO2_LW (CRITUO2) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
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	
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	

2) UO2_LW (CRITUO2) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Obsevs.
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

3) UO2_LB (WWERCR) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Bcon	Obsevs.
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	Pu238	Pu239	Pu240	Pu241	Pu242	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

4) MOX_LW (CRITMOX) (cont.)

FUE-CO-LAB	–Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242	Obsevs.
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	
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 non-benchmarked materials is included.

WIMS library materials are classified as light elements, structural materials, fission products, actinides and dosimetry reactions and others.

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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

TEM	C	MAT	AT.DENS.	B	NAME/S
				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

TEM	C	MAT	AT.DENS.	B	NAME/S
					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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

TEM	C	MAT	AT.DENS.	B	NAME/S
			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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

TEM	C	MAT	AT.DENS.	B	NAME/S
		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)

TEM	C	MAT	AT.DENS.	B	NAME/S
		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

TEM	C	MAT	AT.DENS.	B	NAME/S
		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

TEM	C	MAT	AT.DENS.	B	NAME/S
			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

TEM	C	MAT	AT.DENS.	B	NAME/S
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

Non-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

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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 cut-off: 0.625 eV).

Calculated parameters

(1) Effective multiplication factor k_{eff};
(2) ρ^{28};
(3) δ^{25};
(4) δ^{28};
(5) C^*.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
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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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% U-235) in a square pattern. Material buckling was measured.

Calculated parameter

Effective multiplication factor k_{eff}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
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**)

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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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
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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1.04) 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

ENRu5	Enrichment on U-235 (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 squared (1/(m^2))
TEMP	Temperature (ºC)
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

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE
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	H_2O
Fuel material	U met. bnl-uma: 1.016 wt% bnl-umb: 1.027 wt% bnl-umc: 1.143 wt% bnl-umd: 1.299 wt%
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, WA, 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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
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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LLOYD, R.C., Exponential Experiments with Poisoned Moderator, Nuclear Physics Research Quarterly Report for July–September 1959, Rep. HW-62727, Hanford Atomic Products Operation, Richland, WA (1959) 61.

LLOYD, R.C., Summary Listing of Subcritical Measurements of Heterogeneous Water Uranium Lattices Made at Hanford, Rep. HW-65552, Hanford Atomic Products Operation, Richland, WA (1960).

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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	U met. (3 wt% U-235 enrichment)
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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IV.2. H_2O MODERATED URANIUM OXIDE CRITICAL LATTICES UO2-LW (CRITUO2)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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

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 (bapl1–3) and three additional (bapl4–6) 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.[1]
(b) δ^{25}: ratio of epithermal to thermal U-235 fission reaction rate.[1]
(c) δ^{28}: ratio of U-238 fission to U-235 fission reaction rate (thermal cut-off: 0.625 eV).

Calculated parameters

(1) Effective multiplication factor k_{eff};
(2) ρ^{28};[1]
(3) δ^{25};[1]
(4) δ^{28}.

[1] bapl1–3 only.

Summary data

ENRu5	Enrichment on U-235 (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 squared ($1/(m^2)$)
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	H_2O
Fuel material	UO_2 (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**)

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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 cut-off: 0.625 eV).

Calculated parameters

(1) Effective multiplication factor k_{eff};
(2) δ^{28};[2]
(3) RCR.[2]

[2] For R1/100H and R3/100H only.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (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**)

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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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (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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BERNOCCHI, E., MARTINELLI, R. (Eds), Light Water Lattice Data, Quaderno RIT/FIS(77)1, Rep. NEACRP-U-190, Comitato Nazionale per l'Energia Nucleare, Bologna (1977) 13.

MIZUTA, H., MAKINO, K., Few group diffusion calculations of a light water moderated lattice, J. Nucl. Sci. Technol. **8** 4 (1971) 201.

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 cut-off: 0.625 eV).

Calculated parameters

(a) Effective multiplication factor k_{eff};
(b) δ^{28} (for CURL_ZPR3 only).

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (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 cut-off: 0.625 eV).

Calculated parameters

(a) Effective multiplication factor k_{eff};
(b) ρ^{28}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 baw_bay2a: 2.459 wt% enrichment baw/bay2b: 4.02 wt% enrichment
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.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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

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 cut-off: 0.625 eV).

Calculated parameters

(a) Effective multiplication factor k_{eff};
(b) ρ^{28}.

General data

Pitch (cm)	1.6358 (square)
Water/fuel volume ratio	1.841
Moderator	H_2O
Fuel material	UO_2 (2.459 wt% enrichment)
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 cut-off: 0.625 eV).

Calculated parameters

(1) Effective multiplication factor k_{eff};
(2) ρ^{28}.
(3) δ^{28}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (2.49 wt% enrichment)
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**)

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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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 jaeri_tca1-3: 2.588 wt% enrichment jaeri_tca4-7: 2.596 wt% enrichment
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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BERNOCCHI, E., MARTINELLI, R. (Eds), Light Water Lattice Data, Quaderno RIT/FIS(77)1, Rep. NEACRP-U-190, Comitato Nazionale per l'Energia Nucleare, Bologna (1977) 27–29.

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2.09) UO2-LW-WAPD-CRX

Moderated uranium oxide critical lattices.
Laboratory: WAPD (Westinghouse Atomic Power Department), USA.
Facility: CRX.

These benchmarks are 12 H_2O moderated lattices of enriched (2.7–5.74 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 cut-off: 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

ENRu5	Enrichment on U-235 (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 squared (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

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	H_2O
Fuel material	UO_2 wapd_crxa: 2.7 wt% enrichment wapd_crxb: 3.7 wt% enrichment wapd_crxc: 4.43 wt% enrichment wapd_crxd: 5.742 wt% enrichment
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 stainless steel
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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HELLENS, R.L., PRICE, G.A., "Reactor-physics data for water-moderated lattices of slightly enriched uranium", Reactor Technology — Selected Reviews (LINK, L.E., Ed.), Rep. USATID-8540, Argonne Natl Lab., IL (1964) 529–611.

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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (3.003 wt% enrichment)
Fuel density (g/cm^3)	10.44
Radius of fuel rods (cm)	0.506
Clad material	18/8/1 stainless steel
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**)

BIBLIOGRAPHY

BERNOCCHI, E., MARTINELLI, R. (Eds), Light Water Lattice Data, Quaderno RIT/FIS(77)1, NEACRP-U-190, Comitato Nazionale per l'Energia Nucleare, Bologna (1977) 49.

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 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 cut-off: 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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (3.006 wt%)
Fuel density (g/cm^3)	9.30
Radius of fuel rods (cm)	0.564
Clad material	304 stainless steel
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**)

BIBLIOGRAPHY

BERNOCCHI, E., MARTINELLI, R. (Eds), Light Water Lattice Data, Quaderno RIT/FIS(77)1, Rep. NEACRP-U-190, Comitato Nazionale per l'Energia Nucleare, Bologna (1977) 51–55.

HELLENS, R.L., PRICE, G.A., "Reactor-physics data for water-moderated lattices of slightly enriched uranium", Reactor Technology — Selected Reviews (LINK, L.E., Ed.), Rep. USATID-8540, Argonne Natl Lab., IL (1964) 529–611.

PRICE, G.A., Uranium–Water Lattice Compilation Part I, BNL Exponential Assemblies, Rep. BNL 50035 (T-449) (Reactor Technology-4500), Brookhaven Natl Lab., Upton, NY (1966).

