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# Burn-up Credit Criticality Benchmark

## Phase II-D

## PWR-$UO_2$ Assembly
## Study of Control Rod Effects on Spent Fuel Composition

Anne BARREAU
Commissariat à l'énergie atomique
France


NEA No. 6227

NUCLEAR ENERGY AGENCY
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## FOREWORD

This report describes the final results of the Phase II-D Burn-up Credit Criticality Benchmark conducted by the NEA Expert Group on Burn-up Credit Criticality Safety. The objective of the Phase II-D benchmark was to study the impact of control rod (CR) insertion on spent fuel composition and on reactivity for a PWR-$UO_2$ assembly. For this purpose, a range of CR insertion profiles during irradiation were defined, and participants were asked to calculate the spent fuel inventory and the neutron multiplication factor for each case. To assist in the evaluation of the benchmark results, the sensitivity of the neutron multiplication factor to a variation of isotope concentration was performed by a limited number of participants.

In total, 14 contributions (from 10 companies/organisations in 8 countries) were submitted to the Phase II-D benchmark exercise. One contribution did not perform the neutron multiplication factors. Sensitivity calculations were submitted by four contributors.

Analysis of the nuclide concentration effect of CR insertion shows good agreement between participants, except for the $^{155}$Gd nuclide: the absolute difference from the mean value is less than 10%, but reaches 50% for the $^{155}$Gd.

Analysis of the Kinf effect of CR insertion shows good agreement between participants. The relative standard deviation is about 6%, which corresponds to 300 pcm. The percentage differences relative to the mean value lie between -15% and +15%. Most of the participants are in the range of ±5%.

Analysis of the sensitivity exercises shows that the nuclides which have the most important effect on Kinf or Keff are the $^{235}$U (+140 pcm/%), $^{238}$U (-120 pcm/%), $^{239}$Pu (+140 pcm/%), $^{240}$Pu (-40 pcm/%) and $^{241}$Pu (+50 pcm/%). The effect of other nuclides is less than 20 pcm/%, with most contributing less than 5 pcm/%.

This publication is available in colour on the NEA website at: www.nea.fr/html/science/nea6227-burnupIID.pdf.

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# INTRODUCTION

Taking credit for changes in fuel composition during irradiation in spent fuel criticality analyses (BUC) normally requires that a depletion calculation be made. Some depletion parameters have an important effect on nuclide concentration, and therefore on spent fuel reactivity. This benchmark proposes a study of the effect of control rod (CR) modelling on calculated spent fuel composition and on the neutron multiplication factor.

The presence of control rods during the depletion of a $UO_2$ assembly results in hardening of the irradiation neutron spectrum (due to the removal of thermal neutrons by capture and by displacement of the moderator). This in turn leads to an increased production rate of plutonium isotopes and a decrease in the $^{235}U$ fission rate. An assembly that experienced CR insertion during irradiation can therefore have a higher reactivity than a similar assembly that had not been exposed to CRs.

The main part of this benchmark is divided into two sets of calculations:

- depletion calculations for a $UO_2$ assembly;
- Kinf calculations on an infinite array of irradiated $UO_2$ assemblies in cold water.

The depletion calculations are performed for two levels of burn-up, 30 GWd/tU and 45 GWd/tU, and two cooling times, zero and five years. A range of CR insertion profiles during irradiation has been defined and participants were asked to calculate the spent fuel inventory in each case.

The Kinf values for the infinite array provide a simple means of assessing the impact of differences in calculated inventory on neutron multiplication factors for spent fuel.

This benchmark investigates the spectral effects of CR insertion; effects of CR insertion on axial profile are not considered here.

To facilitate more detailed analysis of the effects of differences in calculated fuel inventories, further calculations have been carried out by a limited number of participants. These have provided sensitivity coefficients by isotope j, $\left(\frac{\delta K}{\delta N_j}\right)$, for both the infinite array and a spent fuel cask environment.

The complete specification of the benchmark is presented in Appendix A.

## *Chapter 2*

## BENCHMARK CONTRIBUTIONS

### 2.1 Fuel inventory calculations

A total of 14 contributions were made to the depletion exercise, from 10 different companies/ organisations coming from 8 countries around the world. Codes and nuclear data libraries used by the benchmark participants are presented in Table 2.1. A detailed description of the participants' methods, data and assumptions can be obtained from Appendix B.

**Table 2.1. Participant, code and nuclear data source for depletion calculations**

| No. | Country | Institute | Code | Model | Origin | Number of groups | Processing code |
|---|---|---|---|---|---|---|---|
| 1 | Switzerland | PSI | Monteburns-2.0<br>MCNPX-2.4.0<br>ORIGEN-2.1 | 3-D | ENDF/B-VI<br>JEF2.2<br>MCNPDAT<br>A DLC-200 | Continuous | – |
| 2 | Japan | JNES | MVP2.0<br>ORIGEN2.1 | 3-D<br>0-D | JENDL-3.3 | Continuous | ART |
| 3 | Japan | JAERI | SWAT2 | 2-D | JENDL-3.3 | Continuous | ART |
| 4 | Japan | JAERI | SWAT2 | 2-D | JENDL-3.2 | Continuous | ART |
| 5 | Korea | KAERI | LIBERTE | 2-D | ENDF/B-VI | 35 | NJOY,<br>RABBLE |
| 6 | UK | Serco Assurance | WIMS8 | 2-D | JEF2.2 | 172 | NJOY |
| 7 | UK | BNFL | WIMS8A | 2-D | JEF2.2 | 172 | NJOY |
| 8 | Finland | VTT | CASMO-4 | 2-D | ENDF/B-IV | 70 | CASLIB |
| 9 | Germany | AREVA<br>Framatome-ANP | CASMO-4 | 2-D | JEF2.2 | 70 | NJOY |
| 10 | France | CEA | APOLLO2.5 | 2-D | JEF2.2 | 172 | NJOY |
| 11 | USA | ORNL | HELIOS | 2-D | ENDF/B-V | 45 | – |
| 12 | USA | ORNL | SAS2H | 1-D | ENDF/B-V | 44 | BONAMI/NIT<br>AWL |
| 13 | USA | ORNL | TRITON/KENO | 3-D | ENDF/B-V | 44 | BONAMI/NIT<br>AWL |
| 14 | USA | ORNL | TRITON/NEWT | 2-D | ENDF/B-V | 44 | BONAMI/NIT<br>AWL |

### 2.2 Criticality calculations

A total of 13 contributions were made to the criticality exercise, from 9 different companies/ organisations coming from 7 countries around the world. Codes and nuclear data libraries used by the benchmark participants are presented in Table 2.2. A detailed description of the participants' methods, data and assumptions can be obtained from Appendix B.

**Table 2.2. Participant, code and nuclear data source for criticality calculations**

| No. | Country | Institute | Code | Model | Origin | Number of groups | Processing code | No. of fuel inventory (Table 2.1) |
|---|---|---|---|---|---|---|---|---|
| 1 | Switzerland | PSI | MCNPX-2.4.0 | 3-D | ENDF/B-VI JEF2.2 MCNPDATA DLC-200 | Continuous | – | 1 |
| 2 | Japan | JNES | MVP2.0 | 3-D | JENDL-3.3 | Continuous | ART | 2 |
| 3 | Japan | JAERI | MVP | 2-D | JENDL-3.3 | Continuous | ART | 3 |
| 4 | Japan | JAERI | MVP | 2-D | JENDL-3.2 | Continuous | ART | 4 |
| 5 | UK | Serco Assurance | MONK8B | 3-D | JEF2.2 | 13 193 | NJOY | 6 |
| 6 | UK | BNFL | MONK8B | 3-D | JEF2.2 | 13 193 | DICE | 7 |
| 7 | Finland | VTT | MCNP4C | 3-D | ENDF/B-V.8 | Continuous | NJOY | 8 |
| 8 | Germany | AREVA Framatome-ANP | KENO V.a | 3-D | JEF2.2 | 44 | BONAMI/ NITAWL | 9 |
| 9 | France | CEA | CRISTAL1.0 | 2-D | JEF2.2 | 20 | NJOY | 10 |
| 10 | USA | ORNL | KENO V.a | 3-D | ENDF/B-V | 238 | BONAMI/ NITAWL | 11 |
| 11 | USA | ORNL | KENO V.a | 3-D | ENDF/B-V | 238 | BONAMI/ NITAWL | 12 |
| 12 | USA | ORNL | KENO V.a | 3-D | ENDF/B-V | 238 | BONAMI/ NITAWL | 13 |
| 13 | USA | ORNL | KENO V.a | 3-D | ENDF/B-V | 238 | BONAMI/ NITAWL | 14 |

## 2.3 Sensitivity calculations

A total of 4 contributions were made to the sensitivity exercise, from 4 different companies/ organisations coming from 4 countries around the world. Codes and nuclear data libraries used by the benchmark participants are presented in Table 2.3. Note that France has only performed sensitivity calculations on the array. The other participants have performed sensitivity calculations both on the array and on the cask. A detailed description of the participants' methods, data and assumptions can be obtained from Appendix B.

**Table 2.3. Participant, code and nuclear data source for sensitivity calculations**

| No. | Country | Institute | Code | Model | Origin | Number of groups | Processing code |
|---|---|---|---|---|---|---|---|
| 1 | UK | Serco Assurance | MONK8B | 3-D | JEF2.2 | 13 193 | NJOY |
| 2 | Finland | VTT | MCNP4C | 3-D | ENDF/ B-V.8 | Continuous | NJOY |
| 3 | France | CEA | CRISTAL1.0 | 2-D | JEF2.2 | 20 | NJOY |
| 4 | USA | ORNL | KENO V.a | 3-D | ENDF/B-V | 238 | BONAMI/NITAW L |

## *Chapter 3*

## SPENT FUEL INVENTORY CALCULATIONS

### 3.1 Results

The results from the participants in the spent fuel inventory calculations are presented in Tables 3.1 to 3.12. These results are expressed in atom/barn.cm. In addition to this, these tables also present the mean calculated nuclide concentrations, the standard deviation from the 14 individual contributions and the relative standard deviation.

The average, standard deviation (SD) and relative standard deviation (RSD) are defined as follows:

$$\text{Average} = \frac{1}{I}\sum_{i=1}^{I} N_i$$

$$SD = \sqrt{\frac{\sum_{i=1}^{I}(Ni - \text{Average})^2}{I}}$$

$$RSD = \frac{SD}{\text{Average}}$$

Here, $N_i$ is the atomic number concentration or other parameter of interest calculated by participant i (where the number of participants is denoted by I).

The RSD on fuel inventory is graphically presented in Figure 3.1 for actinides and Figure 3.2 for fission products (FPs). We do not give the relative difference from the mean value for each participant, because the main interest of this benchmark is to compare the effects of CR insertion on nuclide concentration and not the calculated nuclide concentrations. Nevertheless, some general comments about the RSD observed are presented below.

### 3.2 Comparison of the calculated concentrations

#### *3.2.1 Actinide concentration*

Figure 3.1 shows that the RSD are less than 6% for most of the actinides. Only $^{234}U$ and $^{243}Am$ RSD exceed 6% (7% and 9% respectively).

*$^{234}$U actinide*. The high RSD are due mainly to the JNES results which are always lower than the results of the other participants. The RSD increases with the CR insertion: when CRs are inserted from 0 to 45 GWd/t, the $^{234}$U concentration calculated by JNES is 20% lower than the mean value. If the JNES results are excluded, the RSD decreases to 3%. It is interesting to note that the results of JAERI, using the same library (JENDL3.3), are higher than the JNES results, and closer to the mean value.

*$^{243}$Am actinide*. The high RSD are due to the dispersion of the results around the mean value from about 10%. $^{243}$Am concentrations calculated by USA (except those calculated with HELIOS code) and by JNES are higher than all other results. The dispersion of the $^{243}$Am concentration has been soon noticed in the UOx Phase I-B benchmark, and USA results were higher than the other results.

*$^{238}$Pu actinide*. The concentrations calculated by FINLAND and JNES are always higher than the concentrations calculated by the other participants. FINNISH and JNES values are 10% higher than the mean values. If FINNISH and JNES results are excluded, the RSD decreases to 3%. Again, it is interesting to note that the results of JAERI, using the same library (JENDL3.3), are about 12% lower than the JNES results.

*$^{235}$U actinide*. The concentrations calculated by USA with the SAS2h code are lower than the concentrations calculated by the other participants when there are no CRs (7% lower than the mean value at 45 GWd/t).

### *3.2.2 Fission product concentration*

Figure 3.2 shows that the RSD are less than 10% for the majority of FPs. Only $^{155}$Gd RSD exceed 30%, while $^{103}$Rh and $^{109}$Ag RSD are a little more than 10%.

*$^{155}$Gd nuclide*. There is a large disagreement between participants: the French results are about 30% higher than the average computed concentration and Finnish results are about 110% higher, while Korean and USA results are about 30% to 40% under. This large disagreement has been soon observed in the UOX Phase I-B benchmark [2]

*$^{103}$Rh nuclide*. The high RSD are due mainly to the Korean results, which are 60% lower than the mean value. If Korean results are excluded, the RSD decrease to 5%. It is interesting to note that the results of Switzerland, using the same library (ENDF/B-VI), are close to the mean value.

*$^{109}$Ag nuclide*. The Japanese results are always 15% higher than the mean values, while the Finnish results are 25% lower. The low values of Finland compared to the mean value were already observed in the MOX Phase IV-B benchmark, in which the NUPEC results, which use the same library as Finland (ENDF/B-IV), are lower than the mean values by about 20%.

The SAS2h results (ORNL) are higher than the results of the other participants when CRs are inserted (40% higher than the mean value when CRs are inserted from 0 to 45 GWd/t). This cause of this problem is known by ORNL; the presence of the $^{109}$Ag in the control rods leads to improper cell-weighting of the $^{109}$Ag cross-sections used in the fuel. With the 1-D calculation approach in SAS2h, cross-sections are calculated by cell weighing based on the flux through the material – in this case, the $^{109}$Ag cross-sections are calculated, based on the extremely low flux in the control rod region. The lower cross-section results in less destruction of $^{109}$Ag in the fuel region as it is being produced, and thus explains the final overestimated concentration. A detailed explanation is given in Appendix B, Part A.11.

# Table 3.1. Case 1: UOX 30 GWd/t, no CRs, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 5.076E-06 | 5.289E-06 | 5.189E-06 | 5.283E-06 | 5.110E-06 | 4.867E-06 | 5.203E-06 | 5.214E-06 | 5.040E-06 | 5.127E-06 | 5.169E-06 | 5.166E-06 | 5.142E-06 | 5.090E-06 | 5.140E-06 | 1.067E-07 | 2.1% |
| **U235** | 3.397E-04 | 3.458E-04 | 3.409E-04 | 3.478E-04 | 3.386E-04 | 3.367E-04 | 3.411E-04 | 3.429E-04 | 3.436E-04 | 3.441E-04 | 3.283E-04 | 3.384E-04 | 3.340E-04 | 3.430E-04 | 3.403E-04 | 5.044E-06 | 1.5% |
| **U236** | 9.855E-05 | 9.849E-05 | 1.016E-04 | 9.855E-05 | 1.021E-04 | 1.028E-04 | 1.010E-04 | 9.744E-05 | 9.891E-05 | 1.016E-04 | 1.028E-04 | 1.020E-04 | 1.026E-04 | 9.790E-05 | 1.005E-04 | 2.011E-06 | 2.0% |
| **U238** | 2.106E-02 | 2.110E-02 | 2.111E-02 | 2.110E-02 | 2.112E-02 | 2.110E-02 | 2.111E-02 | 2.111E-02 | 2.111E-02 | 2.111E-02 | 2.112E-02 | 2.111E-02 | 2.111E-02 | 2.120E-02 | 2.111E-02 | 2.933E-05 | 0.1% |
| **Pu238** | 2.112E-06 | 1.944E-06 | 2.271E-06 | 1.967E-06 | 2.122E-06 | 2.255E-06 | 1.981E-06 | 1.896E-06 | 2.062E-06 | 2.051E-06 | 2.061E-06 | 2.092E-06 | 2.142E-06 | 1.970E-06 | 2.050E-06 | 1.108E-07 | 5.4% |
| **Pu239** | 1.235E-04 | 1.290E-04 | 1.229E-04 | 1.295E-04 | 1.196E-04 | 1.267E-04 | 1.245E-04 | 1.241E-04 | 1.222E-04 | 1.272E-04 | 1.181E-04 | 1.234E-04 | 1.235E-04 | 1.220E-04 | 1.240E-04 | 3.257E-06 | 2.6% |
| **Pu240** | 4.137E-05 | 4.191E-05 | 3.947E-05 | 4.192E-05 | 4.010E-05 | 4.150E-05 | 4.068E-05 | 4.061E-05 | 3.884E-05 | 4.118E-05 | 4.189E-05 | 4.184E-05 | 4.224E-05 | 4.080E-05 | 4.103E-05 | 1.008E-06 | 2.5% |
| **Pu241** | 2.471E-05 | 2.487E-05 | 2.446E-05 | 2.510E-05 | 2.390E-05 | 2.620E-05 | 2.515E-05 | 2.514E-05 | 2.423E-05 | 2.442E-05 | 2.316E-05 | 2.376E-05 | 2.401E-05 | 2.430E-05 | 2.453E-05 | 7.504E-07 | 3.1% |
| **Pu242** | 6.366E-06 | 6.130E-06 | 6.149E-06 | 6.171E-06 | 5.916E-06 | 6.855E-06 | 6.415E-06 | 6.388E-06 | 6.056E-06 | 5.802E-06 | 6.643E-06 | 6.503E-06 | 6.671E-06 | 6.030E-06 | 6.292E-06 | 3.069E-07 | 4.9% |
| **Np237** | 8.153E-06 | 7.329E-06 | 8.725E-06 | 7.389E-06 | 8.105E-06 | 8.541E-06 | 8.011E-06 | 7.652E-06 | 8.100E-06 | 8.041E-06 | 8.254E-06 | 8.349E-06 | 8.456E-06 | 7.770E-06 | 8.063E-06 | 4.116E-07 | 5.1% |
| **Am241** | 6.068E-07 | 6.096E-07 | 5.986E-07 | 6.164E-07 | 5.963E-07 | 6.294E-07 | 6.091E-07 | 6.291E-07 | 5.874E-07 | 5.992E-07 | 5.758E-07 | 5.977E-07 | 6.020E-07 | 6.040E-07 | 6.044E-07 | 1.445E-08 | 2.4% |
| **Am243** | 9.270E-07 | 8.652E-07 | 9.120E-07 | 8.756E-07 | 8.933E-07 | 1.107E-06 | 9.471E-07 | 9.160E-07 | 8.581E-07 | 9.091E-07 | 1.067E-06 | 1.072E-06 | 1.113E-06 | 9.790E-07 | 9.601E-07 | 9.127E-08 | 9.5% |
| **Rh103** | 2.015E-05 | 1.998E-05 | 1.925E-05 | 2.003E-05 | 1.148E-05 | 2.063E-05 | 2.021E-05 | 2.015E-05 | 1.992E-05 | 2.029E-05 | 2.064E-05 | 2.054E-05 | 2.071E-05 | 1.990E-05 | 1.956E-05 | 2.358E-06 | 12.1% |
| **Cs133** | 4.174E-05 | 4.136E-05 | 4.147E-05 | 4.136E-05 | 4.194E-05 | 4.277E-05 | 4.351E-05 | 4.353E-05 | 4.104E-05 | 4.232E-05 | 4.277E-05 | 4.226E-05 | 4.265E-05 | 4.170E-05 | 4.217E-05 | 7.927E-07 | 1.9% |
| **Nd143** | 2.990E-05 | 2.981E-05 | 3.068E-05 | 2.983E-05 | 2.957E-05 | 2.990E-05 | 2.958E-05 | 2.964E-05 | 2.978E-05 | 2.951E-05 | 2.966E-05 | 2.955E-05 | 2.974E-05 | 2.950E-05 | 2.976E-05 | 2.997E-07 | 1.0% |
| **Nd145** | 2.388E-05 | 2.371E-05 | 2.306E-05 | 2.371E-05 | 2.349E-05 | 2.408E-05 | 2.378E-05 | 2.380E-05 | 2.385E-05 | 2.345E-05 | 2.391E-05 | 2.361E-05 | 2.381E-05 | 2.360E-05 | 2.370E-05 | 2.491E-07 | 1.1% |
| **Gd155** | 1.653E-09 | 1.416E-09 | 3.236E-09 | 1.441E-09 | 1.022E-09 | 1.576E-09 | 1.571E-09 | 1.554E-09 | 1.055E-09 | 1.001E-09 | 1.050E-09 | 1.116E-09 | 1.117E-09 | 1.250E-09 | 1.433E-09 | 5.705E-10 | 39.8% |
| **Mo95** | 3.377E-05 | 3.346E-05 | nodata | 3.343E-05 | 3.316E-05 | 3.372E-05 | 3.324E-05 | 3.327E-05 | 3.358E-05 | 3.310E-05 | 3.371E-05 | 3.326E-05 | 3.357E-05 | 3.310E-05 | 3.341E-05 | 2.409E-07 | 0.7% |
| **Tc99** | 4.017E-05 | 4.003E-05 | nodata | 4.003E-05 | 3.624E-05 | 4.063E-05 | 4.060E-05 | 4.081E-05 | 3.962E-05 | 3.912E-05 | 4.090E-05 | 4.041E-05 | 4.079E-05 | 3.880E-05 | 3.986E-05 | 1.266E-06 | 3.2% |
| **Ru101** | 3.778E-05 | 3.739E-05 | nodata | 3.742E-05 | 3.631E-05 | 3.775E-05 | 3.672E-05 | 3.671E-05 | 3.751E-05 | 3.686E-05 | 3.773E-05 | 3.730E-05 | 3.768E-05 | 3.670E-05 | 3.722E-05 | 4.976E-07 | 1.3% |
| **Ag109** | 2.712E-06 | 2.681E-06 | 2.242E-06 | 2.692E-06 | 2.561E-06 | 3.454E-06 | 3.278E-06 | 3.265E-06 | 2.644E-06 | 2.836E-06 | 2.742E-06 | 2.720E-06 | 2.762E-06 | 2.840E-06 | 2.816E-06 | 3.173E-07 | 11.3% |
| **Sm147** | 2.189E-06 | 2.167E-06 | 2.223E-06 | 2.164E-06 | 2.244E-06 | 2.162E-06 | 2.203E-06 | 2.207E-06 | 2.124E-06 | 2.189E-06 | 2.180E-06 | 2.147E-06 | 2.156E-06 | 1.900E-06 | 2.161E-06 | 8.146E-08 | 3.8% |
| **Sm149** | 9.896E-08 | 9.755E-08 | 1.049E-07 | 9.833E-08 | 9.579E-08 | 9.103E-08 | 9.270E-08 | 9.313E-08 | 1.022E-07 | 1.013E-07 | 9.459E-08 | 9.954E-08 | 9.924E-08 | 1.080E-07 | 9.838E-08 | 4.773E-09 | 4.9% |
| **Sm150** | 9.391E-06 | 9.115E-06 | 9.441E-06 | 9.128E-06 | 9.191E-06 | 9.028E-06 | 9.150E-06 | 9.136E-06 | 9.346E-06 | 9.049E-06 | 9.445E-06 | 9.328E-06 | 9.441E-06 | 1.040E-05 | 9.328E-06 | 3.434E-07 | 3.7% |
| **Sm151** | 4.856E-07 | 4.825E-07 | 5.047E-07 | 4.870E-07 | 4.905E-07 | 4.482E-07 | 4.356E-07 | 4.366E-07 | 5.065E-07 | 4.955E-07 | 5.306E-07 | 5.534E-07 | 5.540E-07 | 4.620E-07 | 4.909E-07 | 3.791E-08 | 7.7% |
| **Sm152** | 3.746E-06 | 3.672E-06 | 3.650E-06 | 3.683E-06 | 4.011E-06 | 3.640E-06 | 3.650E-06 | 3.646E-06 | 3.959E-06 | 3.822E-06 | 4.126E-06 | 4.073E-06 | 4.115E-06 | 3.680E-06 | 3.820E-06 | 1.935E-07 | 5.1% |
| **Eu153** | 3.533E-06 | 3.474E-06 | 3.377E-06 | 3.483E-06 | 3.412E-06 | 3.426E-06 | 3.282E-06 | 3.283E-06 | 3.393E-06 | 3.334E-06 | 3.241E-06 | 3.197E-06 | 3.241E-06 | 3.430E-06 | 3.365E-06 | 1.031E-07 | 3.1% |

## Table 3.2. Case 2: UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 4.824E-06 | 5.016E-06 | 4.909E-06 | 5.035E-06 | 4.805E-06 | 4.188E-06 | 4.957E-06 | 4.962E-06 | 4.735E-06 | 4.855E-06 | 4.944E-06 | 4.944E-06 | 4.927E-06 | 4.810E-06 | 4.851E-06 | 2.091E-07 | 4.3% |
| **U235** | 3.771E-04 | 3.872E-04 | 3.783E-04 | 3.844E-04 | 3.735E-04 | 3.754E-04 | 3.828E-04 | 3.852E-04 | 3.796E-04 | 3.785E-04 | 3.751E-04 | 3.840E-04 | 3.805E-04 | 3.850E-04 | 3.805E-04 | 4.351E-06 | 1.1% |
| **U236** | 9.802E-05 | 9.751E-05 | 1.011E-04 | 9.852E-05 | 1.028E-04 | 1.030E-04 | 1.007E-04 | 9.642E-05 | 9.882E-05 | 1.027E-04 | 1.014E-04 | 1.008E-04 | 1.013E-04 | 9.720E-05 | 1.000E-04 | 2.234E-06 | 2.2% |
| **U238** | 2.096E-02 | 2.099E-02 | 2.101E-02 | 2.100E-02 | 2.102E-02 | 2.098E-02 | 2.100E-02 | 2.100E-02 | 2.101E-02 | 2.101E-02 | 2.102E-02 | 2.102E-02 | 2.101E-02 | 2.100E-02 | 2.100E-02 | 1.767E-05 | 0.1% |
| **Pu238** | 2.885E-06 | 2.697E-06 | 3.168E-06 | 2.665E-06 | 2.883E-06 | 3.089E-06 | 2.755E-06 | 2.623E-06 | 2.818E-06 | 2.815E-06 | 2.758E-06 | 2.763E-06 | 2.809E-06 | 2.690E-06 | 2.816E-06 | 1.540E-07 | 5.5% |
| **Pu239** | 1.725E-04 | 1.853E-04 | 1.721E-04 | 1.826E-04 | 1.671E-04 | 1.829E-04 | 1.806E-04 | 1.796E-04 | 1.724E-04 | 1.772E-04 | 1.689E-04 | 1.755E-04 | 1.755E-04 | 1.780E-04 | 1.764E-04 | 5.428E-06 | 3.1% |
| **Pu240** | 4.596E-05 | 4.730E-05 | 4.405E-05 | 4.720E-05 | 4.444E-05 | 4.689E-05 | 4.588E-05 | 4.578E-05 | 4.359E-05 | 4.554E-05 | 4.661E-05 | 4.620E-05 | 4.645E-05 | 4.630E-05 | 4.587E-05 | 1.133E-06 | 2.5% |
| **Pu241** | 3.179E-05 | 3.261E-05 | 3.124E-05 | 3.240E-05 | 3.054E-05 | 3.372E-05 | 3.277E-05 | 3.277E-05 | 3.133E-05 | 3.128E-05 | 3.020E-05 | 3.059E-05 | 3.083E-05 | 3.180E-05 | 3.170E-05 | 1.031E-06 | 3.3% |
| **Pu242** | 6.585E-06 | 6.241E-06 | 6.374E-06 | 6.457E-06 | 6.130E-06 | 7.054E-06 | 6.587E-06 | 6.561E-06 | 6.322E-06 | 6.013E-06 | 6.611E-06 | 6.394E-06 | 6.520E-06 | 6.150E-06 | 6.429E-06 | 2.618E-07 | 4.1% |
| **Np237** | 1.014E-05 | 9.314E-06 | 1.099E-05 | 9.124E-06 | 1.010E-05 | 1.069E-05 | 1.009E-05 | 9.597E-06 | 1.010E-05 | 1.010E-05 | 1.029E-05 | 1.031E-05 | 1.039E-05 | 9.720E-06 | 1.007E-05 | 5.011E-07 | 5.0% |
| **Am241** | 8.293E-07 | 8.335E-07 | 7.915E-07 | 8.221E-07 | 7.874E-07 | 8.474E-07 | 8.299E-07 | 8.520E-07 | 7.852E-07 | 7.936E-07 | 7.872E-07 | 8.046E-07 | 8.093E-07 | 8.230E-07 | 8.140E-07 | 2.298E-08 | 2.8% |
| **Am243** | 1.155E-06 | 1.070E-06 | 1.155E-06 | 1.115E-06 | 1.116E-06 | 1.360E-06 | 1.183E-06 | 1.136E-06 | 1.089E-06 | 1.137E-06 | 1.252E-06 | 1.244E-06 | 1.279E-06 | 1.210E-06 | 1.179E-06 | 8.143E-08 | 6.9% |
| **Rh103** | 2.073E-05 | 2.081E-05 | 1.966E-05 | 2.067E-05 | 1.179E-05 | 2.159E-05 | 2.106E-05 | 2.100E-05 | 2.053E-05 | 2.090E-05 | 2.128E-05 | 2.107E-05 | 2.119E-05 | 2.050E-05 | 2.020E-05 | 2.464E-06 | 12.2% |
| **Cs133** | 4.082E-05 | 4.057E-05 | 4.045E-05 | 4.057E-05 | 4.099E-05 | 4.213E-05 | 4.271E-05 | 4.272E-05 | 4.010E-05 | 4.157E-05 | 4.147E-05 | 4.087E-05 | 4.117E-05 | 4.060E-05 | 4.120E-05 | 8.288E-07 | 2.0% |
| **Nd143** | 3.045E-05 | 3.061E-05 | 3.137E-05 | 3.042E-05 | 3.007E-05 | 3.065E-05 | 3.022E-05 | 3.027E-05 | 3.035E-05 | 2.998E-05 | 3.012E-05 | 2.987E-05 | 3.004E-05 | 3.010E-05 | 3.032E-05 | 3.802E-07 | 1.3% |
| **Nd145** | 2.330E-05 | 2.324E-05 | 2.241E-05 | 2.320E-05 | 2.294E-05 | 2.376E-05 | 2.328E-05 | 2.331E-05 | 2.333E-05 | 2.290E-05 | 2.308E-05 | 2.274E-05 | 2.290E-05 | 2.310E-05 | 2.311E-05 | 3.214E-07 | 1.4% |
| **Gd155** | 3.455E-09 | 3.097E-09 | 5.849E-09 | 3.020E-09 | 1.620E-09 | 2.275E-09 | 2.722E-09 | 2.690E-09 | 1.846E-09 | 1.672E-09 | 1.817E-09 | 1.912E-09 | 1.912E-09 | 2.290E-09 | 2.584E-09 | 1.105E-09 | 42.8% |
| **Mo95** | 3.305E-05 | 3.270E-05 | nodata | 3.264E-05 | 3.244E-05 | 3.305E-05 | 3.238E-05 | 3.242E-05 | 3.279E-05 | 3.235E-05 | 3.242E-05 | 3.192E-05 | 3.216E-05 | 3.230E-05 | 3.251E-05 | 3.280E-07 | 1.0% |
| **Tc99** | 3.942E-05 | 3.944E-05 | nodata | 3.943E-05 | 3.548E-05 | 4.029E-05 | 4.000E-05 | 4.023E-05 | 3.891E-05 | 3.846E-05 | 3.970E-05 | 3.913E-05 | 3.942E-05 | 3.810E-05 | 3.908E-05 | 1.252E-06 | 3.2% |
| **Ru101** | 3.766E-05 | 3.753E-05 | nodata | 3.743E-05 | 3.620E-05 | 3.795E-05 | 3.671E-05 | 3.669E-05 | 3.750E-05 | 3.670E-05 | 3.713E-05 | 3.657E-05 | 3.686E-05 | 3.670E-05 | 3.705E-05 | 5.207E-07 | 1.4% |
| **Ag109** | 2.935E-06 | 2.903E-06 | 2.373E-06 | 2.939E-06 | 2.920E-06 | 3.797E-06 | 3.623E-06 | 3.605E-06 | 2.877E-06 | 3.114E-06 | 3.913E-06 | 2.847E-06 | 2.879E-06 | 3.170E-06 | 3.135E-06 | 4.366E-07 | 13.9% |
| **Sm147** | 2.043E-06 | 1.982E-06 | 2.038E-06 | 1.971E-06 | 2.039E-06 | 1.973E-06 | 2.016E-06 | 2.019E-06 | 1.918E-06 | 2.004E-06 | 1.975E-06 | 1.942E-06 | 1.949E-06 | 1.650E-06 | 1.966E-06 | 9.870E-08 | 5.0% |
| **Sm149** | 1.481E-07 | 1.527E-07 | 1.611E-07 | 1.492E-07 | 1.429E-07 | 1.459E-07 | 1.441E-07 | 1.448E-07 | 1.541E-07 | 1.518E-07 | 1.451E-07 | 1.528E-07 | 1.519E-07 | 1.760E-07 | 1.515E-07 | 8.622E-09 | 5.7% |
| **Sm150** | 9.499E-06 | 9.359E-06 | 9.780E-06 | 9.307E-06 | 9.355E-06 | 9.506E-06 | 9.357E-06 | 9.336E-06 | 9.502E-06 | 9.152E-06 | 9.417E-06 | 9.294E-06 | 9.379E-06 | 1.110E-05 | 9.524E-06 | 4.757E-07 | 5.0% |
| **Sm151** | 6.740E-07 | 6.908E-07 | 7.054E-07 | 6.798E-07 | 6.818E-07 | 6.253E-07 | 6.041E-07 | 6.053E-07 | 7.105E-07 | 6.867E-07 | 7.432E-07 | 7.671E-07 | 7.671E-07 | 6.560E-07 | 6.855E-07 | 5.220E-08 | 7.6% |
| **Sm152** | 3.456E-06 | 3.433E-06 | 3.416E-06 | 3.413E-06 | 3.782E-06 | 3.350E-06 | 3.346E-06 | 3.340E-06 | 3.755E-06 | 3.542E-06 | 3.836E-06 | 3.766E-06 | 3.797E-06 | 3.370E-06 | 3.543E-06 | 1.965E-07 | 5.5% |
| **Eu153** | 3.720E-06 | 3.670E-06 | 3.611E-06 | 3.680E-06 | 3.598E-06 | 3.631E-06 | 3.465E-06 | 3.470E-06 | 3.570E-06 | 3.524E-06 | 3.369E-06 | 3.309E-06 | 3.340E-06 | 3.630E-06 | 3.542E-06 | 1.324E-07 | 3.7% |

