"Total Monte Carlo" Uncertainty propagation applied to the Phase II-2 burnup calculation

(A report for the Assembly Physics of TMI-1 PWR unit cell of the OECD/UAM working group)

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Abstract

The effects of nuclear data uncertainties are studied on a typical PWR fuel assembly model in the framework of the OECD Nuclear Energy Agency UAM (Uncertainty Analysis in Modeling) expert working group. The 'fast Total Monte Carlo' method is applied on a model for the Monte Carlo transport and burn-up code SERPENT. Uncertainties on k_∞, reaction rates, two-group cross sections, inventory and local pin power density during burn-up are obtained, due to transport cross sections for the actinides and fission products, fission yields and thermal scattering data. These results are submitted to the working group for the Phase-II study.

Chapter 1

Introduction

Since the beginning of the century, the nuclear data evaluation community is putting more and more attention to the assessment of uncertainties. This increased interest concerns both basic data (cross sections, emission spectra...) and calculated quantities for large systems, such as neutron multiplication factor (k_{eff}) for a reactor, void coefficient, leakage flux and others.
In the following we will apply the fast Total Monte Carlo (fast TMC) method for the benchmark exercise of the Phase II-2 burnup calculation as defined in Ref. [1].
The proposed approach for uncertainty calculations, now called "fast Total Monte Carlo", makes use of today's tremendous computational power and was extensively presented in dedicated references [2, 3]. The propagation of nuclear data uncertainties to reactor-type systems can be realized by means of Monte Carlo calculations, by repeating a large number of times the same simulations calculation (typically a thousand times), each time using a different nuclear data file for the isotope of interest. This collection of random nuclear data files are produced by running the nuclear reaction code TALYS [4] many times and contains cross sections, resonance parameters, single- and double-differential distributions. All these quantities are thus randomly varied from one benchmark calculation to another. In the present case, the NJOY processing code [5] processes all these nuclear data libraries into ACE files which are then used by the Monte Carlo code SERPENT [6]. Finally, for every random nuclear data library an entire SERPENT calculation is performed. In the TALYS calculations, the different data files are obtained by randomly changing the nuclear model input parameters (optical models, level densities. . .). With this "fast Total Monte Carlo" approach, the pin cell calculations are presented with inclusion of their uncertainties, using a method without linearization, and implicitly taking into account cross section correlations, cross correlation between reactions and the uncertainties of single- and double-differential distributions.
This is the underlying method which is applied in this work. The generalization of this method to a large number of nuclear data (cross sections, resonance parameters, neutron emission...) and of systems (a few tens of criticality benchmarks) is called "fast Total Monte Carlo" in the following. The following results are also based on this methodology: the robustness of TALYS coupled to Monte Carlo calculations [7, 8], the Total Monte Carlo method for nuclear uncertainty propagation [2], criticality benchmarks [9, 10, 11], fusion benchmarks [12, 13], reactor calculations [14, 15, 16, 17], self-shielding [18], nuclear data adjustment [19, 20] and finally the massive production of nuclear data evaluations and covariances for the TENDL libraries [21, 22, 23, 24].

Chapter 2

Uncertainty propagation

In this application of the fast TMC method, a few parameters and nuclear data have been randomized such as:

- Major actinides: ^{235}U, ^{238}U, ^{239}Pu,
- Thermal scattering data: H in H_2O,
- 12 Fission yields: ^{234,235,236,238}U, ^{239,240,241}Pu, ^{237}Np, ^{241,243}Am, ^{243,244}Cm,
- 13 Minor actinides: ^{234,236,237}U, ^{237}Np, ^{238,240,241,242}Pu, ^{241,242g,243}Am, ^{242,245}Cm
- 138 fission products: $^{72-74,76}$Ge, ^{75}As, $^{76-80,82}$Se, ^{79,81}Br, $^{80-84,86}$Kr, ^{85,87}Rb, $^{86-88,92}$Sr, ^{89}Y, ^{93,95}Zr, ^{94,95}Nb, $^{95-97}$Mo, ^{99}Tc, $^{99-104,106}$Ru, ^{103,105,106}Rh, $^{104-108,110}$Pd, ^{109}Ag, $^{111-114,116}$Cd, ^{113,115}In, $^{115,117-119,126}$Sn, ^{121,123,125}Sb, $^{122-128,130}$Te, ^{127,129,135}I, $^{128,130-132,134-136}$Xe, $^{133-137}$Cs, $^{134-138}$Ba, ^{140}La, ^{140,142}Ce, ^{141,144}Pr, $^{142-146,148,150}$Nd, $^{147-149}$Pm, $^{147,149-152,154}$Sm, $^{151-156}$Eu, $^{152,154-158,160}$Gd, ^{159,160}Tb, $^{160-164}$Dy, ^{165}Ho, ^{166,167}Er.

In the whole calculation process, the reactor power is kept constant (see Ref. [1] for details).

The uncertainty on a quantity x is defined as $\Delta\sigma/\sigma \times 100$, with $\Delta\sigma$ the standard deviations of the probability distributions obtained by varying the element of interest:

$$\Delta\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\sigma_i - \overline{\sigma})^2} \tag{2.1}$$

with σ_i the quantity for the run i and $\overline{\sigma}$ the average of σ_i.

2.1 Methodology

The same SERPENT model for each of the calculation is used in the Monte Carlo method. In the same way, the same version of the processing tool NJOY [25, 5] (version 99.364) is used for the entire study.
The procedure to generate random ENDF files together with an ENDF file containing the average cross sections and the covariance information was detailed in Ref. [2, 3]. In summary, 20 to 30 theoretical parameters are all varied together within pre-determined ranges to create TALYS inputs. With the addition of a large number of random resonance parameters, nuclear reactions from thermal energy up to 20 MeV are covered. The TALYS system creates random ENDF nuclear data files based on these random inputs. At the end of the random file generation, the covariance information (average, uncertainties and correlations) are extracted and formatted into an ENDF file.
After the generation of random nuclear data files, a few codes and programs are used: SERPENT and NJOY. To produce files used by SERPENT, the ACER module of NJOY is needed.

We emphasize that automation and a disciplined, quality assured working method (with emphasis on reproducibility) is imperative to accomplish this. First of all, the codes TALYS, NJOY and SERPENT need to very

robust and secured against relatively large variations in input parameters. Next, all detailed knowledge about the material/benchmark in question should be present in the input files of these codes. It is clear that manual intervention must be completely excluded in the sequence of code calculations. Once all that is assured, the rest is relatively simple: if we can do a full calculation loop once, we can also do it 1000 times.
The input files for this method are a SERPENT geometry input file and n random ENDF files. Each random ENDF file is produced by the TALYS system (see Fig. 2.2), is fully reproducible and consists of a unique set of nuclear data. Each random file is completely different from another one: nu-bar and energy released per fission ("*MF1*" in ENDF language), resonance parameters ("*MF2*"), cross sections ("*MF3*"), angular distributions ("*MF4*"), fission neutron spectrum ("*MF5*"), double differential data ("*MF6*"), isomeric data ("*MF8-10*") and gamma production data ("*MF12-15*") are varied. Examples of random cross sections for important actinides are presented in Ref. [26].

Only the main outlines will be repeated here. The fast TMC method takes advantages of associating the randomization of nuclear data inputs together with the random source neutrons. It simply consists of repeating identical calculations with each time different random nuclear data files and random seeds for random number generator of the Monte Carlo transport code. Additionally, the neutron history for each random calculation is a relatively small: if m neutron histories is desirable to obtain a sufficiently small statistical uncertainty for a given calculation, then each random set is using m/n neutron history, n being the number of random files. In Ref. [3], it is advised to take $n = 300$. m/n should not be too small, and n can be decreased to obtain an acceptable m/n value. The obtained spread in a calculated quantity will then reflect the spread of input parameters such as nuclear data.

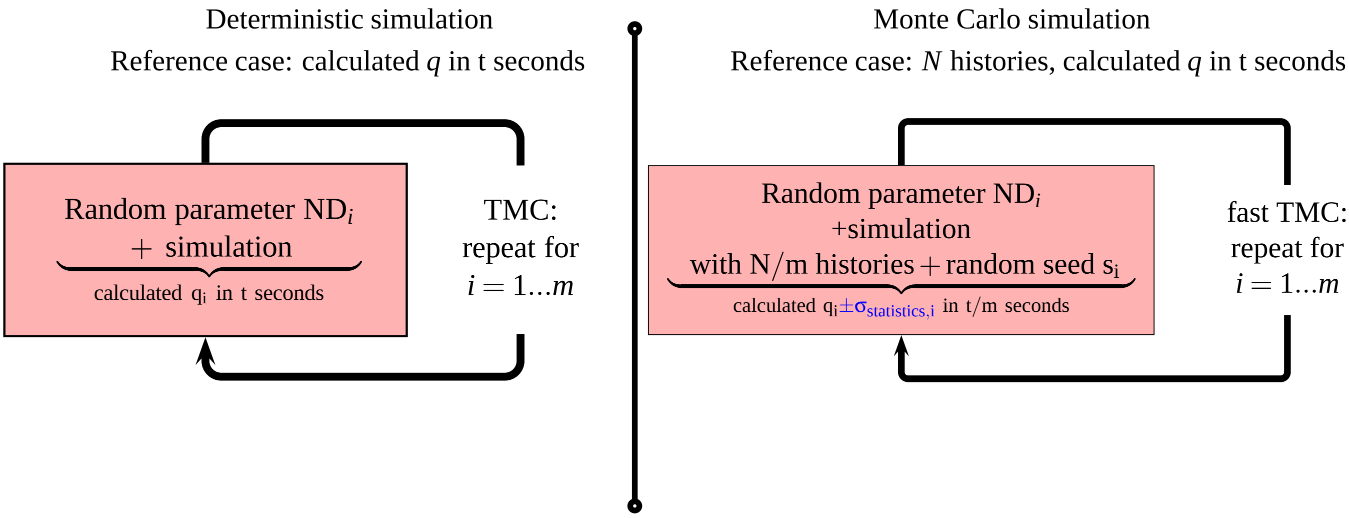

Figure 2.1: Simplified presentation of the TMC and fast TMC methods in case of deterministic and Monte Carlo simulations.

This method can be applied to quantities during burn-up calculations: k_{eff}, nuclide inventory, reaction rates, grouped cross sections... As fast TMC will be applied with the Monte Carlo transport and depletion code SERPENT, the observed spread (for instance in k_{eff}) can be related to nuclear data with the following equation:

$$\sigma^2_{\text{observed}} = \sigma^2_{\text{nuclear data}} + \overline{\sigma}^2_{\text{statistics}} \tag{2.2}$$

In the following, σ is the standard deviation of a distribution and will be used for the definition of uncertainty. σ_{observed} is the observed standard deviation from the n realizations of the same SERPENT calculation, each time with different nuclear data. $\sigma_{\text{nuclear data}}$ is the uncertainty on the calculated quantity due to the variations of nuclear data. $\overline{\sigma}_{\text{statistics}}$ is the statistical uncertainty from the m neutron history.
If σ_{observed} is simply "*observed*", $\overline{\sigma}_{\text{statistics}}$ needs to be calculated. In the case of quantity provided by SERPENT

with their own statistical uncertainty, $\overline{\sigma}_{\mathrm{statistics}}$ can be obtained with the following equation:

$$\overline{\sigma}_{\mathrm{statistics}} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\sigma^2_{\mathrm{statistics,i}}} \tag{2.3}$$

$\sigma_{\mathrm{statistics,i}}$ is the statistical uncertainty provided by SERPENT for the run i, with i from 0 to n. Eq. (2.3) is valid if the seed of the random number generator of the Monte Carlo transport part of the code is randomly changed. In the case of the original TMC description, the seed is set to a unique value for all the n runs, making the use of Eq. (2.3) not possible. In fast TMC, n calculations with m/n neutron histories is realized in the equivalent time of one unique calculation with m neutron history.
In the case of quantities not provided with their own statistical uncertainties, such as number densities for the isotope inventory, one needs to independently evaluate $\sigma_{\mathrm{statistics,i}}$. In this case, n calculations are also realized, but only changing randomly the seed. Thus, the spread in the observed quantity is only due to the statistics. This assessment of $\sigma_{\mathrm{statistics,i}}$ is increasing the calculation time by a factor 2, leading to the calculation of $\sigma_{\mathrm{nuclear\ data}}$ in twice the time of one unique calculation with m neutron history.
Finally, in the case of possible bias in $\sigma_{\mathrm{statistics,i}}$ (as explained in Ref. [3]), the independently evaluation of $\sigma_{\mathrm{statistics,i}}$ is recommended.

In practice, the following is performed:

1. realize a first SERPENT calculation for a given geometry and all nuclear data set to ENDF/B-VII.1, with $n = 2000 \times 500$ (2000 neutron histories for 500 cycles),

2. repeat the same calculation m times (m from 100 to 300, depending on the convergence rate of the uncertainties), with each time different random seeds and nuclear data (see next section),

3. extract k_{eff} distributions and use Eqs. (2.2) and (2.3) to extract $\sigma_{\mathrm{nuclear\ data}}$.

Burnup calculations are performed up to 60 GWd/tHM, followed by cooling time. In each burnup steps, the random nuclear data are used, thus propagating the effect of nuclear data through depletion steps.

2.2 Production of nuclear data

The method applied in this paper, fast Total Monte Carlo, is based on Monte Carlo calculations, complete control over nuclear data and because of the large number of calculations involved, no manual intervention. The simple idea of the TMC method is to repeat the same reactor physics calculation a large number of times, randomly varying each time the entire nuclear data library. Therefore, each calculation will give a different result, defining a probability distribution for the calculated quantity. Depending on the variation of the nuclear data, different distributions (average and standard deviation) can be obtained for quantities such as k_{eff}, inventory, void coefficient and so on. To obtain random sets of nuclear data, one can start from existing covariance files found in nuclear data libraries and generate random cross sections. Then each random simulation would use these random cross sections. This approach, if already more exact and easier to use than a perturbation-based calculation, suffers from the limited availability of covariance files, often restricted to cross sections.
The method proposed in the following is not using covariance files, but is instead generating random nuclear data from fundamental theoretical nuclear quantities with the help of a nuclear reaction code (such as TALYS [4]). The TMC method has already been presented in a few dedicated papers (see for instance Ref. [2, 7] for the description of the methodology). It was already successfully applied to different systems: validation of ^{23}Na [8], ^{63,65}Cu [27] and ^{239}Pu [19], void coefficient, k_{eff}, β_{eff}, burn-up and radiotoxicity for a Kalimer-type Sodium Fast Reactor [17], fusion systems [12], criticality-safety benchmarks [10]. The TMC Method was compared with traditional methods of uncertainty propagation [15] and has proved to be simpler to use with the bypass of covariance processing codes.
It revolves around the idea to calculate a large number of times the same quantity, each time randomly changing parts of the nuclear data. In order to achieve that, a complete control on the nuclear data production is required. It is not specific to actinides, although it should be mentioned that the main difference between an evaluation of a major actinide and a regular isotope is the amount of time spent to obtain the best possible TALYS input parameters.

Once these input parameters are known (together with their uncertainties), they are stored to be re-used as needed. The complete schematic approach is presented in Fig. 2.2.

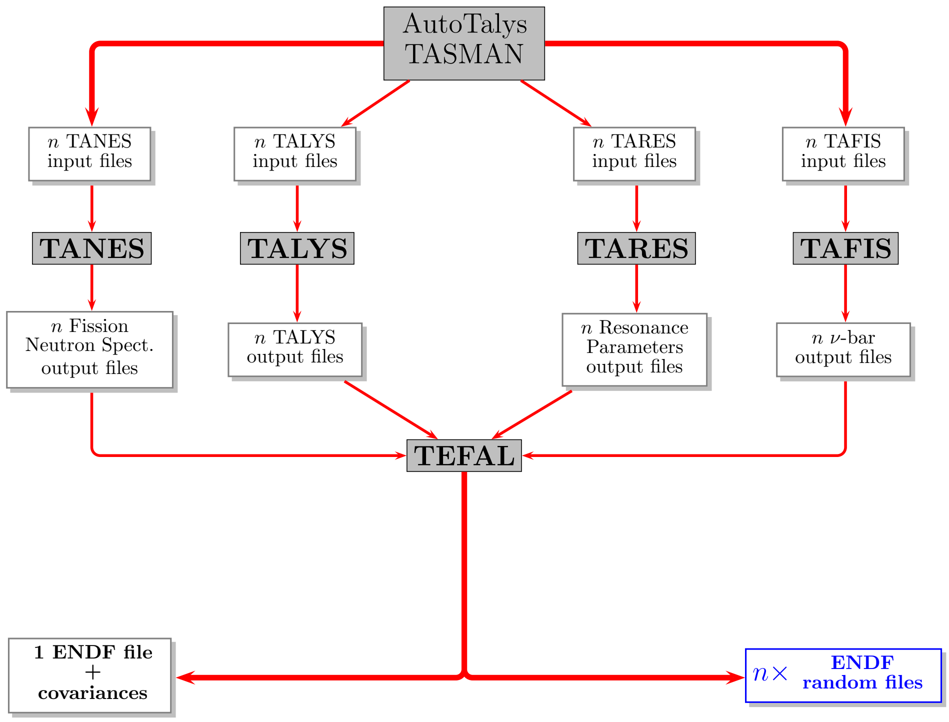

Figure 2.2: Flowchart of the nuclear data file evaluation and production with the TALYS system.

The full nuclear data file production relies on a small number of codes and programs, automatically linked together. The output of this system is either one ENDF-6 formatted file, including covariances if needed, or a large number of random ENDF-6 files. The central evaluation tool is the TALYS code. A few other satellite programs are used to complete missing information and randomize input files. At the end of the calculation scheme, the formatting code TEFAL produces the ENDF files. The following programs are used in this work:

- The TALYS code
  The nuclear reaction code TALYS has been extensively described in many publications (see Refs. [4, 28]). It simulates reactions that involve neutrons, gamma-rays, *etc* from thermal to 200 MeV energy range. With a single run, cross-sections, energy spectra, angular distributions *etc* for all open channels over the whole incident energy range are predicted. The nuclear reaction models are driven by a restricted set of parameters, such as optical model, level density, photon strength and fission parameters, which can all be varied in a TALYS input file. All information that is required in a nuclear data file, above the resonance range, is provided by TALYS.