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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 cut-off: 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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 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 stainless steel
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**)

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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 cut-off: 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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (3.410 wt%)
Fuel density (g/cm^3)	10.4

Radius of fuel rods (cm)	0.635
Clad material	304 stainless steel
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**)

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2.14) UO2-LW-SCKBN-VENUS

H_2O moderated uranium oxide critical lattices.
Laboratory: SCK–BN (Studie Centrum voor Kernenergie, Belgonucléaire 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

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	UO_2 (4.01 wt%)
Fuel density (g/cm^3)	10.29
Radius of fuel rods (cm)	0.445
Clad material	304 stainless steel
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**)

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BERNOCCHI, E., MARTINELLI, R. (Eds), Light Water Lattice Data, Quaderno RIT/FIS(77)1, Rep. NEACRP-U-190, Comitato Nazionale per l'Energia Nucleare, Bologna (1977) 73, 74.

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IV.3. WWER TYPE UO_2–H_2O CRITICAL LATTICES UO2-LB (WWER)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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

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 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

ENRu5	Enrichment on U-235 (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 squared (1/(m^2))
TEMP	Temperature (°C)
GE	Geometry of the lattice (he: hexagonal)
Bcon	Boron concentration (g/L of boric acid (H_3BO_3) 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

FUE-CO-LAB-Short_Name	ENRu5	Q-VAL	FUELd	CL	PITCH	Vm/Vf	Bm**2	TEMP	GE	Bcon
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	0.64
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 is the lattice pitch (cm), E is the atomic enrichment (at.%), B is the boron concentration (g H_3BO_3/L) and T is the temperature (°C).

Index	0	1	2	3	4	5	6	7
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

Name	Code	B^2	Deviation
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	H_2O with different concentrations of H_3BO_3
Fuel material	UO_2
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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IV.4. H_2O MODERATED UO_2–PuO_2 (MOX) CRITICAL LATTICES MOX-LW (CRITMOX)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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

ENRu5	Enrichment on U-235 (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 squared ($1/(m^2)$)
TEMP	Temperature (°C)
GE	Geometry of the lattice (sq: square)
%Pu	wt% PuO_2 in PuO_2–UO_2 mixture
Pu238	wt% Pu-238 in Pu
Pu239	wt% Pu-239 in Pu
Pu240	wt% Pu-240 in Pu
Pu241	wt% Pu-241 in Pu
Pu242	wt% Pu-242 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

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	H_2O	
Fuel material	wcrx_pu1-5: UO_2 (nat.) + 2.0 wt% PuO_2 wcrx_pu6: UO_2 (nat.) + 6.6 wt% PuO_2	
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	Pu-239: 91.610 Pu-240: 7.654 Pu-241: 0.701 Pu-242: 0.031
	wcrx_pu3,4	Pu-239: 71.760 Pu-240: 23.500 Pu-241: 4.080 Pu-242: 0.656
	wcrx_pu6	Pu-239: 90.490 Pu-240: 8.570 Pu-241: 0.890 Pu-242: 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

ENRu5	Enrichment on U-235 (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 squared (1/(m^2))
TEMP	Temperature (°C)
GE	Geometry of the lattice (sq: square)
%Pu	wt% PuO_2 in PuO_2–UO_2 mixture
Pu238	wt% Pu-238 in Pu
Pu239	wt% Pu-239 in Pu
Pu240	wt% Pu-240 in Pu
Pu241	wt% Pu-241 in Pu
Pu242	wt% Pu-242 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	H_2O
Fuel material	UO_2 (nat.) + 3.01% PuO_2
Americium-241 content	530 ppm in PuO_2[a]
Impurity content	0.9 ppm equivalent boron concentration in PuO_2–UO_2
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%)	Pu-238: 0.494 Pu-239: 68.180 Pu-240: 22.020 Pu-241: 7.260 Pu-242: 2.040

[a] On 16 August 1971.

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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TSURUTA, H., et al., Critical Sizes of Light Water Moderated UO_2 and PuO_2–UO_2 Lattice, Rep. JAERI 1254, Japan Atomic Energy Research Institute, Tokai-mura (1978).

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% U-235)–plutonium oxide rods in hexagonal patterns. Material bucklings were measured from exponential experiments.

Calculated parameter

Effective multiplication factor k_{eff}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (1/(m^2))
TEMP	Temperature (°C)
GE	Geometry of the lattice (he: hexagonal)
%Pu	wt% PuO_2 in PuO_2–UO_2 mixture
Pu238	wt% Pu-238 in Pu
Pu239	wt% Pu-239 in Pu
Pu240	wt% Pu-240 in Pu
Pu241	wt% Pu-241 in Pu
Pu242	wt% Pu-242 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 volume 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	H_2O
Fuel material	UO_2 (0.22 wt% U-235) + 1.5 wt% PuO_2
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%)	Pu-239: 91.41 Pu-240: 7.83 Pu-241: 0.73 Pu-242: 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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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

ENRu5	Enrichment on U-235 (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 squared (1/(m^2))
TEMP	Temperature (°C)
GE	Geometry of the lattice (he: hexagonal)
%Pu	wt% PuO_2 in PuO_2–UO_2 mixture
Pu238	wt% Pu-238 in Pu
Pu239	wt% Pu-239 in Pu
Pu240	wt% Pu-240 in Pu
Pu241	wt% Pu-241 in Pu
Pu242	wt% Pu-242 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

FUE-CO-LAB-Short_Name	%Pu	Pu238	Pu239	Pu240	Pu241	Pu242
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	H_2O
Fuel material	bnw_pua-c: Natural UO_2 + 2.0 wt% PuO_2 bnw_pud: Natural UO_2 + 4.0 wt% PuO_2
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	Pu-238: 0.0 Pu-239: 91.62 Pu-240: 7.65 Pu-241: 0.70 Pu-242: 0.03
	bnw_pub	Pu-238: 0.0 Pu-239: 81.11 Pu-240: 16.54 Pu-241: 2.15 Pu-242: 0.20
	bnw_puc	Pu-238: 0.0 Pu-239: 71.76 Pu-240: 23.50 Pu-241: 4.08 Pu-242: 0.66
	bnw_pud	Pu-238: 0.28 Pu-239: 75.38 Pu-240: 18.10 Pu-241: 5.08 Pu-242: 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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OECD NUCLEAR ENERGY AGENCY, "Hexagonal lattices of mixed oxide fuel pins UO_2 2 wt% PuO_2 (16% ^{240}Pu), natural uranium", International Handbook of Evaluated Criticality Safety Benchmark Experiments, Rep. NEA/NSC/DOC(95)03/VI, Vol. VI, MIX-COMP-THERM-007, OECD, Paris (2001).

OECD NUCLEAR ENERGY AGENCY, "Hexagonal lattices of mixed oxide fuel pins UO_2–2.0 wt% PuO_2, 24% ^{240}Pu, natural uranium", International Handbook of Evaluated Criticality Safety Benchmark Experiments, Rep. NEA/NSC/DOC(95)03/VI, Vol. VI, MIX-COMP-THERM-008, OECD, Paris (2001).

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, Rep. BNWL-963, Pacific Northwest Laboratories, Richland, WA (1969).

STINSON, W.P., UOTINEN, V.O., Destructive and Nondestructive Analysis of Plutonium Fuels Used in Lattice Experiments, Rep. BNWL-1627, Battelle Pacific Northwest Laboratories, Richland, WA (1971).

IV.5. URANIUM AND PLUTONIUM INTERMEDIATE SPECTRUM CRITICAL HOMOGENEOUS SYSTEMS U-MI, Pu-MI (CRITISP)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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 modelled as one infinite homogeneous critical mixture of uranium–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**)

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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. Br. Nucl. Energy Soc. **9** (1970) 15–27.

OECD NUCLEAR ENERGY AGENCY, "K_8 experiments in intermediate neutron spectra for ^{235}U", International Handbook of Evaluated Criticality Safety Benchmark Experiments, Rep. NEA/NSC/DOC(95)03/II, Vol. II, HEU-COMP-INTER-004, OECD, Paris (2001).

5.02) Pu-MI-AEEW-HECTOR

Plutonium intermediate spectrum critical homogeneous system.