# Table 3.3. Case 3: UOX 45 GWd/t, without CRs, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.954E-06 | 4.202E-06 | 4.059E-06 | 4.200E-06 | 3.948E-06 | 3.658E-06 | 4.092E-06 | 4.099E-06 | 3.875E-06 | 4.004E-06 | 4.037E-06 | 4.053E-06 | 4.019E-06 | 3.940E-06 | 4.010E-06 | 1.378E-07 | 3.4% |
| **U235** | 1.845E-04 | 1.910E-04 | 1.833E-04 | 1.924E-04 | 1.804E-04 | 1.825E-04 | 1.856E-04 | 1.871E-04 | 1.859E-04 | 1.879E-04 | 1.711E-04 | 1.830E-04 | 1.783E-04 | 1.860E-04 | 1.842E-04 | 5.350E-06 | 2.9% |
| **U236** | 1.180E-04 | 1.190E-04 | 1.218E-04 | 1.193E-04 | 1.227E-04 | 1.226E-04 | 1.213E-04 | 1.171E-04 | 1.186E-04 | 1.223E-04 | 1.229E-04 | 1.222E-04 | 1.226E-04 | 1.180E-04 | 1.206E-04 | 2.131E-06 | 1.8% |
| **U238** | 2.079E-02 | 2.083E-02 | 2.085E-02 | 2.083E-02 | 2.086E-02 | 2.082E-02 | 2.084E-02 | 2.084E-02 | 2.085E-02 | 2.084E-02 | 2.086E-02 | 2.085E-02 | 2.084E-02 | 2.090E-02 | 2.084E-02 | 2.342E-05 | 0.1% |
| **Pu238** | 5.550E-06 | 5.098E-06 | 5.881E-06 | 5.131E-06 | 5.588E-06 | 5.908E-06 | 5.304E-06 | 5.099E-06 | 5.541E-06 | 5.407E-06 | 5.405E-06 | 5.463E-06 | 5.584E-06 | 5.200E-06 | 5.440E-06 | 2.611E-07 | 4.8% |
| **Pu239** | 1.267E-04 | 1.355E-04 | 1.259E-04 | 1.349E-04 | 1.222E-04 | 1.323E-04 | 1.301E-04 | 1.297E-04 | 1.255E-04 | 1.316E-04 | 1.216E-04 | 1.284E-04 | 1.282E-04 | 1.270E-04 | 1.286E-04 | 4.178E-06 | 3.3% |
| **Pu240** | 5.881E-05 | 6.031E-05 | 5.565E-05 | 6.012E-05 | 5.671E-05 | 5.952E-05 | 5.824E-05 | 5.785E-05 | 5.486E-05 | 5.841E-05 | 5.952E-05 | 5.974E-05 | 6.019E-05 | 5.840E-05 | 5.845E-05 | 1.698E-06 | 2.9% |
| **Pu241** | 3.528E-05 | 3.653E-05 | 3.516E-05 | 3.663E-05 | 3.442E-05 | 3.725E-05 | 3.655E-05 | 3.667E-05 | 3.487E-05 | 3.593E-05 | 3.331E-05 | 3.447E-05 | 3.465E-05 | 3.540E-05 | 3.551E-05 | 1.123E-06 | 3.2% |
| **Pu242** | 1.603E-05 | 1.570E-05 | 1.577E-05 | 1.579E-05 | 1.543E-05 | 1.684E-05 | 1.627E-05 | 1.630E-05 | 1.568E-05 | 1.504E-05 | 1.695E-05 | 1.641E-05 | 1.680E-05 | 1.530E-05 | 1.602E-05 | 5.944E-07 | 3.7% |
| **Np237** | 1.340E-05 | 1.200E-05 | 1.443E-05 | 1.202E-05 | 1.345E-05 | 1.407E-05 | 1.341E-05 | 1.287E-05 | 1.357E-05 | 1.331E-05 | 1.373E-05 | 1.387E-05 | 1.402E-05 | 1.290E-05 | 1.336E-05 | 7.149E-07 | 5.4% |
| **Am241** | 1.076E-06 | 1.121E-06 | 1.066E-06 | 1.126E-06 | 1.085E-06 | 1.098E-06 | 1.097E-06 | 1.156E-06 | 1.048E-06 | 1.111E-06 | 1.029E-06 | 1.092E-06 | 1.088E-06 | 1.100E-06 | 1.092E-06 | 3.225E-08 | 3.0% |
| **Am243** | 3.463E-06 | 3.274E-06 | 3.560E-06 | 3.317E-06 | 3.343E-06 | 4.000E-06 | 3.572E-06 | 3.478E-06 | 3.147E-06 | 3.478E-06 | 4.047E-06 | 3.997E-06 | 4.137E-06 | 3.640E-06 | 3.604E-06 | 3.181E-07 | 8.8% |
| **Rh103** | 2.814E-05 | 2.819E-05 | 2.576E-05 | 2.819E-05 | 1.745E-05 | 2.856E-05 | 2.825E-05 | 2.816E-05 | 2.789E-05 | 2.856E-05 | 2.893E-05 | 2.891E-05 | 2.911E-05 | 2.740E-05 | 2.739E-05 | 2.976E-06 | 10.9% |
| **Cs133** | 5.835E-05 | 5.805E-05 | 5.771E-05 | 5.804E-05 | 5.877E-05 | 6.002E-05 | 6.124E-05 | 6.126E-05 | 5.708E-05 | 5.989E-05 | 6.017E-05 | 5.950E-05 | 6.003E-05 | 5.820E-05 | 5.917E-05 | 1.318E-06 | 2.2% |
| **Nd143** | 3.747E-05 | 3.778E-05 | 3.866E-05 | 3.780E-05 | 3.717E-05 | 3.772E-05 | 3.739E-05 | 3.749E-05 | 3.757E-05 | 3.735E-05 | 3.684E-05 | 3.713E-05 | 3.726E-05 | 3.730E-05 | 3.749E-05 | 4.286E-07 | 1.1% |
| **Nd145** | 3.290E-05 | 3.281E-05 | 3.155E-05 | 3.281E-05 | 3.251E-05 | 3.342E-05 | 3.309E-05 | 3.312E-05 | 3.308E-05 | 3.248E-05 | 3.295E-05 | 3.257E-05 | 3.283E-05 | 3.280E-05 | 3.278E-05 | 4.361E-07 | 1.3% |
| **Gd155** | 3.079E-09 | 2.345E-09 | 5.188E-09 | 2.344E-09 | 1.835E-09 | 2.577E-09 | 2.680E-09 | 2.652E-09 | 2.147E-09 | 1.851E-09 | 1.889E-09 | 2.039E-09 | 2.036E-09 | 2.240E-09 | 2.493E-09 | 8.560E-10 | 34.3% |
| **Mo95** | 5.080E-05 | 5.050E-05 | nodata | 5.048E-05 | 5.022E-05 | 5.082E-05 | 5.025E-05 | 5.031E-05 | 5.081E-05 | 5.010E-05 | 5.075E-05 | 5.010E-05 | 5.055E-05 | 5.010E-05 | 5.044E-05 | 2.851E-07 | 0.6% |
| **Tc99** | 5.699E-05 | 5.693E-05 | nodata | 5.692E-05 | 5.172E-05 | 5.789E-05 | 5.793E-05 | 5.842E-05 | 5.608E-05 | 5.571E-05 | 5.790E-05 | 5.722E-05 | 5.774E-05 | 5.530E-05 | 5.667E-05 | 1.755E-06 | 3.1% |
| **Ru101** | 5.596E-05 | 5.565E-05 | nodata | 5.568E-05 | 5.381E-05 | 5.611E-05 | 5.466E-05 | 5.465E-05 | 5.587E-05 | 5.468E-05 | 5.600E-05 | 5.531E-05 | 5.591E-05 | 5.460E-05 | 5.530E-05 | 7.340E-07 | 1.3% |
| **Ag109** | 4.861E-06 | 4.843E-06 | 3.925E-06 | 4.857E-06 | 4.263E-06 | 6.018E-06 | 5.832E-06 | 5.811E-06 | 4.749E-06 | 5.172E-06 | 5.016E-06 | 4.897E-06 | 4.973E-06 | 5.010E-06 | 5.016E-06 | 5.718E-07 | 11.4% |
| **Sm147** | 3.436E-06 | 3.411E-06 | 3.501E-06 | 3.408E-06 | 3.564E-06 | 3.408E-06 | 3.521E-06 | 3.535E-06 | 3.297E-06 | 3.502E-06 | 3.421E-06 | 3.379E-06 | 3.380E-06 | 2.830E-06 | 3.400E-06 | 1.795E-07 | 5.3% |
| **Sm149** | 9.093E-08 | 9.215E-08 | 9.471E-08 | 9.171E-08 | 8.571E-08 | 8.407E-08 | 8.631E-08 | 8.693E-08 | 9.409E-08 | 9.405E-08 | 8.656E-08 | 9.249E-08 | 9.213E-08 | 9.800E-08 | 9.070E-08 | 4.112E-09 | 4.5% |
| **Sm150** | 1.432E-05 | 1.395E-05 | 1.439E-05 | 1.395E-05 | 1.373E-05 | 1.381E-05 | 1.415E-05 | 1.414E-05 | 1.427E-05 | 1.374E-05 | 1.435E-05 | 1.419E-05 | 1.437E-05 | 1.610E-05 | 1.425E-05 | 5.817E-07 | 4.1% |
| **Sm151** | 5.544E-07 | 5.599E-07 | 5.718E-07 | 5.597E-07 | 5.537E-07 | 4.982E-07 | 4.870E-07 | 4.881E-07 | 5.866E-07 | 5.716E-07 | 6.042E-07 | 6.350E-07 | 6.358E-07 | 5.240E-07 | 5.593E-07 | 4.802E-08 | 8.6% |
| **Sm152** | 5.045E-06 | 4.942E-06 | 4.869E-06 | 4.962E-06 | 5.553E-06 | 4.770E-06 | 4.861E-06 | 4.853E-06 | 5.495E-06 | 5.211E-06 | 5.777E-06 | 5.710E-06 | 5.769E-06 | 4.910E-06 | 5.195E-06 | 3.812E-07 | 7.3% |
| **Eu153** | 6.017E-06 | 5.942E-06 | 5.600E-06 | 5.945E-06 | 5.784E-06 | 5.580E-06 | 5.448E-06 | 5.468E-06 | 5.915E-06 | 5.709E-06 | 5.628E-06 | 5.536E-06 | 5.608E-06 | 5.710E-06 | 5.706E-06 | 1.869E-07 | 3.3% |

## Table 3.4. Case 4: UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.748E-06 | 3.970E-06 | 3.813E-06 | 3.988E-06 | 3.677E-06 | 2.954E-06 | 3.894E-06 | 3.894E-06 | 3.605E-06 | 3.762E-06 | 3.880E-06 | 3.886E-06 | 3.863E-06 | 3.710E-06 | 3.760E-06 | 2.571E-07 | 6.8% |
| **U235** | 2.370E-04 | 2.484E-04 | 2.365E-04 | 2.444E-04 | 2.306E-04 | 2.366E-04 | 2.434E-04 | 2.459E-04 | 2.377E-04 | 2.374E-04 | 2.329E-04 | 2.432E-04 | 2.394E-04 | 2.450E-04 | 2.399E-04 | 5.231E-06 | 2.2% |
| **U236** | 1.162E-04 | 1.169E-04 | 1.199E-04 | 1.182E-04 | 1.224E-04 | 1.219E-04 | 1.200E-04 | 1.149E-04 | 1.171E-04 | 1.226E-04 | 1.208E-04 | 1.203E-04 | 1.207E-04 | 1.160E-04 | 1.191E-04 | 2.544E-06 | 2.1% |
| **U238** | 2.066E-02 | 2.068E-02 | 2.071E-02 | 2.069E-02 | 2.073E-02 | 2.066E-02 | 2.068E-02 | 2.069E-02 | 2.071E-02 | 2.070E-02 | 2.072E-02 | 2.072E-02 | 2.072E-02 | 2.070E-02 | 2.070E-02 | 2.274E-05 | 0.1% |
| **Pu238** | 7.339E-06 | 6.794E-06 | 7.895E-06 | 6.710E-06 | 7.327E-06 | 7.743E-06 | 7.058E-06 | 6.736E-06 | 7.311E-06 | 7.157E-06 | 6.981E-06 | 6.989E-06 | 7.100E-06 | 6.790E-06 | 7.138E-06 | 3.599E-07 | 5.0% |
| **Pu239** | 1.914E-04 | 2.103E-04 | 1.911E-04 | 2.052E-04 | 1.850E-04 | 2.067E-04 | 2.040E-04 | 2.032E-04 | 1.917E-04 | 1.977E-04 | 1.876E-04 | 1.966E-04 | 1.963E-04 | 2.010E-04 | 1.977E-04 | 7.663E-06 | 3.9% |
| **Pu240** | 6.614E-05 | 6.892E-05 | 6.305E-05 | 6.847E-05 | 6.353E-05 | 6.828E-05 | 6.664E-05 | 6.605E-05 | 6.230E-05 | 6.518E-05 | 6.710E-05 | 6.687E-05 | 6.713E-05 | 6.720E-05 | 6.620E-05 | 2.028E-06 | 3.1% |
| **Pu241** | 4.770E-05 | 5.017E-05 | 4.734E-05 | 4.945E-05 | 4.623E-05 | 5.049E-05 | 4.997E-05 | 5.007E-05 | 4.748E-05 | 4.819E-05 | 4.590E-05 | 4.681E-05 | 4.702E-05 | 4.860E-05 | 4.824E-05 | 1.556E-06 | 3.2% |
| **Pu242** | 1.533E-05 | 1.474E-05 | 1.510E-05 | 1.522E-05 | 1.475E-05 | 1.605E-05 | 1.539E-05 | 1.546E-05 | 1.510E-05 | 1.437E-05 | 1.566E-05 | 1.506E-05 | 1.532E-05 | 1.430E-05 | 1.513E-05 | 4.764E-07 | 3.1% |
| **Np237** | 1.632E-05 | 1.488E-05 | 1.769E-05 | 1.453E-05 | 1.638E-05 | 1.707E-05 | 1.639E-05 | 1.563E-05 | 1.656E-05 | 1.635E-05 | 1.670E-05 | 1.677E-05 | 1.688E-05 | 1.570E-05 | 1.628E-05 | 8.451E-07 | 5.2% |
| **Am241** | 1.624E-06 | 1.689E-06 | 1.564E-06 | 1.645E-06 | 1.583E-06 | 1.645E-06 | 1.657E-06 | 1.737E-06 | 1.550E-06 | 1.612E-06 | 1.575E-06 | 1.632E-06 | 1.633E-06 | 1.660E-06 | 1.629E-06 | 5.068E-08 | 3.1% |
| **Am243** | 3.846E-06 | 3.607E-06 | 4.031E-06 | 3.749E-06 | 3.710E-06 | 4.323E-06 | 3.924E-06 | 3.804E-06 | 3.544E-06 | 3.864E-06 | 4.271E-06 | 4.211E-06 | 4.316E-06 | 3.990E-06 | 3.942E-06 | 2.590E-07 | 6.6% |
| **Rh103** | 2.935E-05 | 2.980E-05 | 2.676E-05 | 2.946E-05 | 1.812E-05 | 3.039E-05 | 2.996E-05 | 2.985E-05 | 2.917E-05 | 2.978E-05 | 3.034E-05 | 3.014E-05 | 3.029E-05 | 2.870E-05 | 2.872E-05 | 3.191E-06 | 11.1% |
| **Cs133** | 5.686E-05 | 5.673E-05 | 5.604E-05 | 5.672E-05 | 5.717E-05 | 5.897E-05 | 5.996E-05 | 6.003E-05 | 5.547E-05 | 5.866E-05 | 5.836E-05 | 5.755E-05 | 5.793E-05 | 5.650E-05 | 5.764E-05 | 1.403E-06 | 2.4% |
| **Nd143** | 4.009E-05 | 4.085E-05 | 4.154E-05 | 4.036E-05 | 3.966E-05 | 4.064E-05 | 4.020E-05 | 4.028E-05 | 4.017E-05 | 3.972E-05 | 3.975E-05 | 3.967E-05 | 3.983E-05 | 4.010E-05 | 4.020E-05 | 5.274E-07 | 1.3% |
| **Nd145** | 3.211E-05 | 3.218E-05 | 3.059E-05 | 3.211E-05 | 3.174E-05 | 3.310E-05 | 3.247E-05 | 3.251E-05 | 3.232E-05 | 3.171E-05 | 3.193E-05 | 3.148E-05 | 3.167E-05 | 3.210E-05 | 3.200E-05 | 5.814E-07 | 1.8% |
| **Gd155** | 7.335E-09 | 6.136E-09 | 1.122E-08 | 5.854E-09 | 3.421E-09 | 3.960E-09 | 5.420E-09 | 5.366E-09 | 4.174E-09 | 3.559E-09 | 3.784E-09 | 4.040E-09 | 4.027E-09 | 4.960E-09 | 5.232E-09 | 2.064E-09 | 39.4% |
| **Mo95** | 4.949E-05 | 4.929E-05 | nodata | 4.913E-05 | 4.904E-05 | 4.969E-05 | 4.885E-05 | 4.891E-05 | 4.946E-05 | 4.885E-05 | 4.881E-05 | 4.808E-05 | 4.841E-05 | 4.890E-05 | 4.899E-05 | 4.393E-07 | 0.9% |
| **Tc99** | 5.579E-05 | 5.594E-05 | nodata | 5.592E-05 | 5.037E-05 | 5.730E-05 | 5.701E-05 | 5.753E-05 | 5.483E-05 | 5.460E-05 | 5.618E-05 | 5.540E-05 | 5.577E-05 | 5.440E-05 | 5.547E-05 | 1.811E-06 | 3.3% |
| **Ru101** | 5.554E-05 | 5.562E-05 | nodata | 5.544E-05 | 5.337E-05 | 5.622E-05 | 5.444E-05 | 5.443E-05 | 5.557E-05 | 5.417E-05 | 5.491E-05 | 5.405E-05 | 5.447E-05 | 5.440E-05 | 5.482E-05 | 8.057E-07 | 1.5% |
| **Ag109** | 5.071E-06 | 5.025E-06 | 3.947E-06 | 5.107E-06 | 4.710E-06 | 6.425E-06 | 6.246E-06 | 6.212E-06 | 4.968E-06 | 5.486E-06 | 7.859E-06 | 4.897E-06 | 4.949E-06 | 5.390E-06 | 5.449E-06 | 9.612E-07 | 17.6% |
| **Sm147** | 3.153E-06 | 3.075E-06 | 3.152E-06 | 3.046E-06 | 3.173E-06 | 3.067E-06 | 3.179E-06 | 3.193E-06 | 2.912E-06 | 3.153E-06 | 3.079E-06 | 3.030E-06 | 3.032E-06 | 2.410E-06 | 3.047E-06 | 1.990E-07 | 6.5% |
| **Sm149** | 1.520E-07 | 1.616E-07 | 1.631E-07 | 1.554E-07 | 1.431E-07 | 1.529E-07 | 1.516E-07 | 1.525E-07 | 1.589E-07 | 1.574E-07 | 1.484E-07 | 1.580E-07 | 1.571E-07 | 1.820E-07 | 1.567E-07 | 8.978E-09 | 5.7% |
| **Sm150** | 1.438E-05 | 1.425E-05 | 1.483E-05 | 1.415E-05 | 1.388E-05 | 1.467E-05 | 1.448E-05 | 1.446E-05 | 1.437E-05 | 1.380E-05 | 1.422E-05 | 1.408E-05 | 1.420E-05 | 1.730E-05 | 1.451E-05 | 8.510E-07 | 5.9% |
| **Sm151** | 8.410E-07 | 8.779E-07 | 8.783E-07 | 8.540E-07 | 8.429E-07 | 7.549E-07 | 7.320E-07 | 7.323E-07 | 9.026E-07 | 8.656E-07 | 9.214E-07 | 9.580E-07 | 9.577E-07 | 8.120E-07 | 8.522E-07 | 7.405E-08 | 8.7% |
| **Sm152** | 4.589E-06 | 4.568E-06 | 4.502E-06 | 4.543E-06 | 5.180E-06 | 4.309E-06 | 4.349E-06 | 4.339E-06 | 5.160E-06 | 4.763E-06 | 5.306E-06 | 5.217E-06 | 5.260E-06 | 4.430E-06 | 4.751E-06 | 3.853E-07 | 8.1% |
| **Eu153** | 6.130E-06 | 6.069E-06 | 5.866E-06 | 6.074E-06 | 5.932E-06 | 5.731E-06 | 5.576E-06 | 5.601E-06 | 6.034E-06 | 5.843E-06 | 5.685E-06 | 5.574E-06 | 5.621E-06 | 5.820E-06 | 5.825E-06 | 1.994E-07 | 3.4% |