- The TASMAN code
  TASMAN is a computer code for the production of covariance data using results of the nuclear model code TALYS, and for automatic optimization of the TALYS results with respect to experimental data. The essential idea is to assume that each nuclear model (*i.e.* TALYS input) parameter has its own uncertainty, where often the uncertainty distribution is assumed to have either a Gaussian or uniform shape. Running TALYS many times, whereby each time all elements of the input parameter vector are *randomly* sampled from a distribution with a specific width for each parameter, provides all needed statistical information to produce a full covariance matrix. The basic objective behind the construction of TASMAN is to facilitate all this.
  TASMAN is using central value parameters, as well as a probability distribution function. The central values were chosen to globally obtain the best fit to experimental cross sections and angular distributions (see for instance Ref. [29]). The uncertainties on parameters (or widths of the distributions) are also obtained by

comparison with experimental data, directly taken from the EXFOR database [30]. The distribution probability can then be chosen between, equiprobable, Normal or other. In principle, with the least information available (no measurement, no theoretical information), the equiprobable probability distribution should be chosen. Otherwise, the Normal distribution is considered.
An important quantity to obtain rapid statistical convergence in the Monte Carlo process is the selection of random numbers. Several tests were performed using pseudo-random numbers, quasi-random numbers (Sobol sequence), Latin Hypercube random numbers or Centroidal Voronoi Tessellations random numbers. As the considered dimension (number of parameters for a TALYS calculation) is rather high (from 50 to 80), not all random number generators perform as required (covering as fast as possible the full parameter space, without repeating very similar configurations and avoiding correlations). For the time being, the random data files are produced using the Sobol quasi-random number generator.

- The TEFAL code
  TEFAL is a computer code for the translation of the nuclear reaction results of TALYS, and data from other sources if TALYS is not adequate, into ENDF-6 formatted nuclear data libraries. The basic objective behind the construction of TEFAL is to create nuclear data files without error-prone human interference. Hence, the idea is to first run TALYS for a projectile-target combination and a range of incident energies, and to obtain a ready to use nuclear data library from the TEFAL code through processing of the TALYS results, possibly in combination with experimental data or data from existing data libraries. This procedure is completely automated, so that the chance of *ad hoc* human errors is minimized.

- The TARES program
  This is a code to generate resonance information in the ENDF-6 format, including covariance information. It makes use of resonance parameter databases such as the EXFOR database [30], resonance parameters from other libraries (ENDF/B-VII.0 [31]) or compilations (Ref. [32]). ENDF-6 procedures can be selected, for different R-matrix approximations, such as the Multi-level Breit Wigner or Reich Moore formalism. The covariance information is stored either in the "regular" covariance format or in the compact format. For short range correlation between resonance parameters, simple formulas as presented in Ref. [7] are used, based on the capture kernel. No long-range correlations are considered for now.
  In the case of major actinides, resonance parameters are taken from evaluated libraries, such as ENDF/B-VII.0 or JEFF-3.1. These values are almost never given with uncertainties. In this case, uncertainties from compilations or measurements are assigned to the evaluated resonance parameters. Although not the best alternative, it nevertheless allows to combine central values with uncertainties.
  For the unresolved resonance range, an alternative solution to the average parameters from TALYS is to adopt parameters from existing evaluations. In the following, this solution is followed. The output of this program is a resonance file with central values (MF2), a resonance file with random resonance parameters (MF2) and two covariance files (MF32 standard and compact).

- The TANES program
  TANES is a simple program to calculate fission neutron spectrum based on the Los Alamos model [33]. The original Madland-Nix [34] or Los Alamos model for the calculation of prompt fission neutrons characteristics (spectra and multiplicity) has been implemented in a stand-alone module. The TANES code is using this stand-alone module, combined with parameter uncertainties (on the total kinetic energy, released energy and multi-chance fission probabilities) to reproduce and randomize the fission neutron spectrum. The output of this program is the central and random values for the fission neutron spectra at different incident energies (MF5) and their covariances (MF35).

- The TAFIS program
  TAFIS is used to calculate fission yields, prompt neutron emission from fission and other necessary fission quantities (kinetic energy of the fission products, kinetic energy of the prompt and delayed fission neutrons, total energy released by prompt and delayed gamma rays). For fission yields, it is using the systematics of fission-product yields from A.C. Wahl [35], combined with *ad hoc* uncertainties. It calculates the independent and cumulative fission yields at any incident energy up to 200 MeV and for different incident particles (spontaneous, neutrons, protons, deuterons, *etc*). Empirical equations representing systematics of fission-product yields are

derived from experimental data. The systematics give some insight into nuclear-structure effects on yields, and the equations allow estimation of yields from fission of any nuclide ($Z = 90$ to 98 and $A = 230$ to 252). For neutron emission, different models are used depending on the energy range and are presented in Ref. [35]. The output of this program is a fission yield file with uncertainties, prompt neutron emission files for central and random values (MF1 MT452), a list of central and random fission quantities (MF1 MT458) and prompt neutron covariances (MF31).

- Autotalys
  Autotalys is a script which takes care of the communication between all software and packages described above and runs the complete sequence of codes, if necessary for the whole nuclide chart. Many options regarding TALYS and all other codes can be set, and it makes the library production straightforward.

2.3 Type of nuclear data

Because of the different stages of the reactor calculations (transport, depletion and radiotoxicity), the nuclear data have been historically divided in different categories. The underlying quantities are nevertheless the same. For instance, because different codes are used to calculate the transport of neutrons and the depletion of fuel, different nuclear data (namely transport and activation data) happened to be used for the same reactions. With SERPENT, it is now possible to specify a unique source of nuclear data for the whole chain of calculations, from the first irradiation time to centuries of decay.
For convenience, some parts of the nuclear data are still separated because of the type of physics they represent: fission yields, decay data (half-lifes, Q-values, gamma decay scheme...) and reactions of a nucleus with an incident neutron (cross sections, emitted particles, emission spectra, angular distributions...). These three types of data are also measured and evaluated by different communities with different knowledge. In the following we will separate these three types of nuclear data to assess their individual impacts. In the following, the next three terms will be used:

1. *transport data*: it will be associated with cross sections, angular distributions, single and double differential data, emission spectra. These quantities are used in the transport calculations as well as with the depletion code. The uncertainties on these quantities were verified in many different calculations and references (see for instance Refs. [2, 7, 8, 27, 19, 17, 12, 10]), These data are usually grouped in a file called *ENDF file*, divided in different parts, called *MF1, MF2,...,MF35*.

2. *fission yields*: In the depletion calculations, the fission products produced from the fission of actinides are accounted based on the fission yields taken from separated evaluated files. In the present case, they are obtained from the TAFIS code and normalized to the ENDF/B-VII.0 yields and uncertainties. If a yield (and its uncertainty) is present in ENDF/B-VII.0, it is used in this work, and in the contrary, the Wahl systematics is used [35]. For the present calculations, yield uncertainties are limited to a maximum of 100 %.

3. and the *decay data* are the decay properties of an excited or unstable nucleus (half-lifes, Q-values, decay scheme).

Chapter 3

Description of the SERPENT model

The description of the geometry of the benchmark is given in Ref. [1].
This test case is modeled to the parameters of TMI-1 and based on an experiment performed at the Takahama-3 reactor. It is a long-term irradiation case with a constant power level at all times. The case is modeled using a single fuel assembly, and all of the parameters are defined in Ref. [1]. The geometry of the TMI-1 FA is defined in Fig. 3.1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	g	-	-	-	-	-	-	-	-	-	-	-	g	-
3	-	-	-	-	-	G	-	-	-	G	-	-	-	-	-
4	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	G	-	-	G	-	-	-	G	-	-	G	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	I	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	G	-	-	G	-	-	-	G	-	-	G	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-
13	-	-	-	-	-	G	-	-	-	G	-	-	-	-	-
14	-	g	-	-	-	-	-	-	-	-	-	-	-	g	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 3.1: TMI-1 FA Pin Layout.

The numbers in the above figure represent the various rods that are in the FA, and they are defined in Fig. 3.2. Other details about this FA are given in Fig. 3.3. The physical dimensions and parameters of the fuel rods are found

Marker	Rod Type
g	2.0 w/o Gd 4.12% 235U pin
G	Guide Tube
I	Instrumentation Tube
-	4.12% 235U fuel pin

Figure 3.2: TMI-1 FA Pin Descriptions.

FA Pitch	218.1 mm
Active Height	3657.6 mm
# Guide Tubes	16
# Instrumentation Tubes	1
# 2.0 w/o Gd pins	4
# 4.12% 235U pins	204
Total rods/FA	225

Figure 3.3: TMI-1 FA Details.

in Fig. 3.4. The TMI-1 core's boundary conditions define the nominal operating conditions of the entire core. They

Cladding OD	10.922 mm
Cladding ID	9.58 mm
Cladding Thickness	0.673 mm
Pin Pitch	14.427 mm
Fuel Pellet OD	9.390 mm
Fuel Pellet Height	11.4 mm
% Density	93.8% TD
Guide Tube OD	13.462 mm
Guide Tube ID	12.649 mm
Instrumentation Tube OD	12.522 mm
Instrumentation Tube ID	11.201 mm

Figure 3.4: TMI-1 Fuel, Guide, and Instrumentation Rod Dimensions and Parameters.

are given in Fig. 3.5.

Core Power	2772 MWt
Coolant Temperature	578 K
Core Pressure	15.51 MPa
Core Coolant Flow Rate	16052.4 kg/sec

Figure 3.5: TMI-1 Core Boundary Conditions

Chapter 4

Results

The complete results for all modified parameters and nuclear data are presented in Appendix D.1 to J and some results are also presented in Figures A.1 to B.10. The amount of available data is rather large and only the main contributors to the uncertainties will be presented in this section.
The "engineering parameters" such as the pellet diameter, the fuel enrichment, the fuel density and the moderator density are not part of the benchmark requirements and therefore will not be included in the following ranking. But readers interested in these quantities can refer to the Appendix. In Tables 4.1 to 4.4 are presented the most important reactions in terms of uncertainties for quantities of interest.

Table 4.1: Total uncertainties for k_∞ and reaction rates (%) varying ^{235}U, ^{238}U, ^{239}Pu, fission products, minor actinides, fission yields and H in H_2O thermal scattering. Details are given in appendix.

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.710	0.698	0.699	0.741	0.737	0.748
rr $^{235}U_{n,\gamma}$	2.06	2.04	2.03	2.14	2.30	2.56
rr $^{238}U_{n,\gamma}$	1.82	1.81	1.72	1.70	1.49	1.31
rr $^{239}Pu_{n,\gamma}$	2.68	2.64	2.13	1.96	1.95	2.04
rr $^{240}Pu_{n,\gamma}$	4.89	5.11	4.93	4.55	4.54	4.66
rr $^{241}Pu_{n,\gamma}$	1.80	2.07	1.70	1.67	1.85	2.13
rr $^{235}U_{n,f}$	0.57	0.59	0.79	1.17	1.58	2.10
rr $^{238}U_{n,f}$	7.38	7.41	5.78	4.94	4.41	4.10
rr $^{239}Pu_{n,f}$	2.24	2.21	2.22	2.12	2.17	2.36
rr $^{240}Pu_{n,f}$	3.08	3.11	2.53	2.20	2.02	1.81
rr $^{241}Pu_{n,f}$	1.60	1.59	1.32	1.33	1.56	1.93

Table 4.2: Total uncertainties for macroscopic cross sections (%) varying ^{235}U, ^{238}U, ^{239}Pu, fission products, minor actinides, fission yields and H in H_2O thermal scattering. Details are given in appendix.

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
Σ_{abs1}	1.25	1.18	1.22	1.27	1.23	1.30

Continued on next page

Table 4.2 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
Σ_{abs2}	1.67	1.64	1.32	1.20	1.25	1.36
Σ_{fiss1}	1.80	1.80	1.85	1.90	1.88	1.96
Σ_{fiss2}	2.13	2.11	1.76	1.59	1.57	1.69
$\nu\Sigma_{fiss1}$	2.13	2.13	2.16	2.23	2.26	2.42
$\nu\Sigma_{fiss2}$	2.12	2.10	1.68	1.54	1.55	1.69
D_1	2.14	2.23	1.81	1.56	1.40	1.28
D_2	5.64	5.63	5.64	5.54	5.62	5.39
Σ_{trn1}	2.26	2.36	1.98	1.75	1.63	1.53
Σ_{trn2}	5.39	5.41	5.36	5.34	5.38	5.20
InvVel_1	3.63	3.64	3.45	3.34	3.22	3.18
InvVel_2	1.56	1.59	1.58	1.56	1.56	1.51
scatt. gr. 1 to gr. 1	1.48	1.49	1.35	1.27	1.22	1.20
scatt. gr. 2 to gr. 1	6.81	6.96	6.84	7.51	7.55	7.67
scatt. gr. 1 to gr. 2	1.67	1.68	1.56	1.50	1.46	1.45
scatt. gr. 2 to gr. 2	6.38	6.35	6.33	6.34	6.32	6.30
ADF, side W, gr. 1	0.25	0.22	0.32	0.43	0.21	0.18
ADF, side S, gr. 1	0.25	0.22	0.32	0.43	0.21	0.18
ADF, side E, gr. 1	0.25	0.22	0.32	0.43	0.21	0.18
ADF, side N, gr. 1	0.25	0.22	0.32	0.43	0.21	0.18
ADF, side W, gr. 2	0.70	0.75	0.64	0.81	0.66	0.74
ADF, side S, gr. 2	0.70	0.75	0.64	0.81	0.66	0.74
ADF, side E, gr. 2	0.70	0.75	0.64	0.81	0.66	0.74
ADF, side N, gr. 2	0.70	0.75	0.64	0.81	0.66	0.74

Table 4.3: Total uncertainties for actinides number densities (%) varying ^{235}U, ^{238}U, ^{239}Pu, fission products, minor actinides, fission yields and H in H_2O thermal scattering. Details are given in appendix.

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
N_d ^{234}U	0	0.03	1.63	3.26	4.98	6.63
N_d ^{235}U	0	0	0.17	0.41	0.79	1.35
N_d ^{236}U	0	2.06	1.95	1.92	1.90	1.89
N_d ^{238}U	0	0	0.01	0.02	0.03	0.04
N_d ^{237}Np	0	36.16	10.94	6.70	5.29	4.84
N_d ^{238}Pu	0	36.89	15.85	11.07	9.43	8.97
N_d ^{239}Pu	0	1.90	1.81	2.10	2.40	2.69
N_d ^{240}Pu	0	4.32	2.06	2.23	2.69	3.19
N_d ^{241}Pu	0	8.85	5.79	4.48	3.61	3.23
N_d ^{242}Pu	0	10.70	7.24	5.42	4.14	3.38
N_d ^{241}Am	0	9.43	5.98	4.79	4.72	5.57
N_d ^{243}Am	0	16.59	13.76	11.95	10.50	9.07
N_d ^{242}Cm	0	14.69	11.82	10.05	8.60	7.32
N_d ^{244}Cm	0	21.43	18.67	16.90	15.47	14.07

Table 4.4: Total uncertainties for the number densities of fission products (%) varying ^{235}U, ^{238}U, ^{239}Pu, fission products, minor actinides, fission yields and H in H_2O thermal scattering. Details are given in appendix.

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
N_d ^{90}Sr	0	6.17	5.95	5.80	5.69	5.61
N_d ^{95}Mo	0	5.55	5.33	5.49	5.93	6.49
N_d ^{99}Tc	0	12.45	11.11	10.29	9.75	9.42
N_d ^{101}Ru	0	2.62	2.68	3.04	3.48	3.92
N_d ^{103}Rh	0	13.29	11.72	11.28	11.38	11.71
N_d ^{109}Ag	0	34.82	26.65	25.45	23.25	21.29
N_d ^{129}I	0	8.18	8.49	10.71	12.47	13.75
N_d ^{133}Xe	0	11.27	9.68	8.91	8.47	8.31
N_d ^{135}Xe	0	7.08	6.97	7.09	7.28	7.53
N_d ^{133}Cs	0	3.74	3.51	3.54	3.78	4.15
N_d ^{134}Cs	0	14.22	12.19	11.97	11.65	11.25
N_d ^{137}Cs	0	2.11	2.05	2.03	2.02	2.03
N_d ^{144}Ce	0	2.57	2.87	3.55	4.34	5.14
N_d ^{142}Nd	0	22.08	22.01	22.03	21.91	21.78
N_d ^{143}Nd	0	4.09	4.08	4.55	5.27	6.03
N_d ^{144}Nd	0	2.44	3.96	4.29	4.44	4.50
N_d ^{145}Nd	0	4.71	4.67	5.25	6.21	7.34
N_d ^{146}Nd	0	16.54	15.01	13.94	13.10	12.45
N_d ^{148}Nd	0	16.56	14.59	13.52	12.76	12.22
N_d ^{147}Sm	0	9.59	9.75	11.52	14.17	16.89
N_d ^{149}Sm	0	12.41	9.40	8.76	8.79	9.07
N_d ^{150}Sm	0	12.50	10.26	9.13	8.59	8.34
N_d ^{151}Sm	0	29.31	21.93	16.72	13.52	11.65
N_d ^{152}Sm	0	29.05	16.65	14.38	12.68	11.53
N_d ^{153}Eu	0	30.01	16.75	13.39	12.26	11.74
N_d ^{154}Eu	0	34.94	24.66	19.43	16.00	13.55
N_d ^{155}Eu	0	32.71	16.92	14.58	13.67	12.12
N_d ^{155}Gd	0	32.81	18.17	13.47	12.42	11.95
N_d ^{156}Gd	0	36.47	16.96	13.18	12.05	11.45
N_d ^{157}Gd	0	33.77	22.79	20.87	19.03	17.96
N_d ^{158}Gd	0	31.14	17.18	16.60	16.17	16.15

Chapter 5

Conclusion

In this work, the fast "Total Monte Carlo" method is used to propagate nuclear data uncertaintiesfor the PWR burnup assembly benchmark as defined in the Uncertainty Analysis in Modeling (UAM) benchmark. Results for k_∞, reaction rates, number densities and local power are presented as function of burn-up steps. These results can now be compared with results from other methods. Depending on the quantity of interest, different quantities can play an important role. In the case of k_∞, ^{235}U(n,f) and ^{239}Pu(n,f) are the two main contributors to the total uncertainty (see Table 4.1). The engineering parameters (pellet diameter, fuel enrichment and density, and moderator density) have an important effect on the calculated quantities, often higher than the effect of nuclear data.
This work is submitted to the UAM working group, and after feedback, it will be condensed in a paper submitted for an peer-reviewed journal.