This benchmark is an assembly were the central region experiment is modelled as one infinite homogeneous critical mixture of plutonium–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**)

BIBLIOGRAPHY

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. Br. Nucl. Energy Soc. **9** (1970) 15–27.

OECD NUCLEAR ENERGY AGENCY, "K_8 experiments in intermediate neutron spectra for ^{239}Pu", International Handbook of Evaluated Criticality Safety Benchmark Experiments, Rep. NEA/NSC/DOC(95)03/I, Vol. I, PU-COMP-INTER-001, OECD, Paris (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 cut-off: 0.625 eV).

Calculated parameter

(1) Effective multiplication factor k_{eff};
(2) ρ_c^{02}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	H_2O
Fuel material	3 wt% $^{233}UO_2$–97 wt% 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**)

BIBLIOGRAPHY

SEHGAL, B.R., "Brookhaven $^{233}UO_2$-ThO_2 thermal lattice experiments", paper EACRP-U32, presented at the Tokyo meeting of the European–American Committee on Reactor Physics, 1967.

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** (1970) 150–161.

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 cut-off: 0.625 eV).

Calculated parameter

(1) Effective multiplication factor k_{eff};
(2) ρ_c^{02};
(3) δ_{02}^{23}.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	D_2O
Fuel material	3 wt% $^{233}UO_2$–97 wt% 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**)

BIBLIOGRAPHY

SEHGAL, B.R., "Brookhaven $^{233}UO_2$–ThO_2 thermal lattice experiments", paper EACRP-U32, presented at the Tokyo meeting of the European–American Committee on Reactor Physics, 1967.

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** (1970) 150–161.

IV.8. D_2O MODERATED URANIUM OXIDE CRITICAL LATTICES UO2-HW (CRITD2O)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of case	.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 HWR ZED-2. They were made using UO_2 (nat.) 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.

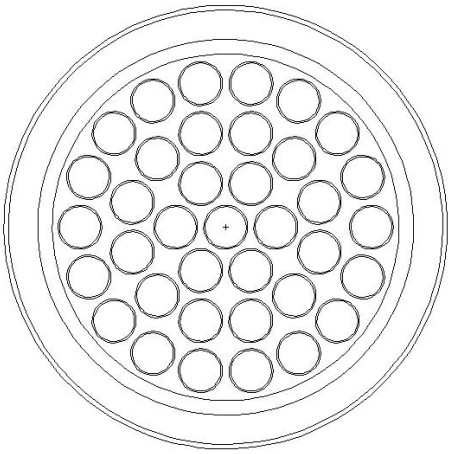
(a) Analysis of experiments with 37 rod fuel clusters

Measurements were made on single pitch 28.58 cm square UO_2 (nat.) fuel with 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-235 fis.) 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 = U-238 fis./U-235 fis.
(3) Initial conversion ratio C = Cx/Cth; Cx = (U-238 capt./U-235 fis.)x; Cth = thermal ref. value.
(4) U-235 fission rate U5FR = (U-235 fis.)x/(U-235 fis.)fa.
(5) Relative copper activity RCA = (Cu-63 abs.).
(6) Lutetium–manganese activity ratio LMAR = LMARx/LMARth, where LMARx = (Lu176 abss.)x/(Mn abss.)x; LMARth is the thermal ref. value, x is the position of the fuel rods A, B, C, D (from inner to outer annulus), fa is the fuel average.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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-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)
Coolant	zed2t1d2o: D_2O zed2t1air: Air
Moderator	D_2O
Number of rods	37 (1/6/12/18)
Radius of rod centres (cm)	0.0/1.4885/2.8755/4.3305
Fuel material	UO_2 (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**)

BIBLIOGRAPHY

INTERNATIONAL ATOMIC ENERGY AGENCY, In-core Fuel Management Benchmarks for PHWRs, IAEA-TECDOC-887, IAEA, Vienna (1996) 111–117.

KAY, R.E., Lattice Measurements with 37-Element Bruce Reactor Fuel in Heavy Water Moderator: Detailed Lattice Cell Parameters, Rep. AECL-5307, Atomic Energy of Canada Ltd, Chalk River, Ontario (1976).

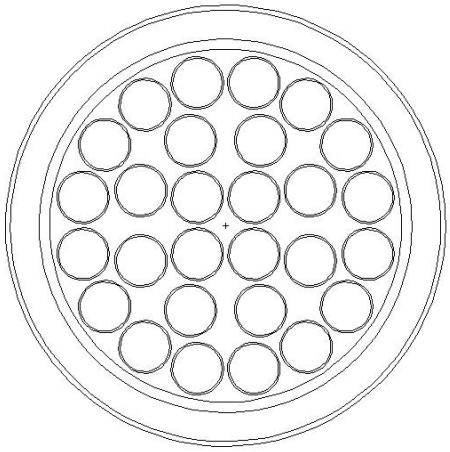
(b) Analysis of experiments with 28 rod fuel clusters (hexagonal pitches)

Measurements were made using UO_2 (nat.) fuel with heavy water and air as coolants. Buckling measurements were performed at eight 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 four 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), where pt is the pressure tube, ct is the calandria tube, m is the moderator, f is the fuel.

Cluster geometry



Calculated parameters

(1) Effective multiplication factor k_{eff}.
(2) Fast fission ratio δ = (U-238 fis./U-235 fis.)fa.
(3) Initial conversion ratio C = Cfa/Cth, where Cfa = (U-238 capt./U-235 abs.)fa, Cth is the thermal reference value, fa is the fuel average, capt. is the absorption–fission, abs. is the capture + fission.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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	D_2O
Moderator	D_2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.163/2.652/4.206
Fuel material	UO_2 (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**)

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INTERNATIONAL ATOMIC ENERGY AGENCY, In-core Fuel Management Benchmarks for PHWRs, IAEA-TECDOC-887, IAEA, Vienna (1996) 117–122.

SERDULA, K.J., Lattice Measurements with 28-Element Natural UO_2 Fuel Assemblies. Part I. Bucklings for a Range of Spacings with Three Coolants, Rep. AECL-2606, Atomic Energy of Canada Ltd, Chalk River, Ontario (1966).

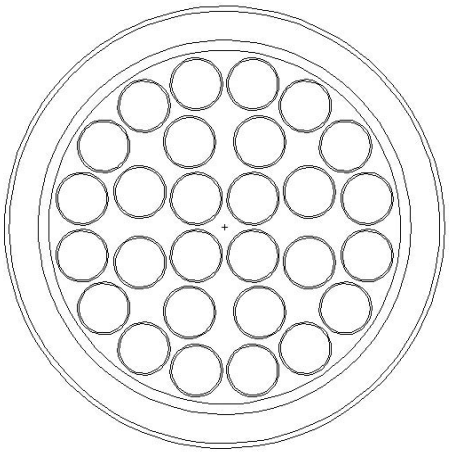
(c) Analysis of experiments with 28 rod fuel clusters (square pitch)

Measurement of material buckling was made on single pitch 28.575 cm square UO_2 (nat.) fuel with heavy water as coolant.

Experimental result

Material bucklings.

Cluster geometry



Calculated parameters

Effective multiplication factor k_{eff}.

Summary data

ENRu5	Enrichment on U-235 (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 squared ($1/(m^2)$)
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	D_2O
Moderator	D_2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.163/2.652/4.206
Fuel material	UO_2 (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)	—

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JONES, R.T., Adjuster rod experiments in ZED-2, Rep. AECL-5853, Atomic Energy of Canada Ltd, Chalk River, Ontario (1977).