# Table 3.5. Case 5: UOX 45 GWd/t, CRs 0-15 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.915E-06 | 4.162E-06 | 4.011E-06 | 4.167E-06 | 3.894E-06 | 3.445E-06 | 4.056E-06 | 4.066E-06 | 3.820E-06 | 3.950E-06 | 4.017E-06 | 4.026E-06 | 3.999E-06 | 3.900E-06 | 3.959E-06 | 1.777E-07 | 4.5% |
| **U235** | 2.065E-04 | 2.171E-04 | 2.056E-04 | 2.155E-04 | 2.013E-04 | 2.070E-04 | 2.108E-04 | 2.127E-04 | 2.080E-04 | 2.091E-04 | 1.972E-04 | 2.088E-04 | 2.046E-04 | 2.120E-04 | 2.083E-04 | 5.322E-06 | 2.6% |
| **U236** | 1.191E-04 | 1.197E-04 | 1.229E-04 | 1.203E-04 | 1.244E-04 | 1.242E-04 | 1.225E-04 | 1.179E-04 | 1.198E-04 | 1.241E-04 | 1.240E-04 | 1.232E-04 | 1.236E-04 | 1.190E-04 | 1.218E-04 | 2.337E-06 | 1.9% |
| **U238** | 2.076E-02 | 2.079E-02 | 2.081E-02 | 2.079E-02 | 2.083E-02 | 2.077E-02 | 2.080E-02 | 2.080E-02 | 2.082E-02 | 2.081E-02 | 2.082E-02 | 2.082E-02 | 2.081E-02 | 2.080E-02 | 2.080E-02 | 1.939E-05 | 0.1% |
| **Pu238** | 5.897E-06 | 5.467E-06 | 6.279E-06 | 5.464E-06 | 5.931E-06 | 6.324E-06 | 5.692E-06 | 5.457E-06 | 5.888E-06 | 5.791E-06 | 5.715E-06 | 5.779E-06 | 5.877E-06 | 5.540E-06 | 5.793E-06 | 2.735E-07 | 4.7% |
| **Pu239** | 1.336E-04 | 1.439E-04 | 1.330E-04 | 1.428E-04 | 1.287E-04 | 1.403E-04 | 1.381E-04 | 1.379E-04 | 1.325E-04 | 1.388E-04 | 1.283E-04 | 1.356E-04 | 1.354E-04 | 1.350E-04 | 1.360E-04 | 4.665E-06 | 3.4% |
| **Pu240** | 6.219E-05 | 6.423E-05 | 5.886E-05 | 6.378E-05 | 5.981E-05 | 6.340E-05 | 6.201E-05 | 6.161E-05 | 5.811E-05 | 6.173E-05 | 6.283E-05 | 6.315E-05 | 6.347E-05 | 6.220E-05 | 6.196E-05 | 1.846E-06 | 3.0% |
| **Pu241** | 3.803E-05 | 3.969E-05 | 3.796E-05 | 3.964E-05 | 3.704E-05 | 4.029E-05 | 3.967E-05 | 3.990E-05 | 3.774E-05 | 3.875E-05 | 3.598E-05 | 3.720E-05 | 3.735E-05 | 3.850E-05 | 3.841E-05 | 1.295E-06 | 3.4% |
| **Pu242** | 1.656E-05 | 1.625E-05 | 1.628E-05 | 1.634E-05 | 1.594E-05 | 1.741E-05 | 1.682E-05 | 1.685E-05 | 1.625E-05 | 1.555E-05 | 1.743E-05 | 1.687E-05 | 1.720E-05 | 1.580E-05 | 1.654E-05 | 5.857E-07 | 3.5% |
| **Np237** | 1.383E-05 | 1.243E-05 | 1.491E-05 | 1.243E-05 | 1.389E-05 | 1.456E-05 | 1.390E-05 | 1.329E-05 | 1.403E-05 | 1.383E-05 | 1.415E-05 | 1.431E-05 | 1.442E-05 | 1.330E-05 | 1.381E-05 | 7.298E-07 | 5.3% |
| **Am241** | 1.240E-06 | 1.309E-06 | 1.232E-06 | 1.306E-06 | 1.248E-06 | 1.276E-06 | 1.284E-06 | 1.355E-06 | 1.215E-06 | 1.279E-06 | 1.194E-06 | 1.260E-06 | 1.256E-06 | 1.290E-06 | 1.268E-06 | 4.164E-08 | 3.3% |
| **Am243** | 3.590E-06 | 3.388E-06 | 3.686E-06 | 3.440E-06 | 3.444E-06 | 4.103E-06 | 3.711E-06 | 3.597E-06 | 3.258E-06 | 3.598E-06 | 4.152E-06 | 4.102E-06 | 4.219E-06 | 3.770E-06 | 3.718E-06 | 3.109E-07 | 8.4% |
| **Rh103** | 2.903E-05 | 2.922E-05 | 2.648E-05 | 2.912E-05 | 1.789E-05 | 2.959E-05 | 2.928E-05 | 2.919E-05 | 2.882E-05 | 2.945E-05 | 2.985E-05 | 2.979E-05 | 2.996E-05 | 2.840E-05 | 2.829E-05 | 3.114E-06 | 11.0% |
| **Cs133** | 5.844E-05 | 5.819E-05 | 5.773E-05 | 5.815E-05 | 5.880E-05 | 6.014E-05 | 6.126E-05 | 6.133E-05 | 5.721E-05 | 5.999E-05 | 6.011E-05 | 5.940E-05 | 5.986E-05 | 5.830E-05 | 5.921E-05 | 1.284E-06 | 2.2% |
| **Nd143** | 3.841E-05 | 3.881E-05 | 3.967E-05 | 3.874E-05 | 3.805E-05 | 3.873E-05 | 3.843E-05 | 3.854E-05 | 3.853E-05 | 3.822E-05 | 3.783E-05 | 3.801E-05 | 3.814E-05 | 3.840E-05 | 3.846E-05 | 4.548E-07 | 1.2% |
| **Nd145** | 3.283E-05 | 3.276E-05 | 3.148E-05 | 3.274E-05 | 3.242E-05 | 3.340E-05 | 3.303E-05 | 3.306E-05 | 3.302E-05 | 3.239E-05 | 3.278E-05 | 3.238E-05 | 3.261E-05 | 3.270E-05 | 3.269E-05 | 4.495E-07 | 1.4% |
| **Gd155** | 3.450E-09 | 2.698E-09 | 5.885E-09 | 2.679E-09 | 2.036E-09 | 2.797E-09 | 3.003E-09 | 2.997E-09 | 2.365E-09 | 2.049E-09 | 2.086E-09 | 2.248E-09 | 2.240E-09 | 2.540E-09 | 2.791E-09 | 9.835E-10 | 35.2% |
| **Mo95** | 5.040E-05 | 5.012E-05 | nodata | 5.009E-05 | 4.988E-05 | 5.048E-05 | 4.984E-05 | 4.989E-05 | 5.045E-05 | 4.973E-05 | 5.013E-05 | 4.946E-05 | 4.984E-05 | 4.970E-05 | 5.000E-05 | 3.119E-07 | 0.6% |
| **Tc99** | 5.698E-05 | 5.696E-05 | nodata | 5.693E-05 | 5.170E-05 | 5.800E-05 | 5.801E-05 | 5.849E-05 | 5.611E-05 | 5.573E-05 | 5.774E-05 | 5.704E-05 | 5.749E-05 | 5.540E-05 | 5.666E-05 | 1.747E-06 | 3.1% |
| **Ru101** | 5.611E-05 | 5.589E-05 | nodata | 5.584E-05 | 5.391E-05 | 5.632E-05 | 5.481E-05 | 5.481E-05 | 5.605E-05 | 5.478E-05 | 5.591E-05 | 5.519E-05 | 5.570E-05 | 5.480E-05 | 5.539E-05 | 7.232E-07 | 1.3% |
| **Ag109** | 5.050E-06 | 5.050E-06 | 4.066E-06 | 5.057E-06 | 4.428E-06 | 6.278E-06 | 6.085E-06 | 6.065E-06 | 4.945E-06 | 5.383E-06 | 5.271E-06 | 5.064E-06 | 5.127E-06 | 5.240E-06 | 5.222E-06 | 6.053E-07 | 11.6% |
| **Sm147** | 3.444E-06 | 3.419E-06 | 3.492E-06 | 3.411E-06 | 3.560E-06 | 3.417E-06 | 3.529E-06 | 3.538E-06 | 3.296E-06 | 3.502E-06 | 3.412E-06 | 3.362E-06 | 3.364E-06 | 2.810E-06 | 3.397E-06 | 1.849E-07 | 5.4% |
| **Sm149** | 9.760E-08 | 9.980E-08 | 1.021E-07 | 9.879E-08 | 9.193E-08 | 9.153E-08 | 9.348E-08 | 9.464E-08 | 1.012E-07 | 1.009E-07 | 9.342E-08 | 9.976E-08 | 9.934E-08 | 1.070E-07 | 9.796E-08 | 4.440E-09 | 4.5% |
| **Sm150** | 1.433E-05 | 1.401E-05 | 1.448E-05 | 1.399E-05 | 1.376E-05 | 1.399E-05 | 1.421E-05 | 1.420E-05 | 1.429E-05 | 1.374E-05 | 1.428E-05 | 1.413E-05 | 1.428E-05 | 1.630E-05 | 1.429E-05 | 6.174E-07 | 4.3% |
| **Sm151** | 5.871E-07 | 5.981E-07 | 6.084E-07 | 5.951E-07 | 5.861E-07 | 5.318E-07 | 5.190E-07 | 5.217E-07 | 6.223E-07 | 6.052E-07 | 6.401E-07 | 6.734E-07 | 6.731E-07 | 5.610E-07 | 5.945E-07 | 4.943E-08 | 8.3% |
| **Sm152** | 5.093E-06 | 5.008E-06 | 4.924E-06 | 5.016E-06 | 5.606E-06 | 4.843E-06 | 4.905E-06 | 4.890E-06 | 5.549E-06 | 5.256E-06 | 5.818E-06 | 5.748E-06 | 5.801E-06 | 4.980E-06 | 5.246E-06 | 3.744E-07 | 7.1% |
| **Eu153** | 6.070E-06 | 6.013E-06 | 5.697E-06 | 6.003E-06 | 5.835E-06 | 5.654E-06 | 5.525E-06 | 5.549E-06 | 5.973E-06 | 5.759E-06 | 5.642E-06 | 5.549E-06 | 5.607E-06 | 5.780E-06 | 5.761E-06 | 1.895E-07 | 3.3% |

# Table 3.6. Case 6: UOX 45 GWd/t, CRs 15-30 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.898E-06 | 4.138E-06 | 3.990E-06 | 4.143E-06 | 3.872E-06 | 3.407E-06 | 4.047E-06 | 4.046E-06 | 3.798E-06 | 3.935E-06 | 4.003E-06 | 4.013E-06 | 3.984E-06 | 3.880E-06 | 3.940E-06 | 1.821E-07 | 4.6% |
| **U235** | 2.051E-04 | 2.145E-04 | 2.042E-04 | 2.130E-04 | 2.004E-04 | 2.041E-04 | 2.085E-04 | 2.104E-04 | 2.065E-04 | 2.076E-04 | 1.960E-04 | 2.054E-04 | 2.021E-04 | 2.100E-04 | 2.063E-04 | 4.958E-06 | 2.4% |
| **U236** | 1.169E-04 | 1.175E-04 | 1.206E-04 | 1.183E-04 | 1.220E-04 | 1.217E-04 | 1.202E-04 | 1.157E-04 | 1.175E-04 | 1.218E-04 | 1.215E-04 | 1.209E-04 | 1.213E-04 | 1.170E-04 | 1.195E-04 | 2.214E-06 | 1.9% |
| **U238** | 2.075E-02 | 2.078E-02 | 2.081E-02 | 2.079E-02 | 2.082E-02 | 2.077E-02 | 2.079E-02 | 2.079E-02 | 2.081E-02 | 2.080E-02 | 2.081E-02 | 2.081E-02 | 2.080E-02 | 2.080E-02 | 2.079E-02 | 1.822E-05 | 0.1% |
| **Pu238** | 6.165E-06 | 5.716E-06 | 6.584E-06 | 5.682E-06 | 6.194E-06 | 6.544E-06 | 5.916E-06 | 5.689E-06 | 6.171E-06 | 6.022E-06 | 5.981E-06 | 6.007E-06 | 6.129E-06 | 5.770E-06 | 6.041E-06 | 2.861E-07 | 4.7% |
| **Pu239** | 1.417E-04 | 1.535E-04 | 1.410E-04 | 1.517E-04 | 1.366E-04 | 1.498E-04 | 1.474E-04 | 1.471E-04 | 1.407E-04 | 1.472E-04 | 1.365E-04 | 1.430E-04 | 1.436E-04 | 1.440E-04 | 1.446E-04 | 5.177E-06 | 3.6% |
| **Pu240** | 6.423E-05 | 6.631E-05 | 6.086E-05 | 6.578E-05 | 6.164E-05 | 6.554E-05 | 6.406E-05 | 6.352E-05 | 6.018E-05 | 6.360E-05 | 6.508E-05 | 6.460E-05 | 6.530E-05 | 6.470E-05 | 6.396E-05 | 1.862E-06 | 2.9% |
| **Pu241** | 3.909E-05 | 4.078E-05 | 3.909E-05 | 4.074E-05 | 3.817E-05 | 4.166E-05 | 4.096E-05 | 4.120E-05 | 3.889E-05 | 3.975E-05 | 3.712E-05 | 3.794E-05 | 3.829E-05 | 3.960E-05 | 3.952E-05 | 1.386E-06 | 3.5% |
| **Pu242** | 1.589E-05 | 1.546E-05 | 1.561E-05 | 1.566E-05 | 1.527E-05 | 1.661E-05 | 1.604E-05 | 1.605E-05 | 1.554E-05 | 1.487E-05 | 1.664E-05 | 1.617E-05 | 1.644E-05 | 1.500E-05 | 1.580E-05 | 5.586E-07 | 3.5% |
| **Np237** | 1.431E-05 | 1.296E-05 | 1.546E-05 | 1.287E-05 | 1.438E-05 | 1.505E-05 | 1.437E-05 | 1.378E-05 | 1.455E-05 | 1.431E-05 | 1.470E-05 | 1.476E-05 | 1.493E-05 | 1.380E-05 | 1.430E-05 | 7.408E-07 | 5.2% |
| **Am241** | 1.284E-06 | 1.347E-06 | 1.270E-06 | 1.343E-06 | 1.291E-06 | 1.323E-06 | 1.329E-06 | 1.397E-06 | 1.254E-06 | 1.315E-06 | 1.239E-06 | 1.289E-06 | 1.294E-06 | 1.330E-06 | 1.308E-06 | 4.160E-08 | 3.2% |
| **Am243** | 3.434E-06 | 3.225E-06 | 3.538E-06 | 3.297E-06 | 3.306E-06 | 3.894E-06 | 3.509E-06 | 3.423E-06 | 3.131E-06 | 3.441E-06 | 3.946E-06 | 3.935E-06 | 4.031E-06 | 3.580E-06 | 3.549E-06 | 2.914E-07 | 8.2% |
| **Rh103** | 2.891E-05 | 2.910E-05 | 2.639E-05 | 2.899E-05 | 1.793E-05 | 2.958E-05 | 2.922E-05 | 2.915E-05 | 2.871E-05 | 2.935E-05 | 2.978E-05 | 2.960E-05 | 2.983E-05 | 2.830E-05 | 2.820E-05 | 3.080E-06 | 10.9% |
| **Cs133** | 5.800E-05 | 5.770E-05 | 5.727E-05 | 5.773E-05 | 5.835E-05 | 5.977E-05 | 6.086E-05 | 6.091E-05 | 5.669E-05 | 5.960E-05 | 5.966E-05 | 5.901E-05 | 5.943E-05 | 5.780E-05 | 5.877E-05 | 1.314E-06 | 2.2% |
| **Nd143** | 3.874E-05 | 3.916E-05 | 4.005E-05 | 3.906E-05 | 3.840E-05 | 3.911E-05 | 3.879E-05 | 3.889E-05 | 3.886E-05 | 3.853E-05 | 3.820E-05 | 3.827E-05 | 3.846E-05 | 3.870E-05 | 3.880E-05 | 4.681E-07 | 1.2% |
| **Nd145** | 3.269E-05 | 3.262E-05 | 3.127E-05 | 3.261E-05 | 3.229E-05 | 3.334E-05 | 3.292E-05 | 3.295E-05 | 3.287E-05 | 3.225E-05 | 3.262E-05 | 3.225E-05 | 3.247E-05 | 3.260E-05 | 3.255E-05 | 4.756E-07 | 1.5% |
| **Gd155** | 3.690E-09 | 2.900E-09 | 6.317E-09 | 2.878E-09 | 2.171E-09 | 2.856E-09 | 3.188E-09 | 3.182E-09 | 2.496E-09 | 2.177E-09 | 2.225E-09 | 2.373E-09 | 2.380E-09 | 2.710E-09 | 2.967E-09 | 1.062E-09 | 35.8% |
| **Mo95** | 5.030E-05 | 5.007E-05 | nodata | 5.004E-05 | 4.983E-05 | 5.047E-05 | 4.977E-05 | 4.983E-05 | 5.036E-05 | 4.967E-05 | 5.003E-05 | 4.942E-05 | 4.977E-05 | 4.970E-05 | 4.994E-05 | 3.027E-07 | 0.6% |
| **Tc99** | 5.669E-05 | 5.664E-05 | nodata | 5.666E-05 | 5.132E-05 | 5.773E-05 | 5.773E-05 | 5.822E-05 | 5.575E-05 | 5.541E-05 | 5.738E-05 | 5.672E-05 | 5.715E-05 | 5.510E-05 | 5.635E-05 | 1.769E-06 | 3.1% |
| **Ru101** | 5.590E-05 | 5.569E-05 | nodata | 5.565E-05 | 5.370E-05 | 5.616E-05 | 5.463E-05 | 5.462E-05 | 5.583E-05 | 5.455E-05 | 5.568E-05 | 5.499E-05 | 5.547E-05 | 5.460E-05 | 5.519E-05 | 7.242E-07 | 1.3% |
| **Ag109** | 5.011E-06 | 4.992E-06 | 4.017E-06 | 5.017E-06 | 4.478E-06 | 6.244E-06 | 6.067E-06 | 6.031E-06 | 4.906E-06 | 5.341E-06 | 5.658E-06 | 4.992E-06 | 5.055E-06 | 5.210E-06 | 5.216E-06 | 6.168E-07 | 11.8% |
| **Sm147** | 3.336E-06 | 3.286E-06 | 3.370E-06 | 3.283E-06 | 3.427E-06 | 3.297E-06 | 3.411E-06 | 3.415E-06 | 3.160E-06 | 3.382E-06 | 3.292E-06 | 3.253E-06 | 3.251E-06 | 2.660E-06 | 3.273E-06 | 1.919E-07 | 5.9% |
| **Sm149** | 9.997E-08 | 1.024E-07 | 1.047E-07 | 1.013E-07 | 9.439E-08 | 9.462E-08 | 9.641E-08 | 9.723E-08 | 1.037E-07 | 1.034E-07 | 9.574E-08 | 1.015E-07 | 1.014E-07 | 1.090E-07 | 1.004E-07 | 4.271E-09 | 4.3% |
| **Sm150** | 1.436E-05 | 1.408E-05 | 1.457E-05 | 1.405E-05 | 1.381E-05 | 1.415E-05 | 1.428E-05 | 1.427E-05 | 1.432E-05 | 1.378E-05 | 1.432E-05 | 1.418E-05 | 1.432E-05 | 1.650E-05 | 1.436E-05 | 6.524E-07 | 4.5% |
| **Sm151** | 6.053E-07 | 6.189E-07 | 6.291E-07 | 6.146E-07 | 6.055E-07 | 5.527E-07 | 5.378E-07 | 5.394E-07 | 6.422E-07 | 6.242E-07 | 6.608E-07 | 6.903E-07 | 6.928E-07 | 5.830E-07 | 6.140E-07 | 4.931E-08 | 8.0% |
| **Sm152** | 5.039E-06 | 4.963E-06 | 4.885E-06 | 4.963E-06 | 5.554E-06 | 4.745E-06 | 4.821E-06 | 4.799E-06 | 5.513E-06 | 5.199E-06 | 5.755E-06 | 5.685E-06 | 5.734E-06 | 4.910E-06 | 5.183E-06 | 3.804E-07 | 7.3% |
| **Eu153** | 6.015E-06 | 5.951E-06 | 5.665E-06 | 5.950E-06 | 5.807E-06 | 5.594E-06 | 5.453E-06 | 5.473E-06 | 5.934E-06 | 5.712E-06 | 5.607E-06 | 5.513E-06 | 5.572E-06 | 5.700E-06 | 5.710E-06 | 1.910E-07 | 3.3% |

# Table 3.7. Case 7: UOX 45 GWd/t, CRs 30-45 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.850E-06 | 4.073E-06 | 3.927E-06 | 4.081E-06 | 3.804E-06 | 3.336E-06 | 3.978E-06 | 3.984E-06 | 3.732E-06 | 3.883E-06 | 3.942E-06 | 3.964E-06 | 3.930E-06 | 3.820E-06 | 3.879E-06 | 1.842E-07 | 4.8% |
| **U235** | 1.974E-04 | 2.043E-04 | 1.954E-04 | 2.033E-04 | 1.917E-04 | 1.934E-04 | 1.984E-04 | 2.001E-04 | 1.974E-04 | 1.989E-04 | 1.871E-04 | 1.963E-04 | 1.930E-04 | 2.000E-04 | 1.969E-04 | 4.612E-06 | 2.3% |
| **U236** | 1.159E-04 | 1.168E-04 | 1.197E-04 | 1.178E-04 | 1.209E-04 | 1.209E-04 | 1.193E-04 | 1.150E-04 | 1.166E-04 | 1.209E-04 | 1.203E-04 | 1.201E-04 | 1.203E-04 | 1.160E-04 | 1.186E-04 | 2.154E-06 | 1.8% |
| **U238** | 2.073E-02 | 2.077E-02 | 2.079E-02 | 2.077E-02 | 2.080E-02 | 2.075E-02 | 2.077E-02 | 2.078E-02 | 2.079E-02 | 2.078E-02 | 2.080E-02 | 2.080E-02 | 2.079E-02 | 2.080E-02 | 2.078E-02 | 2.083E-05 | 0.1% |
| **Pu238** | 6.364E-06 | 5.868E-06 | 6.840E-06 | 5.856E-06 | 6.409E-06 | 6.726E-06 | 6.082E-06 | 5.854E-06 | 6.380E-06 | 6.200E-06 | 6.166E-06 | 6.176E-06 | 6.308E-06 | 5.920E-06 | 6.225E-06 | 3.081E-07 | 4.9% |
| **Pu239** | 1.705E-04 | 1.833E-04 | 1.677E-04 | 1.795E-04 | 1.629E-04 | 1.791E-04 | 1.775E-04 | 1.766E-04 | 1.682E-04 | 1.744E-04 | 1.658E-04 | 1.664E-04 | 1.699E-04 | 1.750E-04 | 1.726E-04 | 6.118E-06 | 3.5% |
| **Pu240** | 5.872E-05 | 6.023E-05 | 5.553E-05 | 6.022E-05 | 5.645E-05 | 6.019E-05 | 5.830E-05 | 5.790E-05 | 5.473E-05 | 5.773E-05 | 5.932E-05 | 5.814E-05 | 5.920E-05 | 5.820E-05 | 5.820E-05 | 1.691E-06 | 2.9% |
| **Pu241** | 4.191E-05 | 4.345E-05 | 4.153E-05 | 4.330E-05 | 4.072E-05 | 4.395E-05 | 4.340E-05 | 4.355E-05 | 4.146E-05 | 4.242E-05 | 4.002E-05 | 4.093E-05 | 4.115E-05 | 4.250E-05 | 4.216E-05 | 1.240E-06 | 2.9% |
| **Pu242** | 1.478E-05 | 1.443E-05 | 1.462E-05 | 1.473E-05 | 1.429E-05 | 1.560E-05 | 1.493E-05 | 1.499E-05 | 1.458E-05 | 1.390E-05 | 1.541E-05 | 1.521E-05 | 1.534E-05 | 1.390E-05 | 1.477E-05 | 5.276E-07 | 3.6% |
| **Np237** | 1.521E-05 | 1.373E-05 | 1.646E-05 | 1.349E-05 | 1.522E-05 | 1.578E-05 | 1.514E-05 | 1.458E-05 | 1.544E-05 | 1.510E-05 | 1.559E-05 | 1.540E-05 | 1.567E-05 | 1.460E-05 | 1.510E-05 | 7.890E-07 | 5.2% |
| **Am241** | 1.284E-06 | 1.289E-06 | 1.228E-06 | 1.284E-06 | 1.247E-06 | 1.262E-06 | 1.277E-06 | 1.336E-06 | 1.208E-06 | 1.273E-06 | 1.212E-06 | 1.255E-06 | 1.262E-06 | 1.280E-06 | 1.264E-06 | 3.362E-08 | 2.7% |
| **Am243** | 3.708E-06 | 3.565E-06 | 3.910E-06 | 3.611E-06 | 3.622E-06 | 4.264E-06 | 3.847E-06 | 3.724E-06 | 3.444E-06 | 3.758E-06 | 4.277E-06 | 4.272E-06 | 4.385E-06 | 3.920E-06 | 3.879E-06 | 3.057E-07 | 7.9% |
| **Rh103** | 2.807E-05 | 2.811E-05 | 2.565E-05 | 2.801E-05 | 1.735E-05 | 2.872E-05 | 2.828E-05 | 2.817E-05 | 2.771E-05 | 2.838E-05 | 2.884E-05 | 2.858E-05 | 2.887E-05 | 2.720E-05 | 2.728E-05 | 2.975E-06 | 10.9% |
| **Cs133** | 5.720E-05 | 5.687E-05 | 5.646E-05 | 5.695E-05 | 5.759E-05 | 5.909E-05 | 6.015E-05 | 6.016E-05 | 5.572E-05 | 5.887E-05 | 5.886E-05 | 5.835E-05 | 5.870E-05 | 5.680E-05 | 5.798E-05 | 1.381E-06 | 2.4% |
| **Nd143** | 3.868E-05 | 3.904E-05 | 3.997E-05 | 3.891E-05 | 3.833E-05 | 3.899E-05 | 3.863E-05 | 3.872E-05 | 3.871E-05 | 3.842E-05 | 3.811E-05 | 3.814E-05 | 3.833E-05 | 3.860E-05 | 3.868E-05 | 4.709E-07 | 1.2% |
| **Nd145** | 3.245E-05 | 3.240E-05 | 3.096E-05 | 3.240E-05 | 3.209E-05 | 3.325E-05 | 3.276E-05 | 3.279E-05 | 3.262E-05 | 3.205E-05 | 3.239E-05 | 3.207E-05 | 3.226E-05 | 3.240E-05 | 3.235E-05 | 5.149E-07 | 1.6% |
| **Gd155** | 6.047E-09 | 4.699E-09 | 9.002E-09 | 4.628E-09 | 2.838E-09 | 3.437E-09 | 4.429E-09 | 4.375E-09 | 3.500E-09 | 2.952E-09 | 3.105E-09 | 3.104E-09 | 3.218E-09 | 4.000E-09 | 4.238E-09 | 1.637E-09 | 38.6% |
| **Mo95** | 5.044E-05 | 5.001E-05 | nodata | 4.993E-05 | 4.977E-05 | 5.040E-05 | 4.969E-05 | 4.975E-05 | 5.024E-05 | 4.963E-05 | 5.005E-05 | 4.950E-05 | 4.985E-05 | 4.960E-05 | 4.991E-05 | 3.029E-07 | 0.6% |
| **Tc99** | 5.617E-05 | 5.613E-05 | nodata | 5.618E-05 | 5.074E-05 | 5.741E-05 | 5.721E-05 | 5.771E-05 | 5.512E-05 | 5.487E-05 | 5.676E-05 | 5.622E-05 | 5.659E-05 | 5.460E-05 | 5.582E-05 | 1.795E-06 | 3.2% |
| **Ru101** | 5.548E-05 | 5.534E-05 | nodata | 5.529E-05 | 5.338E-05 | 5.595E-05 | 5.430E-05 | 5.429E-05 | 5.542E-05 | 5.416E-05 | 5.528E-05 | 5.469E-05 | 5.512E-05 | 5.420E-05 | 5.484E-05 | 7.255E-07 | 1.3% |
| **Ag109** | 4.767E-06 | 4.715E-06 | 3.741E-06 | 4.780E-06 | 4.359E-06 | 6.004E-06 | 5.805E-06 | 5.773E-06 | 4.649E-06 | 5.134E-06 | 6.684E-06 | 4.729E-06 | 4.766E-06 | 5.000E-06 | 5.065E-06 | 7.586E-07 | 15.0% |
| **Sm147** | 3.264E-06 | 3.164E-06 | 3.279E-06 | 3.153E-06 | 3.301E-06 | 3.161E-06 | 3.278E-06 | 3.290E-06 | 3.033E-06 | 3.260E-06 | 3.189E-06 | 3.174E-06 | 3.162E-06 | 2.570E-06 | 3.163E-06 | 1.862E-07 | 5.9% |
| **Sm149** | 1.352E-07 | 1.405E-07 | 1.418E-07 | 1.359E-07 | 1.257E-07 | 1.301E-07 | 1.311E-07 | 1.312E-07 | 1.393E-07 | 1.387E-07 | 1.305E-07 | 1.334E-07 | 1.354E-07 | 1.560E-07 | 1.361E-07 | 7.320E-09 | 5.4% |
| **Sm150** | 1.440E-05 | 1.417E-05 | 1.466E-05 | 1.411E-05 | 1.386E-05 | 1.429E-05 | 1.437E-05 | 1.436E-05 | 1.438E-05 | 1.382E-05 | 1.438E-05 | 1.424E-05 | 1.439E-05 | 1.680E-05 | 1.444E-05 | 7.131E-07 | 4.9% |
| **Sm151** | 7.624E-07 | 7.750E-07 | 7.799E-07 | 7.614E-07 | 7.577E-07 | 6.589E-07 | 6.443E-07 | 6.454E-07 | 8.107E-07 | 7.801E-07 | 8.296E-07 | 8.357E-07 | 8.511E-07 | 7.110E-07 | 7.574E-07 | 6.881E-08 | 9.1% |
| **Sm152** | 4.544E-06 | 4.463E-06 | 4.409E-06 | 4.457E-06 | 5.106E-06 | 4.235E-06 | 4.273E-06 | 4.257E-06 | 5.072E-06 | 4.697E-06 | 5.262E-06 | 5.233E-06 | 5.254E-06 | 4.320E-06 | 4.684E-06 | 4.086E-07 | 8.7% |
| **Eu153** | 6.102E-06 | 6.016E-06 | 5.760E-06 | 6.041E-06 | 5.888E-06 | 5.668E-06 | 5.554E-06 | 5.578E-06 | 5.979E-06 | 5.819E-06 | 5.705E-06 | 5.610E-06 | 5.671E-06 | 5.780E-06 | 5.798E-06 | 1.812E-07 | 3.1% |