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Appendix A

Plots of uncertainties for k_∞

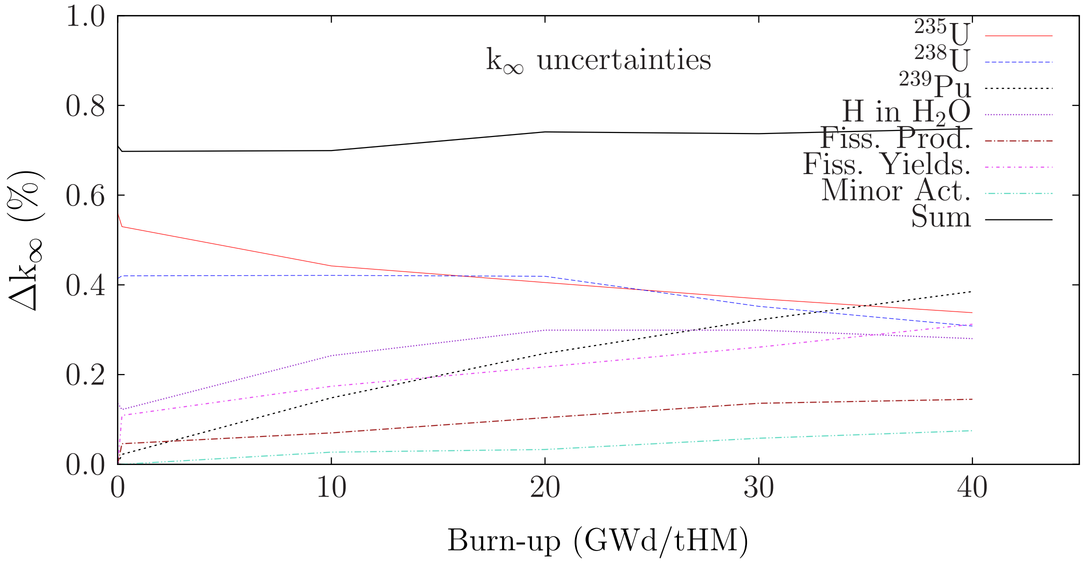

Figure A.1: Uncertainties during the burn-up for k_∞ for different reactions and nuclear data quantities.

Appendix B

Plots of uncertainties for reaction rates

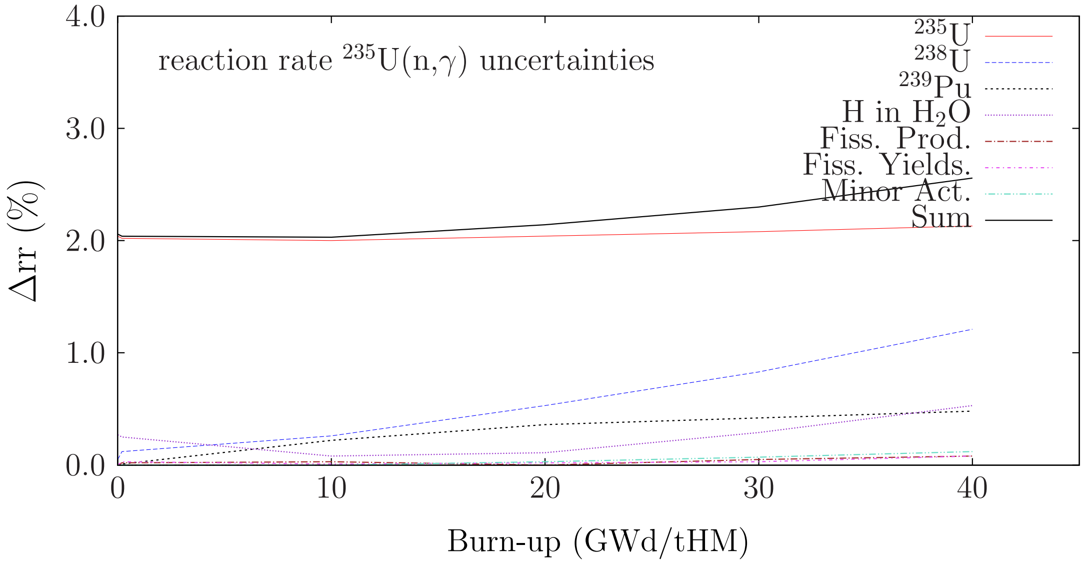

Figure B.1: Uncertainties on reaction rate for ^{235}U(n,γ) for nuclear data quantities.

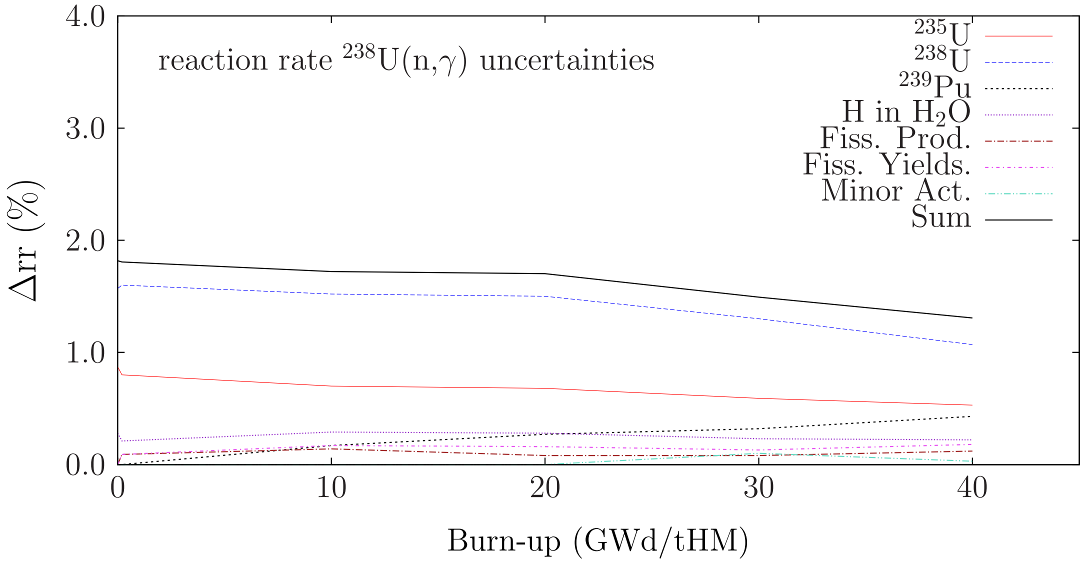

Figure B.2: Uncertainties on reaction rate for ^{238}U(n,γ) for nuclear data quantities

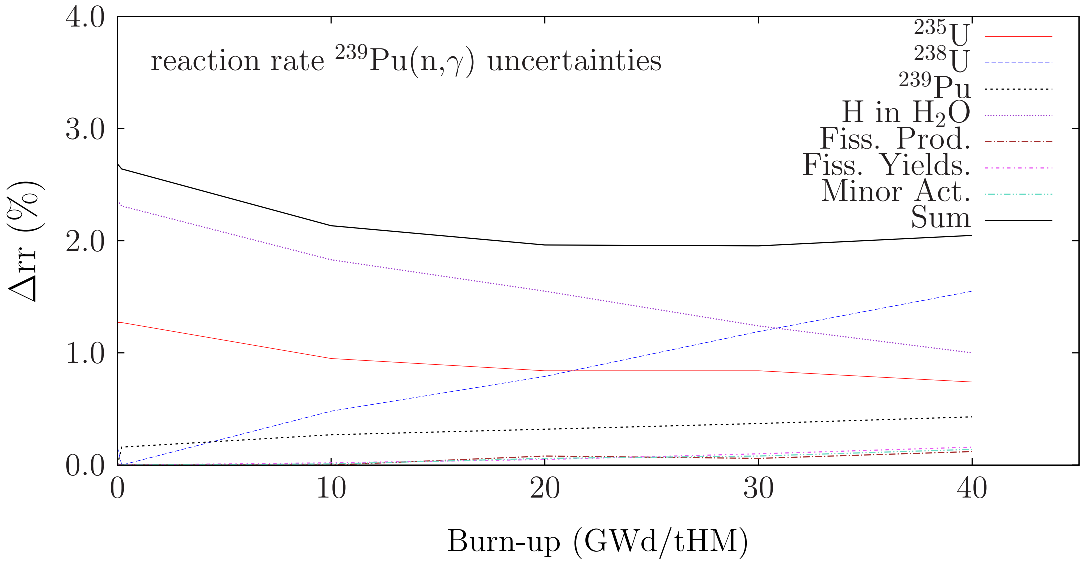

Figure B.3: Uncertainties on reaction rate for ^{239}Pu(n,γ) for nuclear data quantities

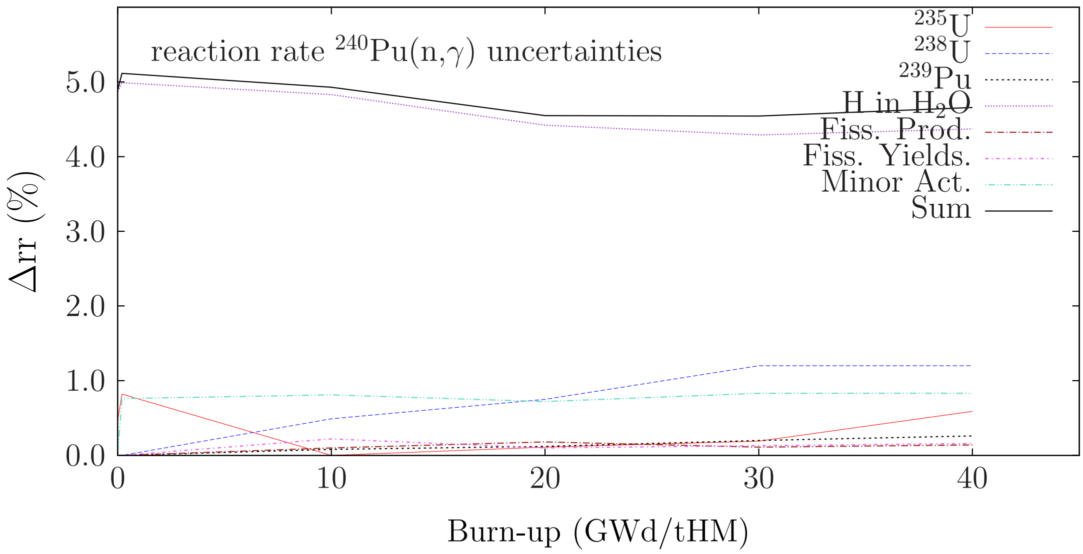

Figure B.4: Uncertainties on reaction rate for ^{240}Pu(n,γ) for nuclear data quantities

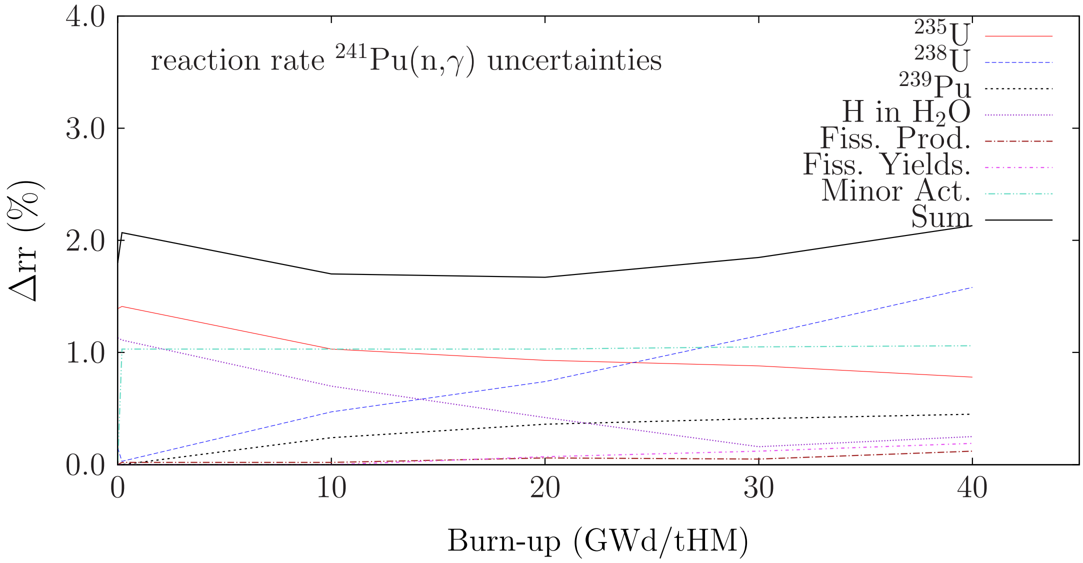

Figure B.5: Uncertainties on reaction rate for ^{241}Pu(n,γ) for nuclear data quantities

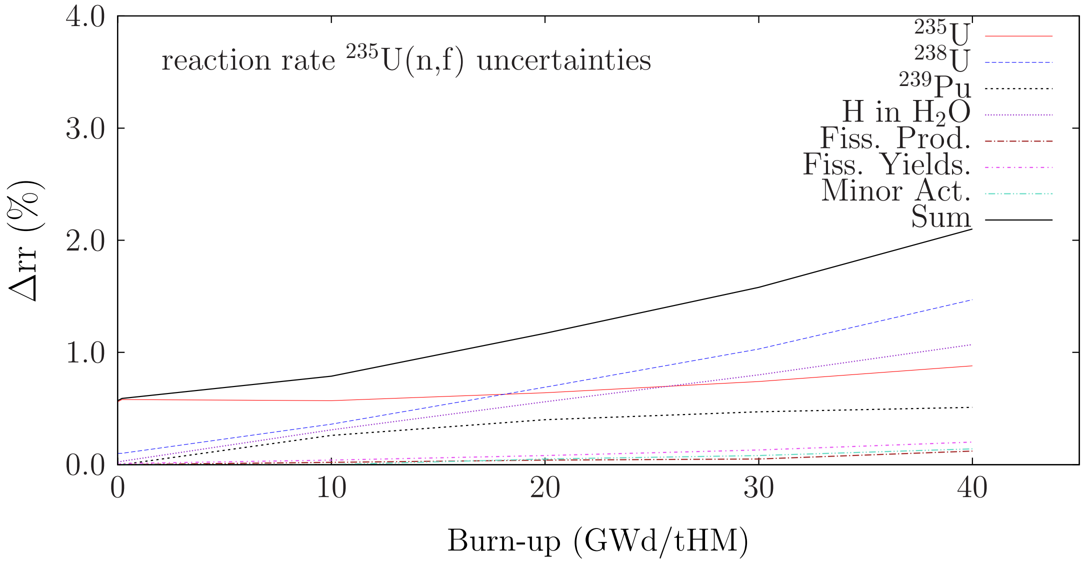

Figure B.6: Uncertainties on reaction rate for ^{235}U(n,f) for nuclear data quantities

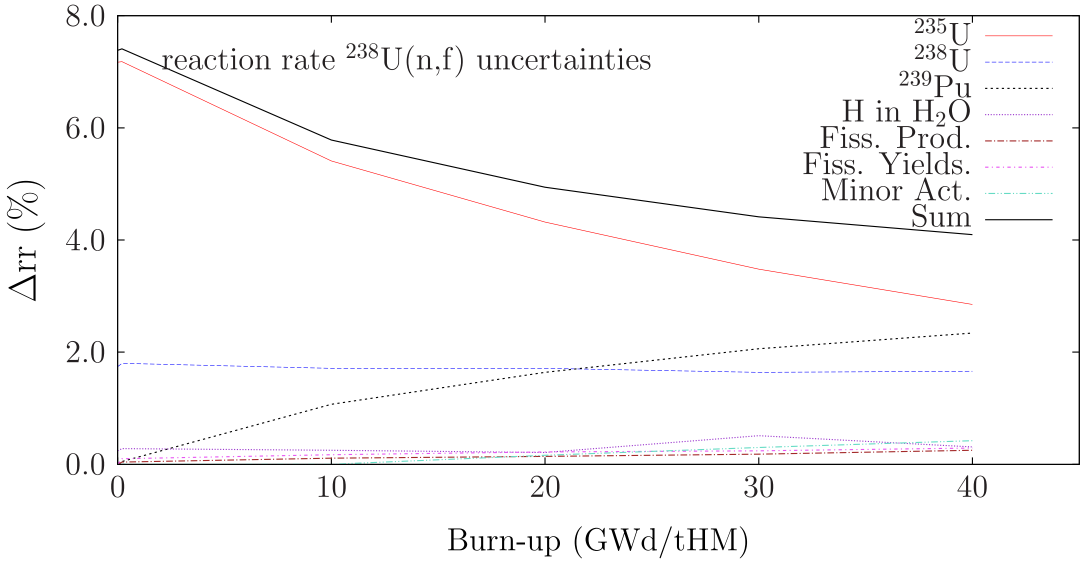

Figure B.7: Uncertainties on reaction rate for ^{238}U(n,f) for nuclear data quantities