8.02) UO2-HW-JNCDI-DCA

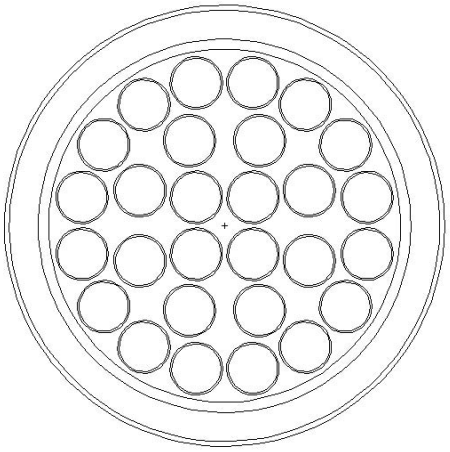
D_2O moderated uranium oxide critical lattices.
Laboratory: Japan Nuclear Cycle Development Institute, Japan.
Facility: DCA (deuterium critical assembly).

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% U-235). 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

ENRu5	Enrichment on U-235 (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 squared ($1/(m^2)$)
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: D_2O dcat1a: Air dcat1h: H_2O
Moderator	D_2O
Number of rods	28 (4/8/16)
Radius of rod centres (cm)	1.3125/3.0/4.7575
Fuel material	UO_2 1.2 wt%
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 at.% of D_2O) (2) Void fraction: 70% (88.88 at.% of D_2O)	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**)

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KOWATA, Y., FUKUMURA, N., Nucl. Sci. Eng. **99** (1988) 299–312.

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, Rep. CNEA-RE-CA 94-07, Bariloche Atomic Center, National Atomic Energy Commission, Argentina (1994) (in Spanish).

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** (1978) 492–507.

IV.9. D_2O MODERATED $^{235}UO_2$–ThO_2 CRITICAL LATTICES Th5-HW (CRITD2O)

Index

List of benchmarks by U-235 enrichment

Benchmark identification	U-235 (wt%)	Number of 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

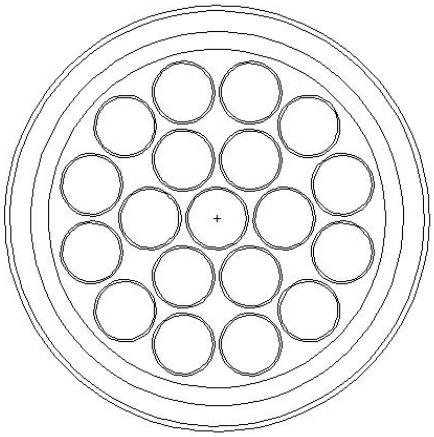
Analysis of lattice experiments with 19 rod clusters with ThO_2–UO_2 fuel.

Measurements were made with ThO_2 fuel containing 1.5 wt% enriched UO_2 (93.02 at.% U-235) with 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) Th-232 fis./U-235 fis.
(c) Th-232 cap./U-235 fis.

Cluster geometry



Calculated parameters

(1) Effective multiplication factor k_{eff}.
(2) Th-232/U-235 fission ratio, δ = (Th-232 fis./U-235 fis.)fa.
(3) Conversion ratio, C = (Th-232 capt./U-235 fis.)fa, where fa is the fuel average, capt. is the absorption–fission.

Summary data

ENRu5	Enrichment on U-235 (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 squared (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: D_2O zed2t4a22,a28: Air
Moderator	D_2O
Number of rods	19 (1/6/12)
Radius of rod centres (cm)	0.0/1.468/2.837
Fuel material	(ThO_2 (98.5 wt%))– (UO_2 93 at.% (1.5 wt%))

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**)

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KRISHNANI, P.D., Analysis of lattice experiments with ThO_2–UO_2 fuel using WIMS library, Ann. Nucl. Energy **16** 3 (1989) 151–155.

OKAZAKI, A., Lattice Measurements with 19-Element Rods of ThO_2 $^{235}UO_2$ in Heavy Water Moderator. Part II. Relative Fission Rates, Fast Fission Ratio, Conversion Ratio, and Comparison with Calculations. Rep. AECL-2779, Atomic Energy of Canada Ltd, Chalk River, Ontario (1968).

OKAZAKI, A., DURRANI, S.A., Lattice Measurements with 19-Element Rods of ThO_2 $^{235}UO_2$ in Heavy Water Moderator. Part 1. Buckling, Fine Structure, and Neutron Spectrum Parameters, Rep. AECL-2778, Atomic Energy of Canada Ltd, Chalk River, Ontario (1967).

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) OECD/NEA burnup credit criticality benchmark. H_2O moderated uranium oxide lattices. Analysis of isotopic composition as a function of burnup (BUCR1A, BUCR1B).
(3) LWR plutonium 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.

NPD is a Canadian demonstration PHWR (25 MW electrical power) shut down in 1987. The moderator and coolant were heavy water. The fuel was in the form of 19 natural UO_2 rod CANDU type clusters.

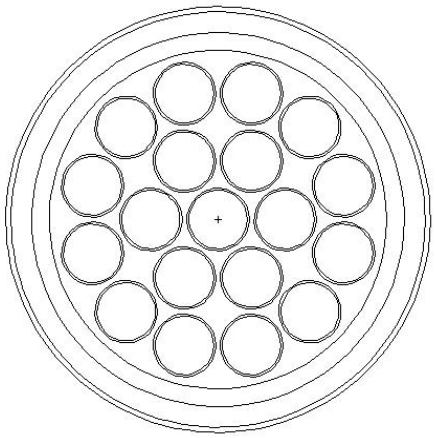
Analysis of isotopic composition for 19 rod fuel cluster

Isotopic measurements of irradiated 19 element fuel bundles were carried out in 1971 at the Commissariat à l'énergie atomique in France. The measurements included a series of eight bundles with irradiation in the range 1000–10 000 MW·d/t U, 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 eight burnups ranged from 1000 to 10 000 MW·d/t.[3]

Geometry



Calculated parameters

N*i*/N*j* in function of burnup.

[3] N235, N236 and N238 refer to the number densities of uranium isotopes with the corresponding mass numbers; N239, N240 and N241 refer to the number densities of plutonium isotopes with the corresponding mass numbers.

General data

Pitch (cm)	26.035 (square)
Coolant	D_2O
Moderator	D_2O
Number of rods	19 (1/6/12)
Radius of rod centres (cm)	0.0/1.65/3.18755
Angular distance from reference axis (radians)	0.0/0.0/0.2617994
Fuel material	UO_2 (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**)

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DURET, M.F., et al., Plutonium Production in NPD: A Comparison Between Experiment and Calculation, Rep. AECL-3995, Atomic Energy of Canada Ltd, Chalk River, Ontario (1971).

INTERNATIONAL ATOMIC ENERGY AGENCY, In-core Fuel Management Benchmarks for PHWRs, IAEA-TECDOC-887, IAEA, Vienna (1996) 122–127.

2) OECD/NEA burnup credit criticality benchmark

LWR burnup credit criticality benchmark. Isotopic composition prediction.
Laboratory: Pacific Northwest Laboratory, Richland, WA, USA.
Facility: ATM-104 (approved testing material, combustion engineering (CE) 14 × 14 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 in the bibliography for the CE 14 × 14 assembly designated as approved testing material ATM-104 for a series of experiments designed to characterize spent fuel for LWRs. The chemical assay data measured in these experiments are of particular value in validating the isotopic predictions used in burnup credit.

General data

Cell radius (cm)	0.879346
Moderator	H_2O
Moderator density (g/cm^3)	0.7569
Moderator temperature (K)	558
Fuel material	UO_2 (3 at.% U-235 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 average boron concentration (ppm)	331

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 three cumulative burnups: 27.35, 37.12 and 44.34 GW·d/Mt U.

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 and Eu-153, for three cumulative burnups: 27.35, 37.12 and 44.34 GW·d/Mt U.

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

Note: Burn: fuel irradiation time. Down: downtime between cycles except for cycle 4, which includes the decay time from reactor to measurement (cooling time). Boron: cycle average boron concentration as a percentage of the cycle 1 concentration.