## Table 3.8. Case 8: UOX 45 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON/NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 3.855E-06 | 4.093E-06 | 3.938E-06 | 4.104E-06 | 3.814E-06 | 3.217E-06 | 4.006E-06 | 4.010E-06 | 3.740E-06 | 3.877E-06 | 3.975E-06 | 3.980E-06 | 3.956E-06 | 3.840E-06 | 3.886E-06 | 2.187E-07 | 5.6% |
| **U235** | 2.262E-04 | 2.386E-04 | 2.258E-04 | 2.351E-04 | 2.207E-04 | 2.275E-04 | 2.328E-04 | 2.348E-04 | 2.278E-04 | 2.279E-04 | 2.204E-04 | 2.312E-04 | 2.273E-04 | 2.340E-04 | 2.293E-04 | 5.372E-06 | 2.3% |
| **U236** | 1.179E-04 | 1.183E-04 | 1.217E-04 | 1.194E-04 | 1.238E-04 | 1.232E-04 | 1.214E-04 | 1.165E-04 | 1.188E-04 | 1.237E-04 | 1.226E-04 | 1.219E-04 | 1.224E-04 | 1.180E-04 | 1.207E-04 | 2.441E-06 | 2.0% |
| **U238** | 2.071E-02 | 2.074E-02 | 2.077E-02 | 2.075E-02 | 2.078E-02 | 2.072E-02 | 2.075E-02 | 2.075E-02 | 2.077E-02 | 2.076E-02 | 2.078E-02 | 2.077E-02 | 2.077E-02 | 2.080E-02 | 2.076E-02 | 2.414E-05 | 0.1% |
| **Pu238** | 6.540E-06 | 6.071E-06 | 6.978E-06 | 6.012E-06 | 6.543E-06 | 6.959E-06 | 6.315E-06 | 6.031E-06 | 6.512E-06 | 6.399E-06 | 6.274E-06 | 6.317E-06 | 6.417E-06 | 6.100E-06 | 6.391E-06 | 3.055E-07 | 4.8% |
| **Pu239** | 1.495E-04 | 1.631E-04 | 1.491E-04 | 1.607E-04 | 1.441E-04 | 1.593E-04 | 1.568E-04 | 1.559E-04 | 1.488E-04 | 1.554E-04 | 1.442E-04 | 1.527E-04 | 1.524E-04 | 1.530E-04 | 1.532E-04 | 5.762E-06 | 3.8% |
| **Pu240** | 6.747E-05 | 7.005E-05 | 6.400E-05 | 6.930E-05 | 6.466E-05 | 6.915E-05 | 6.762E-05 | 6.705E-05 | 6.333E-05 | 6.677E-05 | 6.827E-05 | 6.836E-05 | 6.867E-05 | 6.800E-05 | 6.733E-05 | 2.027E-06 | 3.0% |
| **Pu241** | 4.173E-05 | 4.381E-05 | 4.177E-05 | 4.360E-05 | 4.068E-05 | 4.450E-05 | 4.405E-05 | 4.411E-05 | 4.164E-05 | 4.242E-05 | 3.970E-05 | 4.085E-05 | 4.100E-05 | 4.260E-05 | 4.232E-05 | 1.506E-06 | 3.6% |
| **Pu242** | 1.637E-05 | 1.591E-05 | 1.607E-05 | 1.615E-05 | 1.572E-05 | 1.711E-05 | 1.650E-05 | 1.657E-05 | 1.605E-05 | 1.533E-05 | 1.706E-05 | 1.643E-05 | 1.673E-05 | 1.550E-05 | 1.625E-05 | 5.343E-07 | 3.3% |
| **Np237** | 1.476E-05 | 1.336E-05 | 1.591E-05 | 1.325E-05 | 1.481E-05 | 1.554E-05 | 1.488E-05 | 1.417E-05 | 1.498E-05 | 1.481E-05 | 1.508E-05 | 1.523E-05 | 1.534E-05 | 1.420E-05 | 1.474E-05 | 7.628E-07 | 5.2% |
| **Am241** | 1.448E-06 | 1.539E-06 | 1.434E-06 | 1.520E-06 | 1.452E-06 | 1.504E-06 | 1.516E-06 | 1.591E-06 | 1.420E-06 | 1.480E-06 | 1.408E-06 | 1.470E-06 | 1.468E-06 | 1.520E-06 | 1.484E-06 | 5.091E-08 | 3.4% |
| **Am243** | 3.567E-06 | 3.332E-06 | 3.676E-06 | 3.433E-06 | 3.419E-06 | 4.020E-06 | 3.660E-06 | 3.540E-06 | 3.249E-06 | 3.572E-06 | 4.048E-06 | 3.993E-06 | 4.097E-06 | 3.710E-06 | 3.665E-06 | 2.775E-07 | 7.6% |
| **Rh103** | 2.969E-05 | 3.001E-05 | 2.701E-05 | 2.981E-05 | 1.832E-05 | 3.048E-05 | 3.012E-05 | 3.004E-05 | 2.952E-05 | 3.014E-05 | 3.058E-05 | 3.045E-05 | 3.061E-05 | 2.920E-05 | 2.900E-05 | 3.205E-06 | 11.1% |
| **Cs133** | 5.805E-05 | 5.782E-05 | 5.725E-05 | 5.780E-05 | 5.834E-05 | 5.990E-05 | 6.105E-05 | 6.107E-05 | 5.679E-05 | 5.966E-05 | 5.958E-05 | 5.882E-05 | 5.924E-05 | 5.780E-05 | 5.880E-05 | 1.335E-06 | 2.3% |
| **Nd143** | 3.942E-05 | 3.997E-05 | 4.077E-05 | 3.973E-05 | 3.901E-05 | 3.989E-05 | 3.953E-05 | 3.961E-05 | 3.954E-05 | 3.914E-05 | 3.893E-05 | 3.898E-05 | 3.913E-05 | 3.940E-05 | 3.950E-05 | 4.937E-07 | 1.2% |
| **Nd145** | 3.259E-05 | 3.256E-05 | 3.118E-05 | 3.252E-05 | 3.218E-05 | 3.330E-05 | 3.283E-05 | 3.287E-05 | 3.279E-05 | 3.215E-05 | 3.245E-05 | 3.202E-05 | 3.223E-05 | 3.250E-05 | 3.244E-05 | 4.971E-07 | 1.5% |
| **Gd155** | 4.103E-09 | 3.303E-09 | 7.087E-09 | 3.259E-09 | 2.385E-09 | 3.083E-09 | 3.558E-09 | 3.511E-09 | 2.729E-09 | 2.386E-09 | 2.436E-09 | 2.618E-09 | 2.608E-09 | 3.030E-09 | 3.293E-09 | 1.206E-09 | 36.6% |
| **Mo95** | 4.990E-05 | 4.972E-05 | nodata | 4.966E-05 | 4.949E-05 | 5.015E-05 | 4.938E-05 | 4.945E-05 | 5.000E-05 | 4.930E-05 | 4.944E-05 | 4.873E-05 | 4.908E-05 | 4.930E-05 | 4.951E-05 | 3.847E-07 | 0.8% |
| **Tc99** | 5.665E-05 | 5.667E-05 | nodata | 5.664E-05 | 5.130E-05 | 5.784E-05 | 5.774E-05 | 5.823E-05 | 5.576E-05 | 5.541E-05 | 5.722E-05 | 5.647E-05 | 5.689E-05 | 5.510E-05 | 5.630E-05 | 1.763E-06 | 3.1% |
| **Ru101** | 5.604E-05 | 5.592E-05 | nodata | 5.581E-05 | 5.379E-05 | 5.637E-05 | 5.478E-05 | 5.476E-05 | 5.600E-05 | 5.465E-05 | 5.558E-05 | 5.480E-05 | 5.526E-05 | 5.470E-05 | 5.527E-05 | 7.510E-07 | 1.4% |
| **Ag109** | 5.187E-06 | 5.177E-06 | 4.143E-06 | 5.201E-06 | 4.635E-06 | 6.479E-06 | 6.306E-06 | 6.278E-06 | 5.087E-06 | 5.539E-06 | 5.965E-06 | 5.134E-06 | 5.192E-06 | 5.420E-06 | 5.410E-06 | 6.567E-07 | 12.1% |
| **Sm147** | 3.337E-06 | 3.294E-06 | 3.358E-06 | 3.281E-06 | 3.417E-06 | 3.300E-06 | 3.408E-06 | 3.420E-06 | 3.155E-06 | 3.377E-06 | 3.285E-06 | 3.232E-06 | 3.235E-06 | 2.650E-06 | 3.268E-06 | 1.939E-07 | 5.9% |
| **Sm149** | 1.068E-07 | 1.103E-07 | 1.123E-07 | 1.086E-07 | 1.008E-07 | 1.023E-07 | 1.043E-07 | 1.048E-07 | 1.110E-07 | 1.104E-07 | 1.027E-07 | 1.096E-07 | 1.090E-07 | 1.190E-07 | 1.080E-07 | 4.819E-09 | 4.5% |
| **Sm150** | 1.436E-05 | 1.411E-05 | 1.464E-05 | 1.406E-05 | 1.383E-05 | 1.430E-05 | 1.433E-05 | 1.430E-05 | 1.433E-05 | 1.377E-05 | 1.424E-05 | 1.409E-05 | 1.422E-05 | 1.670E-05 | 1.438E-05 | 7.041E-07 | 4.9% |
| **Sm151** | 6.389E-07 | 6.582E-07 | 6.670E-07 | 6.512E-07 | 6.388E-07 | 5.881E-07 | 5.731E-07 | 5.726E-07 | 6.792E-07 | 6.587E-07 | 6.976E-07 | 7.332E-07 | 7.327E-07 | 6.200E-07 | 6.507E-07 | 5.129E-08 | 7.9% |
| **Sm152** | 5.084E-06 | 5.025E-06 | 4.937E-06 | 5.015E-06 | 5.605E-06 | 4.829E-06 | 4.872E-06 | 4.869E-06 | 5.563E-06 | 5.243E-06 | 5.792E-06 | 5.716E-06 | 5.763E-06 | 4.980E-06 | 5.235E-06 | 3.684E-07 | 7.0% |
| **Eu153** | 6.062E-06 | 6.014E-06 | 5.750E-06 | 6.002E-06 | 5.853E-06 | 5.657E-06 | 5.511E-06 | 5.524E-06 | 5.987E-06 | 5.757E-06 | 5.620E-06 | 5.515E-06 | 5.569E-06 | 5.770E-06 | 5.756E-06 | 1.998E-07 | 3.5% |

# Table 3.9. Case 9: UOX 30 GWd/t, without CRs, Ctime = 5 years

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 5.165E-06 | 5.370E-06 | 5.279E-06 | 5.365E-06 | 5.199E-06 | 4.960E-06 | 5.287E-06 | 5.294E-06 | 5.118E-06 | 5.127E-06 | 5.254E-06 | 5.253E-06 | 5.231E-06 | 5.170E-06 | 5.219E-06 | 1.079E-07 | 2.1% |
| **U235** | 3.397E-04 | 3.458E-04 | 3.409E-04 | 3.478E-04 | 3.386E-04 | 3.367E-04 | 3.411E-04 | 3.429E-04 | 3.437E-04 | 3.441E-04 | 3.283E-04 | 3.384E-04 | 3.340E-04 | 3.430E-04 | 3.404E-04 | 5.052E-06 | 1.5% |
| **U236** | 9.856E-05 | 9.852E-05 | 1.016E-04 | 9.857E-05 | 1.021E-04 | 1.028E-04 | 1.010E-04 | 9.747E-05 | 9.891E-05 | 1.016E-04 | 1.028E-04 | 1.020E-04 | 1.026E-04 | 9.790E-05 | 1.005E-04 | 2.007E-06 | 2.0% |
| **U238** | 2.106E-02 | 2.110E-02 | 2.111E-02 | 2.110E-02 | 2.112E-02 | 2.110E-02 | 2.111E-02 | 2.111E-02 | 2.111E-02 | 2.111E-02 | 2.112E-02 | 2.111E-02 | 2.111E-02 | 2.120E-02 | 2.111E-02 | 2.933E-05 | 0.1% |
| **Pu238** | 2.220E-06 | 2.031E-06 | 2.347E-06 | 2.054E-06 | 2.214E-06 | 2.374E-06 | 2.093E-06 | 2.002E-06 | 2.007E-06 | 2.144E-06 | 2.147E-06 | 2.177E-06 | 2.229E-06 | 2.080E-06 | 2.151E-06 | 1.174E-07 | 5.5% |
| **Pu239** | 1.254E-04 | 1.309E-04 | 1.248E-04 | 1.315E-04 | 1.213E-04 | 1.287E-04 | 1.264E-04 | 1.260E-04 | 1.241E-04 | 1.291E-04 | 1.200E-04 | 1.253E-04 | 1.254E-04 | 1.240E-04 | 1.259E-04 | 3.278E-06 | 2.6% |
| **Pu240** | 4.137E-05 | 4.192E-05 | 3.950E-05 | 4.194E-05 | 4.012E-05 | 4.152E-05 | 4.070E-05 | 4.063E-05 | 3.865E-05 | 4.116E-05 | 4.191E-05 | 4.185E-05 | 4.226E-05 | 4.080E-05 | 4.102E-05 | 1.042E-06 | 2.5% |
| **Pu241** | 1.942E-05 | 1.956E-05 | 1.920E-05 | 1.973E-05 | 1.879E-05 | 2.060E-05 | 1.975E-05 | 1.974E-05 | 1.918E-05 | 1.918E-05 | 1.819E-05 | 1.866E-05 | 1.886E-05 | 1.920E-05 | 1.929E-05 | 5.890E-07 | 3.1% |
| **Pu242** | 6.366E-06 | 6.130E-06 | 6.149E-06 | 6.171E-06 | 5.917E-06 | 6.855E-06 | 6.415E-06 | 6.388E-06 | 6.057E-06 | 5.802E-06 | 6.643E-06 | 6.503E-06 | 6.671E-06 | 6.040E-06 | 6.293E-06 | 3.062E-07 | 4.9% |
| **Np237** | 8.394E-06 | 7.519E-06 | 8.726E-06 | 7.580E-06 | 8.340E-06 | 8.796E-06 | 8.250E-06 | 7.883E-06 | 8.425E-06 | 8.252E-06 | 8.498E-06 | 8.595E-06 | 8.705E-06 | 8.010E-06 | 8.284E-06 | 4.049E-07 | 4.9% |
| **Am241** | 5.865E-06 | 5.922E-06 | 5.834E-06 | 5.985E-06 | 5.679E-06 | 6.207E-06 | 5.978E-06 | 5.995E-06 | 5.782E-06 | 5.812E-06 | 5.520E-06 | 5.670E-06 | 5.728E-06 | 5.780E-06 | 5.840E-06 | 1.717E-07 | 2.9% |
| **Am243** | 9.267E-07 | 8.652E-07 | 9.121E-07 | 8.756E-07 | 8.928E-07 | 1.109E-06 | 9.484E-07 | 9.172E-07 | 8.615E-07 | 9.087E-07 | 1.068E-06 | 1.074E-06 | 1.114E-06 | 9.840E-07 | 9.613E-07 | 9.179E-08 | 9.5% |
| **Rh103** | 2.261E-05 | 2.244E-05 | 1.925E-05 | 2.249E-05 | 1.171E-05 | 2.320E-05 | 2.270E-05 | 2.264E-05 | 2.237E-05 | 2.278E-05 | 2.317E-05 | 2.303E-05 | 2.324E-05 | 2.240E-05 | 2.172E-05 | 3.041E-06 | 14.0% |
| **Cs133** | 4.219E-05 | 4.181E-05 | 4.148E-05 | 4.181E-05 | 4.237E-05 | 4.333E-05 | 4.402E-05 | 4.405E-05 | 4.149E-05 | 4.277E-05 | 4.330E-05 | 4.279E-05 | 4.318E-05 | 4.220E-05 | 4.263E-05 | 8.628E-07 | 2.0% |
| **Nd143** | 3.078E-05 | 3.070E-05 | 3.069E-05 | 3.072E-05 | 3.050E-05 | 3.088E-05 | 3.056E-05 | 3.062E-05 | 3.077E-05 | 3.048E-05 | 3.064E-05 | 3.051E-05 | 3.072E-05 | 3.050E-05 | 3.065E-05 | 1.245E-07 | 0.4% |
| **Nd145** | 2.388E-05 | 2.371E-05 | 2.306E-05 | 2.371E-05 | 2.349E-05 | 2.409E-05 | 2.379E-05 | 2.381E-05 | 2.385E-05 | 2.345E-05 | 2.392E-05 | 2.362E-05 | 2.383E-05 | 2.370E-05 | 2.371E-05 | 2.503E-07 | 1.1% |
| **Gd155** | 1.122E-07 | 1.116E-07 | 2.540E-07 | 1.126E-07 | 6.075E-08 | 1.085E-07 | 1.101E-07 | 1.082E-07 | 6.405E-08 | 6.206E-08 | 7.473E-08 | 7.395E-08 | 7.514E-08 | 8.000E-08 | 1.005E-07 | 4.882E-08 | 48.6% |
| **Mo95** | 4.094E-05 | 4.063E-05 | nodata | 4.060E-05 | 4.000E-05 | 4.095E-05 | 4.038E-05 | 4.041E-05 | 4.079E-05 | 4.016E-05 | 4.085E-05 | 4.031E-05 | 4.069E-05 | 4.020E-05 | 4.053E-05 | 3.131E-07 | 0.8% |
| **Tc99** | 4.039E-05 | 4.003E-05 | nodata | 4.003E-05 | 3.627E-05 | 4.086E-05 | 4.083E-05 | 4.105E-05 | 3.984E-05 | 3.933E-05 | 4.114E-05 | 4.064E-05 | 4.102E-05 | 3.900E-05 | 4.003E-05 | 1.317E-06 | 3.3% |
| **Ru101** | 3.778E-05 | 3.739E-05 | nodata | 3.742E-05 | 3.631E-05 | 3.775E-05 | 3.672E-05 | 3.671E-05 | 3.751E-05 | 3.686E-05 | 3.773E-05 | 3.730E-05 | 3.768E-05 | 3.670E-05 | 3.722E-05 | 4.977E-07 | 1.3% |
| **Ag109** | 2.712E-06 | 2.681E-06 | 2.242E-06 | 2.692E-06 | 2.561E-06 | 3.462E-06 | 3.286E-06 | 3.272E-06 | 2.651E-06 | 2.836E-06 | 2.749E-06 | 2.727E-06 | 2.769E-06 | 2.850E-06 | 2.821E-06 | 3.197E-07 | 11.3% |
| **Sm147** | 7.730E-06 | 7.680E-06 | 7.267E-06 | 7.674E-06 | 7.691E-06 | 7.779E-06 | 7.865E-06 | 7.878E-06 | 7.370E-06 | 7.783E-06 | 7.638E-06 | 7.537E-06 | 7.574E-06 | 6.470E-06 | 7.567E-06 | 3.596E-07 | 4.8% |
| **Sm149** | 1.511E-07 | 1.479E-07 | 1.573E-07 | 1.492E-07 | 1.429E-07 | 1.375E-07 | 1.413E-07 | 1.416E-07 | 1.574E-07 | 1.516E-07 | 1.481E-07 | 1.521E-07 | 1.526E-07 | 1.630E-07 | 1.495E-07 | 7.086E-09 | 4.7% |
| **Sm150** | 9.391E-06 | 9.115E-06 | 9.441E-06 | 9.128E-06 | 9.191E-06 | 9.028E-06 | 9.150E-06 | 9.136E-06 | 9.346E-06 | 9.049E-06 | 9.445E-06 | 9.328E-06 | 9.442E-06 | 1.040E-05 | 9.328E-06 | 3.434E-07 | 3.7% |
| **Sm151** | 4.761E-07 | 4.731E-07 | 4.832E-07 | 4.755E-07 | 4.807E-07 | 4.408E-07 | 4.284E-07 | 4.294E-07 | 4.976E-07 | 4.857E-07 | 5.195E-07 | 5.414E-07 | 5.421E-07 | 4.530E-07 | 4.805E-07 | 3.628E-08 | 7.6% |
| **Sm152** | 3.746E-06 | 3.672E-06 | 3.650E-06 | 3.683E-06 | 4.011E-06 | 3.640E-06 | 3.650E-06 | 3.646E-06 | 3.957E-06 | 3.822E-06 | 4.126E-06 | 4.073E-06 | 4.115E-06 | 3.670E-06 | 3.819E-06 | 1.939E-07 | 5.1% |
| **Eu153** | 3.566E-06 | 3.506E-06 | 3.377E-06 | 3.515E-06 | 3.443E-06 | 3.459E-06 | 3.313E-06 | 3.314E-06 | 3.424E-06 | 3.366E-06 | 3.271E-06 | 3.227E-06 | 3.271E-06 | 3.470E-06 | 3.394E-06 | 1.046E-07 | 3.1% |

# Table 3.10. Case 10: UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 5 years

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 4.944E-06 | 5.127E-06 | 5.033E-06 | 5.145E-06 | 4.925E-06 | 4.316E-06 | 5.072E-06 | 5.071E-06 | 4.843E-06 | 4.855E-06 | 5.058E-06 | 5.058E-06 | 5.042E-06 | 4.930E-06 | 4.959E-06 | 2.076E-07 | 4.2% |
| **U235** | 3.771E-04 | 3.873E-04 | 3.783E-04 | 3.844E-04 | 3.735E-04 | 3.754E-04 | 3.828E-04 | 3.852E-04 | 3.796E-04 | 3.785E-04 | 3.752E-04 | 3.840E-04 | 3.805E-04 | 3.850E-04 | 3.805E-04 | 4.343E-06 | 1.1% |
| **U236** | 9.802E-05 | 9.753E-05 | 1.011E-04 | 9.855E-05 | 1.029E-04 | 1.030E-04 | 1.007E-04 | 9.644E-05 | 9.882E-05 | 1.027E-04 | 1.014E-04 | 1.009E-04 | 1.013E-04 | 9.720E-05 | 1.000E-04 | 2.233E-06 | 2.2% |
| **U238** | 2.096E-02 | 2.099E-02 | 2.101E-02 | 2.100E-02 | 2.102E-02 | 2.098E-02 | 2.100E-02 | 2.100E-02 | 2.101E-02 | 2.101E-02 | 2.102E-02 | 2.102E-02 | 2.101E-02 | 2.100E-02 | 2.100E-02 | 1.768E-05 | 0.1% |
| **Pu238** | 3.006E-06 | 2.788E-06 | 3.241E-06 | 2.761E-06 | 2.983E-06 | 3.217E-06 | 2.877E-06 | 2.737E-06 | 2.736E-06 | 2.914E-06 | 2.848E-06 | 2.850E-06 | 2.898E-06 | 2.800E-06 | 2.904E-06 | 1.608E-07 | 5.5% |
| **Pu239** | 1.746E-04 | 1.875E-04 | 1.743E-04 | 1.848E-04 | 1.692E-04 | 1.853E-04 | 1.828E-04 | 1.819E-04 | 1.743E-04 | 1.794E-04 | 1.711E-04 | 1.776E-04 | 1.777E-04 | 1.800E-04 | 1.786E-04 | 5.499E-06 | 3.1% |
| **Pu240** | 4.598E-05 | 4.732E-05 | 4.409E-05 | 4.722E-05 | 4.447E-05 | 4.694E-05 | 4.591E-05 | 4.581E-05 | 4.342E-05 | 4.552E-05 | 4.663E-05 | 4.623E-05 | 4.648E-05 | 4.620E-05 | 4.587E-05 | 1.162E-06 | 2.5% |
| **Pu241** | 2.499E-05 | 2.564E-05 | 2.452E-05 | 2.547E-05 | 2.401E-05 | 2.651E-05 | 2.574E-05 | 2.574E-05 | 2.475E-05 | 2.457E-05 | 2.372E-05 | 2.402E-05 | 2.422E-05 | 2.510E-05 | 2.493E-05 | 8.139E-07 | 3.3% |
| **Pu242** | 6.585E-06 | 6.241E-06 | 6.375E-06 | 6.457E-06 | 6.130E-06 | 7.054E-06 | 6.587E-06 | 6.561E-06 | 6.324E-06 | 6.013E-06 | 6.611E-06 | 6.394E-06 | 6.521E-06 | 6.160E-06 | 6.429E-06 | 2.609E-07 | 4.1% |
| **Np237** | 1.043E-05 | 9.547E-06 | 1.099E-05 | 9.355E-06 | 1.039E-05 | 1.100E-05 | 1.039E-05 | 9.881E-06 | 1.049E-05 | 1.036E-05 | 1.058E-05 | 1.061E-05 | 1.069E-05 | 1.000E-05 | 1.034E-05 | 4.863E-07 | 4.7% |
| **Am241** | 7.594E-06 | 7.805E-06 | 7.478E-06 | 7.751E-06 | 7.282E-06 | 8.026E-06 | 7.825E-06 | 7.848E-06 | 7.488E-06 | 7.471E-06 | 7.234E-06 | 7.335E-06 | 7.392E-06 | 7.610E-06 | 7.581E-06 | 2.396E-07 | 3.2% |
| **Am243** | 1.155E-06 | 1.070E-06 | 1.155E-06 | 1.115E-06 | 1.115E-06 | 1.361E-06 | 1.184E-06 | 1.137E-06 | 1.091E-06 | 1.136E-06 | 1.253E-06 | 1.245E-06 | 1.281E-06 | 1.210E-06 | 1.179E-06 | 8.171E-08 | 6.9% |
| **Rh103** | 2.320E-05 | 2.336E-05 | 1.966E-05 | 2.322E-05 | 1.203E-05 | 2.428E-05 | 2.366E-05 | 2.359E-05 | 2.308E-05 | 2.349E-05 | 2.385E-05 | 2.362E-05 | 2.376E-05 | 2.310E-05 | 2.242E-05 | 3.180E-06 | 14.2% |
| **Cs133** | 4.125E-05 | 4.101E-05 | 4.045E-05 | 4.102E-05 | 4.142E-05 | 4.269E-05 | 4.323E-05 | 4.324E-05 | 4.056E-05 | 4.202E-05 | 4.199E-05 | 4.139E-05 | 4.169E-05 | 4.120E-05 | 4.165E-05 | 8.896E-07 | 2.1% |
| **Nd143** | 3.130E-05 | 3.148E-05 | 3.137E-05 | 3.129E-05 | 3.100E-05 | 3.162E-05 | 3.118E-05 | 3.123E-05 | 3.132E-05 | 3.093E-05 | 3.107E-05 | 3.081E-05 | 3.098E-05 | 3.110E-05 | 3.119E-05 | 2.252E-07 | 0.7% |
| **Nd145** | 2.330E-05 | 2.324E-05 | 2.241E-05 | 2.320E-05 | 2.294E-05 | 2.377E-05 | 2.329E-05 | 2.332E-05 | 2.333E-05 | 2.290E-05 | 2.310E-05 | 2.275E-05 | 2.291E-05 | 2.310E-05 | 2.311E-05 | 3.225E-07 | 1.4% |
| **Gd155** | 1.587E-07 | 1.615E-07 | 3.156E-07 | 1.606E-07 | 6.756E-08 | 1.035E-07 | 1.229E-07 | 1.207E-07 | 7.572E-08 | 6.891E-08 | 8.188E-08 | 8.090E-08 | 8.180E-08 | 8.870E-08 | 1.206E-07 | 6.572E-08 | 54.5% |
| **Mo95** | 3.987E-05 | 3.973E-05 | nodata | 3.967E-05 | 3.918E-05 | 4.020E-05 | 3.937E-05 | 3.942E-05 | 3.988E-05 | 3.927E-05 | 3.933E-05 | 3.873E-05 | 3.902E-05 | 3.930E-05 | 3.946E-05 | 3.983E-07 | 1.0% |
| **Tc99** | 3.963E-05 | 3.944E-05 | nodata | 3.943E-05 | 3.551E-05 | 4.052E-05 | 4.023E-05 | 4.047E-05 | 3.913E-05 | 3.867E-05 | 3.993E-05 | 3.936E-05 | 3.964E-05 | 3.840E-05 | 3.926E-05 | 1.290E-06 | 3.3% |
| **Ru101** | 3.766E-05 | 3.753E-05 | nodata | 3.743E-05 | 3.620E-05 | 3.796E-05 | 3.671E-05 | 3.669E-05 | 3.750E-05 | 3.670E-05 | 3.713E-05 | 3.657E-05 | 3.686E-05 | 3.670E-05 | 3.705E-05 | 5.223E-07 | 1.4% |
| **Ag109** | 2.935E-06 | 2.903E-06 | 2.374E-06 | 2.939E-06 | 2.920E-06 | 3.807E-06 | 3.632E-06 | 3.614E-06 | 2.884E-06 | 3.114E-06 | 3.921E-06 | 2.855E-06 | 2.886E-06 | 3.170E-06 | 3.140E-06 | 4.392E-07 | 14.0% |
| **Sm147** | 7.215E-06 | 7.162E-06 | 6.735E-06 | 7.147E-06 | 7.115E-06 | 7.281E-06 | 7.365E-06 | 7.373E-06 | 6.792E-06 | 7.277E-06 | 7.048E-06 | 6.940E-06 | 6.970E-06 | 5.720E-06 | 7.010E-06 | 4.200E-07 | 6.0% |
| **Sm149** | 1.990E-07 | 2.040E-07 | 2.155E-07 | 2.009E-07 | 1.914E-07 | 1.945E-07 | 1.928E-07 | 1.934E-07 | 2.094E-07 | 2.027E-07 | 1.979E-07 | 2.050E-07 | 2.046E-07 | 2.370E-07 | 2.034E-07 | 1.179E-08 | 5.8% |
| **Sm150** | 9.499E-06 | 9.359E-06 | 9.780E-06 | 9.307E-06 | 9.355E-06 | 9.506E-06 | 9.357E-06 | 9.336E-06 | 9.502E-06 | 9.152E-06 | 9.417E-06 | 9.294E-06 | 9.379E-06 | 1.110E-05 | 9.524E-06 | 4.757E-07 | 5.0% |
| **Sm151** | 6.573E-07 | 6.738E-07 | 6.755E-07 | 6.611E-07 | 6.652E-07 | 6.115E-07 | 5.909E-07 | 5.920E-07 | 6.922E-07 | 6.700E-07 | 7.243E-07 | 7.472E-07 | 7.472E-07 | 6.400E-07 | 6.677E-07 | 4.981E-08 | 7.5% |
| **Sm152** | 3.456E-06 | 3.433E-06 | 3.416E-06 | 3.413E-06 | 3.782E-06 | 3.350E-06 | 3.346E-06 | 3.341E-06 | 3.756E-06 | 3.542E-06 | 3.837E-06 | 3.766E-06 | 3.798E-06 | 3.370E-06 | 3.543E-06 | 1.967E-07 | 5.6% |
| **Eu153** | 3.754E-06 | 3.705E-06 | 3.611E-06 | 3.715E-06 | 3.631E-06 | 3.666E-06 | 3.498E-06 | 3.502E-06 | 3.603E-06 | 3.558E-06 | 3.401E-06 | 3.340E-06 | 3.372E-06 | 3.660E-06 | 3.572E-06 | 1.322E-07 | 3.7% |