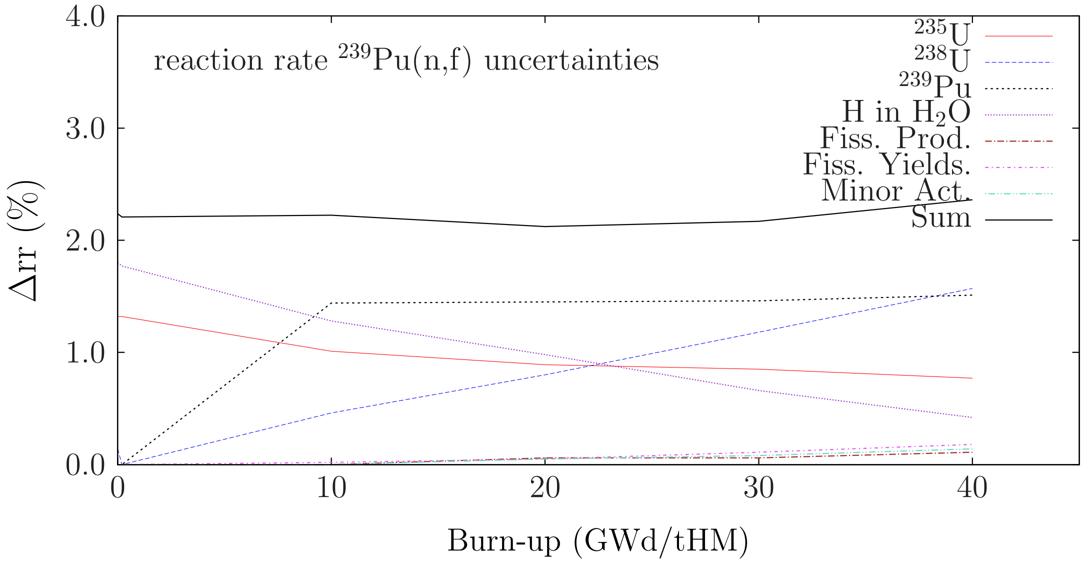

Figure B.8: Uncertainties on reaction rate for ^{239}Pu(n,f) for nuclear data quantities

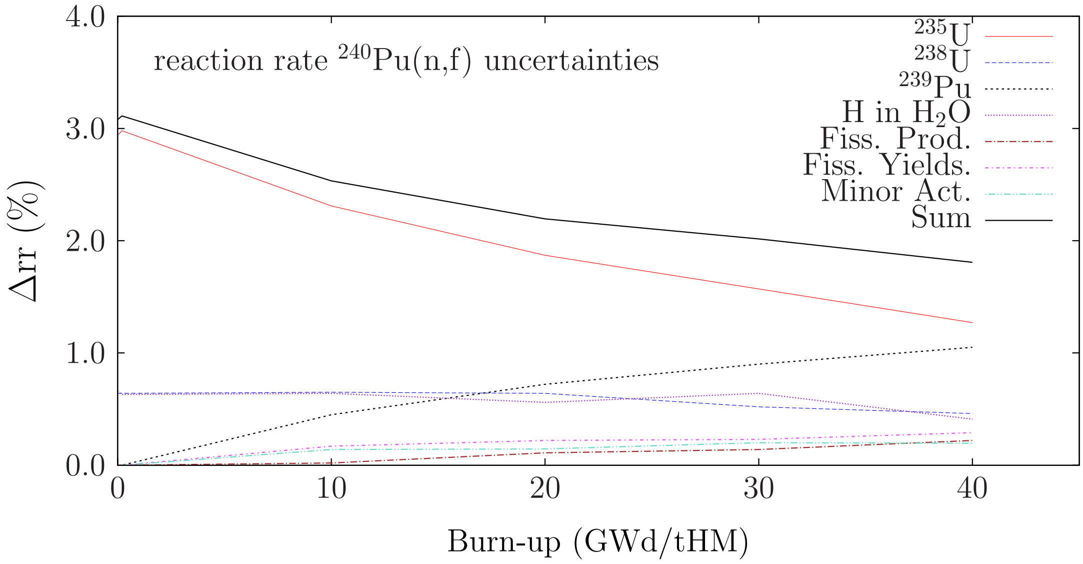

Figure B.9: Uncertainties on reaction rate for ^{240}Pu(n,f) for nuclear data quantities

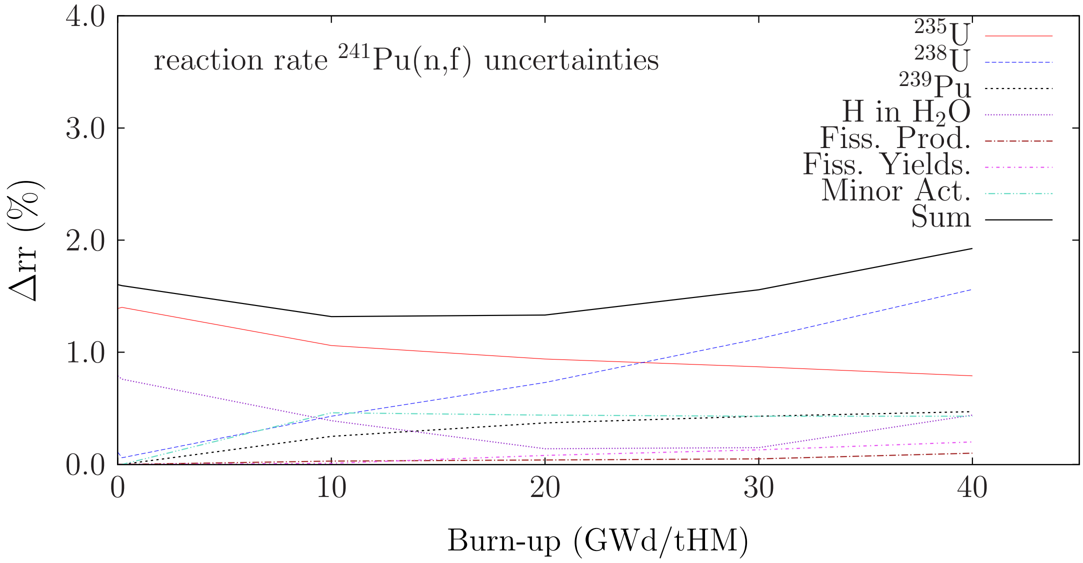

Figure B.10: Uncertainties on reaction rate for ^{241}Pu(n,f) for nuclear data quantities

Appendix C

Table for nominal values

Table C.1: Nominal values

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	1.39	1.35	1.26	1.17	1.09	1.02
rr $^{235}U_{n,\gamma}$	3.53e+17	3.56e+17	3.73e+17	4.09e+17	4.56e+17	5.08e+17
rr $^{238}U_{n,\gamma}$	3.49e+16	3.59e+16	3.88e+16	4.28e+16	4.71e+16	5.15e+16
rr $^{239}Pu_{n,\gamma}$	2.37e+18	2.40e+18	2.28e+18	2.37e+18	2.56e+18	2.81e+18
rr $^{240}Pu_{n,\gamma}$	9.42e+18	9.76e+18	7.97e+18	6.51e+18	5.88e+18	5.66e+18
rr $^{241}Pu_{n,\gamma}$	1.50e+18	1.51e+18	1.49e+18	1.58e+18	1.74e+18	1.93e+18
rr $^{235}U_{n,f}$	1.51e+18	1.52e+18	1.56e+18	1.70e+18	1.90e+18	2.13e+18
rr $^{238}U_{n,f}$	4.22e+15	4.37e+15	4.81e+15	5.31e+15	5.80e+15	6.28e+15
rr $^{239}Pu_{n,f}$	4.12e+18	4.16e+18	4.00e+18	4.20e+18	4.57e+18	5.05e+18
rr $^{240}Pu_{n,f}$	2.58e+16	2.67e+16	2.86e+16	3.09e+16	3.33e+16	3.59e+16
rr $^{241}Pu_{n,f}$	4.07e+18	4.09e+18	4.08e+18	4.37e+18	4.82e+18	5.37e+18
Σ_{abs1}	1.06e-2	1.06e-2	1.10e-2	1.13e-2	1.15e-2	1.17e-2
Σ_{abs2}	1.08e-1	1.12e-1	1.17e-1	1.17e-1	1.15e-1	1.11e-1
Σ_{fiss1}	3.59e-3	3.58e-3	3.18e-3	2.80e-3	2.47e-3	2.21e-3
Σ_{fiss2}	7.77e-2	7.65e-2	7.57e-2	7.09e-2	6.49e-2	5.90e-2
$\nu\Sigma_{fiss1}$	9.08e-3	9.06e-3	8.16e-3	7.32e-3	6.56e-3	5.94e-3
$\nu\Sigma_{fiss2}$	1.89e-1	1.86e-1	1.91e-1	1.83e-1	1.71e-1	1.58e-1
D_1	1.03e+	1.04e+	1.07e+	1.09e+	1.11e+	1.12e+
D_2	3.65e-1	3.70e-1	3.63e-1	3.61e-1	3.62e-1	3.64e-1
Σ_{trn1}	3.24e-1	3.20e-1	3.14e-1	3.07e-1	3.02e-1	2.97e-1
Σ_{trn2}	9.34e-1	9.20e-1	9.35e-1	9.38e-1	9.36e-1	9.29e-1
$InvVel_1$	5.59e-8	5.59e-8	5.47e-8	5.38e-8	5.32e-8	5.27e-8
$InvVel_2$	2.33e-6	2.32e-6	2.34e-6	2.37e-6	2.39e-6	2.41e-6
scatt. gr. 1 to gr. 1	5.08e-1	5.08e-1	5.08e-1	5.09e-1	5.10e-1	5.11e-1
scatt. gr. 2 to gr. 1	1.96e-3	2.02e-3	2.11e-3	2.10e-3	2.06e-3	1.97e-3
scatt. gr. 1 to gr. 2	1.63e-2	1.63e-2	1.59e-2	1.55e-2	1.53e-2	1.51e-2
scatt. gr. 2 to gr. 2	1.24e+0	1.24e+0	1.24e+0	1.25e+0	1.25e+0	1.26e+0
ADF, side W, gr. 1	9.85e-1	9.85e-1	9.94e-1	9.94e-1	9.94e-1	9.94e-1
ADF, side S, gr. 1	9.85e-1	9.85e-1	9.94e-1	9.94e-1	9.94e-1	9.94e-1
ADF, side E, gr. 1	9.85e-1	9.85e-1	9.94e-1	9.94e-1	9.94e-1	9.94e-1
ADF, side N, gr. 1	9.85e-1	9.85e-1	9.94e-1	9.94e-1	9.94e-1	9.94e-1
ADF, side W, gr. 2	9.47e-1	9.47e-1	9.62e-1	9.59e-1	9.57e-1	9.54e-1
ADF, side S, gr. 2	9.47e-1	9.47e-1	9.62e-1	9.59e-1	9.57e-1	9.54e-1
ADF, side E, gr. 2	9.47e-1	9.47e-1	9.62e-1	9.59e-1	9.57e-1	9.54e-1
ADF, side N, gr. 2	9.47e-1	9.47e-1	9.62e-1	9.59e-1	9.57e-1	9.54e-1
N_d ^{234}U	1.26e-6	1.26e-6	1.13e-6	1.01e-6	9.01e-7	8.04e-7
N_d ^{235}U	1.13e-3	1.12e-3	8.71e-4	6.62e-4	4.89e-4	3.56e-4
N_d ^{236}U	0.00	1.08e-6	4.77e-5	8.50e-5	1.14e-4	1.34e-4
N_d ^{238}U	2.18e-2	2.18e-2	2.17e-2	2.16e-2	2.14e-2	2.13e-2
N_d ^{237}Np	0.00	2.38e-9	1.55e-6	4.58e-6	8.35e-6	1.21e-5
N_d ^{238}Pu	0.00	9.28e-13	1.06e-7	6.48e-7	1.86e-6	3.71e-6
N_d ^{239}Pu	0.00	9.13e-7	7.35e-5	1.11e-4	1.29e-4	1.36e-4
N_d ^{240}Pu	0.00	3.40e-9	8.86e-6	2.33e-5	3.81e-5	5.08e-5
N_d ^{241}Pu	0.00	2.64e-11	3.21e-6	1.24e-5	2.28e-5	3.10e-5
N_d ^{242}Pu	0.00	2.48e-14	1.84e-7	1.61e-6	4.95e-6	9.79e-6
N_d ^{241}Am	0.00	3.57e-15	2.41e-8	1.81e-7	4.61e-7	7.42e-7
N_d ^{243}Am	0.00	1.17e-17	7.33e-9	1.42e-7	6.80e-7	1.78e-6
N_d ^{242}Cm	0.00	3.01e-18	2.30e-9	3.45e-8	1.31e-7	2.79e-7
N_d ^{244}Cm	0.00	5.36e-21	3.95e-10	1.72e-8	1.36e-7	5.05e-7

Continued on next page

Table C.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
N_d ^{90}Sr	0.00	2.85e-7	1.32e-5	2.48e-5	3.52e-5	4.38e-5
N_d ^{95}Mo	0.00	2.21e-10	6.92e-6	2.09e-5	3.48e-5	4.71e-5
N_d ^{99}Tc	0.00	1.11e-7	1.49e-5	2.94e-5	4.30e-5	5.49e-5
N_d ^{101}Ru	0.00	2.53e-7	1.28e-5	2.56e-5	3.83e-5	5.01e-5
N_d ^{103}Rh	0.00	5.57e-9	5.57e-6	1.27e-5	1.93e-5	2.48e-5
N_d ^{109}Ag	0.00	8.58e-10	2.44e-7	7.67e-7	1.48e-6	2.29e-6
N_d ^{129}I	0.00	1.67e-8	1.37e-6	3.14e-6	5.10e-6	7.07e-6
N_d ^{133}Xe	0.00	2.10e-8	6.12e-6	1.17e-5	1.64e-5	2.00e-5
N_d ^{135}Xe	0.00	1.25e-8	1.25e-8	1.18e-8	1.09e-8	9.98e-9
N_d ^{133}Cs	0.00	4.50e-8	1.46e-5	2.86e-5	4.15e-5	5.25e-5
N_d ^{134}Cs	0.00	1.96e-11	4.38e-7	1.70e-6	3.63e-6	5.93e-6
N_d ^{137}Cs	0.00	3.21e-7	1.59e-5	3.16e-5	4.71e-5	6.15e-5
N_d ^{144}Ce	0.00	2.70e-7	1.01e-5	1.54e-5	1.81e-5	1.94e-5
N_d ^{142}Nd	0.00	2.70e-13	3.35e-8	1.70e-7	4.30e-7	8.06e-7
N_d ^{143}Nd	0.00	1.44e-8	1.21e-5	2.34e-5	3.26e-5	3.92e-5
N_d ^{144}Nd	0.00	1.53e-9	3.77e-6	1.32e-5	2.65e-5	4.14e-5
N_d ^{145}Nd	0.00	1.83e-7	9.45e-6	1.81e-5	2.60e-5	3.27e-5
N_d ^{146}Nd	0.00	1.57e-7	8.01e-6	1.63e-5	2.51e-5	3.37e-5
N_d ^{148}Nd	0.00	8.90e-8	4.48e-6	8.92e-6	1.33e-5	1.75e-5
N_d ^{147}Sm	0.00	1.60e-11	3.25e-7	1.13e-6	2.10e-6	2.99e-6
N_d ^{149}Sm	0.00	1.95e-8	1.11e-7	1.20e-7	1.20e-7	1.16e-7
N_d ^{150}Sm	0.00	4.62e-9	2.83e-6	6.29e-6	1.00e-5	1.37e-5
N_d ^{151}Sm	0.00	1.52e-8	4.29e-7	5.10e-7	5.59e-7	5.94e-7
N_d ^{152}Sm	0.00	1.42e-8	1.37e-6	2.74e-6	3.84e-6	4.68e-6
N_d ^{153}Eu	0.00	4.02e-9	6.73e-7	1.90e-6	3.43e-6	4.94e-6
N_d ^{154}Eu	0.00	8.78e-12	6.12e-8	2.65e-7	5.86e-7	9.37e-7
N_d ^{155}Eu	0.00	1.66e-9	4.35e-8	1.07e-7	2.11e-7	3.33e-7
N_d ^{155}Gd	0.00	1.39e-12	3.67e-10	8.87e-10	1.68e-9	2.47e-9
N_d ^{156}Gd	0.00	5.48e-11	1.34e-7	5.12e-7	1.31e-6	2.64e-6
N_d ^{157}Gd	0.00	1.75e-10	1.45e-9	2.35e-9	3.37e-9	4.51e-9
N_d ^{158}Gd	0.00	1.83e-10	5.32e-8	1.67e-7	3.50e-7	6.06e-7