Specific power

Operating cycle	Specific power (kW/kg U)		
	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 (GW·d/Mt U)	27.35	37.12	44.34

Initial fuel number densities

Nuclide	Number density (10^{24} atoms/cm^3)
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 (10^{24} atoms/cm^3)
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**)

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OECD NUCLEAR ENERGY AGENCY, Burnup Credit Criticality Benchmark, Isotopic Composition Prediction, Rep. NEA/NSC/DOC(92)/10, NEA Package ID No. NEA 1401/02, http://www.nea.fr/html/dbprog

3) LWR plutonium recycling benchmarks

LWR plutonium 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 and Eu-155, for cases (A) and (B) at 50 GW·d/Mt U 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 and Eu-155, for cases (A) and (B) at 50 GW·d/Mt U burnup.

General data

Pitch (cm)	1.3133 (square)
Moderator	H_2O (+B nat.)
Moderator temperature (K)	579
Fuel material	UO_2–PuO_2
Effective fuel temperature (K)	933
Radius of fuel rods (cm)	0.4095
Clad material	Zr
Atomic density of clad material (10^{24} atoms/cm^3)	0.043248
Radius of clad (cm)	0.4750
Clad temperature (K)	579

Initial fuel number densities

Nuclide	Number density (10^{24} atoms/cm^3)	
	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 (10^{24} atoms/cm^3)
H-1	4.7716E-02
O-16	2.3858E-02
B (nat.)	1.98606E-05

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**)

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OECD NUCLEAR ENERGY AGENCY, Package ID: OECD/NEA 1505/01.

Appendix V

SUPPLEMENTARY BENCHMARK SPECIFICATIONS

List of benchmarks

(1) MARIA tubular fuel with moderator of beryllium benchmark. Beryllium moderated 80% enriched uranium–aluminium tubular fuel. Multiplication factor (K) comparison with results obtained with the MCNP code with the standard library based on ENDF/B-VI, for heterogeneous and homogenized cases (BE).
(2) DOPPLER numerical benchmark. H_2O moderated uranium oxide lattices. Reactivity temperature coefficient comparison with results obtained with the MCNP code with the 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 four 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 gadolinium 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 a 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 U-235 isotope in function of burnup, and numerical comparison of isotopic concentration of actinides at end of the 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 BERYLLIUM MODERATOR)

Beryllium moderated 80% enriched uranium–aluminium tubular fuel.
Laboratory: IAE (Institute of Atomic Energy), Poland.
Facility: MARIA reactor.

Details of the MARIA reactor and MCNP calculations were given by Andrzejewski and Kulikowska. It is strongly recommended to read their paper (see the bibliography) to understand the characteristics of the MARIA reactor. Geometry and material data included in this section were extracted from the information that they provided.

The benchmark consists 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 the reference result calculated by the MCNP code with its standard library based on ENDF/B-VI.

An MCNP calculation for a cell with white or reflective boundary conditions is representative of an infinite array of cells, and the calculated multiplication factor is k_∞. Thus, in the case of a tubular cell, the parameter compared is k_∞. The case of a homogenized cell is the same as the tubular case, with materials mixed with volume weights. The k_∞ of the homogenized case is lower because of boron, which is added to model the boron safety and control rods.

Reference results

Calculated with the MCNP-C code with the standard library based on ENDF/B-VI Rev. 7.

(1) k_∞: infinity medium 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 a reflective boundary condition applied at all boundaries. The square boundary of the elementary cell was preserved.

The uncertainty for k_∞ was taken as the standard deviation calculated by the code.

The uncertainties for other integral parameters were obtained from Monte Carlo standard deviations using the fact of dependence of each calculated reaction rate on the calculated neutron flux. An approximate formula was used:

$$\frac{\delta x(\phi)}{x(\phi)} = \sqrt{\left(\frac{\delta\phi_{\text{epi}}}{\phi_{\text{epi}}}\right)^2 + \left(\frac{\delta\phi_{\text{th}}}{\phi_{\text{th}}}\right)^2}, \quad x = \rho_{28} \text{ or } x = \delta_{25}$$

$$\frac{\delta y(\phi)}{y(\phi)} = \sqrt{\left(\frac{\delta\phi_{\text{tot}}}{\phi_{\text{tot}}}\right)^2 \times 2}, \quad y = \delta_{28} \text{ or } y = C^*$$

The elementary cell has a side size equal to 13 cm (i.e. the average size of the beryllium block used in the beryllium matrix with its adjacent water gap). In the centre of Fig. V.1.2 there is a fuel channel, in the middle of which the fuel element is placed (cf. Fig. V.1.1) in an aluminium guiding tube. Four water gaps separating beryllium blocks are directed outwards from the channel.

Calculated parameters

(1) k_∞: infinity medium multiplication factor.
(2) ρ^{28}.
(3) δ^{25}.
(4) δ^{28}.
(5) C^*.

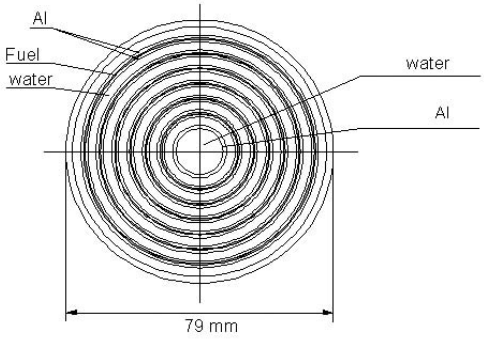

FIG. V.1.1. Geometry of benchmark b horizontal cross-section of the fuel assembly.

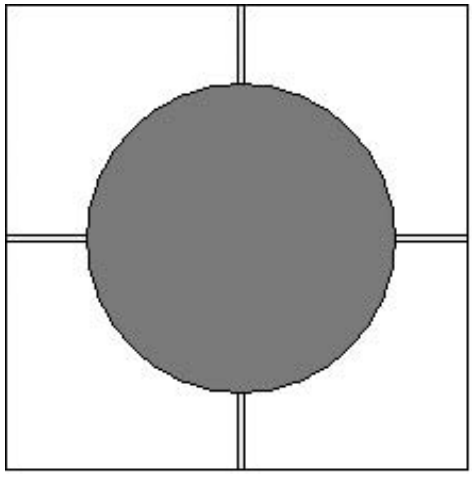

FIG. V.1.2. Elementary MARIA cell used in Monte Carlo lattice calculations.

Number densities (atoms/(barn·cm))

Isotope	Homogeneous test cell (case a)	Tubular test cell (case b)			
		Fuel	Can	Coolant	Moderator[a]
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			

[a] Fresh beryllium blocks homogenized with water gaps (atoms/(barn·cm)).

General data

Pitch (cm)	13.0 (square)		
Moderator to fuel volume	42.717[a]		
Coolant	H_2O		
Moderator material	Be		
Fuel material	U–Al (80 wt% enrichment)		
Radius of each annulus and material for case b (see Figs V.1.1 and V.1.2) (cm)	Annulus	Radius	Mat.
	1	0.7	3
	2	0.8	2
Material 1: fuel	3	1.05	3
Material 2: can	4	1.13	2
Material 3: water	5	1.17	1
Material 4: beryllium with impurities	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		

[a] Vm/Vf was calculated with the volume of both the water coolant and the beryllium moderator. For the 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**)

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V.2. DOPPLER NUMERICAL BENCHMARK

H_2O moderated uranium oxide lattices.

An infinite array of infinitely long PWR pin cells at the beginning of life.

Reactivity temperature coefficient comparison with results obtained with the MCNP code with its standard library based on ENDF/B-VI (DOPPLER).

This benchmark consist of five different enrichment values for fuel pins. The two thermal conditions considered were that of hot zero power (HZP) (i.e. 600 K) and hot full power (HFP) (i.e. 900 K).