# Table 3.11. Case 11: UOX 45 GWd/t, without CRs, Ctime = 5 years

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 4.186E-06 | 4.415E-06 | 4.291E-06 | 4.414E-06 | 4.183E-06 | 3.907E-06 | 4.315E-06 | 4.313E-06 | 4.085E-06 | 4.004E-06 | 4.261E-06 | 4.280E-06 | 4.250E-06 | 4.150E-06 | 4.218E-06 | 1.454E-07 | 3.4% |
| **U235** | 1.845E-04 | 1.910E-04 | 1.833E-04 | 1.925E-04 | 1.804E-04 | 1.825E-04 | 1.856E-04 | 1.872E-04 | 1.860E-04 | 1.879E-04 | 1.711E-04 | 1.830E-04 | 1.784E-04 | 1.860E-04 | 1.842E-04 | 5.349E-06 | 2.9% |
| **U236** | 1.180E-04 | 1.191E-04 | 1.218E-04 | 1.193E-04 | 1.227E-04 | 1.226E-04 | 1.213E-04 | 1.171E-04 | 1.186E-04 | 1.223E-04 | 1.229E-04 | 1.222E-04 | 1.227E-04 | 1.180E-04 | 1.206E-04 | 2.133E-06 | 1.8% |
| **U238** | 2.079E-02 | 2.083E-02 | 2.085E-02 | 2.083E-02 | 2.086E-02 | 2.082E-02 | 2.084E-02 | 2.084E-02 | 2.085E-02 | 2.084E-02 | 2.086E-02 | 2.085E-02 | 2.084E-02 | 2.090E-02 | 2.084E-02 | 2.341E-05 | 0.1% |
| **Pu238** | 5.818E-06 | 5.338E-06 | 6.096E-06 | 5.374E-06 | 5.828E-06 | 6.189E-06 | 5.584E-06 | 5.368E-06 | 5.387E-06 | 5.652E-06 | 5.624E-06 | 5.680E-06 | 5.804E-06 | 5.460E-06 | 5.657E-06 | 2.684E-07 | 4.7% |
| **Pu239** | 1.288E-04 | 1.377E-04 | 1.281E-04 | 1.371E-04 | 1.241E-04 | 1.345E-04 | 1.323E-04 | 1.319E-04 | 1.278E-04 | 1.337E-04 | 1.239E-04 | 1.305E-04 | 1.304E-04 | 1.290E-04 | 1.307E-04 | 4.201E-06 | 3.2% |
| **Pu240** | 5.902E-05 | 6.049E-05 | 5.585E-05 | 6.030E-05 | 5.691E-05 | 5.977E-05 | 5.844E-05 | 5.805E-05 | 5.480E-05 | 5.837E-05 | 5.975E-05 | 5.996E-05 | 6.042E-05 | 5.860E-05 | 5.862E-05 | 1.749E-06 | 3.0% |
| **Pu241** | 2.773E-05 | 2.872E-05 | 2.760E-05 | 2.879E-05 | 2.706E-05 | 2.928E-05 | 2.871E-05 | 2.880E-05 | 2.753E-05 | 2.822E-05 | 2.617E-05 | 2.707E-05 | 2.722E-05 | 2.780E-05 | 2.791E-05 | 8.807E-07 | 3.2% |
| **Pu242** | 1.603E-05 | 1.570E-05 | 1.577E-05 | 1.579E-05 | 1.543E-05 | 1.684E-05 | 1.627E-05 | 1.630E-05 | 1.566E-05 | 1.504E-05 | 1.695E-05 | 1.641E-05 | 1.680E-05 | 1.530E-05 | 1.602E-05 | 5.953E-07 | 3.7% |
| **Np237** | 1.371E-05 | 1.224E-05 | 1.443E-05 | 1.226E-05 | 1.375E-05 | 1.439E-05 | 1.373E-05 | 1.318E-05 | 1.399E-05 | 1.358E-05 | 1.405E-05 | 1.419E-05 | 1.434E-05 | 1.320E-05 | 1.365E-05 | 7.116E-07 | 5.2% |
| **Am241** | 8.583E-06 | 8.930E-06 | 8.589E-06 | 8.960E-06 | 8.404E-06 | 9.027E-06 | 8.898E-06 | 8.982E-06 | 8.500E-06 | 8.780E-06 | 8.140E-06 | 8.448E-06 | 8.484E-06 | 8.630E-06 | 8.668E-06 | 2.662E-07 | 3.1% |
| **Am243** | 3.463E-06 | 3.274E-06 | 3.560E-06 | 3.317E-06 | 3.341E-06 | 4.004E-06 | 3.574E-06 | 3.480E-06 | 3.160E-06 | 3.476E-06 | 4.050E-06 | 4.000E-06 | 4.140E-06 | 3.650E-06 | 3.606E-06 | 3.182E-07 | 8.8% |
| **Rh103** | 3.085E-05 | 3.093E-05 | 2.576E-05 | 3.092E-05 | 1.771E-05 | 3.141E-05 | 3.101E-05 | 3.091E-05 | 3.063E-05 | 3.134E-05 | 3.174E-05 | 3.167E-05 | 3.192E-05 | 3.020E-05 | 2.979E-05 | 3.787E-06 | 12.7% |
| **Cs133** | 5.879E-05 | 5.849E-05 | 5.771E-05 | 5.849E-05 | 5.919E-05 | 6.054E-05 | 6.177E-05 | 6.180E-05 | 5.752E-05 | 6.034E-05 | 6.070E-05 | 6.002E-05 | 6.056E-05 | 5.880E-05 | 5.962E-05 | 1.390E-06 | 2.3% |
| **Nd143** | 3.830E-05 | 3.863E-05 | 3.866E-05 | 3.864E-05 | 3.803E-05 | 3.866E-05 | 3.831E-05 | 3.842E-05 | 3.851E-05 | 3.827E-05 | 3.777E-05 | 3.804E-05 | 3.818E-05 | 3.830E-05 | 3.834E-05 | 2.715E-07 | 0.7% |
| **Nd145** | 3.290E-05 | 3.281E-05 | 3.155E-05 | 3.281E-05 | 3.251E-05 | 3.343E-05 | 3.310E-05 | 3.313E-05 | 3.308E-05 | 3.248E-05 | 3.296E-05 | 3.258E-05 | 3.285E-05 | 3.280E-05 | 3.279E-05 | 4.385E-07 | 1.3% |
| **Gd155** | 2.156E-07 | 2.181E-07 | 4.950E-07 | 2.182E-07 | 1.136E-07 | 1.918E-07 | 2.046E-07 | 2.007E-07 | 1.273E-07 | 1.179E-07 | 1.431E-07 | 1.413E-07 | 1.437E-07 | 1.490E-07 | 1.914E-07 | 9.565E-08 | 50.0% |
| **Mo95** | 5.746E-05 | 5.721E-05 | nodata | 5.719E-05 | 5.651E-05 | 5.763E-05 | 5.693E-05 | 5.700E-05 | 5.758E-05 | 5.669E-05 | 5.737E-05 | 5.663E-05 | 5.715E-05 | 5.680E-05 | 5.709E-05 | 3.646E-07 | 0.6% |
| **Tc99** | 5.720E-05 | 5.693E-05 | nodata | 5.692E-05 | 5.175E-05 | 5.811E-05 | 5.815E-05 | 5.863E-05 | 5.629E-05 | 5.592E-05 | 5.813E-05 | 5.744E-05 | 5.797E-05 | 5.560E-05 | 5.685E-05 | 1.794E-06 | 3.2% |
| **Ru101** | 5.596E-05 | 5.565E-05 | nodata | 5.568E-05 | 5.381E-05 | 5.611E-05 | 5.466E-05 | 5.465E-05 | 5.587E-05 | 5.468E-05 | 5.601E-05 | 5.531E-05 | 5.591E-05 | 5.460E-05 | 5.530E-05 | 7.349E-07 | 1.3% |
| **Ag109** | 4.861E-06 | 4.843E-06 | 3.926E-06 | 4.857E-06 | 4.263E-06 | 6.028E-06 | 5.842E-06 | 5.821E-06 | 4.758E-06 | 5.172E-06 | 5.027E-06 | 4.907E-06 | 4.983E-06 | 5.020E-06 | 5.022E-06 | 5.747E-07 | 11.4% |
| **Sm147** | 9.257E-06 | 9.242E-06 | 8.685E-06 | 9.233E-06 | 9.206E-06 | 9.442E-06 | 9.624E-06 | 9.642E-06 | 8.719E-06 | 9.492E-06 | 9.098E-06 | 9.013E-06 | 9.032E-06 | 7.350E-06 | 9.074E-06 | 5.748E-07 | 6.3% |
| **Sm149** | 1.484E-07 | 1.480E-07 | 1.526E-07 | 1.480E-07 | 1.364E-07 | 1.347E-07 | 1.396E-07 | 1.402E-07 | 1.556E-07 | 1.500E-07 | 1.457E-07 | 1.504E-07 | 1.511E-07 | 1.590E-07 | 1.471E-07 | 7.116E-09 | 4.8% |
| **Sm150** | 1.432E-05 | 1.395E-05 | 1.439E-05 | 1.395E-05 | 1.373E-05 | 1.381E-05 | 1.415E-05 | 1.414E-05 | 1.427E-05 | 1.374E-05 | 1.435E-05 | 1.419E-05 | 1.437E-05 | 1.610E-05 | 1.425E-05 | 5.817E-07 | 4.1% |
| **Sm151** | 5.430E-07 | 5.484E-07 | 5.475E-07 | 5.461E-07 | 5.423E-07 | 4.897E-07 | 4.789E-07 | 4.799E-07 | 5.765E-07 | 5.599E-07 | 5.913E-07 | 6.208E-07 | 6.217E-07 | 5.140E-07 | 5.471E-07 | 4.606E-08 | 8.4% |
| **Sm152** | 5.045E-06 | 4.942E-06 | 4.869E-06 | 4.962E-06 | 5.553E-06 | 4.770E-06 | 4.861E-06 | 4.853E-06 | 5.490E-06 | 5.211E-06 | 5.777E-06 | 5.710E-06 | 5.770E-06 | 4.920E-06 | 5.195E-06 | 3.805E-07 | 7.3% |
| **Eu153** | 6.065E-06 | 5.989E-06 | 5.600E-06 | 5.992E-06 | 5.829E-06 | 5.626E-06 | 5.491E-06 | 5.512E-06 | 5.962E-06 | 5.755E-06 | 5.674E-06 | 5.579E-06 | 5.653E-06 | 5.750E-06 | 5.748E-06 | 1.903E-07 | 3.3% |

# Table 3.12. Case 12: UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 5 years

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **U234** | 4.053E-06 | 4.253E-06 | 4.124E-06 | 4.266E-06 | 3.982E-06 | 3.279E-06 | 4.188E-06 | 4.175E-06 | 3.883E-06 | 3.761E-06 | 4.168E-06 | 4.174E-06 | 4.156E-06 | 4.000E-06 | 4.033E-06 | 2.598E-07 | 6.4% |
| **U235** | 2.370E-04 | 2.481E-04 | 2.365E-04 | 2.445E-04 | 2.307E-04 | 2.366E-04 | 2.434E-04 | 2.459E-04 | 2.378E-04 | 2.374E-04 | 2.329E-04 | 2.432E-04 | 2.394E-04 | 2.450E-04 | 2.399E-04 | 5.184E-06 | 2.2% |
| **U236** | 1.163E-04 | 1.169E-04 | 1.199E-04 | 1.183E-04 | 1.224E-04 | 1.219E-04 | 1.200E-04 | 1.149E-04 | 1.172E-04 | 1.226E-04 | 1.209E-04 | 1.203E-04 | 1.207E-04 | 1.160E-04 | 1.192E-04 | 2.540E-06 | 2.1% |
| **U238** | 2.066E-02 | 2.068E-02 | 2.071E-02 | 2.069E-02 | 2.073E-02 | 2.066E-02 | 2.068E-02 | 2.069E-02 | 2.071E-02 | 2.070E-02 | 2.072E-02 | 2.072E-02 | 2.072E-02 | 2.070E-02 | 2.070E-02 | 2.262E-05 | 0.1% |
| **Pu238** | 7.626E-06 | 7.042E-06 | 8.103E-06 | 6.971E-06 | 7.576E-06 | 8.033E-06 | 7.352E-06 | 7.020E-06 | 7.084E-06 | 7.411E-06 | 7.206E-06 | 7.210E-06 | 7.323E-06 | 7.060E-06 | 7.358E-06 | 3.623E-07 | 4.9% |
| **Pu239** | 1.937E-04 | 2.113E-04 | 1.934E-04 | 2.076E-04 | 1.872E-04 | 2.092E-04 | 2.064E-04 | 2.056E-04 | 1.939E-04 | 2.001E-04 | 1.898E-04 | 1.989E-04 | 1.986E-04 | 2.030E-04 | 1.999E-04 | 7.566E-06 | 3.8% |
| **Pu240** | 6.639E-05 | 6.893E-05 | 6.329E-05 | 6.871E-05 | 6.378E-05 | 6.857E-05 | 6.689E-05 | 6.630E-05 | 6.232E-05 | 6.515E-05 | 6.735E-05 | 6.711E-05 | 6.738E-05 | 6.740E-05 | 6.640E-05 | 2.053E-06 | 3.1% |
| **Pu241** | 3.749E-05 | 3.941E-05 | 3.716E-05 | 3.887E-05 | 3.635E-05 | 3.969E-05 | 3.925E-05 | 3.933E-05 | 3.741E-05 | 3.785E-05 | 3.606E-05 | 3.677E-05 | 3.693E-05 | 3.820E-05 | 3.791E-05 | 1.220E-06 | 3.2% |
| **Pu242** | 1.533E-05 | 1.478E-05 | 1.510E-05 | 1.522E-05 | 1.475E-05 | 1.605E-05 | 1.539E-05 | 1.546E-05 | 1.508E-05 | 1.437E-05 | 1.566E-05 | 1.506E-05 | 1.532E-05 | 1.430E-05 | 1.513E-05 | 4.741E-07 | 3.1% |
| **Np237** | 1.668E-05 | 1.511E-05 | 1.769E-05 | 1.480E-05 | 1.674E-05 | 1.745E-05 | 1.676E-05 | 1.600E-05 | 1.704E-05 | 1.666E-05 | 1.707E-05 | 1.714E-05 | 1.726E-05 | 1.610E-05 | 1.661E-05 | 8.406E-07 | 5.1% |
| **Am241** | 1.177E-05 | 1.240E-05 | 1.169E-05 | 1.222E-05 | 1.141E-05 | 1.239E-05 | 1.232E-05 | 1.242E-05 | 1.167E-05 | 1.190E-05 | 1.137E-05 | 1.162E-05 | 1.167E-05 | 1.200E-05 | 1.192E-05 | 3.727E-07 | 3.1% |
| **Am243** | 3.845E-06 | 3.616E-06 | 4.031E-06 | 3.749E-06 | 3.708E-06 | 4.328E-06 | 3.926E-06 | 3.807E-06 | 3.553E-06 | 3.862E-06 | 4.274E-06 | 4.214E-06 | 4.318E-06 | 4.000E-06 | 3.945E-06 | 2.586E-07 | 6.6% |
| **Rh103** | 3.203E-05 | 3.256E-05 | 2.676E-05 | 3.226E-05 | 1.838E-05 | 3.333E-05 | 3.279E-05 | 3.268E-05 | 3.196E-05 | 3.262E-05 | 3.316E-05 | 3.292E-05 | 3.309E-05 | 3.150E-05 | 3.114E-05 | 4.019E-06 | 12.9% |
| **Cs133** | 5.729E-05 | 5.719E-05 | 5.604E-05 | 5.717E-05 | 5.760E-05 | 5.953E-05 | 6.050E-05 | 6.056E-05 | 5.592E-05 | 5.911E-05 | 5.889E-05 | 5.807E-05 | 5.846E-05 | 5.710E-05 | 5.810E-05 | 1.473E-06 | 2.5% |
| **Nd143** | 4.089E-05 | 4.166E-05 | 4.154E-05 | 4.120E-05 | 4.053E-05 | 4.157E-05 | 4.112E-05 | 4.121E-05 | 4.110E-05 | 4.063E-05 | 4.065E-05 | 4.056E-05 | 4.073E-05 | 4.100E-05 | 4.103E-05 | 3.829E-07 | 0.9% |
| **Nd145** | 3.211E-05 | 3.218E-05 | 3.059E-05 | 3.211E-05 | 3.175E-05 | 3.311E-05 | 3.248E-05 | 3.252E-05 | 3.233E-05 | 3.171E-05 | 3.194E-05 | 3.149E-05 | 3.168E-05 | 3.210E-05 | 3.201E-05 | 5.831E-07 | 1.8% |
| **Gd155** | 3.128E-07 | 3.218E-07 | 6.285E-07 | 3.187E-07 | 1.251E-07 | 1.689E-07 | 2.259E-07 | 2.218E-07 | 1.468E-07 | 1.291E-07 | 1.554E-07 | 1.539E-07 | 1.554E-07 | 1.640E-07 | 2.306E-07 | 1.345E-07 | 58.3% |
| **Mo95** | 5.586E-05 | 5.595E-05 | nodata | 5.577E-05 | 5.528E-05 | 5.645E-05 | 5.546E-05 | 5.552E-05 | 5.615E-05 | 5.535E-05 | 5.527E-05 | 5.446E-05 | 5.484E-05 | 5.550E-05 | 5.553E-05 | 5.287E-07 | 1.0% |
| **Tc99** | 5.600E-05 | 5.595E-05 | nodata | 5.592E-05 | 5.040E-05 | 5.757E-05 | 5.724E-05 | 5.775E-05 | 5.505E-05 | 5.482E-05 | 5.641E-05 | 5.562E-05 | 5.600E-05 | 5.470E-05 | 5.565E-05 | 1.853E-06 | 3.3% |
| **Ru101** | 5.554E-05 | 5.563E-05 | nodata | 5.544E-05 | 5.337E-05 | 5.622E-05 | 5.444E-05 | 5.443E-05 | 5.558E-05 | 5.417E-05 | 5.492E-05 | 5.405E-05 | 5.447E-05 | 5.440E-05 | 5.482E-05 | 8.065E-07 | 1.5% |
| **Ag109** | 5.071E-06 | 5.027E-06 | 3.947E-06 | 5.107E-06 | 4.710E-06 | 6.440E-06 | 6.258E-06 | 6.223E-06 | 4.978E-06 | 5.486E-06 | 7.869E-06 | 4.907E-06 | 4.959E-06 | 5.400E-06 | 5.456E-06 | 9.644E-07 | 17.7% |
| **Sm147** | 8.634E-06 | 8.616E-06 | 8.021E-06 | 8.565E-06 | 8.461E-06 | 8.845E-06 | 9.026E-06 | 9.035E-06 | 7.993E-06 | 8.848E-06 | 8.451E-06 | 8.333E-06 | 8.350E-06 | 6.490E-06 | 8.405E-06 | 6.381E-07 | 7.6% |
| **Sm149** | 2.064E-07 | 2.155E-07 | 2.214E-07 | 2.110E-07 | 1.938E-07 | 2.049E-07 | 2.034E-07 | 2.044E-07 | 2.187E-07 | 2.123E-07 | 2.048E-07 | 2.138E-07 | 2.135E-07 | 2.450E-07 | 2.121E-07 | 1.189E-08 | 5.6% |
| **Sm150** | 1.438E-05 | 1.425E-05 | 1.483E-05 | 1.415E-05 | 1.388E-05 | 1.467E-05 | 1.448E-05 | 1.446E-05 | 1.437E-05 | 1.380E-05 | 1.422E-05 | 1.408E-05 | 1.420E-05 | 1.730E-05 | 1.451E-05 | 8.510E-07 | 5.9% |
| **Sm151** | 8.185E-07 | 8.496E-07 | 8.410E-07 | 8.293E-07 | 8.209E-07 | 7.372E-07 | 7.148E-07 | 7.151E-07 | 8.780E-07 | 8.429E-07 | 8.964E-07 | 9.316E-07 | 9.314E-07 | 7.920E-07 | 8.285E-07 | 7.056E-08 | 8.5% |
| **Sm152** | 4.589E-06 | 4.572E-06 | 4.502E-06 | 4.543E-06 | 5.180E-06 | 4.309E-06 | 4.349E-06 | 4.339E-06 | 5.160E-06 | 4.763E-06 | 5.307E-06 | 5.217E-06 | 5.260E-06 | 4.430E-06 | 4.751E-06 | 3.853E-07 | 8.1% |
| **Eu153** | 6.176E-06 | 6.113E-06 | 5.867E-06 | 6.120E-06 | 5.977E-06 | 5.776E-06 | 5.619E-06 | 5.643E-06 | 6.080E-06 | 5.890E-06 | 5.728E-06 | 5.616E-06 | 5.664E-06 | 5.880E-06 | 5.868E-06 | 2.003E-07 | 3.4% |

**Figure 3.1. Relative standard deviation (%) on actinide concentrations**

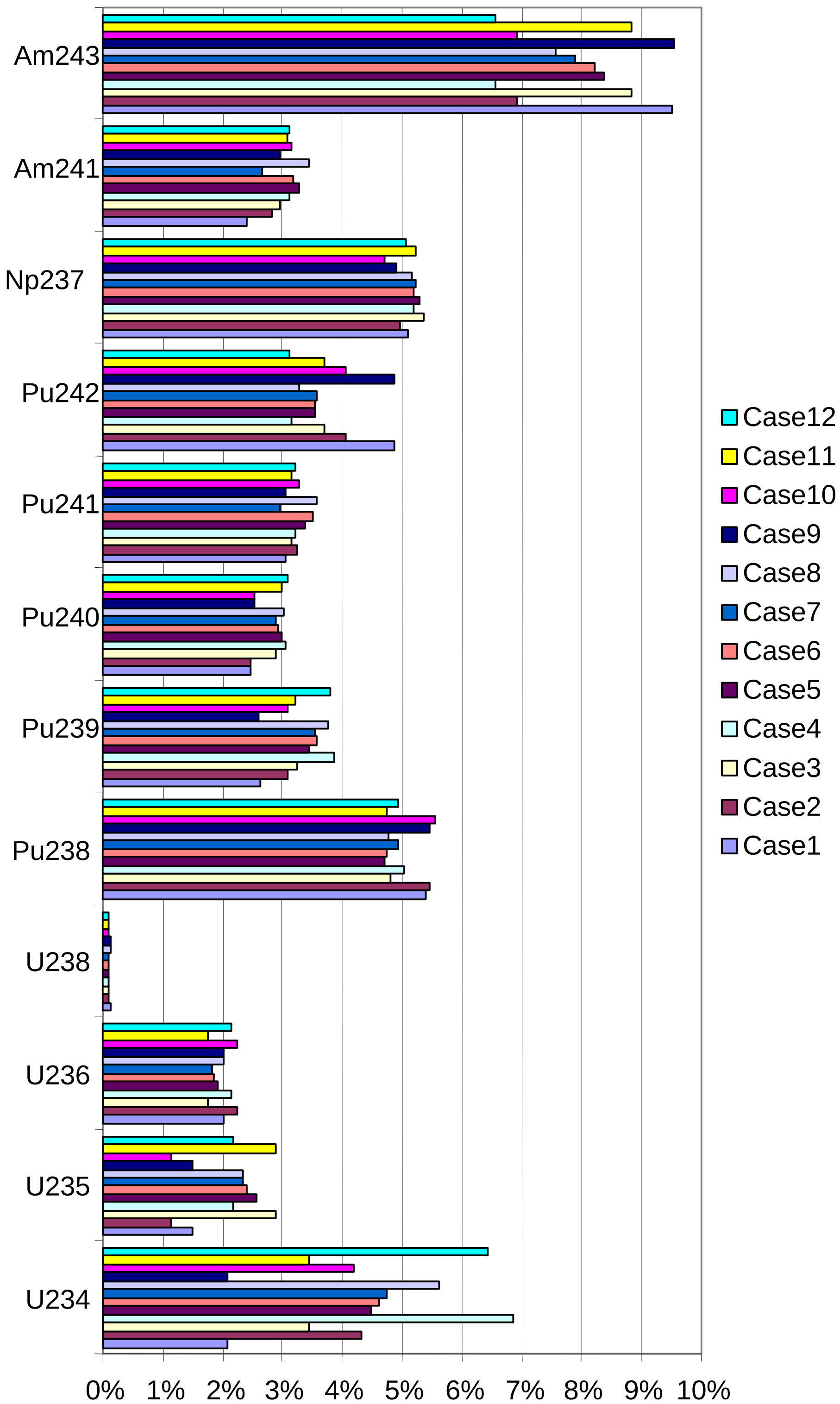
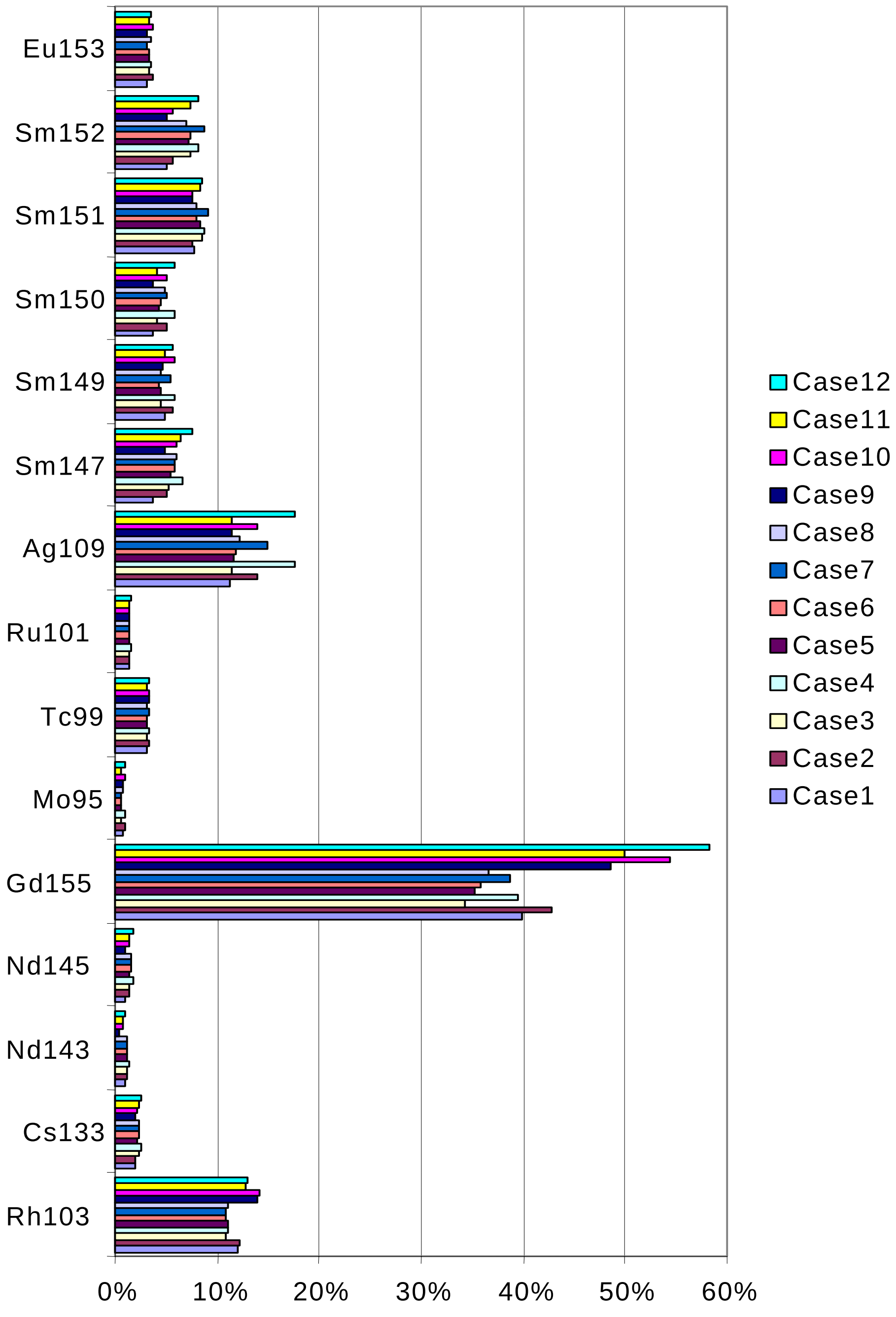


**Figure 3.2. Relative standard deviation (%) on fission product concentrations**



## *Chapter 4*

## CRITICALITY CALCULATIONS

### 4.1 Results

The results from the participants on the neutron multiplication factor calculations are given in Table 4.1, and graphically presented in Figures 4.2 to 4.24.

Table 4.1 also presents the mean calculated neutron multiplication factor, the standard deviation (SD) from the 13 individual contributions and the relative standard deviation (RSD). The mean, the standard deviation and the relative standard deviation are defined in § 3.1. Figure 4.1 presents the Kinf mean value for each case.

Table 4.2 presents the absolute differences of the $Kinf_i$ calculated by participant i from the $Kinf_{mean}$ mean values. These values, expressed in pcm, are defined below:

$$\Delta Kinf_i \text{ (pcm)} = (Kinf_i - Kinf_{mean}) \times 10^5$$

### 4.2 Comparison of the calculated Kinf

#### *4.2.1 Impact of the calculation scheme and/or the library*

Comparison of the Kinf calculated by participants for Cases 13b, 14b and 15 (imposed fuel inventory) gives the impact of the calculation scheme and/or the library between the participants. This impact is slight (standard deviation about 200 pcm), but we may notice that the French results for Cases 13b and 14b are lower than the other results (the absolute difference from the mean value is about -500 pcm). This deviation is due to the calculation scheme: the last row of UOX cells (near the water gap) has not been differentiated from the other cells. If the calculation scheme considers two zones of UOX cells (one for the last range near the water gap and one for the other cells), the difference with the one-zone scheme is +500 pcm.[1] A comparison with TRIPOLI calculations (continuous energy code) confirms that the two-zone scheme yields results closer to the TRIPOLI results.

#### *4.2.2 Impact of differences in calculated fuel inventory*

The SD on Kinf values range between 500 and 1 000 pcm. These values are due partly to the RSD observed in calculated fuel inventories. Thanks to the sensitivity calculations (see § 5), it is easy to link differences in calculated nuclide concentrations with differences in Kinf values.

*RSD on $^{235}U$ concentrations*. Given the impact of the variation of the $^{235}U$ concentration on the Kinf value (~+120 pcm/%), the RSD on $^{235}U$ (~2.5%) has an impact on Kinf values of ±300 pcm. We may point out that the Kinf calculated from SAS2h fuel inventories are in most cases lower than the Kinf calculated by the other participants. This deviation with the other Kinf results increases when there are no CRs. This is due to the $^{235}U$ concentrations calculated using the SAS2h code, which are lower than the concentrations of the other participants when CRs are not inserted (7% lower than the mean value at 45 GWd/t). This deviation has an important effect on the Kinf value (-800 pcm), given the sensitivity of the variation of the $^{235}U$ concentration on it (~+120 pcm/%).

*RSD on $^{239}Pu$ concentrations*. Given the impact of the variation of the $^{239}Pu$ concentration on the Kinf value (+100 to +170 pcm/%), the RSD on $^{239}Pu$ (~3%) has an impact on Kinf values of ±400 pcm.

*RSD on $^{240}Pu$ concentrations*. Given the impact of the variation of the $^{240}Pu$ concentration on the Kinf value (~ -40 pcm/%), the RSD on $^{240}Pu$ (~3%) has an impact on Kinf values of ±120 pcm.

*RSD on $^{241}Pu$ concentrations*. Given the impact of the variation of the $^{241}Pu$ concentration on the Kinf value (~ +50 pcm%), the RSD on $^{241}Pu$ (~3%) has an impact on Kinf values of ±150 pcm.

*RSD on $^{155}Gd$ concentrations*. Given the low impact of the variation of the $^{155}Gd$ concentration on the Kinf value when there is no cooling time (< -0.5 pcm/%), the important RSD on $^{155}Gd$ concentration (~35%) does not have an important impact on Kinf values. But when the cooling time is five years, the impact of the variation of the $^{155}Gd$ concentration on the Kinf value increases and reaches about -15 pcm/%. Then, the RSD on $^{155}Gd$ concentration (~50%) has an important impact on Kinf values (about ±800 pcm).

*RSD on $^{109}Ag$ concentrations*. Given the low impact of the variation of the $^{109}Ag$ concentration on the Kinf value (< -2 pcm/%), the RSD on $^{109}Ag$ concentration (~15%) does not have an important impact on Kinf values (about ±30 pcm). Only the high $^{109}Ag$ concentrations calculated by the SAS2h code when CRs are inserted (40% higher than the mean value) induce an impact on the Kinf value of -70 pcm.