Table C.2: Relative power per pin, central values

	Burnup 0.00GW / MTU														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.44e-1	8.22e-1	8.86e-1	9.31e-1	9.62e-1	9.83e-1	9.66e-1	9.75e-1	9.72e-1	9.78e-1	9.66e-1	9.30e-1	8.87e-1	8.23e-1	8.49e-1
2	8.29e-1	3.47e-1	8.79e-1	9.53e-1	1.01e+0	1.05e+0	1.01e+0	9.95e-1	1.01e+0	1.06e+0	1.01e+0	9.58e-1	8.76e-1	3.48e-1	8.23e-1
3	8.81e-1	8.73e-1	9.53e-1	1.05e+0	1.09e+0	0.00e+0	1.07e+0	1.02e+0	1.08e+0	0.00e+0	1.10e+0	1.06e+0	9.64e-1	8.80e-1	8.86e-1
4	9.32e-1	9.57e-1	1.05e+0	0.00e+0	1.13e+0	1.11e+0	1.04e+0	1.02e+0	1.04e+0	1.12e+0	1.13e+0	0.00e+0	1.06e+0	9.60e-1	9.37e-1
5	9.64e-1	1.01e+0	1.10e+0	1.13e+0	1.10e+0	1.11e+0	1.05e+0	1.02e+0	1.05e+0	1.12e+0	1.10e+0	1.13e+0	1.09e+0	1.01e+0	9.59e-1
6	9.84e-1	1.05e+0	0.00e+0	1.11e+0	1.12e+0	0.00e+0	1.10e+0	1.06e+0	1.10e+0	0.00e+0	1.12e+0	1.12e+0	0.00e+0	1.06e+0	9.70e-1
7	9.75e-1	1.01e+0	1.07e+0	1.05e+0	1.05e+0	1.10e+0	1.08e+0	1.10e+0	1.08e+0	1.11e+0	1.05e+0	1.04e+0	1.07e+0	1.01e+0	9.70e-1
8	9.63e-1	9.90e-1	1.01e+0	1.02e+0	1.02e+0	1.06e+0	1.11e+0	0.00e+0	1.11e+0	1.05e+0	1.02e+0	1.02e+0	1.02e+0	9.93e-1	9.73e-1
9	9.74e-1	1.01e+0	1.07e+0	1.05e+0	1.06e+0	1.10e+0	1.08e+0	1.11e+0	1.09e+0	1.10e+0	1.06e+0	1.05e+0	1.07e+0	1.01e+0	9.76e-1
10	9.79e-1	1.05e+0	0.00e+0	1.11e+0	1.11e+0	0.00e+0	1.11e+0	1.06e+0	1.11e+0	0.00e+0	1.12e+0	1.11e+0	0.00e+0	1.05e+0	9.75e-1
11	9.57e-1	1.01e+0	1.10e+0	1.12e+0	1.10e+0	1.11e+0	1.05e+0	1.03e+0	1.06e+0	1.12e+0	1.09e+0	1.13e+0	1.10e+0	1.01e+0	9.58e-1
12	9.30e-1	9.62e-1	1.06e+0	0.00e+0	1.12e+0	1.11e+0	1.05e+0	1.02e+0	1.04e+0	1.11e+0	1.13e+0	0.00e+0	1.07e+0	9.62e-1	9.22e-1
13	8.82e-1	8.76e-1	9.68e-1	1.06e+0	1.10e+0	0.00e+0	1.07e+0	1.01e+0	1.07e+0	0.00e+0	1.10e+0	1.06e+0	9.50e-1	8.72e-1	8.82e-1
14	8.24e-1	3.50e-1	8.80e-1	9.60e-1	1.01e+0	1.05e+0	9.99e-1	9.86e-1	1.02e+0	1.05e+0	1.01e+0	9.62e-1	8.78e-1	3.47e-1	8.22e-1
15	8.51e-1	8.31e-1	8.81e-1	9.32e-1	9.61e-1	9.82e-1	9.70e-1	9.72e-1	9.71e-1	9.77e-1	9.59e-1	9.29e-1	8.81e-1	8.24e-1	8.44e-1
	Burnup 0.20GW / MTU														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.41e-1	8.28e-1	8.84e-1	9.31e-1	9.64e-1	9.75e-1	9.76e-1	9.68e-1	9.70e-1	9.73e-1	9.63e-1	9.34e-1	8.82e-1	8.22e-1	8.42e-1
2	8.23e-1	3.61e-1	8.84e-1	9.64e-1	1.01e+0	1.05e+0	1.01e+0	9.85e-1	1.02e+0	1.05e+0	1.01e+0	9.59e-1	8.78e-1	3.62e-1	8.27e-1
3	8.82e-1	8.84e-1	9.73e-1	1.06e+0	1.10e+0	0.00e+0	1.07e+0	1.01e+0	1.07e+0	0.00e+0	1.10e+0	1.06e+0	9.61e-1	8.76e-1	8.84e-1
4	9.36e-1	9.65e-1	1.05e+0	0.00e+0	1.13e+0	1.10e+0	1.04e+0	1.02e+0	1.05e+0	1.11e+0	1.13e+0	0.00e+0	1.06e+0	9.60e-1	9.35e-1
5	9.54e-1	1.00e+0	1.09e+0	1.12e+0	1.09e+0	1.11e+0	1.05e+0	1.03e+0	1.05e+0	1.12e+0	1.09e+0	1.13e+0	1.10e+0	1.01e+0	9.62e-1
6	9.74e-1	1.06e+0	0.00e+0	1.11e+0	1.11e+0	0.00e+0	1.11e+0	1.05e+0	1.11e+0	0.00e+0	1.11e+0	1.11e+0	0.00e+0	1.05e+0	9.76e-1
7	9.71e-1	1.01e+0	1.07e+0	1.05e+0	1.05e+0	1.10e+0	1.08e+0	1.11e+0	1.09e+0	1.10e+0	1.06e+0	1.05e+0	1.06e+0	1.01e+0	9.74e-1
8	9.67e-1	9.95e-1	1.01e+0	1.02e+0	1.03e+0	1.05e+0	1.11e+0	0.00e+0	1.11e+0	1.05e+0	1.02e+0	1.01e+0	1.02e+0	9.80e-1	9.66e-1
9	9.73e-1	1.01e+0	1.07e+0	1.04e+0	1.05e+0	1.11e+0	1.09e+0	1.10e+0	1.09e+0	1.10e+0	1.06e+0	1.04e+0	1.07e+0	1.01e+0	9.73e-1
10	9.79e-1	1.05e+0	0.00e+0	1.12e+0	1.12e+0	0.00e+0	1.10e+0	1.05e+0	1.10e+0	0.00e+0	1.12e+0	1.11e+0	0.00e+0	1.05e+0	9.79e-1
11	9.62e-1	1.01e+0	1.10e+0	1.13e+0	1.09e+0	1.12e+0	1.05e+0	1.03e+0	1.05e+0	1.12e+0	1.09e+0	1.12e+0	1.10e+0	1.00e+0	9.56e-1
12	9.32e-1	9.65e-1	1.06e+0	0.00e+0	1.13e+0	1.12e+0	1.04e+0	1.01e+0	1.05e+0	1.11e+0	1.13e+0	0.00e+0	1.06e+0	9.60e-1	9.33e-1
13	8.80e-1	8.80e-1	9.67e-1	1.06e+0	1.11e+0	0.00e+0	1.07e+0	1.02e+0	1.07e+0	0.00e+0	1.10e+0	1.05e+0	9.62e-1	8.72e-1	8.78e-1
14	8.27e-1	3.64e-1	8.73e-1	9.64e-1	1.01e+0	1.06e+0	1.01e+0	9.95e-1	1.01e+0	1.06e+0	1.00e+0	9.62e-1	8.80e-1	3.63e-1	8.29e-1
15	8.49e-1	8.25e-1	8.85e-1	9.32e-1	9.62e-1	9.84e-1	9.70e-1	9.67e-1	9.71e-1	9.90e-1	9.67e-1	9.32e-1	8.83e-1	8.25e-1	8.46e-1
	Burnup 10.0GW / MTU														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.99e-1	9.13e-1	9.15e-1	9.31e-1	9.43e-1	9.53e-1	9.49e-1	9.46e-1	9.46e-1	9.54e-1	9.42e-1	9.29e-1	9.22e-1	9.13e-1	9.06e-1
2	9.12e-1	8.34e-1	9.33e-1	9.64e-1	9.95e-1	1.03e+0	9.89e-1	9.61e-1	9.80e-1	1.03e+0	9.93e-1	9.68e-1	9.36e-1	8.37e-1	9.08e-1
3	9.26e-1	9.38e-1	9.83e-1	1.05e+0	1.08e+0	0.00e+0	1.04e+0	9.88e-1	1.04e+0	0.00e+0	1.08e+0	1.05e+0	9.83e-1	9.35e-1	9.15e-1
4	9.38e-1	9.60e-1	1.05e+0	0.00e+0	1.10e+0	1.09e+0	1.02e+0	9.75e-1	1.02e+0	1.09e+0	1.10e+0	0.00e+0	1.06e+0	9.68e-1	9.36e-1
5	9.42e-1	9.90e-1	1.08e+0	1.10e+0	1.07e+0	1.09e+0	1.02e+0	1.00e+0	1.03e+0	1.09e+0	1.07e+0	1.11e+0	1.08e+0	9.87e-1	9.48e-1
6	9.48e-1	1.03e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.07e+0	1.02e+0	1.08e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.04e+0	9.54e-1
7	9.49e-1	9.83e-1	1.05e+0	1.02e+0	1.03e+0	1.07e+0	1.05e+0	1.08e+0	1.05e+0	1.07e+0	1.02e+0	1.02e+0	1.04e+0	9.84e-1	9.42e-1
8	9.39e-1	9.59e-1	9.82e-1	9.81e-1	9.95e-1	1.02e+0	1.08e+0	0.00e+0	1.07e+0	1.02e+0	9.96e-1	9.83e-1	9.82e-1	9.60e-1	9.42e-1
9	9.44e-1	9.82e-1	1.04e+0	1.02e+0	1.03e+0	1.08e+0	1.06e+0	1.09e+0	1.05e+0	1.08e+0	1.03e+0	1.01e+0	1.04e+0	9.86e-1	9.41e-1
10	9.59e-1	1.03e+0	0.00e+0	1.08e+0	1.09e+0	0.00e+0	1.07e+0	1.03e+0	1.07e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.04e+0	9.57e-1
11	9.49e-1	9.93e-1	1.08e+0	1.11e+0	1.07e+0	1.09e+0	1.03e+0	9.98e-1	1.03e+0	1.08e+0	1.08e+0	1.11e+0	1.08e+0	9.86e-1	9.45e-1
12	9.34e-1	9.64e-1	1.06e+0	0.00e+0	1.11e+0	1.09e+0	1.02e+0	9.83e-1	1.01e+0	1.08e+0	1.11e+0	0.00e+0	1.05e+0	9.62e-1	9.30e-1
13	9.15e-1	9.36e-1	9.83e-1	1.05e+0	1.08e+0	0.00e+0	1.05e+0	9.88e-1	1.04e+0	0.00e+0	1.08e+0	1.06e+0	9.78e-1	9.35e-1	9.21e-1
14	9.11e-1	8.34e-1	9.34e-1	9.62e-1	9.91e-1	1.03e+0	9.86e-1	9.61e-1	9.85e-1	1.03e+0	9.93e-1	9.60e-1	9.34e-1	8.38e-1	9.10e-1
15	9.01e-1	9.10e-1	9.21e-1	9.34e-1	9.40e-1	9.61e-1	9.54e-1	9.43e-1	9.42e-1	9.51e-1	9.51e-1	9.33e-1	9.21e-1	9.14e-1	9.04e-1
	Burnup 20.0GW / MTU														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.98e-1	9.05e-1	9.15e-1	9.26e-1	9.45e-1	9.59e-1	9.39e-1	9.39e-1	9.50e-1	9.51e-1	9.45e-1	9.29e-1	9.21e-1	9.08e-1	9.03e-1
2	9.07e-1	8.62e-1	9.36e-1	9.67e-1	9.95e-1	1.03e+0	9.81e-1	9.57e-1	9.82e-1	1.04e+0	9.93e-1	9.60e-1	9.33e-1	8.63e-1	9.12e-1
3	9.15e-1	9.37e-1	9.80e-1	1.06e+0	1.08e+0	0.00e+0	1.04e+0	9.72e-1	1.04e+0	0.00e+0	1.08e+0	1.05e+0	9.82e-1	9.30e-1	9.13e-1
4	9.30e-1	9.61e-1	1.05e+0	0.00e+0	1.11e+0	1.08e+0	1.02e+0	9.82e-1	1.02e+0	1.09e+0	1.11e+0	0.00e+0	1.06e+0	9.59e-1	9.22e-1
5	9.42e-1	9.90e-1	1.09e+0	1.11e+0	1.08e+0	1.09e+0	1.03e+0	9.90e-1	1.02e+0	1.09e+0	1.08e+0	1.10e+0	1.09e+0	9.85e-1	9.44e-1
6	9.50e-1	1.03e+0	0.00e+0	1.08e+0	1.09e+0	0.00e+0	1.08e+0	1.02e+0	1.07e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.03e+0	9.54e-1
7	9.49e-1	9.80e-1	1.05e+0	1.03e+0	1.02e+0	1.07e+0	1.05e+0	1.07e+0	1.06e+0	1.07e+0	1.02e+0	1.02e+0	1.05e+0	9.82e-1	9.45e-1

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Table C.2 – continued from previous page

8	9.43e-1	9.63e-1	9.87e-1	9.89e-1	9.93e-1	1.02e+0	1.08e+0	0.00e+0	1.08e+0	1.03e+0	9.92e-1	9.89e-1	9.93e-1	9.60e-1	9.39e-1
9	9.43e-1	9.90e-1	1.04e+0	1.02e+0	1.03e+0	1.08e+0	1.06e+0	1.08e+0	1.06e+0	1.07e+0	1.03e+0	1.02e+0	1.04e+0	9.83e-1	9.40e-1
10	9.61e-1	1.03e+0	0.00e+0	1.08e+0	1.08e+0	0.00e+0	1.07e+0	1.02e+0	1.07e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.04e+0	9.53e-1
11	9.42e-1	9.85e-1	1.09e+0	1.11e+0	1.07e+0	1.09e+0	1.02e+0	9.92e-1	1.03e+0	1.10e+0	1.08e+0	1.11e+0	1.08e+0	9.87e-1	9.49e-1
12	9.30e-1	9.64e-1	1.05e+0	0.00e+0	1.10e+0	1.09e+0	1.01e+0	9.89e-1	1.02e+0	1.09e+0	1.11e+0	0.00e+0	1.06e+0	9.58e-1	9.34e-1
13	9.16e-1	9.34e-1	9.74e-1	1.05e+0	1.09e+0	0.00e+0	1.04e+0	9.89e-1	1.04e+0	0.00e+0	1.09e+0	1.06e+0	9.79e-1	9.43e-1	9.16e-1
14	8.99e-1	8.60e-1	9.41e-1	9.56e-1	9.93e-1	1.03e+0	9.87e-1	9.58e-1	9.85e-1	1.04e+0	9.91e-1	9.62e-1	9.35e-1	8.62e-1	9.07e-1
15	9.00e-1	9.07e-1	9.11e-1	9.36e-1	9.43e-1	9.53e-1	9.38e-1	9.41e-1	9.42e-1	9.50e-1	9.43e-1	9.30e-1	9.18e-1	9.12e-1	9.00e-1
	Burnup 30.0GW / MTU														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.96e-1	9.04e-1	9.18e-1	9.30e-1	9.39e-1	9.55e-1	9.45e-1	9.40e-1	9.52e-1	9.53e-1	9.45e-1	9.33e-1	9.16e-1	9.02e-1	9.03e-1
2	9.09e-1	8.81e-1	9.31e-1	9.65e-1	9.87e-1	1.03e+0	9.87e-1	9.63e-1	9.88e-1	1.03e+0	9.95e-1	9.63e-1	9.27e-1	8.81e-1	9.10e-1
3	9.25e-1	9.28e-1	9.77e-1	1.05e+0	1.08e+0	0.00e+0	1.04e+0	9.89e-1	1.05e+0	0.00e+0	1.08e+0	1.05e+0	9.76e-1	9.26e-1	9.16e-1
4	9.36e-1	9.58e-1	1.05e+0	0.00e+0	1.11e+0	1.09e+0	1.02e+0	9.83e-1	1.02e+0	1.09e+0	1.11e+0	0.00e+0	1.05e+0	9.59e-1	9.37e-1
5	9.48e-1	9.94e-1	1.09e+0	1.12e+0	1.07e+0	1.10e+0	1.02e+0	9.99e-1	1.03e+0	1.09e+0	1.08e+0	1.11e+0	1.07e+0	9.89e-1	9.34e-1
6	9.53e-1	1.03e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.08e+0	1.03e+0	1.08e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.02e+0	9.53e-1
7	9.53e-1	9.87e-1	1.04e+0	1.01e+0	1.03e+0	1.07e+0	1.05e+0	1.08e+0	1.06e+0	1.07e+0	1.03e+0	1.02e+0	1.04e+0	9.86e-1	9.44e-1
8	9.40e-1	9.62e-1	9.85e-1	9.88e-1	1.00e+0	1.03e+0	1.07e+0	0.00e+0	1.09e+0	1.02e+0	1.00e+0	9.94e-1	9.84e-1	9.56e-1	9.46e-1
9	9.38e-1	9.83e-1	1.05e+0	1.02e+0	1.03e+0	1.07e+0	1.06e+0	1.09e+0	1.06e+0	1.07e+0	1.03e+0	1.01e+0	1.03e+0	9.82e-1	9.41e-1
10	9.55e-1	1.03e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.07e+0	1.03e+0	1.07e+0	0.00e+0	1.08e+0	1.09e+0	0.00e+0	1.03e+0	9.54e-1
11	9.46e-1	9.89e-1	1.08e+0	1.10e+0	1.07e+0	1.09e+0	1.03e+0	9.94e-1	1.02e+0	1.09e+0	1.07e+0	1.10e+0	1.08e+0	9.87e-1	9.46e-1
12	9.28e-1	9.66e-1	1.05e+0	0.00e+0	1.11e+0	1.09e+0	1.02e+0	9.87e-1	1.02e+0	1.09e+0	1.11e+0	0.00e+0	1.05e+0	9.60e-1	9.36e-1
13	9.13e-1	9.32e-1	9.77e-1	1.05e+0	1.08e+0	0.00e+0	1.05e+0	9.83e-1	1.04e+0	0.00e+0	1.08e+0	1.05e+0	9.76e-1	9.37e-1	9.18e-1
14	8.99e-1	8.79e-1	9.36e-1	9.57e-1	9.91e-1	1.02e+0	9.86e-1	9.63e-1	9.85e-1	1.03e+0	9.88e-1	9.62e-1	9.35e-1	8.79e-1	9.04e-1
15	8.97e-1	9.00e-1	9.09e-1	9.32e-1	9.34e-1	9.50e-1	9.32e-1	9.41e-1	9.45e-1	9.53e-1	9.41e-1	9.30e-1	9.19e-1	9.00e-1	8.99e-1
	shutdown														
pin nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.96e-1	9.07e-1	9.21e-1	9.27e-1	9.45e-1	9.56e-1	9.43e-1	9.39e-1	9.44e-1	9.54e-1	9.48e-1	9.33e-1	9.12e-1	9.09e-1	8.99e-1
2	8.98e-1	9.01e-1	9.34e-1	9.63e-1	9.87e-1	1.03e+0	9.82e-1	9.63e-1	9.87e-1	1.03e+0	9.92e-1	9.60e-1	9.27e-1	8.97e-1	9.01e-1
3	9.10e-1	9.38e-1	9.80e-1	1.05e+0	1.08e+0	0.00e+0	1.04e+0	9.92e-1	1.04e+0	0.00e+0	1.08e+0	1.05e+0	9.80e-1	9.30e-1	9.09e-1
4	9.27e-1	9.59e-1	1.05e+0	0.00e+0	1.11e+0	1.09e+0	1.01e+0	9.85e-1	1.01e+0	1.09e+0	1.11e+0	0.00e+0	1.06e+0	9.57e-1	9.29e-1
5	9.51e-1	9.89e-1	1.07e+0	1.11e+0	1.07e+0	1.09e+0	1.03e+0	9.94e-1	1.02e+0	1.09e+0	1.08e+0	1.11e+0	1.08e+0	9.94e-1	9.44e-1
6	9.56e-1	1.03e+0	0.00e+0	1.08e+0	1.09e+0	0.00e+0	1.07e+0	1.03e+0	1.07e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.03e+0	9.53e-1
7	9.49e-1	9.79e-1	1.04e+0	1.02e+0	1.02e+0	1.07e+0	1.05e+0	1.08e+0	1.06e+0	1.07e+0	1.03e+0	1.02e+0	1.04e+0	9.88e-1	9.53e-1
8	9.34e-1	9.56e-1	9.90e-1	9.90e-1	9.93e-1	1.03e+0	1.08e+0	0.00e+0	1.08e+0	1.03e+0	9.95e-1	9.89e-1	9.95e-1	9.63e-1	9.48e-1
9	9.39e-1	9.83e-1	1.05e+0	1.02e+0	1.03e+0	1.07e+0	1.06e+0	1.08e+0	1.06e+0	1.08e+0	1.02e+0	1.01e+0	1.04e+0	9.84e-1	9.42e-1
10	9.58e-1	1.03e+0	0.00e+0	1.09e+0	1.09e+0	0.00e+0	1.07e+0	1.03e+0	1.08e+0	0.00e+0	1.09e+0	1.08e+0	0.00e+0	1.02e+0	9.55e-1
11	9.43e-1	9.91e-1	1.07e+0	1.10e+0	1.07e+0	1.09e+0	1.03e+0	1.01e+0	1.03e+0	1.08e+0	1.07e+0	1.10e+0	1.08e+0	9.89e-1	9.44e-1
12	9.29e-1	9.67e-1	1.05e+0	0.00e+0	1.10e+0	1.09e+0	1.02e+0	9.94e-1	1.02e+0	1.09e+0	1.11e+0	0.00e+0	1.05e+0	9.63e-1	9.24e-1
13	9.11e-1	9.30e-1	9.79e-1	1.05e+0	1.09e+0	0.00e+0	1.04e+0	9.85e-1	1.04e+0	0.00e+0	1.09e+0	1.05e+0	9.87e-1	9.35e-1	9.12e-1
14	9.02e-1	8.98e-1	9.35e-1	9.60e-1	9.89e-1	1.03e+0	9.76e-1	9.61e-1	9.69e-1	1.03e+0	9.91e-1	9.66e-1	9.35e-1	8.94e-1	9.04e-1
15	9.01e-1	9.08e-1	9.17e-1	9.31e-1	9.39e-1	9.52e-1	9.51e-1	9.36e-1	9.42e-1	9.47e-1	9.41e-1	9.34e-1	9.13e-1	8.99e-1	8.96e-1