Calculated parameter

Effective multiplication factor k_{eff} and Doppler coefficient C_{D}, which is defined by:

$$C_{\text{D}} = \frac{k_{\text{eff}}^{\text{HFP}} - k_{\text{eff}}^{\text{HZP}}}{k_{\text{eff}}^{\text{HFP}} k_{\text{eff}}^{\text{HZP}} \Delta T} \quad \text{with} \quad \Delta T = T^{\text{HFP}} - T^{\text{HZP}}$$

Composition

Fuel temperature (K)	Fuel enrichment (wt%)	Number density in fuel (atoms/(barn·cm))		
		O-16	U-235	U-238
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 density in cladding and moderator (atoms/barn·cm)			
		Natural zirconium	H-1	B-10	O-16
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	H_2O
Fuel material and enrichment	UO_2 wt% enrichment: 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 [a]
Fuel temperature (K)	HZP: 600 HFP: 900
Cladding temperature (K)	HZP: 600 HFP: 600
Moderator temperature (K)	HZP: 600 HFP: 600

[a] 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**)

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RAHNEMA, F., GHEORGHIU, H.N.M., ENDF/B-VI benchmark calculations for the Doppler coefficient of reactivity, Ann. Nucl. Energy **23** (1996) 1011–1019.

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 four 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:

$$\text{D-ALPHA} = \frac{k_{\text{eff}}^{T} - k_{\text{eff}}^{T0}}{k_{\text{eff}}^{T} k_{\text{eff}}^{T0} \Delta T} \quad \text{with} \quad \Delta T = T^{T} - T^{T0}$$

As the P_1 matrices in the WIMS libraries 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 analysed: KRITZ, NORA, R1100H and VVER.

V.3.1. KRITZ benchmark

H_2O moderated uranium and uranium–plutonium oxide critical lattices.
Laboratory: Studsvik, Sweden.
Facility: KRITZ (tank type critical assembly).

These benchmarks are four 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, the D-ALPHA parameter (reactivity temperature coefficient difference between the 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	H_2O
Fuel material	KRITZ_1: UO_2 enrichment: 1.3532 wt% KRITZ_2.1: UO_2 enrichment: 1.86 wt% KRITZ_2.13: UO_2 enrichment: 1.86 wt% KRITZ_2.19: UO_2–PuO_2 (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	Zircaloy 2
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

BIBLIOGRAPHY

JOHANSSON, E., Data and Results from KRITZ Experiments on Regular Water Moderated Fuel Pin Lattices at Temperatures up to 245°C, Rep. Studsvik/NS-90/133, Studsvik, Sweden (1990).

V.3.2. NORA benchmark

H_2O moderated UO_2 critical lattices.
Laboratory: Institute for Atomenergi, Kjeller, Norway.
Facility: 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, the 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	H_2O
Fuel material	UO_2 enrichment: 3.41 wt%
Fuel density (g/cm^3)	10.40
Radius of fuel rods (cm)	0.635
Clad material	304 stainless steel
Outer radius of clad (cm)	0.694
Thickness of clad (cm)	0.048
Temperature (all components) (°C)	20 and 60

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INTERNATIONAL ATOMIC ENERGY AGENCY, Topics in Light Water Reactor Physics: Final Report of the Nora Project, Technical Reports Series No. 113, IAEA, Vienna (1970).

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. R1100H benchmark

H_2O moderated UO_2 critical lattice.

Laboratory: Atomic Energy Establishment, Winfrith, UK.
Facility: DIMPLE and JUNO.

The selected benchmark consists of an H_2O moderated lattice of uranium oxide rods in square patterns. Material bucklings were measured in hot and cold conditions.

Calculated parameter

Effective multiplication factor k_{eff} at 20°C and 80°C and, from these values, the 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	H_2O
Fuel material	UO_2 enrichment: 3.003 wt%
Fuel density (g/cm^3)	10.44
Radius of fuel rods (cm)	0.508
Clad material	304 stainless steel
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 and 80

BIBLIOGRAPHY

AUSTIN, J.W., BROWN, W.A.V., 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, Rep. AEEW-R-455, United Kingdom Atomic Energy Authority, Winfrith (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 the 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, the D-ALPHA parameter (reactivity temperature coefficient difference between the calculated and experimental value).

General data

Lattices are identified by the code P/E/B/T, where P is the lattice pitch (cm), E is the atomic enrichment (at.%), B is the boron concentration (g H_3BO_3/L) and T is the temperature (°C).

Index	0	1	2	3	4	5	6	7
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	H_2O with different concentrations of H_3BO_3
Fuel material	UO_2
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**)

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Final Report of TIC: Experimental Investigations of the Physical Properties of WWER Type Uranium–Water Lattices, Vol. 1, Akademiai Kiado, Budapest (1985).

Final Report of TIC: Experimental Investigations of the Physical Properties of WWER Type Uranium–Water Lattices, Vol. 3, Akademiai Kiado, Budapest (1991).

OECD NUCLEAR ENERGY AGENCY, "The WWER experiments: Regular and perturbed hexagonal lattices of low-enriched UO_2 fuel rods in light water", International Handbook of Evaluated Criticality Safety Benchmark Experiments, Rep. NEA/NSC/DOC/(95)03/IV, Vol. IV, LEU-COMP-THERM-015, OECD, Paris (2001).

V.4. DCA EXPERIMENTAL BENCHMARK WITH GADOLINIUM POISONED RODS

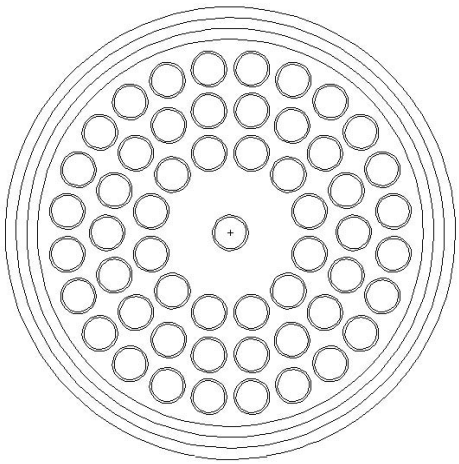
D_2O moderated cluster with 54 uranium oxide rods.
Laboratory: Japan Nuclear Cycle Development Institute, Japan.
Facility: DCA (deuterium critical assembly).

A test fuel cluster of 54 fuel pins composed of UO_2 enriched to 1.5 wt% in U-235 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. A comparison of the measured and calculated thermal flux spatial distribution is made in this benchmark.

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 the test fuel cluster at the centre of the 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)
Coolant	(a) H_2O; (b) air
Moderator	D_2O
Number of rods	54 (12/18/24)
Radius of rod centres (cm)	3.825/5.76/7.68
Fuel material	(i) Normal: UO_2 1.5 wt% (ii) Poisoned fuel pins: UO_2 1.5 wt% + Gd_2O_3 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 pressure and calandria 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**)

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WAKABAYASHI, T., MINATSUKI, I., Critical experiments on gadolinium poisoned cluster-type fuel assemblies in heavy water lattices, Nucl. Sci. Eng. **83** (1983) 50–62.

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 U-235 isotope as a function of burnup, and numerical comparison of isotopic concentration of actinides at the end of the cycle for a single plate cell calculation.

As explained in Wilson et al., the analysed fuel element was subject to varying flux levels and spectra, core power levels, spatial xenon distributions, 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 correspond to the average values reported in Wilson et al.

Experimental results

Measured mean per cent of initial U-235 remaining by cycle, for 17 cycles.

Reference numerical results

Actinide nuclide inventory at the end of the last cycle, calculated with the CINDER-2 and DANDE codes.

Calculated parameters:

(1) Mean per cent of initial U-235 remaining by cycle, for 17 cycles;
(2) Actinide nuclide inventory at the end of the last cycle.

General data

Fuel type	U–Al alloy (enrichment: 93.15 wt% U-235)
Fuel density (g/cm^3)	2.702 (content of Al: 96.33% of full fuel density)
Density of uranium 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 per 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 cycle

Operating cycle	Burn (days)	Specific power (MW/t U)
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 (GW·d/Mt U)	—	330.6268

Note: Burn: fuel irradiation time. Down: decay time from reactor to measurement (cooling time).