*RSD on $^{149}Sm$ concentrations*. Given the impact of the variation of the $^{149}Sm$ concentration on the Kinf value (about 15 pcm/%), the RSD on $^{149}Sm$ (~5%) has an impact on Kinf values of ±90 pcm.

*RSD on $^{151}Sm$ concentrations*. Given the impact of the variation of the $^{151}Sm$ concentration on the Kinf value (about 10 pcm/%), the RSD on $^{151}Sm$ (~9%) has an impact on Kinf values of ±90 pcm.

## 4.3 Coherence of the calculated Kinf values

Figure 4.1 enables us to verify that the Kinf mean values are coherent with physical phenomena:

- The maximum $Kinf_{mean}$ is obtained with fresh fuel.
- The $Kinf_{mean}$ Case 13b is about the same as the $Kinf_{mean}$ Case 11b and the $Kinf_{mean}$ Case 14b is about the same as $Kinf_{mean}$ Case 12b (about the same concentrations, one is imposed, the other is calculated by participants).
- The $Kinf_{mean}$ obtained while taking into account FPs are always lower than the $Kinf_{mean}$ without taking into account FPs.
- The $Kinf_{mean}$ obtained at 30 GWd/t are always higher than the $Kinf_{mean}$ obtained at 45 GWd/t when there are the same irradiation conditions (Case 1 compared to Case 3, Case 2 compared to Case 4, Case 9 compared to Case 11, Case 10 compared to Case 12).
- The $Kinf_{mean}$ obtained when there are CRs are higher than the $Kinf_{mean}$ obtained when there are no CRs (Case 1 compared to Case 2, Case 3 compared to Cases 4, 5, 6, 7 and 8, Case 9 compared to Case 10, Case 11 compared to Case 12).

A detailed analysis of the effect of CR insertion is presented in § 6.

# Table 4.1. Neutron multiplication factors

| Case | FRANCE | UK BNFL | FINLAND | UK SERCO | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1a** | 1.16725 | 1.17710 | 1.16880 | 1.17760 | 1.17254 | 1.17283 | 1.17460 | 1.17485 | 1.17448 | 1.15599 | 1.16666 | 1.16342 | 1.16860 | 1.17036 | 0.00611 | 0.52% |
| **1b** | 1.09260 | 1.10440 | 1.09940 | 1.10310 | 1.09953 | 1.10074 | 1.10281 | 1.10045 | 1.10111 | 1.08079 | 1.09179 | 1.08928 | 1.09420 | 1.09694 | 0.00681 | 0.62% |
| **2a** | 1.21685 | 1.22890 | 1.21886 | 1.22630 | 1.22542 | 1.22698 | 1.22863 | 1.22367 | 1.22202 | 1.21314 | 1.22021 | 1.22007 | 1.22320 | 1.22263 | 0.00472 | 0.39% |
| **2b** | 1.14005 | 1.15340 | 1.14433 | 1.14970 | 1.14952 | 1.15259 | 1.15453 | 1.14689 | 1.14586 | 1.13541 | 1.14435 | 1.14315 | 1.14440 | 1.14648 | 0.00547 | 0.48% |
| **3a** | 1.07583 | 1.09380 | 1.07758 | 1.09370 | 1.08605 | 1.08663 | 1.08893 | 1.08415 | 1.08728 | 1.05893 | 1.07648 | 1.07245 | 1.07980 | 1.08166 | 0.00962 | 0.89% |
| **3b** | 0.98141 | 1.00100 | 0.99117 | 1.00060 | 0.99477 | 0.99514 | 0.99749 | 0.98942 | 0.99570 | 0.96478 | 0.98311 | 0.97882 | 0.98620 | 0.99124 | 0.01025 | 1.03% |
| **4a** | 1.16674 | 1.18750 | 1.16785 | 1.18080 | 1.18040 | 1.18227 | 1.18468 | 1.17552 | 1.17428 | 1.16130 | 1.17258 | 1.17027 | 1.17730 | 1.17550 | 0.00358 | 0.30% |
| **4b** | 1.06966 | 1.09120 | 1.07712 | 1.08580 | 1.08558 | 1.08882 | 1.09144 | 1.07767 | 1.07952 | 1.06330 | 1.07679 | 1.07397 | 1.07980 | 1.08005 | 0.00839 | 0.78% |
| **5b** | 1.00248 | 1.02380 | 1.01273 | 1.02150 | 1.01717 | 1.01798 | 1.02097 | 1.01057 | 1.01538 | 0.99078 | 1.00571 | 1.00237 | 1.01030 | 1.01167 | 0.00940 | 0.93% |
| **6b** | 1.00914 | 1.03220 | 1.02094 | 1.02790 | 1.02501 | 1.02623 | 1.02891 | 1.01829 | 1.02271 | 0.99847 | 1.01199 | 1.00880 | 1.01700 | 1.01905 | 0.00972 | 0.95% |
| **7b** | 1.03605 | 1.05620 | 1.04321 | 1.05100 | 1.04853 | 1.05181 | 1.05373 | 1.04257 | 1.04657 | 1.02558 | 1.03383 | 1.03393 | 1.04320 | 1.04355 | 0.00908 | 0.87% |
| **8b** | 1.02814 | 1.05100 | 1.03779 | 1.04750 | 1.04390 | 1.04621 | 1.04856 | 1.03722 | 1.04006 | 1.01909 | 1.03425 | 1.03096 | 1.03810 | 1.03868 | 0.00908 | 0.87% |
| **9a** | 1.15242 | 1.16340 | 1.15613 | 1.16230 | 1.15683 | 1.15706 | 1.16050 | 1.16120 | 1.15999 | 1.14216 | 1.15246 | 1.14922 | 1.15370 | 1.15595 | 0.00597 | 0.52% |
| **9b** | 1.06155 | 1.07280 | 1.06206 | 1.07200 | 1.06896 | 1.06890 | 1.07245 | 1.07378 | 1.07459 | 1.05431 | 1.06435 | 1.06161 | 1.06490 | 1.06710 | 0.00616 | 0.58% |
| **10a** | 1.20011 | 1.21330 | 1.20319 | 1.20960 | 1.20761 | 1.20981 | 1.21304 | 1.20839 | 1.20578 | 1.19758 | 1.20493 | 1.20368 | 1.20710 | 1.20647 | 0.00463 | 0.38% |
| **10b** | 1.10626 | 1.12030 | 1.10505 | 1.11670 | 1.11920 | 1.12167 | 1.12448 | 1.11919 | 1.12011 | 1.10846 | 1.11664 | 1.11534 | 1.11500 | 1.11603 | 0.00601 | 0.54% |
| **11a** | 1.05069 | 1.06940 | 1.05345 | 1.06900 | 1.06058 | 1.06153 | 1.06462 | 1.06152 | 1.06325 | 1.03590 | 1.05283 | 1.04907 | 1.05510 | 1.05746 | 0.00925 | 0.88% |
| **11b** | 0.93381 | 0.95330 | 0.92814 | 0.95300 | 0.94866 | 0.94756 | 0.95162 | 0.94930 | 0.95582 | 0.92345 | 0.94075 | 0.93758 | 0.94330 | 0.94356 | 0.01023 | 1.08% |
| **12a** | 1.13996 | 1.15940 | 1.14198 | 1.15350 | 1.15221 | 1.15528 | 1.15881 | 1.14998 | 1.14927 | 1.13517 | 1.14711 | 1.14534 | 1.15080 | 1.14914 | 0.00717 | 0.62% |
| **12b** | 1.01933 | 1.03990 | 1.01184 | 1.03530 | 1.04311 | 1.04374 | 1.04690 | 1.03782 | 1.04023 | 1.02269 | 1.03678 | 1.03435 | 1.03780 | 1.03460 | 0.01035 | 1.00% |
| **13b** | 0.93380 | 0.93760 | 0.93729 | 0.93710 | 0.93908 | 0.93841 | 0.94004 | 0.94184 | 0.94025 | 0.94025 | 0.94025 | 0.94025 | 0.93580 | 0.93861 | 0.00223 | 0.24% |
| **14b** | 1.02214 | 1.02520 | 1.02460 | 1.02400 | 1.02537 | 1.02604 | 1.02816 | 1.03012 | 1.02794 | 1.02794 | 1.02794 | 1.02794 | 1.02310 | 1.02619 | 0.00235 | 0.23% |
| **15** | 1.34025 | 1.34180 | 1.33966 | 1.34110 | 1.33913 | 1.33989 | 1.34349 | 1.34025 | 1.33797 | 1.33797 | 1.33797 | 1.33797 | 1.34070 | 1.33986 | 0.00169 | 0.13% |

## Table 4.2. Absolute difference of the Kinf from the mean value (pcm)

| Case | FRANCE | UK BNFL | FINLAND | UK SERCO | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1a** | -312 | 674 | -156 | 724 | 218 | 247 | 424 | 449 | 412 | -1437 | -370 | -694 | -176 |
| **1b** | -434 | 746 | 246 | 616 | 259 | 380 | 587 | 351 | 417 | -1615 | -515 | -766 | -274 |
| **2a** | -578 | 627 | -377 | 367 | 279 | 435 | 600 | 104 | -61 | -949 | -242 | -256 | 57 |
| **2b** | -643 | 692 | -215 | 322 | 304 | 611 | 805 | 41 | -62 | -1107 | -213 | -333 | -208 |
| **3a** | -583 | 1214 | -408 | 1204 | 439 | 497 | 727 | 249 | 562 | -2273 | -518 | -921 | -186 |
| **3b** | -983 | 976 | -7 | 936 | 353 | 390 | 625 | -182 | 446 | -2646 | -813 | -1242 | -504 |
| **4a** | -876 | 1200 | -765 | 530 | 490 | 677 | 918 | 2 | -122 | -1420 | -292 | -523 | 180 |
| **4b** | -1039 | 1115 | -293 | 575 | 553 | 877 | 1139 | -238 | -53 | -1675 | -326 | -608 | -25 |
| **5b** | -919 | 1213 | 106 | 983 | 550 | 631 | 930 | -110 | 371 | -2089 | -596 | -930 | -137 |
| **6b** | -991 | 1315 | 189 | 885 | 596 | 718 | 986 | -76 | 366 | -2058 | -706 | -1025 | -205 |
| **7b** | -750 | 1265 | -34 | 745 | 498 | 826 | 1018 | -98 | 302 | -1797 | -972 | -962 | -35 |
| **8b** | -1053 | 1232 | -89 | 882 | 522 | 753 | 988 | -146 | 138 | -1959 | -443 | -772 | -58 |
| **9a** | -353 | 745 | 18 | 635 | 88 | 111 | 455 | 525 | 404 | -1379 | -349 | -673 | -225 |
| **9b** | -555 | 570 | -504 | 490 | 186 | 180 | 535 | 668 | 749 | -1279 | -275 | -549 | -220 |
| **10a** | -636 | 683 | -328 | 313 | 114 | 334 | 657 | 192 | -69 | -889 | -154 | -279 | 63 |
| **10b** | -977 | 427 | -1098 | 67 | 317 | 564 | 845 | 316 | 408 | -757 | 61 | -69 | -103 |
| **11a** | -677 | 1194 | -401 | 1154 | 312 | 407 | 716 | 406 | 579 | -2156 | -463 | -839 | -236 |
| **11b** | -975 | 974 | -1542 | 944 | 510 | 400 | 806 | 574 | 1226 | -2011 | -281 | -598 | -26 |
| **12a** | -918 | 1026 | -716 | 436 | 307 | 614 | 967 | 84 | 13 | -1397 | -203 | -380 | 166 |
| **12b** | -1527 | 530 | -2276 | 70 | 851 | 914 | 1230 | 322 | 563 | -1191 | 218 | -25 | 320 |
| **13b** | -481 | -101 | -132 | -151 | 47 | -20 | 143 | 323 | 164 | 164 | 164 | 164 | -281 |
| **14b** | -405 | -99 | -159 | -219 | -82 | -15 | 197 | 393 | 175 | 175 | 175 | 175 | -309 |
| **15** | 39 | 194 | -20 | 124 | -73 | 3 | 363 | 39 | -189 | -189 | -189 | -189 | 84 |