Appendix D

Tables for uncertainties from variations of ^{235}U nuclear data

Table D.1: Results of variations in the ^{235}U nuclear data; Uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.560	0.530	0.442	0.405	0.369	0.338
rr $^{235}U_{n,\gamma}$	2.040	2.020	2.000	2.040	2.080	2.130
rr $^{238}U_{n,\gamma}$	0.870	0.800	0.700	0.680	0.590	0.530
rr $^{239}Pu_{n,\gamma}$	1.270	1.270	0.950	0.840	0.840	0.740
rr $^{240}Pu_{n,\gamma}$	0.470	0.820	0.000	0.110	0.190	0.590
rr $^{241}Pu_{n,\gamma}$	1.390	1.410	1.030	0.930	0.880	0.780
rr $^{235}U_{n,f}$	0.560	0.580	0.570	0.640	0.740	0.880
rr $^{238}U_{n,f}$	7.170	7.180	5.410	4.320	3.480	2.850
rr $^{239}Pu_{n,f}$	1.320	1.320	1.010	0.890	0.850	0.770
rr $^{240}Pu_{n,f}$	2.940	2.980	2.310	1.870	1.570	1.270
rr $^{241}Pu_{n,f}$	1.390	1.400	1.060	0.940	0.870	0.790
Σ_{abs1}	0.910	0.840	0.760	0.650	0.520	0.470
Σ_{abs2}	1.090	1.070	0.840	0.720	0.610	0.580
Σ_{fiss1}	1.560	1.570	1.630	1.630	1.540	1.440
Σ_{fiss2}	1.680	1.680	1.370	1.220	1.060	0.980
$\nu\Sigma_{fiss1}$	1.740	1.750	1.750	1.700	1.580	1.470
$\nu\Sigma_{fiss2}$	1.670	1.670	1.300	1.140	0.980	0.910
D_1	2.000	2.090	1.620	1.270	1.020	0.830
D_2	1.000	1.020	0.940	0.830	0.820	0.840
Σ_{trn1}	2.060	2.140	1.690	1.340	1.110	0.950
Σ_{trn2}	0.510	0.690	0.420	0.230	0.350	0.430
$InvVel_1$	1.440	1.420	1.110	0.930	0.800	0.660
$InvVel_2$	0.190	0.180	0.170	0.170	0.130	0.140
scatt. gr. 1 to gr. 1	9.50e-1	9.40e-1	7.30e-1	5.90e-1	4.80e-1	4.00e-1
scatt. gr. 2 to gr. 1	2.74	3.48	3.10	2.72	3.03	3.21
scatt. gr. 1 to gr. 2	1.41	1.41	1.17	9.60e-1	8.00e-1	6.70e-1
scatt. gr. 2 to gr. 2	-	-	-	-	-	-
ADF, side W, gr. 1	1.50e-1	-	2.60e-1	2.20e-1	1.20e-1	1.70e-1
ADF, side S, gr. 1	1.50e-1	-	2.60e-1	2.20e-1	1.20e-1	1.70e-1
ADF, side E, gr. 1	1.50e-1	-	2.60e-1	2.20e-1	1.20e-1	1.70e-1
ADF, side N, gr. 1	1.50e-1	-	2.60e-1	2.20e-1	1.20e-1	1.70e-1
ADF, side W, gr. 2	4.90e-1	5.30e-1	4.30e-1	3.90e-1	-	4.70e-1

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Table D.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side S, gr. 2	4.90e-1	5.30e-1	4.30e-1	3.90e-1	-	4.70e-1
ADF, side E, gr. 2	4.90e-1	5.30e-1	4.30e-1	3.90e-1	-	4.70e-1
ADF, side N, gr. 2	4.90e-1	5.30e-1	4.30e-1	3.90e-1	-	4.70e-1
N_d ^{234}U	0.000	0.015	0.666	1.149	1.570	1.826
N_d ^{235}U	0.000	0.003	0.155	0.317	0.512	0.740
N_d ^{236}U	0.000	2.031	1.932	1.895	1.868	1.857
N_d ^{238}U	0.000	0.000	0.005	0.009	0.012	0.015
N_d ^{237}Np	0.000	35.898	10.659	6.150	4.395	3.486
N_d ^{238}Pu	0.000	35.913	13.730	8.012	5.558	4.273
N_d ^{239}Pu	0.000	0.886	0.414	0.305	0.285	0.325
N_d ^{240}Pu	0.000	1.936	1.334	1.076	0.893	0.679
N_d ^{241}Pu	0.000	2.661	1.694	1.056	0.757	0.555
N_d ^{242}Pu	0.000	3.882	2.993	2.217	1.743	1.475
N_d ^{241}Am	0.000	2.643	1.812	1.061	0.643	0.416
N_d ^{243}Am	0.000	4.929	3.812	3.124	2.648	1.954
N_d ^{242}Cm	0.000	3.635	2.788	2.024	1.485	1.097
N_d ^{244}Cm	0.000	5.655	4.651	3.726	3.283	2.649
N_d ^{90}Sr	0.000	0.439	0.371	0.333	0.307	0.286
N_d ^{95}Mo	0.000	0.388	0.347	0.306	0.274	0.250
N_d ^{99}Tc	0.000	0.373	0.320	0.279	0.249	0.222
N_d ^{101}Ru	0.000	0.374	0.334	0.302	0.276	0.252
N_d ^{103}Rh	0.000	0.484	0.422	0.366	0.317	0.283
N_d ^{109}Ag	0.000	1.463	1.223	1.140	0.970	0.899
N_d ^{129}I	0.000	0.373	0.362	0.351	0.337	0.319
N_d ^{133}Xe	0.000	0.379	0.324	0.288	0.286	0.296
N_d ^{135}Xe	0.000	1.249	0.991	0.846	0.724	0.703
N_d ^{133}Cs	0.000	0.371	0.316	0.275	0.258	0.227
N_d ^{134}Cs	0.000	1.476	0.935	0.959	0.822	0.718
N_d ^{137}Cs	0.000	0.373	0.332	0.303	0.278	0.256
N_d ^{144}Ce	0.000	0.389	0.329	0.285	0.247	0.211
N_d ^{142}Nd	0.000	1.369	1.110	1.039	0.937	0.875
N_d ^{143}Nd	0.000	0.397	0.337	0.315	0.317	0.335
N_d ^{144}Nd	0.000	0.419	0.471	0.439	0.414	0.391
N_d ^{145}Nd	0.000	0.373	0.315	0.277	0.256	0.231
N_d ^{146}Nd	0.000	0.371	0.335	0.315	0.291	0.279
N_d ^{148}Nd	0.000	0.383	0.344	0.314	0.289	0.266
N_d ^{147}Sm	0.000	0.369	0.311	0.296	0.340	0.353
N_d ^{149}Sm	0.000	0.512	1.276	1.104	0.912	0.895
N_d ^{150}Sm	0.000	1.603	0.411	0.388	0.358	0.327
N_d ^{151}Sm	0.000	0.474	0.977	0.826	0.639	0.555
N_d ^{152}Sm	0.000	0.581	0.630	0.604	0.615	0.616
N_d ^{153}Eu	0.000	0.606	0.603	0.610	0.527	0.499
N_d ^{154}Eu	0.000	1.125	0.910	0.880	0.666	0.629
N_d ^{155}Eu	0.000	1.132	0.634	0.779	0.790	0.728
N_d ^{155}Gd	0.000	1.142	1.430	0.943	0.856	0.896
N_d ^{156}Gd	0.000	1.268	0.932	0.998	1.069	1.034
N_d ^{157}Gd	0.000	1.584	0.901	0.672	0.584	0.646
N_d ^{158}Gd	0.000	2.089	1.052	1.006	1.003	1.011

Appendix E

Tables for uncertainties from variations of ^{238}U nuclear data

Table E.1: Results of variations in the ^{238}U nuclear data; Uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.414	0.420	0.421	0.419	0.352	0.308
rr $^{235}U_{n,\gamma}$	0.050	0.120	0.260	0.530	0.830	1.210
rr $^{238}U_{n,\gamma}$	1.570	1.600	1.520	1.500	1.300	1.070
rr $^{239}Pu_{n,\gamma}$	0.160	0.000	0.480	0.790	1.190	1.550
rr $^{240}Pu_{n,\gamma}$	0.000	0.000	0.490	0.750	1.200	1.200
rr $^{241}Pu_{n,\gamma}$	0.150	0.030	0.470	0.740	1.150	1.580
rr $^{235}U_{n,f}$	0.100	0.100	0.360	0.690	1.030	1.470
rr $^{238}U_{n,f}$	1.740	1.800	1.710	1.710	1.640	1.660
rr $^{239}Pu_{n,f}$	0.140	0.000	0.460	0.800	1.180	1.570
rr $^{240}Pu_{n,f}$	0.640	0.640	0.650	0.640	0.520	0.460
rr $^{241}Pu_{n,f}$	0.110	0.060	0.430	0.730	1.120	1.560
Σ_{abs1}	0.730	0.710	0.740	0.810	0.840	0.860
Σ_{abs2}	0.260	0.220	0.360	0.610	0.860	1.090
Σ_{fiss1}	0.450	0.450	0.490	0.550	0.690	0.900
Σ_{fiss2}	0.290	0.230	0.320	0.580	0.890	1.240
$\nu\Sigma_{fiss1}$	0.970	0.980	1.040	1.180	1.340	1.610
$\nu\Sigma_{fiss2}$	0.280	0.230	0.340	0.630	0.950	1.290
D_1	0.730	0.760	0.720	0.740	0.710	0.680
D_2	2.340	2.340	2.320	2.130	2.150	1.990
Σ_{trn1}	0.830	0.860	0.840	0.860	0.850	0.820
Σ_{trn2}	2.160	2.200	2.210	2.060	2.040	1.880
$InvVel_1$	0.430	0.470	0.480	0.470	0.530	0.560
$InvVel_2$	0.110	0.110	0.130	0.130	0.130	0.160
scatt. gr. 1 to gr. 1	1.11	1.12	1.09	1.07	1.05	1.05
scatt. gr. 2 to gr. 1	3.36	2.69	3.12	3.41	3.51	3.55
scatt. gr. 1 to gr. 2	4.10e-1	4.40e-1	4.30e-1	4.90e-1	5.30e-1	5.50e-1
scatt. gr. 2 to gr. 2	1.05	1.03	1.08	1.06	1.03	1.03
ADF, side W, gr. 1	1.60e-1	1.80e-1	1.10e-1	2.40e-1	1.10e-1	-
ADF, side S, gr. 1	1.60e-1	1.80e-1	1.10e-1	2.40e-1	1.10e-1	-
ADF, side E, gr. 1	1.60e-1	1.80e-1	1.10e-1	2.40e-1	1.10e-1	-
ADF, side N, gr. 1	1.60e-1	1.80e-1	1.10e-1	2.40e-1	1.10e-1	-
ADF, side W, gr. 2	3.50e-1	2.60e-1	4.60e-1	5.50e-1	1.70e-1	3.70e-1

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Table E.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side S, gr. 2	3.50e-1	2.60e-1	4.60e-1	5.50e-1	1.70e-1	3.70e-1
ADF, side E, gr. 2	3.50e-1	2.60e-1	4.60e-1	5.50e-1	1.70e-1	3.70e-1
ADF, side N, gr. 2	3.50e-1	2.60e-1	4.60e-1	5.50e-1	1.70e-1	3.70e-1
N_d ^{234}U	0.000	0.003	0.063	0.145	0.237	0.348
N_d ^{235}U	0.000	0.001	0.052	0.187	0.445	0.852
N_d ^{236}U	0.000	0.121	0.153	0.212	0.248	0.258
N_d ^{238}U	0.000	0.000	0.008	0.016	0.024	0.031
N_d ^{237}Np	0.000	3.949	1.556	1.106	0.940	0.832
N_d ^{238}Pu	0.000	3.623	1.875	1.359	1.057	0.971
N_d ^{239}Pu	0.000	1.611	1.695	1.892	2.116	2.339
N_d ^{240}Pu	0.000	1.598	1.432	1.483	1.613	1.767
N_d ^{241}Pu	0.000	1.867	1.237	1.202	1.224	1.364
N_d ^{242}Pu	0.000	1.823	1.076	0.714	0.420	0.378
N_d ^{241}Am	0.000	1.872	1.399	1.311	1.467	1.856
N_d ^{243}Am	0.000	2.631	1.322	1.424	1.396	0.902
N_d ^{242}Cm	0.000	1.906	1.155	0.885	0.733	0.643
N_d ^{244}Cm	0.000	2.898	1.441	1.337	1.129	1.047
N_d ^{90}Sr	0.000	0.055	0.101	0.154	0.191	0.209
N_d ^{95}Mo	0.000	0.032	0.034	0.052	0.066	0.063
N_d ^{99}Tc	0.000	0.025	0.026	0.029	0.047	0.072
N_d ^{101}Ru	0.000	0.034	0.048	0.057	0.068	0.076
N_d ^{103}Rh	0.000	0.091	0.164	0.249	0.344	0.470
N_d ^{109}Ag	0.000	0.371	1.079	1.057	0.997	0.924
N_d ^{129}I	0.000	0.034	0.111	0.161	0.195	0.219
N_d ^{133}Xe	0.000	0.039	0.075	0.127	0.209	0.261
N_d ^{135}Xe	0.000	0.126	0.340	0.633	1.015	1.445
N_d ^{133}Cs	0.000	0.025	0.029	0.041	0.065	0.093
N_d ^{134}Cs	0.000	0.917	0.328	0.446	0.501	0.484
N_d ^{137}Cs	0.000	0.025	0.027	0.029	0.031	0.033
N_d ^{144}Ce	0.000	0.032	0.049	0.076	0.092	0.095
N_d ^{142}Nd	0.000	0.539	0.260	0.382	0.556	0.693
N_d ^{143}Nd	0.000	0.036	0.031	0.023	0.083	0.216
N_d ^{144}Nd	0.000	0.038	0.087	0.162	0.248	0.337
N_d ^{145}Nd	0.000	0.025	0.033	0.043	0.049	0.044
N_d ^{146}Nd	0.000	0.030	0.034	0.051	0.067	0.091
N_d ^{148}Nd	0.000	0.042	0.043	0.043	0.044	0.046
N_d ^{147}Sm	0.000	0.030	0.056	0.101	0.169	0.260
N_d ^{149}Sm	0.000	0.087	0.470	0.743	1.136	1.509
N_d ^{150}Sm	0.000	0.169	0.056	0.069	0.080	0.088
N_d ^{151}Sm	0.000	0.091	0.393	0.719	0.979	1.178
N_d ^{152}Sm	0.000	0.120	0.140	0.283	0.363	0.422
N_d ^{153}Eu	0.000	0.132	0.208	0.349	0.323	0.324
N_d ^{154}Eu	0.000	0.364	0.257	0.361	0.429	0.643
N_d ^{155}Eu	0.000	0.278	0.530	0.509	0.511	0.524
N_d ^{155}Gd	0.000	0.286	0.844	1.036	1.309	1.790
N_d ^{156}Gd	0.000	0.311	0.362	0.247	0.159	0.350
N_d ^{157}Gd	0.000	0.406	1.101	1.300	1.304	1.393
N_d ^{158}Gd	0.000	0.463	0.639	0.635	0.484	0.275