OWR initial number densities

Component	Nuclide	Number density (atoms/(barn·cm))
Fuel	U-234	1.24E-05
	U-235	1.62E-03
	U-238	1.05E-04
	Al	5.81E-02
Clad	Al	6.03E-02
Colant	H	6.684E-02
	O	3.335E-02

OWR measured mean per cent of initial U-235 remaining by cycle

Cycle	U-235 (%)
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 (atoms/(barn·cm))
U-234	1.12E-05
U-235	9.28E-04
U-236	1.02E-04
U-238	1.04E-04
Np-237	1.07E-06
Pu-238	6.03E-08
Pu-239	4.51E-07
Pu-240	7.46E-08
Pu-241	1.23E-08
Pu-242	1.51E-09
Am-241	1.54E-09
Am-242	4.22E-17
Am-242m	3.51E-12
Am-243	3.12E-11
Cm-242	2.36E-12
Cm-243	1.31E-13
Cm-244	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**)

BIBLIOGRAPHY

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, Rep. T-2-IR-86-2, Los Alamos Natl Lab., NM (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_∞ eigenvalue and isotopic concentrations of actinides and fission products as a function of burnup.

The basic geometry is a square infinite lattice pin cell, with zero leakage, burned to in excess of 70 MW·d/kg at constant power using a multigroup transport code.

Reference numerical results

(a) Variation of k_∞ as a function of burnup;
(b) Isotopic concentration of actinides calculated with the 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 MW·d/kg. It is recommended that the burnup steps of Zhao et al. be used for ready comparison of the results with earlier work. These burnup values in days and in MW·d/kg are given in the table below.

Burnup step (days)	Burnup (days)	Burnup (MW·d/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 Th-232 to Pu-242 at 60.749 MW·d/kg, which is at the upper limit of discharge burnup if a three 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 wt%. UO_2 is enriched to 19.5% U-235. The U-235 weight fraction in the total heavy metal is 4.869%. The isotopic composition of the fuel, clad and coolant material is given in the following table.

Material	Nuclide	wt%	Number density (10^{24} atoms/cm^3)
Fuel	Th-232	65.909	1.61215×10^{-2}
	U-234	0.034	8.24518×10^{-6}
	U-235	4.291	1.03615×10^{-3}
	U-238	17.740	4.22957×10^{-3}
	O-16	12.026	4.26835×10^{-2}
Clad[a]	Zr-4	100 or	4.31438×10^{-2}
	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	H-1	11.19	4.71053×10^{-2}
	O-16	88.81	2.35662×10^{-2}

[a] Zr-4 composition is taken from Glasstone, S., Sesonske, A., Nuclear Reactor Engineering, 3rd edn, Van Nostrand Reinhold, New York (1981).

Miscellaneous data

The density, temperature and heat rating data are as follows:

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/kg HM)	38.1347

BIBLIOGRAPHY

ZHAO, X., PILAT, E.E., WEAVER, K.D., HEJZLAR, P., "A PWR thorium pin cell burnup benchmark", PHYSOR 2000: Advances in Reactor Physics and Mathematics and Computation into the Next Millennium (Proc. Int. Conf. Pittsburgh, PA, 2000), American Nuclear Society, La Grange Park, IL (2000) CD-ROM.

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 Ravnik, 1999, Perši et al., 2000, and Jeraj, 2002.

The TRIGLAV program package was used in the calculation. The unit cell calculations in TRIGLAV are performed with the WIMSD-5B code. WIMS input generation and output processing is completely automatic in the TRIGLAV package. The whole core calculation is performed in diffusion approximation in two dimensional geometry using the TRIGA2D module of TRIGLAV.

The TRIGLAV program package with WIMS-D/4 is available through the OECD/NEA Data Bank. In this benchmark, the modified updated version of TRIGLAV was used with WIMSD-5B. This version of TRIGLAV is currently available at the Jožef Stefan Institute. WIMS-D libraries were taken from the WLUP home page.

Benchmark run

The 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 the 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 the WIMS subdirectory. The WIMSD-5B library for TRIGLAV calculation is selected in the **triglav.bat** file in lines 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 MW·d	Measured k_{eff} = 0.9842 ± 0.0016	Burned core 134 average core burnup 1.139 MW·d	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 a 2-D program and k_{eff} calculations are relative due to the free axial buckling parameter. In this benchmark, buckling was set after the first calculation (bM133 with enedf65.bin) to 0.0052 cm^{-2} and was fixed to this value in all other calculations. Test output files are also in the TRIGAbenchmark.zip file.

BIBLIOGRAPHY

JERAJ, R., ŽAGAR, T., RAVNIK, M., Monte Carlo simulation of the TRIGA mark II benchmark with burned fuel, Nucl. Technol. **137** (2002) 169–180.

PERŠI, A., SLAVI, S., RAVNIK, M., ŽAGAR, T., TRIGLAV — A Program Package for Research Reactor Calculations, Rep. IJS-DP-7862, Jožef Stefan Institute, Ljubljana (1998).

PERŠI, A., SLAVI, S., RAVNIK, M., ŽAGAR, T., TRIGLAV — A Program Package for Research Reactor Calculations, Rep. IAEA 1370/01, OECD, Paris (1998).

PERŠI, A., RAVNIK, M., ŽAGAR, T., TRIGA mark II criticality benchmark experiment with burned fuel, Nucl. Technol. **132** (2000) 325–338.

RAVNIK, M., JERAJ, R., "TRIGA mark II benchmark critical experiments", International Handbook of Evaluated Critical Safety Benchmark Experiments, Rep. IEU-OMP-THERM-003, OECD, Paris (1999).

WLUP — WIMS Library Update Project, IAEA Coordinated Research Project (2002), http://www-nds.iaea.org/wimsd

Appendix VI

WIMSD-5B BENCHMARK RESULTS FOR ALL LIBRARIES

The output of the SMRLIB program is included, with comparisons of all the benchmark results using all libraries included on the WLUP CD-ROM.

```
 #
 # 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
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
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
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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

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     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
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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

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
 # ---------------------------------


 SMRDIF - Compare lattice spectr.indices
 =======================================

   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
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

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    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
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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
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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
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

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   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
  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
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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
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

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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
    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
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  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
     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
 ======================================

   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
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   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
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  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)
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  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)
    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)
 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)
#
```

```
#
# 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

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.590E-01|                    -----3**6*2------                    |
U -235  8.190E+00|                        ----|376**                      |
U -236  3.224E+00|                      **3--*|----                        |
U -238  8.375E+02|                            *                            |
Pu-238  9.504E-02<            7 *9-64*--------|-------------               |
Pu-239  4.230E+00|                    --------**-------                    |
Pu-240  1.710E+00|                      --**89*---3--                      |
Pu-241  6.697E-01|                   --------9*2**6-------                 |
Pu-242  2.761E-01|                ------38*5-1*|7------------              |
Am-241  2.426E-01|                      398-**6------                      |
Am-243  4.101E-02|      79    --8--*---6-5-1---|--4--------------          |
Np-237  2.912E-01|             3 *86-5*-7------|-------------             |
Mo- 95  5.666E-01|                           *5*--3                       |
Tc- 99  5.985E-01|                    -----***|--3-----                    |
Ru-101  5.637E-01|                       ***-                            |
Rh-103  3.492E-01|                     3------*-**----                    |
Ag-109  5.892E-02|    *   *4     3  -----------|----*------                |
Cs-133  8.415E-01|                     -----98*3*6----                    |
Cs-135  3.821E-01|                        *-*-|----                       |
Nd-143  6.232E-01|                        5**-|-3--                       |
Nd-145  5.066E-01|                          *3**-                         |
Sm-147  1.806E-01|                   ---3-----|--2**-*8-                  |
Sm-149  2.054E-03|        ---12-4**-----------|---------------------  3    |
Sm-150  1.953E-01|                     --2**4--|---3----                   |
Sm-151  9.742E-03-------14*2597----------------|------------------------------>
Sm-152  9.394E-02|                 -48--1--6-59---2-*-----                  |
Eu-153  7.655E-02|             3   -----------2|--*1-9-*--8-              |
Gd-155  3.879E-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 =    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

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  1.200E-01|                3          4*9 *12                    |
U -235  3.540E+00|             3  7 6 *9*      |                        |
U -236  3.690E+00|                            * 3  *                     |
U -238  8.249E+02|                            *                          |
Pu-238  2.688E-01<         75**18              |                          |
Pu-239  4.357E+00|                         32**|                          |
Pu-240  2.543E+00|                      * **   |3                         |
Pu-241  1.020E+00|                      9*2**6 |                          |
Pu-242  8.401E-01|                *89 21 6 7   |                          |
Am-241  0.000E+00|                            *                          |
Am-243  0.000E+00|                            *                          |
Np-237  4.680E-01|                      *18 6  |*9 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  1.240E+00|                         9 |* * 6                      |
Cs-135  4.300E-01|                      3  * **5                         |
Nd-143  7.630E-01|                         **|        3                 |
Nd-145  7.440E-01|                       45  3**                        |
Sm-147  0.000E+00|                            *                          |
Sm-149  4.700E-03<                           |                          |
Sm-150  3.610E-01|        2176 **        3    |                          |
Sm-151  0.000E+00|                            *                          |
Sm-152  1.210E-01|                            | 4  8  1  6     5  9  2   7  >
Eu-153  1.480E-01|           3             2 15746  98                   |
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 =    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|                             *                            |
#
```