**Figure 4.1. Neutron multiplication factors mean values**

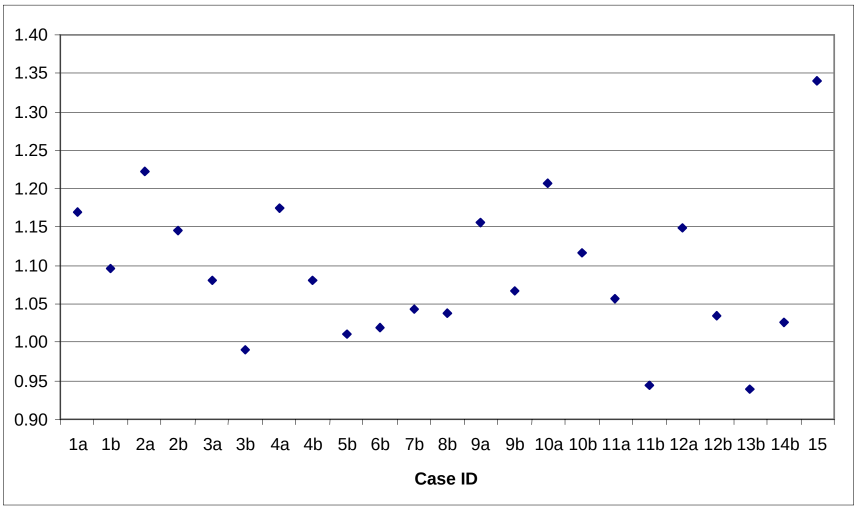



**Figure 4.2. Neutron multiplication factors – Case 1a**

*UOX 30 GWd/t, no CRs, Ctime = 0 days, no FPs*

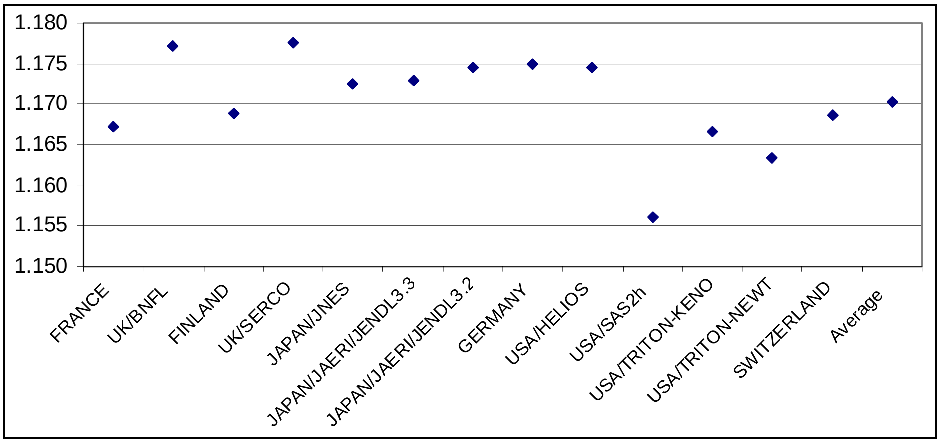



**Figure 4.3. Neutron multiplication factors – Case 1b**

*UOX 30 GWd/t, no CRs, Ctime = 0 days, with FPs*

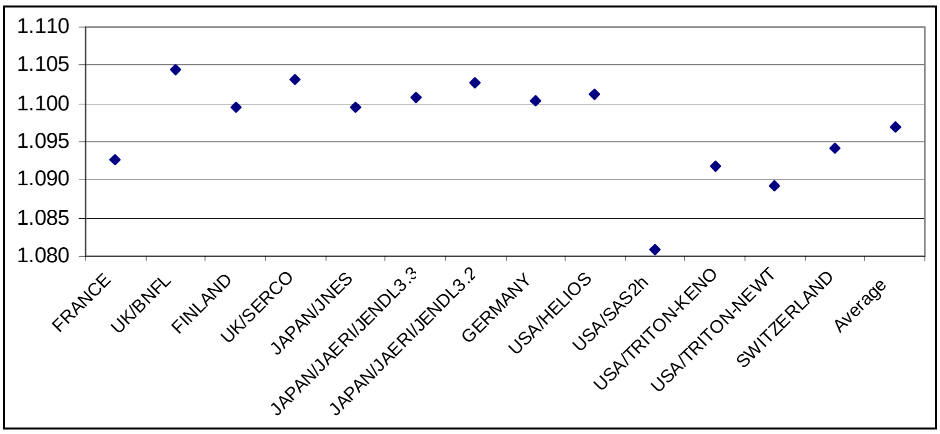


**Figure 4.4. Neutron multiplication factors – Case 2a**

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days, no FPs*

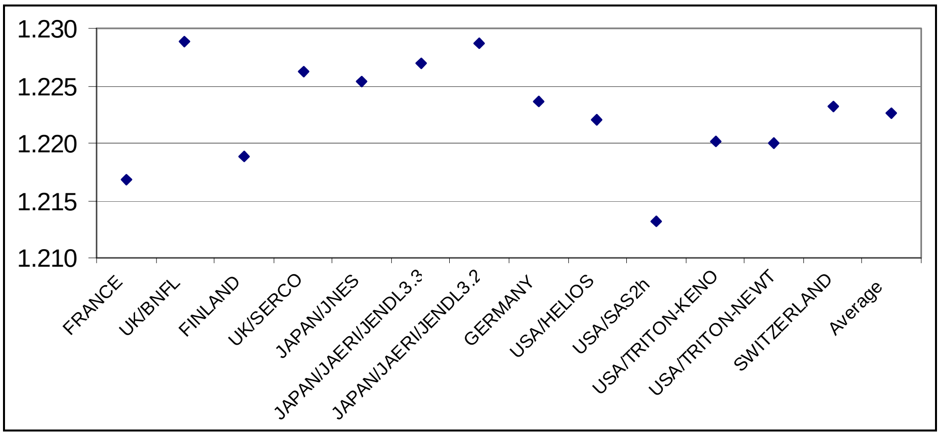



**Figure 4.5. Neutron multiplication factors – Case 2b**

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days, with FPs*

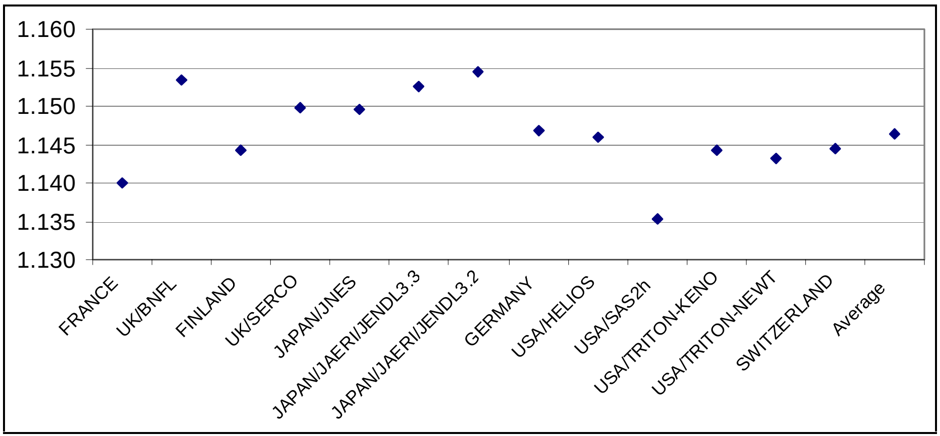



**Figure 4.6. Neutron multiplication factors – Case 3a**

*UOX 45 GWd/t, no CRs, Ctime = 0 days, no FPs*

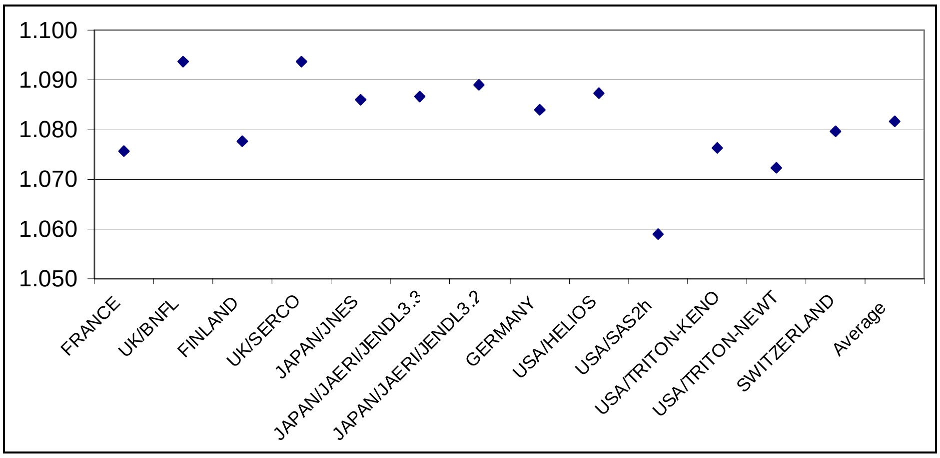


**Figure 4.7. Neutron multiplication factors – Case 3b**

*UOX 45 GWd/t, no CRs, Ctime = 0 days, with FPs*

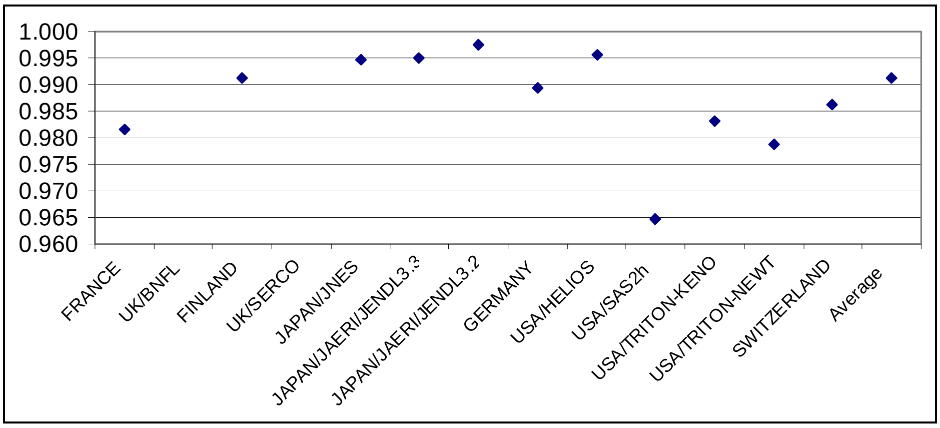



**Figure 4.8. Neutron multiplication factors – Case 4a**

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 0 days, no FPs*

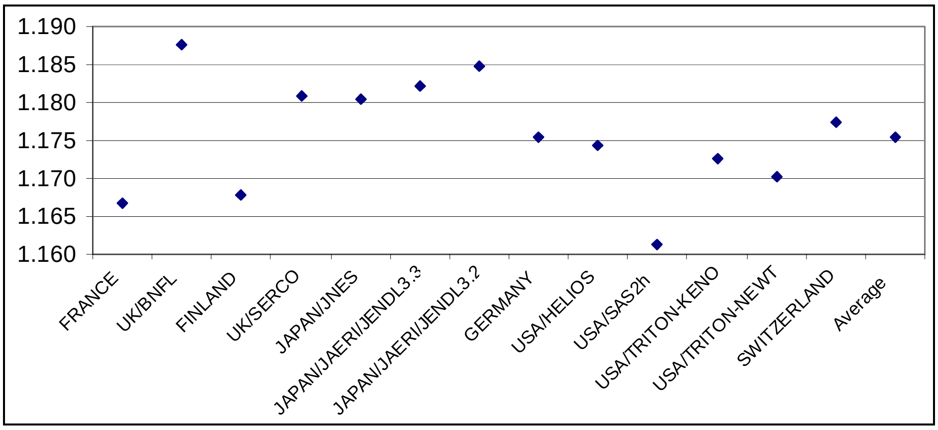



**Figure 4.9. Neutron multiplication factors – Case 4b**

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 0 days, with FPs*

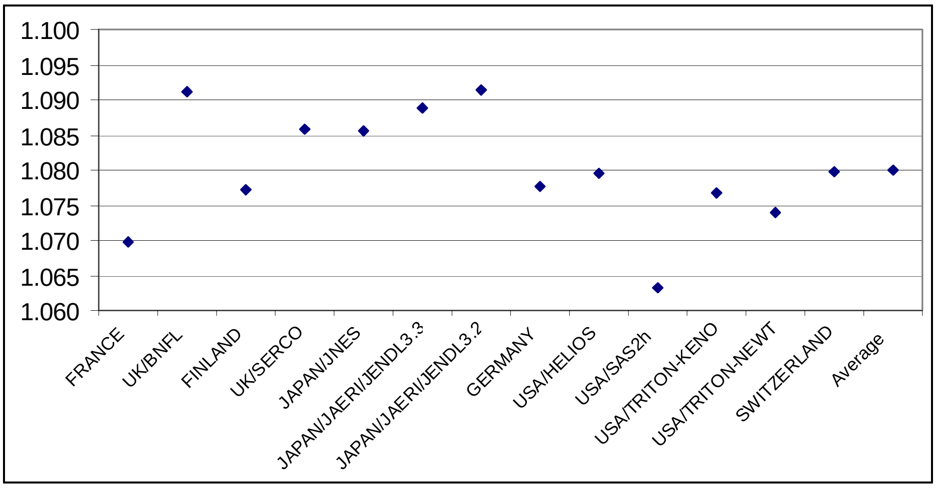


**Figure 4.10. Neutron multiplication factors – Case 5b**

*UOX 45 GWd/t, CRs 0-15 GWd/t, Ctime = 0 days, with FPs*

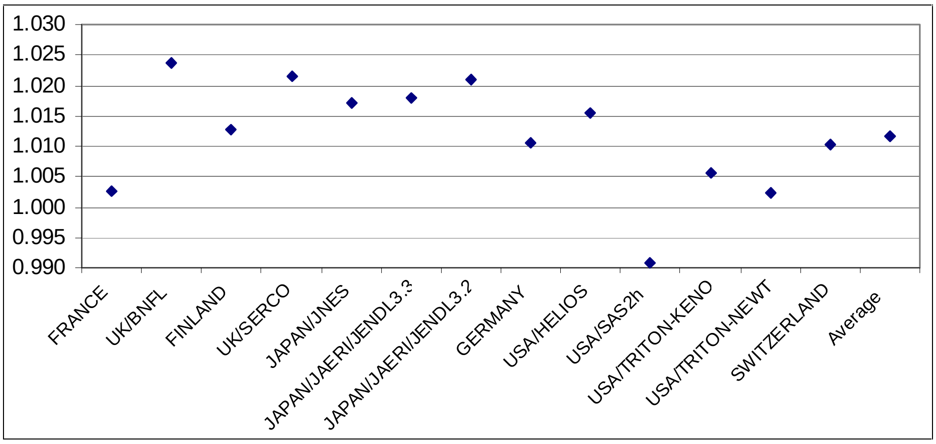



**Figure 4.11. Neutron multiplication factors – Case 6b**

*UOX 45 GWd/t, CRs 15-30 GWd/t, Ctime = 0 days, with FPs*

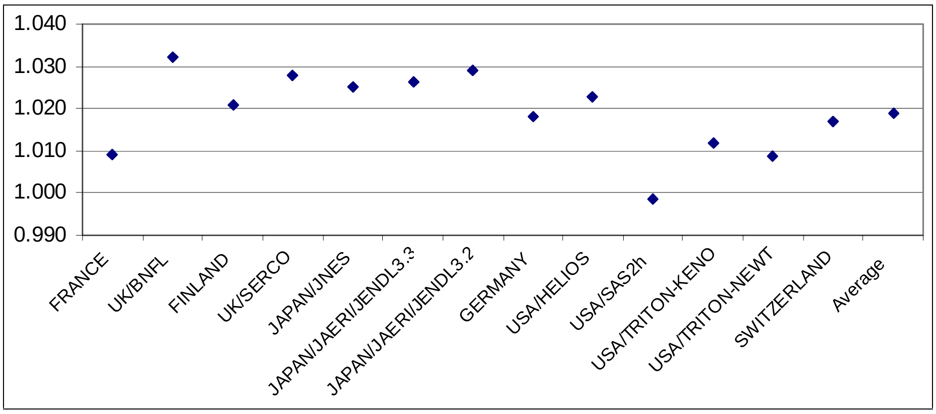



**Figure 4.12. Neutron multiplication factors – Case 7b**

*UOX 45 GWd/t, CRs 30-45 GWd/t, Ctime = 0 days, with FPs*

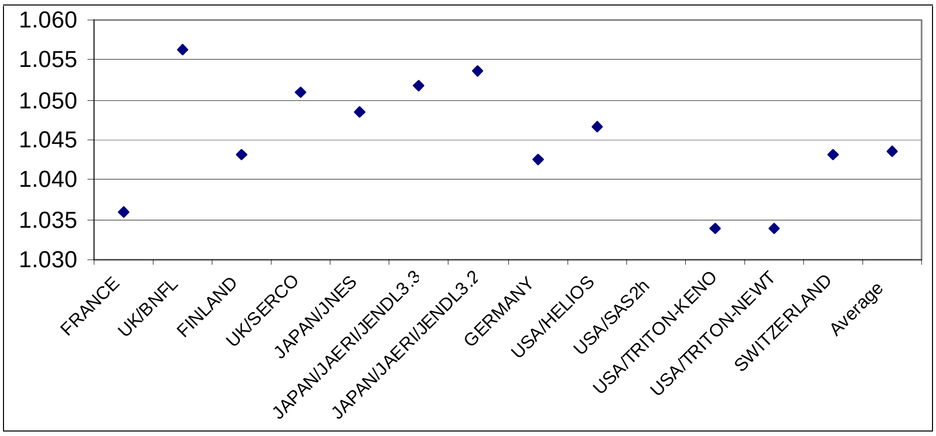


**Figure 4.13. Neutron multiplication factors – Case 8b**

*UOX 45 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days, with FPs*

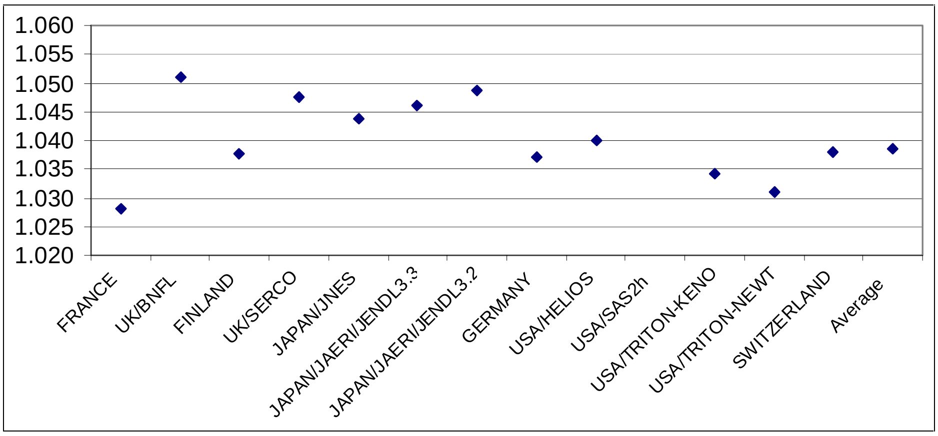



**Figure 4.14. Neutron multiplication factors – Case 9a**

*UOX 30 GWd/t, no CRs, Ctime = 5 years, no FPs*

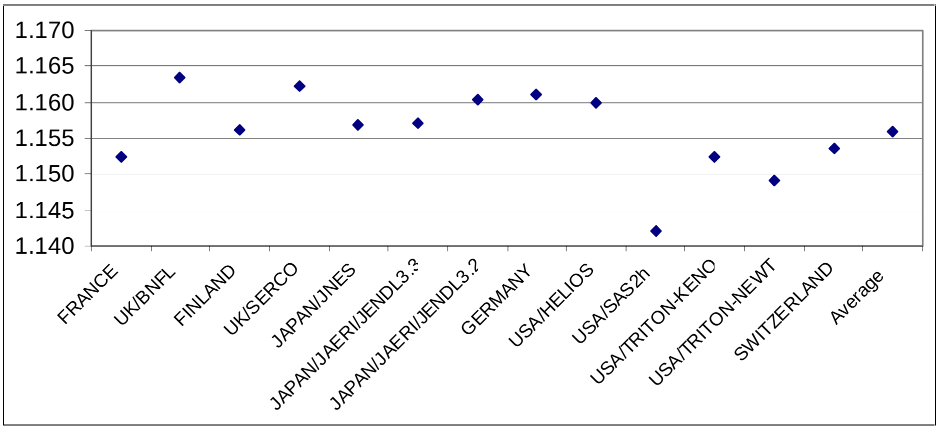



**Figure 4.15. Neutron multiplication factors – Case 9b**

*UOX 30 GWd/t, no CRs, Ctime = 5 years, with FPs*

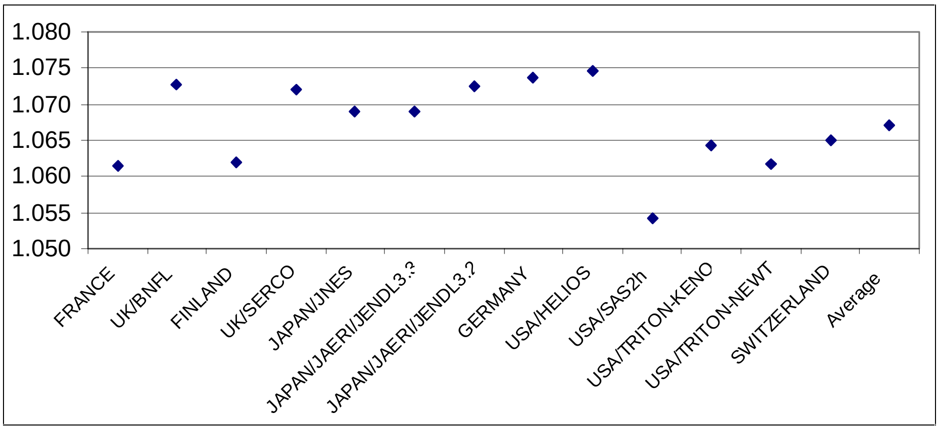


**Figure 4.16. Neutron multiplication factors – Case 10a**

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 5 years, no FPs*

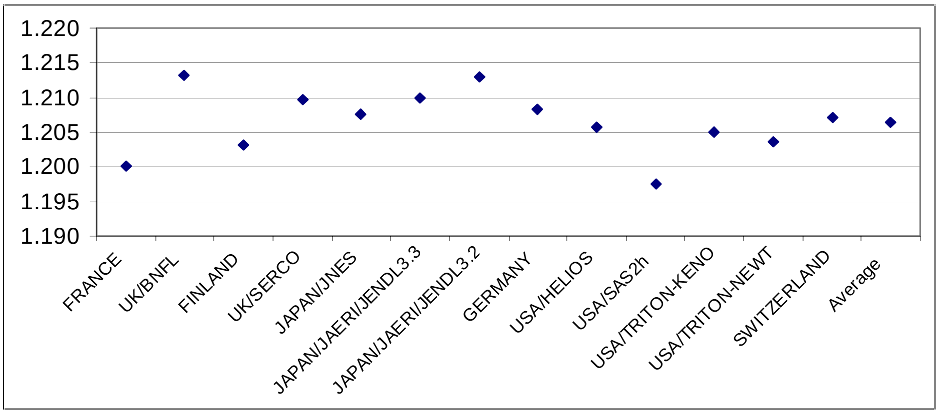



**Figure 4.17. Neutron multiplication factors – Case 10b**

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 5 years, with FPs*

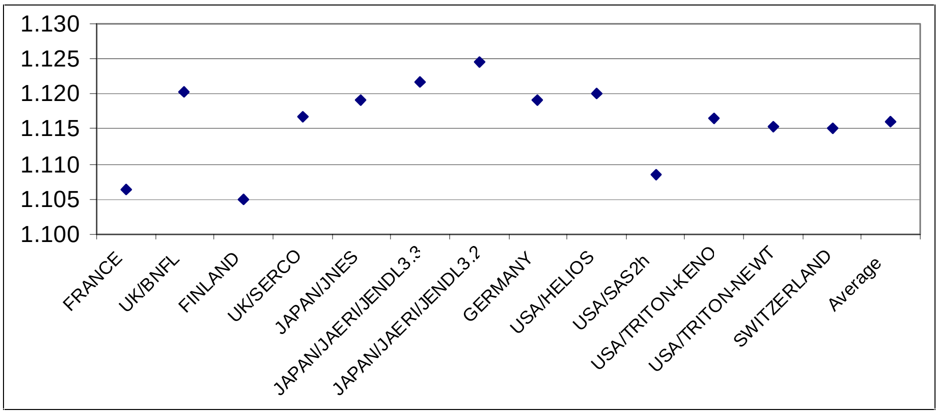



**Figure 4.18. Neutron multiplication factors – Case 11a**

*UOX 45 GWd/t, no CRs, Ctime = 5 years, no FPs*

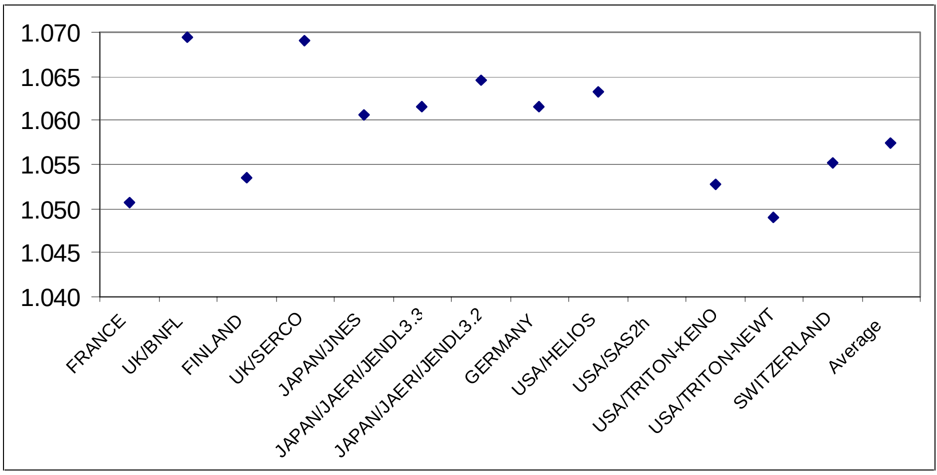


**Figure 4.19. Neutron multiplication factors – Case 11b**

*UOX 45 GWd/t, no CRs, Ctime = 5 years, with FPs*

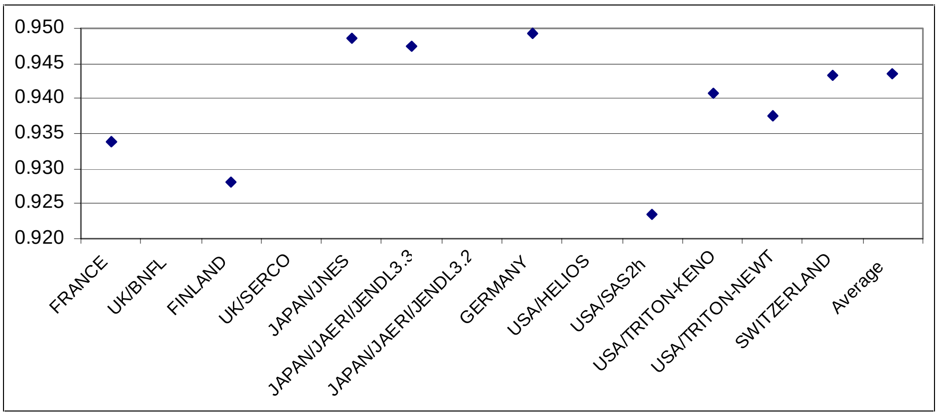



**Figure 4.20. Neutron multiplication factors – Case 12a**

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 5 years, no FPs*

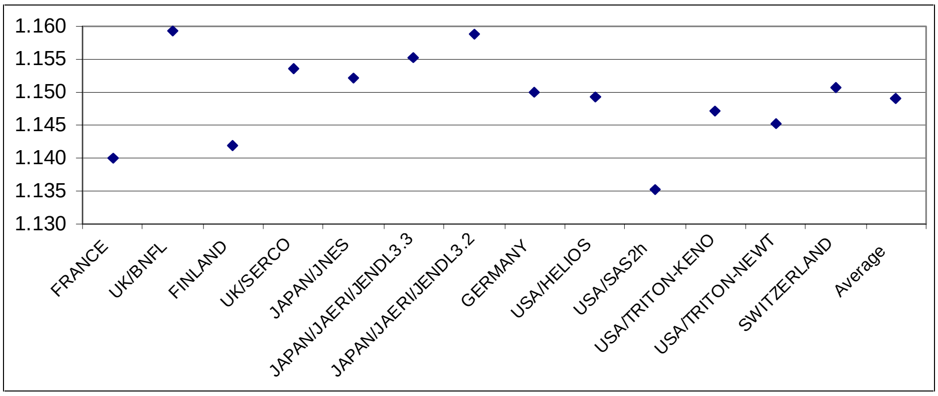



**Figure 4.21. Neutron multiplication factors – Case 12b**

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 5 years, with FPs*

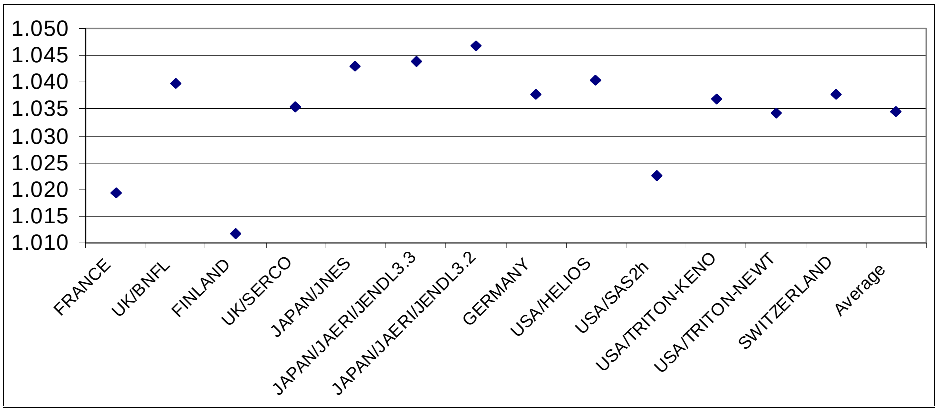


**Figure 4.22. Neutron multiplication factors – Case 13b**

*Imposed UOX, without CR*

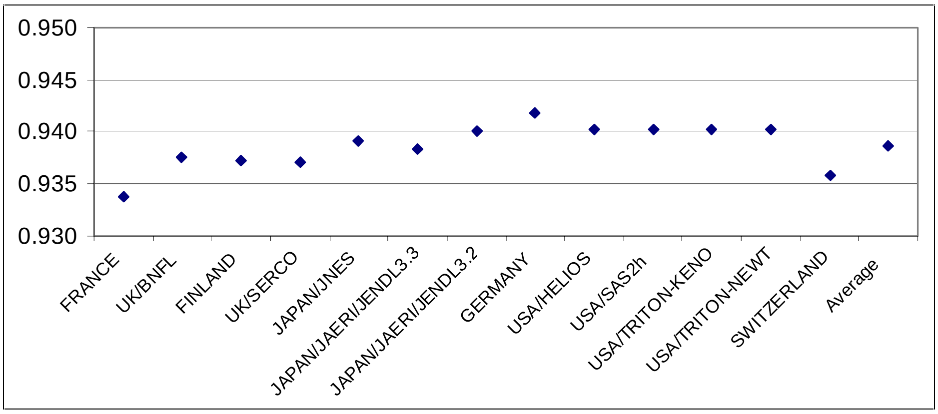



**Figure 4.23. Neutron multiplication factors – Case 14b**

*Imposed UOX, without CR*

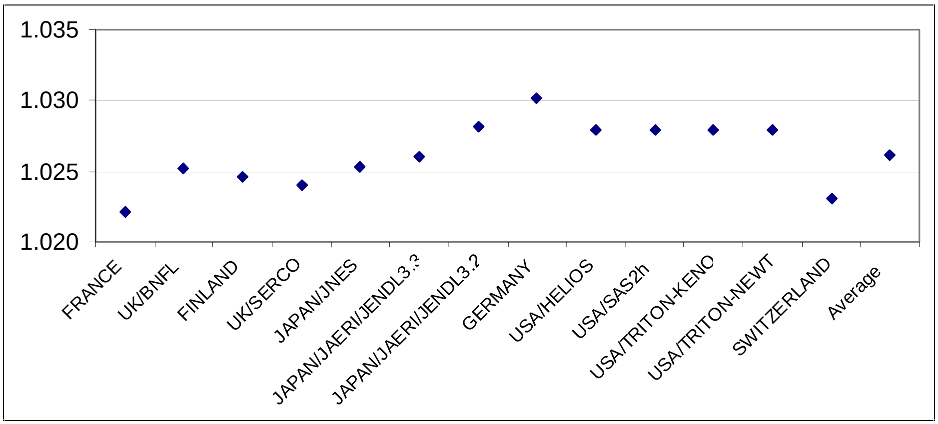
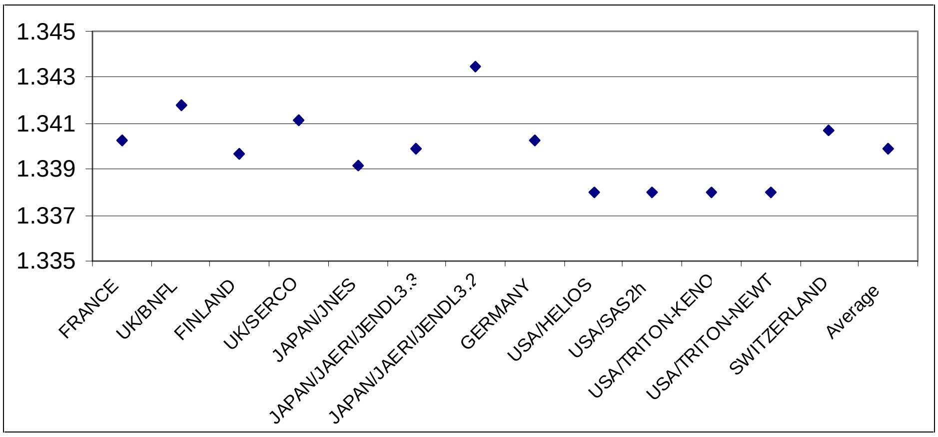



**Figure 4.24. Neutron multiplication factors – Case 15**

*Fresh UOX*



## *Chapter 5*

## SENSITIVITY CALCULATIONS

### 5.1 Results

The neutron multiplication factor sensitivities to a variation of each nuclide j concentration $\left(\frac{\delta K}{\delta N_j}\right)$ are presented in Tables 5.2 to 5.7 for an infinite array of UOX assemblies and in Tables 5.8 to 5.13 for a cask model of 21 PWR spent fuel assemblies in a stainless steel transport flask. The $\left(\frac{\delta K}{\delta N_j}\right)$ are expressed in pcm/%. The tables also present the mean values.

### 5.2 Results analysis

Tables 5.2 to 5.13 show good agreement between the participant results.

Table 5.1 presents the nuclides which have the most significant effect on reactivity. The other nuclide effect is less than -20 pcm/%, most of them have an effect of less than -5 pcm/%. The values presented in Table 5.13 correspond to the average between nuclide effect at 30 GWd/t and nuclide effect at 45 GWd/t with or without cooling time.

**Table 5.1. Nuclides which have the greatest effect on reactivity (mean values)**

| | Infinite array (Kinf) | | Cask (Keff) | |
|---|---|---|---|---|
| | **No CRs** | **CRs** | **No CRs** | **CRs** |
| $^{235}U$ | +140 pcm/% | +110 pcm/% | +140 pcm/% | +110 pcm/% |
| $^{238}U$ | -120 pcm/% | -100 pcm/% | -100 pcm/% | -90 pcm/% |
| $^{239}Pu$ | +140 pcm/% | +130 pcm/% | +150 pcm/% | +140 pcm/% |
| $^{240}Pu$ | -40 pcm/% | -40 pcm/% | -40 pcm/% | -40 pcm/% |
| $^{241}Pu$ | +50 pcm/% | +40 pcm/% | +50 pcm/% | +50 pcm/% |

The cooling time has no impact on the neutron multiplication factor sensitivities to a variation of nuclide concentration, except for a variation of $^{241}Am$ and $^{155}Gd$ concentration. The $^{241}Am$ effect on reactivity goes up from -1 pcm/% to -13 pcm/% with a five-year cooling time, and the $^{155}Gd$ effect goes up from -0.2 pcm/% to -18 pcm/%.

The positive effect of $^{235}U$, $^{239}Pu$ and $^{241}Pu$ and the negative effect of $^{238}U$ is higher when there are no CRs.

The positive effect of $^{235}U$, $^{239}Pu$ and $^{241}Pu$ calculated by the USA and SERCO is a little higher in the case of a cask than in the case of an infinite array (but FINLAND found the opposite), and the negative effect of $^{238}U$ is a little lower. So given the RSD on calculated fuel inventories, the total effect of differences in calculated fuel inventory on the Kinf value is a little lower than the total effect on the Keff value, but the difference is slight.

These sensitivity calculations are used in § 4 and § 7 to explain differences in the Kinf values and in the CR effects between participants.

**Table 5.2. Infinite array – Case 1**

*UOX 30 GWd/t, no CRs, Ctime = 0 days*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -1.1 | -1.4 | -1.3 | -1.3 | -1.3 |
| **U235** | 137.8 | 162.3 | 148.0 | 151.6 | 149.9 |
| **U236** | -3.4 | -4.3 | -4.1 | -3.7 | -3.9 |
| **U238** | -109.5 | -129.9 | -124.0 | -123.2 | -121.6 |
| **Pu238** | -1.3 | -1.8 | -1.4 | -1.5 | -1.5 |
| **Pu239** | 85.4 | 104.4 | 98.1 | 101.1 | 97.3 |
| **Pu240** | -32.4 | -37.4 | -34.9 | -38.1 | -35.7 |
| **Pu241** | 29.0 | 34.5 | 30.2 | 31.3 | 31.2 |
| **Pu242** | -1.3 | -1.7 | -1.3 | -1.7 | -1.5 |
| **Np237** | -3.1 | -4.2 | -3.2 | -3.7 | -3.5 |
| **Am241** | -0.7 | -0.9 | -0.8 | -0.8 | -0.8 |
| **Am243** | -0.4 | -0.5 | -0.4 | -0.5 | -0.4 |
| **Rh103** | -7.2 | -8.6 | -7.9 | -8.5 | -8.0 |
| **Cs133** | -3.8 | -4.7 | -4.2 | -4.0 | -4.2 |
| **Nd143** | -12.9 | -16.4 | -14.0 | -14.5 | -14.4 |
| **Nd145** | -2.2 | -2.9 | -2.5 | -2.5 | -2.5 |
| **Gd155** | -0.1 | -0.2 | -0.1 | -0.1 | -0.1 |
| **Mo95** | -1.3 | - | -1.3 | -1.4 | -1.3 |
| **Tc99** | -2.5 | - | -2.8 | -3.0 | -2.8 |
| **Ru101** | -0.9 | - | -1.1 | -0.9 | -1.0 |
| **Ag109** | -0.9 | -1.0 | -1.0 | -1.0 | -1.0 |
| **Sm147** | -0.5 | -0.5 | -0.4 | -0.5 | -0.5 |
| **Sm149** | -9.9 | -13.1 | -11.0 | -11.0 | -11.3 |
| **Sm150** | -1.6 | -1.6 | -1.5 | -1.6 | -1.6 |
| **Sm151** | -8.0 | -10.0 | -8.7 | -9.5 | -9.0 |
| **Sm152** | -2.6 | -2.9 | -3.1 | -3.1 | -2.9 |
| **Eu153** | -2.1 | -2.7 | -2.4 | -2.2 | -2.4 |
| **TOTAL** | **42.4** | **54.5** | **43.0** | **45.9** | **45.2** |

## Table 5.3. Infinite array – Case 2

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -0.9 | -1.3 | -1.1 | -1.1 | -1.1 |
| **U235** | 107.8 | 137.6 | 118.0 | 119.0 | 120.6 |
| **U236** | -3.2 | -4.2 | -4.0 | -3.6 | -3.7 |
| **U238** | -94.4 | -122.6 | -107.0 | -109.9 | -108.5 |
| **Pu238** | -1.4 | -2.1 | -1.5 | -1.6 | -1.7 |
| **Pu239** | 83.0 | 108.7 | 98.9 | 96.8 | 96.8 |
| **Pu240** | -30.7 | -38.1 | -34.7 | -36.9 | -35.1 |
| **Pu241** | 26.7 | 34.4 | 29.3 | 28.8 | 29.8 |
| **Pu242** | -1.2 | -1.8 | -1.4 | -1.6 | -1.5 |
| **Np237** | -3.3 | -4.9 | -3.5 | -4.0 | -3.9 |
| **Am241** | -0.8 | -1.1 | -1.0 | -0.9 | -1.0 |
| **Am243** | -0.4 | -0.6 | -0.5 | -0.6 | -0.5 |
| **Rh103** | -6.5 | -8.2 | -7.4 | -7.7 | -7.4 |
| **Cs133** | -3.3 | -4.5 | -3.9 | -3.5 | -3.8 |
| **Nd143** | -10.4 | -14.6 | -11.8 | -12.1 | -12.2 |
| **Nd145** | -1.9 | -2.8 | -2.2 | -2.1 | -2.3 |
| **Gd155** | -0.2 | -0.4 | -0.2 | -0.1 | -0.2 |
| **Mo95** | -1.1 | - | -1.2 | -1.2 | -1.2 |
| **Tc99** | -2.2 | - | -2.7 | -2.7 | -2.5 |
| **Ru101** | -0.9 | - | -0.8 | -0.9 | -0.8 |
| **Ag109** | -0.9 | -1.0 | -1.1 | -1.0 | -1.0 |
| **Sm147** | -0.4 | -0.5 | -0.5 | -0.4 | -0.5 |
| **Sm149** | -12.2 | -17.6 | -14.0 | -14.1 | -14.5 |
| **Sm150** | -1.3 | -1.7 | -1.4 | -1.4 | -1.4 |
| **Sm151** | -8.7 | -12.0 | -9.9 | -10.7 | -10.3 |
| **Sm152** | -2.2 | -2.6 | -2.3 | -2.6 | -2.4 |
| **Eu153** | -1.9 | -2.6 | -2.3 | -2.0 | -2.2 |
| **TOTAL** | **27.3** | **35.5** | **30.0** | **21.7** | **27.5** |

## Table 5.4. Infinite array – Case 3

*UOX 45 GWd/t, no CRs, Ctime = 0 days*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -1.0 | -1.1 | -1.1 | -1.1 | -1.1 |
| **U235** | 122.6 | 121.1 | 122.0 | 120.9 | 121.7 |
| **U236** | -4.3 | -4.0 | -4.1 | -4.1 | -4.1 |
| **U238** | -126.8 | -121.0 | -119.0 | -126.8 | -123.4 |
| **Pu238** | -4.1 | -4.6 | -3.6 | -4.4 | -4.2 |
| **Pu239** | 157.3 | 147.5 | 153.0 | 157.4 | 153.8 |
| **Pu240** | -49.8 | -46.0 | -47.8 | -52.0 | -48.9 |
| **Pu241** | 64.9 | 64.3 | 62.6 | 64.5 | 64.1 |
| **Pu242** | -3.1 | -3.3 | -2.8 | -3.5 | -3.2 |
| **Np237** | -5.9 | -6.6 | -5.3 | -6.5 | -6.1 |
| **Am241** | -1.6 | -1.6 | -1.7 | -1.6 | -1.6 |
| **Am243** | -1.5 | -1.6 | -1.4 | -1.9 | -1.6 |
| **Rh103** | -11.5 | -10.8 | -11.4 | -12.3 | -11.5 |
| **Cs133** | -6.0 | -6.1 | -5.9 | -5.8 | -5.9 |
| **Nd143** | -19.7 | -20.9 | -19.1 | -20.2 | -20.0 |
| **Nd145** | -3.6 | -4.0 | -3.4 | -3.6 | -3.7 |
| **Gd155** | -0.2 | -0.4 | -0.2 | -0.2 | -0.2 |
| **Mo95** | -2.2 | - | -2.2 | -2.1 | -2.2 |
| **Tc99** | -4.0 | - | -3.9 | -4.2 | -4.0 |
| **Ru101** | -1.6 | - | -1.4 | -1.4 | -1.4 |
| **Ag109** | -1.9 | -1.6 | -1.9 | -1.9 | -1.8 |
| **Sm147** | -0.8 | -0.8 | -0.7 | -0.9 | -0.8 |
| **Sm149** | -11.3 | -11.9 | -11.1 | -11.3 | -11.4 |
| **Sm150** | -2.9 | -2.6 | -2.5 | -2.7 | -2.7 |
| **Sm151** | -11.3 | -11.7 | -11.0 | -12.4 | -11.6 |
| **Sm152** | -4.0 | -3.6 | -4.1 | -4.4 | -4.0 |
| **Eu153** | -4.3 | -4.3 | -4.2 | -4.1 | -4.2 |
| **TOTAL** | **61.2** | **64.4** | **67.9** | **53.5** | **59.8** |

## Table 5.5. Infinite array – Case 4

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 0 days*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -0.8 | -1.0 | -0.8 | -0.8 | -0.8 |
| **U235** | 90.4 | 101.5 | 92.3 | 94.8 | 94.8 |
| **U236** | -3.9 | -4.4 | -4.4 | -3.9 | -4.1 |
| **U238** | -102.9 | -113.5 | -103.0 | -106.2 | -106.4 |
| **Pu238** | -3.9 | -5.0 | -3.7 | -4.2 | -4.2 |
| **Pu239** | 124.3 | 141.7 | 135.0 | 138.4 | 134.9 |
| **Pu240** | -42.5 | -46.1 | -44.4 | -47.4 | -45.1 |
| **Pu241** | 51.3 | 58.8 | 52.8 | 53.4 | 54.1 |
| **Pu242** | -2.6 | -3.3 | -2.9 | -3.1 | -3.0 |
| **Np237** | -5.6 | -7.5 | -5.5 | -6.5 | -6.3 |
| **Am241** | -1.8 | -2.0 | -1.9 | -1.9 | -1.9 |
| **Am243** | -1.4 | -1.8 | -1.5 | -1.8 | -1.6 |
| **Rh103** | -9.2 | -10.2 | -10.1 | -10.6 | -10.0 |
| **Cs133** | -4.8 | -5.7 | -5.5 | -4.8 | -5.2 |
| **Nd143** | -15.1 | -18.8 | -15.8 | -16.3 | -16.5 |
| **Nd145** | -2.8 | -3.3 | -2.8 | -2.9 | -2.9 |
| **Gd155** | -0.4 | -0.7 | -0.3 | -0.2 | -0.4 |
| **Mo95** | -1.7 | - | -1.6 | -1.7 | -1.7 |
| **Tc99** | -3.2 | - | -3.6 | -3.6 | -3.5 |
| **Ru101** | -1.3 | - | -1.4 | -1.2 | -1.3 |
| **Ag109** | -1.6 | -1.5 | -1.8 | -1.7 | -1.6 |
| **Sm147** | -0.7 | -0.7 | -0.8 | -0.7 | -0.7 |
| **Sm149** | -13.2 | -17.2 | -14.7 | -14.6 | -14.9 |
| **Sm150** | -2.2 | -2.2 | -2.0 | -2.1 | -2.1 |
| **Sm151** | -11.9 | -14.6 | -12.6 | -13.6 | -13.2 |
| **Sm152** | -3.0 | -3.3 | -3.2 | -3.5 | -3.3 |
| **Eu153** | -3.4 | -4.2 | -3.6 | -3.4 | -3.7 |
| **TOTAL** | **26.3** | **35.0** | **32.4** | **30.1** | **29.3** |