Appendix F

Tables for uncertainties from variations of ^{239}Pu nuclear data

Table F.1: Results of variations in the ^{239}Pu nuclear data; Uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.030	0.022	0.148	0.247	0.322	0.385
rr $^{235}U_{n,\gamma}$	0.000	0.010	0.220	0.360	0.420	0.480
rr $^{238}U_{n,\gamma}$	0.000	0.000	0.170	0.270	0.320	0.430
rr $^{239}Pu_{n,\gamma}$	0.000	0.160	0.270	0.320	0.370	0.390
rr $^{240}Pu_{n,\gamma}$	0.000	0.000	0.080	0.120	0.200	0.260
rr $^{241}Pu_{n,\gamma}$	0.020	0.000	0.240	0.360	0.410	0.450
rr $^{235}U_{n,f}$	0.000	0.000	0.260	0.400	0.470	0.510
rr $^{238}U_{n,f}$	0.000	0.050	1.070	1.640	2.060	2.340
rr $^{239}Pu_{n,f}$	0.000	0.000	1.440	1.450	1.460	1.510
rr $^{240}Pu_{n,f}$	0.020	0.000	0.450	0.720	0.900	1.050
rr $^{241}Pu_{n,f}$	0.020	0.000	0.250	0.370	0.430	0.470
Σ_{abs1}	0.000	0.090	0.120	0.140	0.170	0.200
Σ_{abs2}	0.000	0.080	0.150	0.170	0.170	0.120
Σ_{fiss1}	0.000	0.090	0.190	0.340	0.480	0.640
Σ_{fiss2}	0.000	0.080	0.250	0.360	0.430	0.450
$\nu\Sigma_{fiss1}$	0.000	0.090	0.240	0.440	0.610	0.790
$\nu\Sigma_{fiss2}$	0.000	0.080	0.290	0.410	0.470	0.470
D_1	0.000	0.000	0.300	0.470	0.590	0.670
D_2	0.000	0.000	0.280	0.290	0.220	0.250
Σ_{trn1}	0.000	0.000	0.330	0.480	0.610	0.680
Σ_{trn2}	0.000	0.000	0.100	0.160	0.000	0.100
$InvVel_1$	0.000	0.000	0.220	0.310	0.380	0.450
$InvVel_2$	0.000	0.040	0.050	0.060	0.060	0.060
scatt. gr. 1 to gr. 1	0.000	2.00e-2	1.40e-1	2.10e-1	2.70e-1	3.10e-1
scatt. gr. 2 to gr. 1	0.000	9.20e-1	1.04e+0	1.05e+0	9.80e-1	1.04e+0
scatt. gr. 1 to gr. 2	0.000	8.00e-2	2.20e-1	3.10e-1	3.90e-1	4.70e-1
scatt. gr. 2 to gr. 2	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side W, gr. 1	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side S, gr. 1	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side E, gr. 1	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side N, gr. 1	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side W, gr. 2	0.000	0.000	0.000	0.000	6.00e-2	1.10e-1

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Table F.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side S, gr. 2	0.000	0.000	0.000	0.000	6.00e-2	1.10e-1
ADF, side E, gr. 2	0.000	0.000	0.000	0.000	6.00e-2	1.10e-1
ADF, side N, gr. 2	0.000	0.000	0.000	0.000	6.00e-2	1.10e-1
N_d ^{234}U	0.000	0.000	0.055	0.200	0.386	0.581
N_d ^{235}U	0.000	0.000	0.037	0.126	0.255	0.409
N_d ^{236}U	0.000	0.000	0.104	0.147	0.153	0.131
N_d ^{238}U	0.000	0.000	0.000	0.002	0.004	0.007
N_d ^{237}Np	0.000	0.000	1.285	1.483	1.503	1.551
N_d ^{238}Pu	0.000	0.000	1.073	1.314	1.347	1.367
N_d ^{239}Pu	0.000	0.000	0.389	0.673	0.895	1.052
N_d ^{240}Pu	0.000	0.000	0.417	0.742	0.987	1.197
N_d ^{241}Pu	0.000	0.000	0.325	0.451	0.596	0.672
N_d ^{242}Pu	0.000	0.000	0.443	0.689	0.807	0.911
N_d ^{241}Am	0.000	0.000	0.233	0.359	0.402	0.439
N_d ^{243}Am	0.000	0.000	0.353	0.465	0.851	0.948
N_d ^{242}Cm	0.000	0.000	0.318	0.551	0.650	0.720
N_d ^{244}Cm	0.000	0.000	0.453	0.678	0.983	1.255
N_d ^{90}Sr	0.000	0.000	0.079	0.109	0.114	0.105
N_d ^{95}Mo	0.000	0.000	0.022	0.035	0.033	0.029
N_d ^{99}Tc	0.000	0.000	0.011	0.019	0.028	0.040
N_d ^{101}Ru	0.000	0.000	0.023	0.033	0.040	0.047
N_d ^{103}Rh	0.000	0.000	0.110	0.165	0.196	0.217
N_d ^{109}Ag	0.000	0.000	0.914	0.718	0.519	0.370
N_d ^{129}I	0.000	0.000	0.086	0.114	0.119	0.115
N_d ^{133}Xe	0.000	0.000	0.030	0.052	0.065	0.115
N_d ^{135}Xe	0.000	0.000	0.229	0.338	0.400	0.439
N_d ^{133}Cs	0.000	0.000	0.012	0.024	0.035	0.050
N_d ^{134}Cs	0.000	0.000	0.000	0.000	0.071	0.166
N_d ^{137}Cs	0.000	0.000	0.014	0.022	0.029	0.034
N_d ^{144}Ce	0.000	0.000	0.042	0.060	0.063	0.060
N_d ^{142}Nd	0.000	0.000	0.048	0.231	0.310	0.371
N_d ^{143}Nd	0.000	0.000	0.020	0.016	0.039	0.084
N_d ^{144}Nd	0.000	0.000	0.067	0.113	0.144	0.163
N_d ^{145}Nd	0.000	0.000	0.028	0.034	0.034	0.035
N_d ^{146}Nd	0.000	0.000	0.028	0.047	0.061	0.075
N_d ^{148}Nd	0.000	0.000	0.019	0.033	0.043	0.053
N_d ^{147}Sm	0.000	0.000	0.000	0.022	0.086	0.155
N_d ^{149}Sm	0.000	0.000	0.255	0.299	0.350	0.393
N_d ^{150}Sm	0.000	0.000	0.006	0.018	0.043	0.063
N_d ^{151}Sm	0.000	0.000	0.276	0.401	0.404	0.370
N_d ^{152}Sm	0.000	0.000	0.035	0.060	0.000	0.000
N_d ^{153}Eu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{154}Eu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{155}Eu	0.000	0.000	0.292	0.000	0.000	0.000
N_d ^{155}Gd	0.000	0.000	0.599	0.506	0.446	0.405
N_d ^{156}Gd	0.000	0.000	0.250	0.139	0.077	0.201
N_d ^{157}Gd	0.000	0.000	0.783	0.602	0.286	<0.293
N_d ^{158}Gd	0.000	0.000	0.475	0.373	0.188	0.125

Appendix G

Tables for uncertainties from variations of H in H_2O thermal scattering

Table G.1: Results of variations in the H in H_2O thermal scattering; Uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.136	0.122	0.242	0.299	0.299	0.280
rr $^{235}U_{n,\gamma}$	0.270	0.250	0.080	0.110	0.290	0.530
rr $^{238}U_{n,\gamma}$	0.280	0.210	0.290	0.280	0.230	0.220
rr $^{239}Pu_{n,\gamma}$	2.360	2.310	1.830	1.550	1.240	1.000
rr $^{240}Pu_{n,\gamma}$	4.870	4.990	4.830	4.420	4.290	4.370
rr $^{241}Pu_{n,\gamma}$	1.130	1.110	0.700	0.420	0.160	0.250
rr $^{235}U_{n,f}$	0.020	0.030	0.310	0.560	0.800	1.070
rr $^{238}U_{n,f}$	0.240	0.280	0.250	0.210	0.510	0.310
rr $^{239}Pu_{n,f}$	1.800	1.770	1.280	0.980	0.660	0.420
rr $^{240}Pu_{n,f}$	0.660	0.630	0.640	0.560	0.640	0.410
rr $^{241}Pu_{n,f}$	0.790	0.760	0.390	0.140	0.150	0.440
Σ_{abs1}	0.450	0.390	0.550	0.650	0.630	0.750
Σ_{abs2}	1.240	1.210	0.920	0.670	0.550	0.360
Σ_{fiss1}	0.780	0.750	0.690	0.710	0.640	0.690
Σ_{fiss2}	1.270	1.250	1.010	0.740	0.580	0.330
$\nu\Sigma_{fiss1}$	0.750	0.710	0.650	0.680	0.620	0.660
$\nu\Sigma_{fiss2}$	1.270	1.240	0.960	0.680	0.520	0.310
D_1	0.160	0.190	0.170	0.210	0.280	0.060
D_2	5.030	5.020	5.020	5.000	5.090	4.890
Σ_{trn1}	0.430	0.450	0.450	0.480	0.530	0.450
Σ_{trn2}	4.910	4.880	4.860	4.900	4.940	4.800
$InvVel_1$	3.300	3.310	3.220	3.150	3.040	3.010
$InvVel_2$	1.540	1.570	1.560	1.540	1.550	1.490
scatt. gr. 1 to gr. 1	2.60e-1	2.60e-1	2.60e-1	2.50e-1	2.60e-1	2.40e-1
scatt. gr. 2 to gr. 1	5.25e+0	5.15e+0	4.86e+0	5.77e+0	5.53e+0	5.53e+0
scatt. gr. 1 to gr. 2	8.00e-1	7.90e-1	8.90e-1	9.80e-1	1.00e+0	1.03e+0
scatt. gr. 2 to gr. 2	6.29e+0	6.27e+0	6.24e+0	6.25e+0	6.23e+0	6.21e+0
ADF, side W, gr. 1	1.10e-1	-	-	2.40e-1	1.00e-1	-
ADF, side S, gr. 1	1.10e-1	-	-	2.40e-1	1.00e-1	-

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Table G.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side E, gr. 1	1.10e-1	-	-	2.40e-1	1.00e-1	-
ADF, side N, gr. 1	1.10e-1	-	-	2.40e-1	1.00e-1	-
ADF, side W, gr. 2	3.50e-1	3.10e-1	-	2.80e-1	6.00e-1	5.40e-1
ADF, side S, gr. 2	3.50e-1	3.10e-1	-	2.80e-1	6.00e-1	5.40e-1
ADF, side E, gr. 2	3.50e-1	3.10e-1	-	2.80e-1	6.00e-1	5.40e-1
ADF, side N, gr. 2	3.50e-1	3.10e-1	-	2.80e-1	6.00e-1	5.40e-1
N_d ^{234}U	0.000	0.007	0.344	0.700	1.049	1.321
N_d ^{235}U	0.000	0.000	0.031	0.133	0.317	0.592
N_d ^{236}U	0.000	0.312	0.166	0.099	0.073	0.060
N_d ^{238}U	0.000	0.000	0.002	0.004	0.006	0.008
N_d ^{237}Np	0.000	1.907	0.486	0.509	0.454	0.365
N_d ^{238}Pu	0.000	3.036	2.916	2.989	2.939	2.850
N_d ^{239}Pu	0.000	0.431	0.243	0.453	0.515	0.491
N_d ^{240}Pu	0.000	1.943	0.418	0.974	1.642	2.211
N_d ^{241}Pu	0.000	6.999	5.365	4.142	3.218	2.752
N_d ^{242}Pu	0.000	8.016	6.371	4.693	3.376	2.393
N_d ^{241}Am	0.000	6.914	5.412	3.879	2.713	1.940
N_d ^{243}Am	0.000	13.229	12.032	10.223	8.682	7.246
N_d ^{242}Cm	0.000	9.872	8.673	6.979	5.730	4.698
N_d ^{244}Cm	0.000	17.679	16.853	15.225	13.811	12.452
N_d ^{90}Sr	0.000	0.020	0.104	0.154	0.182	0.193
N_d ^{95}Mo	0.000	0.017	0.040	0.064	0.082	0.092
N_d ^{99}Tc	0.000	0.016	0.030	0.054	0.076	0.092
N_d ^{101}Ru	0.000	0.015	0.015	0.026	0.029	0.031
N_d ^{103}Rh	0.000	0.024	0.271	0.574	0.897	1.189
N_d ^{109}Ag	0.000	0.089	0.940	0.609	0.280	0.293
N_d ^{129}I	0.000	0.019	0.092	0.132	0.147	0.148
N_d ^{133}Xe	0.000	0.017	0.037	0.073	0.086	0.139
N_d ^{135}Xe	0.000	0.654	0.946	1.140	1.360	1.557
N_d ^{133}Cs	0.000	0.016	0.023	0.046	0.068	0.077
N_d ^{134}Cs	0.000	1.065	0.571	0.669	0.654	0.534
N_d ^{137}Cs	0.000	0.015	0.006	0.009	0.010	0.010
N_d ^{144}Ce	0.000	0.017	0.055	0.074	0.079	0.071
N_d ^{142}Nd	0.000	0.527	0.217	0.192	0.212	0.248
N_d ^{143}Nd	0.000	0.018	0.043	0.036	0.016	0.093
N_d ^{144}Nd	0.000	0.015	0.050	0.106	0.164	0.218
N_d ^{145}Nd	0.000	0.016	0.099	0.172	0.238	0.296
N_d ^{146}Nd	0.000	0.014	0.047	0.110	0.168	0.217
N_d ^{148}Nd	0.000	0.015	0.009	0.010	0.011	0.013
N_d ^{147}Sm	0.000	0.018	0.249	0.488	0.720	0.913
N_d ^{149}Sm	0.000	0.069	1.192	1.611	1.884	2.109
N_d ^{150}Sm	0.000	0.343	0.229	0.436	0.547	0.618
N_d ^{151}Sm	0.000	0.026	1.049	1.477	1.790	1.959
N_d ^{152}Sm	0.000	0.034	0.159	0.252	0.304	0.369
N_d ^{153}Eu	0.000	0.030	0.201	0.403	0.551	0.773
N_d ^{154}Eu	0.000	2.236	1.911	1.744	1.531	1.267
N_d ^{155}Eu	0.000	0.142	1.832	1.341	1.547	1.747
N_d ^{155}Gd	0.000	0.068	0.226	1.129	1.370	1.462
N_d ^{156}Gd	0.000	0.263	1.279	1.474	1.630	1.532
N_d ^{157}Gd	0.000	0.642	3.288	3.741	4.121	4.218
N_d ^{158}Gd	0.000	0.526	0.924	1.186	1.323	1.368

Appendix H

Tables for uncertainties from variations of fission products

Table H.1: Results of variations in the fission products data; uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.000	0.046	0.070	0.104	0.136	0.145
rr $^{235}U_{n,\gamma}$	0.000	0.020	0.030	0.000	0.050	0.080
rr $^{238}U_{n,\gamma}$	0.000	0.090	0.140	0.080	0.080	0.120
rr $^{239}Pu_{n,\gamma}$	0.000	0.000	0.000	0.080	0.060	0.120
rr $^{240}Pu_{n,\gamma}$	0.000	0.000	0.100	0.180	0.110	0.140
rr $^{241}Pu_{n,\gamma}$	0.000	0.020	0.020	0.060	0.050	0.120
rr $^{235}U_{n,f}$	0.000	0.000	0.020	0.040	0.050	0.120
rr $^{238}U_{n,f}$	0.000	0.040	0.110	0.140	0.180	0.250
rr $^{239}Pu_{n,f}$	0.000	0.000	0.000	0.060	0.060	0.110
rr $^{240}Pu_{n,f}$	0.000	0.000	0.020	0.110	0.140	0.220
rr $^{241}Pu_{n,f}$	0.000	0.000	0.030	0.040	0.050	0.100
Σ_{abs1}	0.000	0.110	0.130	0.200	0.220	0.240
Σ_{abs2}	0.000	0.110	0.110	0.110	0.140	0.140
Σ_{fiss1}	0.000	0.100	0.100	0.110	0.110	0.100
Σ_{fiss2}	0.000	0.110	0.110	0.110	0.130	0.130
$\nu\Sigma_{fiss1}$	0.000	0.100	0.100	0.110	0.120	0.100
$\nu\Sigma_{fiss2}$	0.000	0.110	0.110	0.110	0.130	0.130
D_1	0.000	0.040	0.030	0.020	0.000	0.100
D_2	0.000	0.000	0.300	0.430	0.470	0.550
Σ_{trn1}	0.000	0.140	0.150	0.150	0.130	0.180
Σ_{trn2}	0.000	0.300	0.200	0.390	0.440	0.510
$InvVel_1$	0.000	0.120	0.120	0.130	0.150	0.190
$InvVel_2$	0.000	0.040	0.040	0.050	0.040	0.050
scatt. gr. 1 to gr. 1	0.000	2.00e-2	5.00e-2	1.00e-1	1.30e-1	1.70e-1
scatt. gr. 2 to gr. 1	0.000	9.80e-1	9.70e-1	1.17e+0	1.46e+0	1.48e+0
scatt. gr. 1 to gr. 2	0.000	8.00e-2	1.00e-1	1.30e-1	1.70e-1	1.80e-1
scatt. gr. 2 to gr. 2	0.000	0.000	7.00e-2	1.50e-1	2.10e-1	2.60e-1
ADF, side W, gr. 1	0.000	1.30e-1	1.00e-1	1.10e-1	0.000	5.00e-2
ADF, side S, gr. 1	0.000	1.30e-1	1.00e-1	1.10e-1	0.000	5.00e-2
ADF, side E, gr. 1	0.000	1.30e-1	1.00e-1	1.10e-1	0.000	5.00e-2
ADF, side N, gr. 1	0.000	1.30e-1	1.00e-1	1.10e-1	0.000	5.00e-2