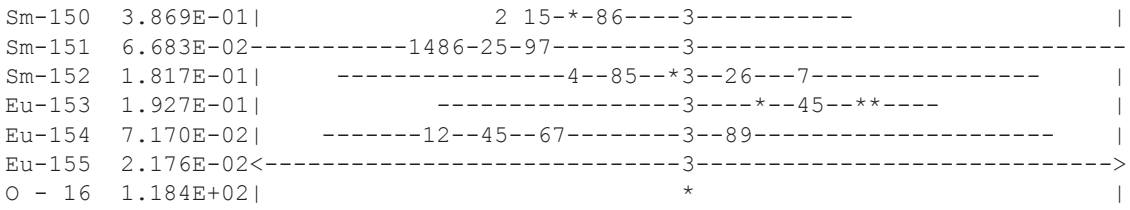
```
#
# NEA/CRP Plutonium Recycling Benchmarks
# --------------------------------------

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

 Isot. Ref.[mg/g]V_-20% _____________________V_____________________+20%_V
U -234  8.095E-02|               3        ----|4**2-                      |
U -235  2.991E+00|                          3 -|--***                      |
U -236  5.746E-01|                    *67 ----3*-----                      |
U -238  7.397E+02|                          *                              |
Np-237  1.952E-01<              --------------|---8*-*-*-5---               |
Pu-238  3.485E+00|                    ----3--|-**-*--                      |
Pu-239  2.475E+01|                        --|-***  3                      |
Pu-240  2.431E+01|                      76**8|-----                         |
Pu-241  1.306E+01|                      3----|--*9*7                        |
Pu-242  2.010E+01|                 ------3-----|---8**------                |
Am-241  1.269E+00|                     ---3--|-*---** *                   |
Am-242m 3.202E-02|    --------3----------------|--45--*92---6-7----------    |
Am-243  3.677E+00----975-*461-----------------|-----3-----------------------
Cm-242  2.043E-01|                275 9----1-*-8-----3--                     |
Cm-243  8.149E-03|         2 75   9 1-6-4-8----|-3---------                 |
Cm-244  1.637E+00|                      -93*7814-6---                        |
Mo- 95  7.557E-01|                 -----------3|-**89--*----                 |
Tc- 99  9.956E-01|                    ---------*2**-6----                   |
Ru-101  1.077E+00|                      3   7**|*--                          |
Rh-103  9.619E-01|                      -----*-|**---3-                      |
Pd-105  9.811E-01|                         -*-***9--                        |
Pd-107  6.822E-01|                      *9*   --|*-                          |
Pd-108  4.914E-01|                        41*9--67----             3         |
Ag-109  2.295E-01| ----------------------------|-----38--9----4-15-2-------- >
Xe-131  5.994E-01|                   ----------762**------                   >
Xe-135  5.065E-04|                        ---*|---1**    3                  |
Cs-133  1.426E+00|                   3 --------98**-76--                     |
Cs-135  1.260E+00|                        *---3-**                          |
Nd-143  1.165E+00|        ---------***-*-------3---------------------        |
Nd-145  8.026E-01|                    -45-*9-*-3---------                   |
Pm-147  1.932E-01-----------------------------3--------2-5-*-1-486-----------
Pm-148m 3.928E-03|          --------------------3-4-18----*-29----7-          |
Sm-149  1.343E-02| ---------12-45**------------3---------------------------- |
```


Sm-150 3.869E-01
Sm-151 6.683E-02
Sm-152 1.817E-01
Eu-153 1.927E-01
Eu-154 7.170E-02
Eu-155 2.176E-02
O - 16 1.184E+02

```
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 (Wt%U235)(DIFF.)
==================================================

      CYC Wt%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
```

Appendix VII

CONTENTS OF THE CD-ROM

A CD-ROM of direct relevence to the WIMS-D library is available on request from the IAEA Nuclear Data Section. This CD-ROM is an image of the contents of the web site and is organized for viewing with an HTML browser by clicking on the index.htm file in the main directory. Additional features of the package are described below.

VII.1. LIBRARY UPDATING PROCEDURE

If users would like to generate their own libraries, preparation of the following directory structure on the hard disk is recommanded:

```
[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 the hard disk:

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 on FOR.SRC and BAT.SRC, specifying extensions FOR and BAT for the expanded files, respectively. Input instructions for DCKSPL are included as comments 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 the hard disk:

MISCINP.ZIP	Miscellaneous input files.
DOP.SRC	Doppler benchmark inputs.
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.

Split all 'name'.SRC files with the DCKSPL code, using 'name' as the extension. Unzip the MISCINP.ZIP file into the same directory. This will create a number of auxiliary files that are needed for generating the libraries, particularly:

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.

The IAEA evaluated nuclear data library is included on the CD-ROM for convenience, and is a compilation of evaluated nuclear data files from different sources.

The following file from the [DOWNLOADS] directory on the CD-ROM need to be loaded to the [DOSMAT] subdirectory on the hard disk:

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 the CD-ROM.

VII.2. ADDITIONAL PROGRAM PACKAGES

XnWlup	Software to plot cross-sections data from the WIMS-D Library (see the **readme** file provided with the package).
NRSC	NRSC package, for detailed resonance spectrum and λ factor calculations (see the **readme** file provided with the package).
TRIGLAV	Package for whole core benchmark calculations (see documentation provided with the package).

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Vienna, Austria: 15–18 February 1999
San Carlos de Bariloche, Argentina: 14–17 August 2000
Vienna, Austria: 19–23 November 2001

WIMSD-5B is an extremely popular reactor lattice code used in many nuclear laboratories for research and power reactor calculations. One major limitation has been the associated nuclear constants library, which was based on nuclear data originating from the 1960s combined with a series of empirical adjustments to improve performance. A new library has now been generated to remove this deficiency, based on the most recent evaluated nuclear data files. The definition of the constants and the data processing methods are described in this report, along with consideration of an extensive set of more than 200 analysed benchmarks that have been used to validate the new library. While the report has been primarily prepared to support the newly generated library, the detailed descriptions of the methods adopted will also make the task of updating the library easier as new data become available.

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