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Table H.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side W, gr. 2	0.000	3.30e-1	9.00e-2	2.90e-1	1.20e-1	2.40e-1
ADF, side S, gr. 2	0.000	3.30e-1	9.00e-2	2.90e-1	1.20e-1	2.40e-1
ADF, side E, gr. 2	0.000	3.30e-1	9.00e-2	2.90e-1	1.20e-1	2.40e-1
ADF, side N, gr. 2	0.000	3.30e-1	9.00e-2	2.90e-1	1.20e-1	2.40e-1
N_d ^{234}U	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{235}U	0.000	0.000	0.003	0.007	0.011	0.033
N_d ^{236}U	0.000	0.000	0.013	0.000	0.000	0.000
N_d ^{238}U	0.000	0.000	0.000	0.000	0.001	0.001
N_d ^{237}Np	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{238}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{239}Pu	0.000	0.000	0.000	0.000	0.000	0.092
N_d ^{240}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{241}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{242}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{241}Am	0.000	0.000	0.000	0.049	0.000	0.000
N_d ^{243}Am	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{242}Cm	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{244}Cm	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{90}Sr	0.000	0.011	0.011	0.011	0.010	0.014
N_d ^{95}Mo	0.000	0.012	0.214	0.515	0.868	1.236
N_d ^{99}Tc	0.000	0.012	0.182	0.386	0.611	0.841
N_d ^{101}Ru	0.000	0.011	0.154	0.326	0.517	0.709
N_d ^{103}Rh	0.000	0.008	0.362	0.789	1.219	1.603
N_d ^{109}Ag	0.000	<0.049	0.339	0.693	1.028	1.348
N_d ^{129}I	0.000	0.012	0.253	0.543	0.863	1.191
N_d ^{133}Xe	0.000	0.018	0.851	1.730	2.603	3.429
N_d ^{135}Xe	0.000	2.043	2.052	2.109	2.160	2.218
N_d ^{133}Cs	0.000	0.013	0.459	0.978	1.541	2.098
N_d ^{134}Cs	0.000	7.882	8.013	7.814	7.529	7.174
N_d ^{137}Cs	0.000	0.011	0.013	0.014	0.015	0.016
N_d ^{144}Ce	0.000	0.011	0.012	0.012	0.012	0.015
N_d ^{142}Nd	0.000	11.380	11.856	12.055	12.095	12.023
N_d ^{143}Nd	0.000	0.011	0.440	0.931	1.419	1.858
N_d ^{144}Nd	0.000	0.055	1.024	1.050	0.997	0.915
N_d ^{145}Nd	0.000	0.020	1.056	2.224	3.490	4.754
N_d ^{146}Nd	0.000	0.027	1.181	2.120	2.836	3.324
N_d ^{148}Nd	0.000	0.011	0.046	0.093	0.147	0.203
N_d ^{147}Sm	0.000	0.060	3.616	7.476	11.205	14.468
N_d ^{149}Sm	0.000	<0.028	<0.161	0.070	0.261	0.351
N_d ^{150}Sm	0.000	<0.104	0.052	0.106	0.163	0.219
N_d ^{151}Sm	0.000	0.007	0.111	0.240	0.359	0.459
N_d ^{152}Sm	0.000	0.027	1.249	2.343	3.206	3.803
N_d ^{153}Eu	0.000	0.053	2.487	3.518	4.201	4.705
N_d ^{154}Eu	0.000	6.521	5.492	4.539	3.500	2.561
N_d ^{155}Eu	0.000	<0.038	2.613	3.593	3.129	2.435
N_d ^{155}Gd	0.000	0.086	2.589	3.649	3.237	2.601
N_d ^{156}Gd	0.000	<0.048	1.011	2.489	3.090	3.208
N_d ^{157}Gd	0.000	0.245	2.647	6.233	9.315	11.254
N_d ^{158}Gd	0.000	0.087	1.114	2.899	5.064	7.036

Appendix I

Tables for uncertainties from variations of minor actinides

Table I.1: Results of variations in the minor actinide data; uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.000	0.000	0.027	0.033	0.058	0.075
rr $^{235}U_{n,\gamma}$	0.000	0.020	0.000	0.030	0.070	0.120
rr $^{238}U_{n,\gamma}$	0.000	0.000	0.000	0.000	0.100	0.030
rr $^{239}Pu_{n,\gamma}$	0.000	0.000	0.010	0.060	0.080	0.140
rr $^{240}Pu_{n,\gamma}$	0.000	0.760	0.810	0.720	0.830	0.830
rr $^{241}Pu_{n,\gamma}$	0.000	1.030	1.030	1.030	1.050	1.060
rr $^{235}U_{n,f}$	0.000	0.000	0.000	0.050	0.080	0.140
rr $^{238}U_{n,f}$	0.000	0.000	0.000	0.160	0.300	0.420
rr $^{239}Pu_{n,f}$	0.000	0.000	0.000	0.050	0.080	0.140
rr $^{240}Pu_{n,f}$	0.000	0.000	0.150	0.140	0.200	0.195
rr $^{241}Pu_{n,f}$	0.000	0.000	0.460	0.440	0.430	0.430
Σ_{abs1}	0.000	0.000	0.090	0.090	0.100	0.110
Σ_{abs2}	0.000	0.070	0.070	0.090	0.120	0.150
Σ_{fiss1}	0.000	0.000	0.100	0.090	0.120	0.190
Σ_{fiss2}	0.000	0.080	0.070	0.090	0.110	0.130
$\nu\Sigma_{fiss1}$	0.000	0.000	0.100	0.100	0.140	0.210
$\nu\Sigma_{fiss2}$	0.000	0.080	0.070	0.100	0.110	0.140
D_1	0.000	0.030	0.000	0.000	0.000	0.110
D_2	0.000	0.000	0.300	0.290	0.220	0.260
Σ_{trn1}	0.000	0.000	0.120	0.120	0.140	0.180
Σ_{trn2}	0.000	0.000	0.150	0.150	<0.280	0.120
$InvVel_1$	0.000	0.000	0.080	0.080	0.110	0.110
$InvVel_2$	0.000	0.000	0.040	0.040	0.040	0.050
scatt. gr. 1 to gr. 1	0.000	0.000	2.00e-2	3.00e-2	5.00e-2	6.00e-2
scatt. gr. 2 to gr. 1	0.000	0.000	9.40e-1	9.00e-1	9.60e-1	9.70e-1
scatt. gr. 1 to gr. 2	0.000	0.000	9.00e-2	9.00e-2	1.10e-1	1.20e-1
scatt. gr. 2 to gr. 2	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side W, gr. 1	0.000	0.000	8.00e-2	8.00e-2	6.00e-2	0.000
ADF, side S, gr. 1	0.000	0.000	8.00e-2	8.00e-2	6.00e-2	0.000
ADF, side E, gr. 1	0.000	0.000	8.00e-2	8.00e-2	6.00e-2	0.000
ADF, side N, gr. 1	0.000	0.000	8.00e-2	8.00e-2	6.00e-2	0.000
ADF, side W, gr. 2	0.000	0.000	0.000	1.20e-1	1.50e-1	2.00e-1

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Table I.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side S, gr. 2	0.000	0.000	0.000	1.20e-1	1.50e-1	2.00e-1
ADF, side E, gr. 2	0.000	0.000	0.000	1.20e-1	1.50e-1	2.00e-1
ADF, side N, gr. 2	0.000	0.000	0.000	1.20e-1	1.50e-1	2.00e-1
N_d ^{234}U	0.000	0.029	1.448	2.961	4.585	6.200
N_d ^{235}U	0.000	0.000	0.005	0.020	0.057	0.133
N_d ^{236}U	0.000	0.055	0.045	0.084	0.122	0.163
N_d ^{238}U	0.000	0.000	0.001	0.002	0.004	0.007
N_d ^{237}Np	0.000	0.000	1.343	1.820	2.283	2.816
N_d ^{238}Pu	0.000	6.999	7.038	6.770	6.813	7.157
N_d ^{239}Pu	0.000	0.178	0.166	0.258	0.353	0.522
N_d ^{240}Pu	0.000	2.932	0.222	0.339	0.420	0.539
N_d ^{241}Pu	0.000	4.340	0.520	0.384	0.467	0.490
N_d ^{242}Pu	0.000	5.636	1.208	1.224	1.367	1.597
N_d ^{241}Am	0.000	5.539	1.106	2.206	3.486	4.841
N_d ^{243}Am	0.000	8.311	5.310	5.118	5.028	4.924
N_d ^{242}Cm	0.000	10.068	7.435	6.864	6.167	5.423
N_d ^{244}Cm	0.000	10.309	6.363	6.133	5.953	5.756
N_d ^{90}Sr	0.000	0.030	0.010	0.018	0.026	0.035
N_d ^{95}Mo	0.000	0.036	0.012	0.021	0.036	0.055
N_d ^{99}Tc	0.000	0.035	0.220	0.464	0.729	0.989
N_d ^{101}Ru	0.000	0.038	0.224	0.472	0.742	1.014
N_d ^{103}Rh	0.000	0.044	0.408	0.852	1.298	1.692
N_d ^{109}Ag	0.000	0.102	0.115	0.328	0.514	0.646
N_d ^{129}I	0.000	0.042	0.077	0.165	0.266	0.368
N_d ^{133}Xe	0.000	0.042	0.182	0.393	0.606	0.833
N_d ^{135}Xe	0.000	5.770	5.742	5.714	5.678	5.638
N_d ^{133}Cs	0.000	0.036	0.271	0.575	0.901	1.223
N_d ^{134}Cs	0.000	8.801	8.432	8.360	8.214	8.008
N_d ^{137}Cs	0.000	0.038	0.003	0.010	0.017	0.026
N_d ^{144}Ce	0.000	0.035	0.004	0.007	0.015	0.024
N_d ^{142}Nd	0.000	18.613	18.273	18.175	18.002	17.880
N_d ^{143}Nd	0.000	0.021	1.011	1.997	2.901	3.680
N_d ^{144}Nd	0.000	0.160	3.071	3.313	3.310	3.188
N_d ^{145}Nd	0.000	0.030	0.430	0.867	1.327	1.761
N_d ^{146}Nd	0.000	0.051	0.526	1.006	1.452	1.817
N_d ^{148}Nd	0.000	0.044	0.001	0.011	0.022	0.035
N_d ^{147}Sm	0.000	0.031	0.616	1.322	2.044	2.696
N_d ^{149}Sm	0.000	0.043	0.094	0.215	0.413	0.718
N_d ^{150}Sm	0.000	0.000	0.021	0.059	0.093	0.127
N_d ^{151}Sm	0.000	0.052	0.065	0.171	0.286	0.515
N_d ^{152}Sm	0.000	0.038	0.709	1.279	1.758	2.136
N_d ^{153}Eu	0.000	0.045	0.584	1.722	2.798	3.640
N_d ^{154}Eu	0.000	16.409	15.047	12.740	10.062	7.841
N_d ^{155}Eu	0.000	0.083	4.176	7.828	8.012	6.515
N_d ^{155}Gd	0.000	1.484	6.153	4.908	4.759	5.065
N_d ^{156}Gd	0.000	0.112	1.040	3.537	5.010	5.193
N_d ^{157}Gd	0.000	5.878	7.726	6.899	5.785	4.814
N_d ^{158}Gd	0.000	6.097	0.727	1.732	3.368	5.159

Appendix J

Tables for uncertainties from variations of fission yields

Table J.1: Results of variations in the fission yield data; uncertainties (%)

	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	0.000	0.109	0.174	0.217	0.261	0.312
rr $^{235}U_{n,\gamma}$	0.000	0.030	0.010	0.020	0.030	0.080
rr $^{238}U_{n,\gamma}$	0.000	0.090	0.170	0.160	0.130	0.180
rr $^{239}Pu_{n,\gamma}$	0.000	0.000	0.020	0.050	0.100	0.160
rr $^{240}Pu_{n,\gamma}$	0.000	0.000	0.220	0.100	0.130	0.160
rr $^{241}Pu_{n,\gamma}$	0.000	0.000	0.000	0.070	0.120	0.190
rr $^{235}U_{n,f}$	0.000	0.010	0.040	0.080	0.130	0.200
rr $^{238}U_{n,f}$	0.000	0.100	0.170	0.220	0.240	0.290
rr $^{239}Pu_{n,f}$	0.000	0.000	0.020	0.050	0.110	0.180
rr $^{240}Pu_{n,f}$	0.000	0.000	0.170	0.220	0.230	0.290
rr $^{241}Pu_{n,f}$	0.000	0.000	0.010	0.080	0.130	0.200
Σ_{abs1}	0.000	0.090	0.130	0.190	0.220	0.260
Σ_{abs2}	0.000	0.120	0.170	0.230	0.280	0.360
Σ_{fiss1}	0.000	0.090	0.080	0.080	0.100	0.100
Σ_{fiss2}	0.000	0.100	0.100	0.100	0.100	0.120
$\nu\Sigma_{fiss1}$	0.000	0.090	0.080	0.080	0.100	0.100
$\nu\Sigma_{fiss2}$	0.000	0.000	0.090	0.100	0.100	0.130
D_1	0.000	0.000	0.000	0.090	0.000	0.040
D_2	0.000	0.000	0.280	0.270	0.270	0.260
Σ_{trn1}	0.000	0.110	0.120	0.160	0.130	0.150
Σ_{trn2}	0.000	0.180	0.100	0.100	0.110	0.120
$InvVel_1$	0.000	0.090	0.100	0.120	0.120	0.150
$InvVel_2$	0.000	0.040	0.050	0.050	0.060	0.070
scatt. gr. 1 to gr. 1	0.000	2.00e-2	2.00e-2	2.00e-2	2.00e-2	2.00e-2
scatt. gr. 2 to gr. 1	0.000	8.60e-1	9.80e-1	9.00e-1	9.60e-1	1.03e+0
scatt. gr. 1 to gr. 2	0.000	8.00e-2	1.10e-1	1.40e-1	1.50e-1	1.80e-1
scatt. gr. 2 to gr. 2	0.000	0.000	0.000	0.000	0.000	0.000
ADF, side W, gr. 1	0.000	0.000	7.00e-2	6.00e-2	6.00e-2	5.00e-2
ADF, side S, gr. 1	0.000	0.000	7.00e-2	6.00e-2	6.00e-2	5.00e-2
ADF, side E, gr. 1	0.000	0.000	7.00e-2	6.00e-2	6.00e-2	5.00e-2
ADF, side N, gr. 1	0.000	0.000	7.00e-2	6.00e-2	6.00e-2	5.00e-2

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Table J.1 – continued from previous page						
	Burnup (GWd/MTU)					
	0	0.2	10	20	30	40
ADF, side W, gr. 2	0.000	1.00e-1	7.00e-2	1.30e-1	1.00e-1	1.10e-1
ADF, side S, gr. 2	0.000	1.00e-1	7.00e-2	1.30e-1	1.00e-1	1.10e-1
ADF, side E, gr. 2	0.000	1.00e-1	7.00e-2	1.30e-1	1.00e-1	1.10e-1
ADF, side N, gr. 2	0.000	1.00e-1	7.00e-2	1.30e-1	1.00e-1	1.10e-1
N_d ^{234}U	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{235}U	0.000	0.000	0.003	0.014	0.038	0.079
N_d ^{236}U	0.000	0.000	0.012	0.011	0.018	0.028
N_d ^{238}U	0.000	0.000	0.001	0.001	0.002	0.003
N_d ^{237}Np	0.000	0.000	0.000	0.174	0.236	0.254
N_d ^{238}Pu	0.000	0.000	0.000	0.217	0.242	0.295
N_d ^{239}Pu	0.000	0.000	0.073	0.104	0.141	0.217
N_d ^{240}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{241}Pu	0.000	0.000	0.000	0.000	0.127	0.127
N_d ^{242}Pu	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{241}Am	0.000	0.000	0.000	0.105	0.119	0.157
N_d ^{243}Am	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{242}Cm	0.000	0.000	0.000	0.080	0.061	0.131
N_d ^{244}Cm	0.000	0.000	0.000	0.000	0.000	0.000
N_d ^{90}Sr	0.000	6.156	5.935	5.785	5.672	5.590
N_d ^{95}Mo	0.000	5.540	5.319	5.455	5.862	6.368
N_d ^{99}Tc	0.000	12.443	11.106	10.272	9.700	9.327
N_d ^{101}Ru	0.000	2.596	2.649	2.973	3.351	3.714
N_d ^{103}Rh	0.000	13.282	11.694	11.194	11.196	11.398
N_d ^{109}Ag	0.000	34.788	26.569	25.370	23.176	21.196
N_d ^{129}I	0.000	8.176	8.479	10.688	12.425	13.690
N_d ^{133}Xe	0.000	11.267	9.637	8.730	8.034	7.506
N_d ^{135}Xe	0.000	3.265	3.058	3.260	3.536	3.845
N_d ^{133}Cs	0.000	3.719	3.452	3.342	3.316	3.349
N_d ^{134}Cs	0.000	7.646	3.452	3.263	3.188	3.146
N_d ^{137}Cs	0.000	2.080	2.022	2.004	2.003	2.012
N_d ^{144}Ce	0.000	2.538	2.854	3.537	4.332	5.130
N_d ^{142}Nd	0.000	3.041	2.933	2.886	2.876	2.931
N_d ^{143}Nd	0.000	4.072	3.910	3.972	4.149	4.387
N_d ^{144}Nd	0.000	2.394	2.237	2.467	2.738	2.992
N_d ^{145}Nd	0.000	4.690	4.519	4.665	4.949	5.289
N_d ^{146}Nd	0.000	16.536	14.954	13.738	12.706	11.854
N_d ^{148}Nd	0.000	16.551	14.589	13.515	12.752	12.219
N_d ^{147}Sm	0.000	9.584	9.026	8.641	8.384	8.218
N_d ^{149}Sm	0.000	12.398	9.225	8.496	8.436	8.598
N_d ^{150}Sm	0.000	12.389	10.248	9.113	8.560	8.305
N_d ^{151}Sm	0.000	29.301	21.882	16.608	13.340	11.388
N_d ^{152}Sm	0.000	29.043	16.579	14.112	12.121	10.639
N_d ^{153}Eu	0.000	30.005	16.542	12.782	11.147	10.073
N_d ^{154}Eu	0.000	30.039	18.629	13.813	11.816	10.632
N_d ^{155}Eu	0.000	32.689	16.063	11.649	10.473	9.733
N_d ^{155}Gd	0.000	32.755	16.808	11.857	10.799	10.197
N_d ^{156}Gd	0.000	36.443	16.818	12.324	10.330	9.499
N_d ^{157}Gd	0.000	33.203	20.954	18.238	14.925	12.354
N_d ^{158}Gd	0.000	30.453	17.053	16.164	14.877	13.477

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