## Table 5.6. Infinite array – Case 11

*UOX 45 GWd/t, no CRs, Ctime = 5 years*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -1.1 | -1.0 | -1.1 | -1.1 | -1.1 |
| **U235** | 143.1 | 130.0 | 133.0 | 135.6 | 135.4 |
| **U236** | -4.5 | -3.8 | -4.6 | -4.0 | -4.2 |
| **U238** | -127.7 | -110.6 | -121.0 | -121.0 | -120.1 |
| **Pu238** | -4.4 | -4.2 | -3.7 | -4.4 | -4.2 |
| **Pu239** | 185.8 | 163.7 | 170.0 | 181.7 | 175.3 |
| **Pu240** | -51.1 | -41.5 | -45.9 | -50.6 | -47.3 |
| **Pu241** | 60.0 | 53.6 | 54.9 | 56.2 | 56.2 |
| **Pu242** | -3.2 | -3.1 | -2.8 | -3.4 | -3.1 |
| **Np237** | -6.5 | -6.0 | -5.3 | -6.4 | -6.1 |
| **Am241** | -12.9 | -11.2 | -12.6 | -11.9 | -12.1 |
| **Am243** | -1.6 | -1.4 | -1.4 | -1.8 | -1.5 |
| **Rh103** | -13.0 | -9.6 | -12.2 | -13.0 | -11.9 |
| **Cs133** | -6.3 | -5.4 | -5.8 | -5.6 | -5.8 |
| **Nd143** | -20.6 | -18.4 | -18.8 | -20.0 | -19.5 |
| **Nd145** | -3.8 | -3.5 | -3.2 | -3.5 | -3.5 |
| **Gd155** | -16.5 | -31.8 | -15.0 | -10.2 | -18.4 |
| **Mo95** | -2.5 | - | -2.3 | -2.3 | -2.4 |
| **Tc99** | -4.2 | - | -4.0 | -4.1 | -4.1 |
| **Ru101** | -1.6 | - | -1.6 | -1.3 | -1.5 |
| **Ag109** | -1.9 | -1.4 | -1.8 | -1.9 | -1.8 |
| **Sm147** | -2.4 | -1.8 | -2.4 | -2.2 | -2.2 |
| **Sm149** | -19.0 | -17.0 | -17.5 | -17.9 | -17.8 |
| **Sm150** | -3.0 | -2.2 | -2.4 | -2.6 | -2.6 |
| **Sm151** | -11.3 | -9.8 | -10.4 | -11.7 | -10.8 |
| **Sm152** | -4.2 | -3.4 | -2.9 | -4.3 | -3.7 |
| **Eu153** | -4.5 | -3.9 | -4.1 | -4.0 | -4.1 |
| **TOTAL** | **61.3** | **56.3** | **55.1** | **64.0** | **57.1** |

## Table 5.7. Infinite array – Case 12

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 5 years*

| | FRANCE | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|---|
| **U234** | -0.9 | -0.9 | -0.8 | -0.9 | -0.9 |
| **U235** | 107.5 | 112.8 | 105.0 | 105.3 | 107.6 |
| **U236** | -3.9 | -4.2 | -4.2 | -3.8 | -4.0 |
| **U238** | -100.2 | -98.2 | -99.1 | -103.5 | -100.3 |
| **Pu238** | -4.1 | -4.6 | -3.7 | -4.2 | -4.2 |
| **Pu239** | 150.3 | 162.7 | 157.0 | 157.6 | 156.9 |
| **Pu240** | -43.6 | -42.6 | -44.3 | -46.8 | -44.3 |
| **Pu241** | 46.3 | 50.2 | 48.8 | 46.0 | 47.8 |
| **Pu242** | -2.6 | -3.1 | -2.8 | -3.1 | -2.9 |
| **Np237** | -6.1 | -6.7 | -5.5 | -6.5 | -6.2 |
| **Am241** | -13.4 | -13.4 | -14.0 | -13.2 | -13.5 |
| **Am243** | -1.4 | -1.7 | -1.4 | -1.7 | -1.6 |
| **Rh103** | -10.4 | -9.2 | -10.9 | -11.3 | -10.5 |
| **Cs133** | -4.9 | -5.2 | -5.1 | -4.8 | -5.0 |
| **Nd143** | -15.8 | -16.6 | -16.1 | -16.4 | -16.2 |
| **Nd145** | -2.8 | -3.2 | -2.6 | -2.9 | -2.9 |
| **Gd155** | -16.0 | -32.9 | -16.4 | -8.2 | -18.4 |
| **Mo95** | -2.0 | - | -1.6 | -1.9 | -1.8 |
| **Tc99** | -3.4 | - | -3.3 | -3.6 | -3.4 |
| **Ru101** | -1.4 | - | -1.5 | -1.2 | -1.4 |
| **Ag109** | -1.7 | -1.4 | -1.8 | -1.7 | -1.6 |
| **Sm147** | -1.8 | -1.7 | -1.8 | -1.9 | -1.8 |
| **Sm149** | -18.9 | -20.8 | -19.3 | -19.6 | -19.7 |
| **Sm150** | -2.2 | -2.1 | -2.1 | -2.0 | -2.1 |
| **Sm151** | -11.9 | -12.3 | -11.9 | -13.1 | -12.3 |
| **Sm152** | -3.1 | -3.2 | -3.2 | -3.5 | -3.3 |
| **Eu153** | -3.6 | -3.7 | -3.6 | -3.4 | -3.6 |
| **TOTAL** | **28.0** | **38.0** | **33.7** | **29.5** | **30.7** |

## Table 5.8. Cask – Case 1

*UOX 30 GWd/t, no CRs, Ctime = 0 days*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -1.2 | -1.3 | -1.3 | -1.3 |
| **U235** | 143.1 | 160.0 | 170.3 | 157.8 |
| **U236** | -4.3 | -4.5 | -4.5 | -4.4 |
| **U238** | -94.3 | -103.0 | -112.0 | -103.1 |
| **Pu238** | -1.2 | -1.0 | -1.2 | -1.2 |
| **Pu239** | 99.2 | 115.0 | 121.9 | 112.0 |
| **Pu240** | -33.2 | -37.0 | -40.5 | -36.9 |
| **Pu241** | 31.2 | 32.5 | 36.0 | 33.2 |
| **Pu242** | -1.8 | -1.8 | -2.1 | -1.9 |
| **Np237** | -3.6 | -3.3 | -3.8 | -3.5 |
| **Am241** | -0.7 | -0.8 | -0.8 | -0.8 |
| **Am243** | -0.5 | -0.5 | -0.6 | -0.5 |
| **Rh103** | -7.5 | -8.5 | -8.8 | -8.3 |
| **Cs133** | -4.4 | -5.0 | -4.4 | -4.6 |
| **Nd143** | -11.8 | -12.2 | -12.4 | -12.1 |
| **Nd145** | -2.6 | -2.6 | -2.6 | -2.6 |
| **Gd155** | -0.2 | -0.1 | -0.1 | -0.1 |
| **Mo95** | - | -1.2 | -1.5 | -1.3 |
| **Tc99** | - | -3.4 | -3.4 | -3.4 |
| **Ru101** | - | -1.2 | -1.1 | -1.2 |
| **Ag109** | -0.9 | -1.1 | -1.2 | -1.1 |
| **Sm147** | -0.5 | -0.5 | -0.6 | -0.5 |
| **Sm149** | -9.3 | -9.4 | -9.2 | -9.3 |
| **Sm150** | -1.3 | -1.3 | -1.5 | -1.4 |
| **Sm151** | -7.0 | -7.3 | -7.8 | -7.4 |
| **Sm152** | -2.8 | -2.9 | -3.5 | -3.1 |
| **Eu153** | -2.3 | -2.4 | -2.3 | -2.3 |
| **TOTAL** | **82.1** | **95.2** | **100.9** | **90.8** |

## Table 5.9. Cask – Case 2

*UOX 30 GWd/t, CRs 0-30 GWd/t, Ctime = 0 days*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -1.1 | -1.1 | -1.1 | -1.1 |
| **U235** | 122.9 | 128.0 | 137.9 | 129.6 |
| **U236** | -4.4 | -5.5 | -4.4 | -4.7 |
| **U238** | -92.1 | -89.0 | -101.7 | -94.3 |
| **Pu238** | -1.5 | -1.2 | -1.3 | -1.3 |
| **Pu239** | 104.3 | 108.0 | 120.6 | 111.0 |
| **Pu240** | -34.3 | -36.5 | -39.5 | -36.8 |
| **Pu241** | 31.7 | 33.4 | 33.9 | 33.0 |
| **Pu242** | -1.9 | -1.6 | -2.0 | -1.8 |
| **Np237** | -4.2 | -3.7 | -4.2 | -4.0 |
| **Am241** | -0.9 | -1.0 | -0.9 | -0.9 |
| **Am243** | -0.6 | -0.5 | -0.7 | -0.6 |
| **Rh103** | -7.3 | -7.9 | -8.1 | -7.8 |
| **Cs133** | -4.3 | -4.5 | -4.0 | -4.2 |
| **Nd143** | -10.7 | -10.6 | -10.3 | -10.5 |
| **Nd145** | -2.3 | -2.3 | -2.3 | -2.3 |
| **Gd155** | -0.2 | -0.1 | -0.1 | -0.1 |
| **Mo95** | - | -1.3 | -1.3 | -1.3 |
| **Tc99** | - | -3.1 | -3.1 | -3.1 |
| **Ru101** | - | -1.2 | -1.1 | -1.1 |
| **Ag109** | -0.9 | -1.2 | -1.2 | -1.1 |
| **Sm147** | -0.5 | -0.6 | -0.5 | -0.5 |
| **Sm149** | -12.4 | -11.8 | -11.6 | -11.9 |
| **Sm150** | -1.2 | -1.0 | -1.3 | -1.1 |
| **Sm151** | -8.4 | -8.3 | -8.7 | -8.5 |
| **Sm152** | -2.6 | -2.9 | -3.1 | -2.9 |
| **Eu153** | -2.3 | -2.4 | -2.2 | -2.3 |
| **TOTAL** | **64.8** | **70.2** | **77.7** | **69.1** |

## Table 5.10. Cask – Case 3

*UOX 45 GWd/t, no CRs, Ctime = 0 days*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -0.9 | -1.1 | -1.1 | -1.0 |
| **U235** | 102.7 | 125.0 | 130.2 | 119.3 |
| **U236** | -4.2 | -5.3 | -4.9 | -4.8 |
| **U238** | -83.2 | -103.0 | -110.7 | -99.0 |
| **Pu238** | -3.1 | -3.4 | -3.5 | -3.3 |
| **Pu239** | 133.1 | 164.0 | 180.5 | 159.2 |
| **Pu240** | -38.7 | -50.0 | -53.0 | -47.2 |
| **Pu241** | 56.0 | 66.8 | 71.2 | 64.7 |
| **Pu242** | -3.3 | -4.0 | -4.3 | -3.8 |
| **Np237** | -5.5 | -5.6 | -6.5 | -5.9 |
| **Am241** | -1.3 | -1.6 | -1.5 | -1.5 |
| **Am243** | -1.6 | -1.7 | -2.2 | -1.8 |
| **Rh103** | -9.2 | -12.1 | -12.4 | -11.2 |
| **Cs133** | -5.6 | -6.6 | -6.2 | -6.1 |
| **Nd143** | -14.9 | -17.5 | -17.1 | -16.5 |
| **Nd145** | -3.3 | -3.9 | -3.7 | -3.6 |
| **Gd155** | -0.3 | -0.1 | -0.1 | -0.2 |
| **Mo95** | - | -2.3 | -2.2 | -2.2 |
| **Tc99** | - | -4.5 | -4.7 | -4.6 |
| **Ru101** | - | -1.7 | -1.7 | -1.7 |
| **Ag109** | -1.4 | -2.0 | -2.2 | -1.9 |
| **Sm147** | -0.8 | -1.1 | -1.0 | -1.0 |
| **Sm149** | -8.3 | -9.6 | -9.3 | -9.1 |
| **Sm150** | -1.8 | -2.4 | -2.4 | -2.2 |
| **Sm151** | -8.0 | -9.4 | -10.1 | -9.1 |
| **Sm152** | -3.4 | -4.2 | -4.9 | -4.2 |
| **Eu153** | -3.6 | -4.4 | -4.2 | -4.1 |
| **TOTAL** | **89.4** | **98.3** | **112.0** | **97.1** |

## Table 5.11. Cask – Case 4

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 0 days*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -0.8 | -1.0 | -0.9 | -0.9 |
| **U235** | 88.1 | 97.4 | 103.0 | 96.2 |
| **U236** | -4.3 | -4.3 | -4.7 | -4.4 |
| **U238** | -81.5 | -91.3 | -96.4 | -89.7 |
| **Pu238** | -3.5 | -3.0 | -3.3 | -3.3 |
| **Pu239** | 130.8 | 152.0 | 159.3 | 147.4 |
| **Pu240** | -40.5 | -47.1 | -49.7 | -45.8 |
| **Pu241** | 52.3 | 58.2 | 59.4 | 56.6 |
| **Pu242** | -3.5 | -3.6 | -3.9 | -3.6 |
| **Np237** | -6.4 | -6.0 | -6.7 | -6.4 |
| **Am241** | -1.7 | -2.0 | -1.9 | -1.9 |
| **Am243** | -1.8 | -1.9 | -2.1 | -1.9 |
| **Rh103** | -9.0 | -10.9 | -11.1 | -10.3 |
| **Cs133** | -5.3 | -6.4 | -5.4 | -5.7 |
| **Nd143** | -13.3 | -13.9 | -13.9 | -13.7 |
| **Nd145** | -2.9 | -2.7 | -3.1 | -2.9 |
| **Gd155** | -0.4 | -0.3 | -0.2 | -0.3 |
| **Mo95** | - | -2.0 | -1.9 | -1.9 |
| **Tc99** | - | -4.2 | -4.1 | -4.2 |
| **Ru101** | - | -1.8 | -1.6 | -1.7 |
| **Ag109** | -1.5 | -2.0 | -2.0 | -1.8 |
| **Sm147** | -0.7 | -1.0 | -0.8 | -0.8 |
| **Sm149** | -12.0 | -12.4 | -12.1 | -12.2 |
| **Sm150** | -1.7 | -1.9 | -1.9 | -1.8 |
| **Sm151** | -10.0 | -10.5 | -11.1 | -10.5 |
| **Sm152** | -3.3 | -3.8 | -4.0 | -3.7 |
| **Eu153** | -3.6 | -3.9 | 0.0 | -2.5 |
| **TOTAL** | **63.5** | **69.9** | **79.2** | **68.3** |

**Table 5.12. Cask – Case 11**

*UOX 45 GWd/t, no CRs, Ctime = 5 years*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -0.8 | -1.1 | -1.1 | -1.0 |
| **U235** | 108.4 | 139.0 | 141.4 | 129.6 |
| **U236** | -3.6 | -5.9 | -4.7 | -4.7 |
| **U238** | -75.5 | -92.4 | -104.9 | -90.9 |
| **Pu238** | -2.8 | -3.2 | -3.5 | -3.2 |
| **Pu239** | 145.1 | 186.0 | 201.1 | 177.4 |
| **Pu240** | -35.6 | -49.0 | -52.0 | -45.5 |
| **Pu241** | 46.0 | 60.0 | 60.3 | 55.4 |
| **Pu242** | -3.1 | -3.6 | -4.2 | -3.7 |
| **Np237** | -5.0 | -5.5 | -6.5 | -5.6 |
| **Am241** | -9.2 | -12.6 | -11.7 | -11.2 |
| **Am243** | -1.4 | -1.7 | -2.1 | -1.7 |
| **Rh103** | -8.3 | -12.7 | -13.3 | -11.4 |
| **Cs133** | -5.1 | -7.2 | -6.1 | -6.1 |
| **Nd143** | -13.2 | -16.7 | -17.0 | -15.6 |
| **Nd145** | -2.9 | -3.5 | -3.6 | -3.4 |
| **Gd155** | -21.5 | -12.3 | -8.2 | -14.0 |
| **Mo95** | - | -2.2 | -2.4 | -2.3 |
| **Tc99** | - | -4.4 | -4.6 | -4.5 |
| **Ru101** | - | -2.0 | -1.7 | -1.8 |
| **Ag109** | -1.3 | -2.1 | -2.1 | -1.8 |
| **Sm147** | -1.8 | -2.7 | -2.5 | -2.3 |
| **Sm149** | -11.9 | -15.0 | -14.9 | -13.9 |
| **Sm150** | -1.7 | -2.0 | -2.4 | -2.0 |
| **Sm151** | -6.8 | -8.8 | -9.6 | -8.4 |
| **Sm152** | -3.1 | -4.7 | -4.8 | -4.2 |
| **Eu153** | -3.3 | -4.3 | -4.1 | -3.9 |
| **TOTAL** | **81.6** | **109.3** | **114.7** | **99.0** |

**Table 5.13. Cask – Case 12**

*UOX 45 GWd/t, CRs 0-45 GWd/t, Ctime = 5 years*

| | FINLAND | UK (SERCO) | USA | Average |
|---|---|---|---|---|
| **U234** | -0.8 | -1.1 | -0.9 | -0.9 |
| **U235** | 95.6 | 109.0 | 112.3 | 105.6 |
| **U236** | -4.2 | -4.8 | -4.6 | -4.5 |
| **U238** | -73.4 | -85.1 | -93.8 | -84.1 |
| **Pu238** | -3.1 | -3.0 | -3.4 | -3.2 |
| **Pu239** | 145.4 | 170.0 | 176.7 | 164.0 |
| **Pu240** | -37.3 | -47.0 | -49.3 | -44.5 |
| **Pu241** | 43.9 | 50.6 | 50.4 | 48.3 |
| **Pu242** | -3.1 | -3.8 | -3.8 | -3.6 |
| **Np237** | -5.9 | -5.6 | -6.8 | -6.1 |
| **Am241** | -11.5 | -14.4 | -13.3 | -13.1 |
| **Am243** | -1.7 | -1.8 | -2.1 | -1.9 |
| **Rh103** | -8.3 | -11.9 | -11.9 | -10.7 |
| **Cs133** | -5.1 | -5.9 | -5.4 | -5.5 |
| **Nd143** | -11.9 | -13.9 | -14.0 | -13.3 |
| **Nd145** | -2.7 | -3.3 | -3.1 | -3.0 |
| **Gd155** | -22.2 | -13.2 | -6.5 | -14.0 |
| **Mo95** | - | -2.5 | -2.1 | -2.3 |
| **Tc99** | - | -4.1 | -4.1 | -4.1 |
| **Ru101** | - | -2.1 | -1.6 | -1.8 |
| **Ag109** | -1.4 | -2.1 | -2.0 | -1.8 |
| **Sm147** | -1.7 | -2.1 | -2.2 | -2.0 |
| **Sm149** | -14.6 | -16.3 | -16.2 | -15.7 |
| **Sm150** | -1.6 | -1.9 | -1.9 | -1.8 |
| **Sm151** | -8.5 | -9.8 | -10.6 | -9.6 |
| **Sm152** | -2.9 | -3.3 | -4.0 | -3.4 |
| **Eu153** | -3.3 | -3.8 | -3.6 | -3.6 |
| **TOTAL** | **59.7** | **67.0** | **72.3** | **63.6** |

*Chapter 6*

# EFFECT OF CONTROL ROD INSERTION ON SPENT FUEL INVENTORY

## 6.1 Results

The effect of control rod (CR) insertion on spent fuel inventory, deduced from the atomic number concentration calculated by each participant (Tables 3.1 to 3.12) is given in Tables 6.1 to 6.8.

This effect, expressed in percentage, is defined as follows:

$$(\text{CR effect})_{ij} = \Delta N_{ij} = ([N_j\ (\text{with CRs})/N_j\ (\text{no CRs}) - 1] \times 100)_i$$

$N_j$ is the atomic number concentration of the nuclide j calculated by participant i.

Furthermore, these tables also present the mean calculated effects of CR insertion $(\Delta N_j)_{mean}$, the standard deviation and the relative standard deviation. These mean values are graphically presented in Figure 6.1 for actinides and Figure 6.2 for fission products.

## 6.2 Effect of CR insertion

The insertion of CRs during depletion results in neutron spectrum hardening, which causes:

- An increase in $^{235}$U (max. 30%), $^{237}$Np (max. 25%) and Pu isotopes (max. 50%) concentrations, due to a decrease in $^{235}$U fission and an increased production of plutonium.

- An increase in $^{241}$Am (max. 45%) and $^{243}$Am (max. 25%), linked to the $^{241}$Pu increase.

- An increase in some fission product concentration, due to the decrease of neutron capture by fission products, mainly those which are absorbing in the thermal range, and also to the modification of the FP yields associated with $^{235}$U fissions or $^{239}$Pu fissions. The cumulative yields of $^{103}$Rh, $^{109}$Ag and $^{151}$Sm, $^{153}$Eu, $^{155}$Eu decaying in $^{155}$Gd, are strongly increased in $^{239}$Pu and $^{241}$Pu fissions [4].

- The FPs which are the most sensitive to the neutron spectrum hardening are $^{149}$Sm (max. increase 65%), $^{151}$Sm (max. increase 45%) and $^{155}$Gd (max. increase 100%).

The $^{235}$U depletion and $^{239}$Pu production with burn-up are presented Appendix C. The $^{235}$U depletion is not as great when CRs are inserted; at the end of irradiation, the $^{235}$U concentration is higher than the concentration when no CRs are inserted. This effect is all the more significant when the CRs are inserted for a long time. The $^{239}$Pu production is greater when CRs are inserted; at the end of irradiation, the $^{239}$Pu concentration is higher than the concentration when no CRs are inserted. This effect is more significant when the CRs are inserted for a long time or at the end of the depletion.

We may also point out that the effect of CR insertion on $^{155}$Gd concentration is more significant when there is no cooling time. Indeed, when the cooling time increases, the $^{155}$Gd concentration increases due to the decay of $^{155}$Eu to $^{155}$Gd. This increase of $^{155}$Gd concentration with cooling time tends to mask the high $^{155}$Gd concentration increase due to the insertion of the CRs.

### 6.3 Comparison of the calculated effect of CR insertion

The absolute difference from the mean value ($\Delta N_i - \Delta N_{mean}$) is graphically presented in Figures 6.3 to 6.18. These figures show good agreement between participants (absolute differences < 6%), except for the following nuclides:

*$^{234}$U*. The JNES effects of CR insertion on this nuclide concentration are always higher than the effects calculated by the other participants. The absolute difference from the mean value reaches a -13% maximum, corresponding to the case when CRs are inserted from 0 to 45 GWd/t. This reflects the low $^{234}$U concentrations calculated by JNES when the CRs are inserted (see § 3.2.1).

*$^{235}$U*. The USA effects of CR insertion on this nuclide concentration, calculated using the SAS2h code, are higher than the effects calculated by the other participants, reflecting the low $^{235}$U concentrations calculated by SAS2h when the CRs are out (see § 3.2.1). The absolute difference from the mean value reaches +6% when the CRs are inserted from 0 to 45 GWd/t.

*$^{243}$Am*. The USA effects of CR insertion on this nuclide concentration (except those calculated with the code HELIOS) are lower than the effects calculated by the other participants, reflecting the high $^{243}$Am concentration, particularly when CRs are not inserted (see § 3.2.1). The absolute difference from the mean value is -8% at 30 GWd/t.

*$^{155}$Gd*. There is considerable disagreement between the participants. The lowest effects of CR insertion on this nuclide concentration are obtained by JNES (50% lower than the mean value when CRs are inserted all along the depletion) while the highest effects are obtained by the CEA, BNFL and SERCO (about 30% to 50% higher than the mean value when the CRs are inserted during all the depletion).

*$^{109}$Ag*. The USA effects of CR insertion on this nuclide concentration, calculated with the SAS2h code, are higher than the effects calculated by the other participants, due to the high $^{109}$Ag concentration calculated by SAS2h when CRs are inserted (see § 3.2.2). The absolute difference from the mean value reaches +40% when CRs are inserted from 0 to 45 GWd/t.

## Table 6.1. (Case 2/Case 1)-1

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -5.0% | -5.2% | -5.4% | -4.7% | -6.0% | -14.0% | -4.7% | -4.8% | -6.1% | -5.3% | -4.4% | -4.3% | -4.2% | -5.5% | -5.7% | 2.5% | -43.2% |
| U235 | 11.0% | 12.0% | 11.0% | 10.5% | 10.3% | 11.5% | 12.2% | 12.3% | 10.5% | 10.0% | 14.3% | 13.5% | 13.9% | 12.2% | 11.8% | 1.4% | 11.6% |
| U236 | -0.5% | -1.0% | -0.6% | 0.0% | 0.7% | 0.2% | -0.3% | -1.1% | -0.1% | 1.1% | -1.3% | -1.2% | -1.3% | -0.7% | -0.4% | 0.8% | -176.5% |
| U238 | -0.5% | -0.5% | -0.5% | -0.5% | -0.5% | -0.6% | -0.5% | -0.5% | -0.5% | -0.5% | -0.5% | -0.4% | -0.5% | -0.9% | -0.5% | 0.1% | -24.4% |
| Pu238 | 36.6% | 38.7% | 39.5% | 35.5% | 35.9% | 37.0% | 39.1% | 38.3% | 36.7% | 37.2% | 33.8% | 32.1% | 31.1% | 36.5% | 36.3% | 2.5% | 6.9% |
| Pu239 | 39.7% | 43.6% | 40.1% | 40.9% | 39.8% | 44.4% | 45.1% | 44.7% | 41.1% | 39.3% | 43.1% | 42.2% | 42.1% | 45.9% | 42.3% | 2.2% | 5.3% |
| Pu240 | 11.1% | 12.9% | 11.6% | 12.6% | 10.8% | 13.0% | 12.8% | 12.7% | 12.2% | 10.6% | 11.3% | 10.4% | 10.0% | 13.5% | 11.8% | 1.1% | 9.5% |
| Pu241 | 28.7% | 31.1% | 27.7% | 29.1% | 27.8% | 28.7% | 30.3% | 30.4% | 29.3% | 28.1% | 30.4% | 28.7% | 28.4% | 30.9% | 29.3% | 1.2% | 3.9% |
| Pu242 | 3.4% | 1.8% | 3.7% | 4.6% | 3.6% | 2.9% | 2.7% | 2.7% | 4.4% | 3.6% | -0.5% | -1.7% | -2.3% | 2.0% | 2.2% | 2.2% | 98.3% |
| Np237 | 24.3% | 27.1% | 26.0% | 23.5% | 24.6% | 25.2% | 26.0% | 25.4% | 24.7% | 25.6% | 24.6% | 23.5% | 22.9% | 25.1% | 24.9% | 1.1% | 4.5% |
| Am241 | 36.7% | 36.7% | 32.2% | 33.4% | 32.0% | 34.6% | 36.2% | 35.4% | 33.7% | 32.4% | 36.7% | 34.6% | 34.4% | 36.3% | 34.7% | 1.7% | 5.0% |
| Am243 | 24.6% | 23.7% | 26.6% | 27.3% | 24.9% | 22.9% | 24.9% | 24.0% | 26.9% | 25.1% | 17.4% | 16.0% | 14.9% | 23.6% | 23.1% | 4.0% | 17.3% |
| Rh103 | 2.9% | 4.1% | 2.1% | 3.2% | 2.7% | 4.7% | 4.2% | 4.2% | 3.1% | 3.0% | 3.1% | 2.6% | 2.3% | 3.0% | 3.2% | 0.8% | 24.2% |
| Cs133 | -2.2% | -1.9% | -2.5% | -1.9% | -2.3% | -1.5% | -1.8% | -1.9% | -2.3% | -1.8% | -3.0% | -3.3% | -3.5% | -2.6% | -2.3% | 0.6% | -25.8% |
| Nd143 | 1.9% | 2.7% | 2.2% | 2.0% | 1.7% | 2.5% | 2.1% | 2.1% | 1.9% | 1.6% | 1.6% | 1.1% | 1.0% | 2.0% | 1.9% | 0.5% | 25.1% |
| Nd145 | -2.4% | -2.0% | -2.8% | -2.1% | -2.3% | -1.3% | -2.1% | -2.0% | -2.2% | -2.3% | -3.5% | -3.7% | -3.8% | -2.1% | -2.5% | 0.7% | -28.7% |
| Gd155 | 108.9% | 118.7% | 80.8% | 109.6% | 58.5% | 44.4% | 73.3% | 73.0% | 74.9% | 67.0% | 73.0% | 71.3% | 71.2% | 83.2% | 79.1% | 20.5% | 25.8% |
| Mo95 | -2.1% | -2.3% | nodata | -2.4% | -2.2% | -2.0% | -2.6% | -2.5% | -2.3% | -2.3% | -3.8% | -4.0% | -4.2% | -2.4% | -2.7% | 0.8% | -28.4% |
| Tc99 | -1.9% | -1.5% | nodata | -1.5% | -2.1% | -0.8% | -1.5% | -1.4% | -1.8% | -1.7% | -2.9% | -3.2% | -3.4% | -1.8% | -2.0% | 0.7% | -38.3% |
| Ru101 | -0.3% | 0.4% | nodata | 0.0% | -0.3% | 0.5% | 0.0% | 0.0% | 0.0% | -0.4% | -1.6% | -2.0% | -2.2% | 0.0% | -0.5% | 0.9% | -188.3% |
| Ag109 | 8.2% | 8.3% | 5.9% | 9.2% | 14.1% | 9.9% | 10.5% | 10.4% | 8.8% | 9.8% | 42.7% | 4.7% | 4.2% | 11.6% | 11.3% | 9.4% | 83.3% |
| Sm147 | -6.7% | -8.5% | -8.3% | -8.9% | -9.1% | -8.7% | -8.5% | -8.5% | -9.7% | -8.4% | -9.4% | -9.5% | -9.6% | -13.2% | -9.1% | 1.4% | -15.4% |
| Sm149 | 49.6% | 56.6% | 53.6% | 51.8% | 49.2% | 60.3% | 55.5% | 55.4% | 50.8% | 49.9% | 53.4% | 53.5% | 53.1% | 63.0% | 54.0% | 4.0% | 7.4% |
| Sm150 | 1.1% | 2.7% | 3.6% | 2.0% | 1.8% | 5.3% | 2.3% | 2.2% | 1.7% | 1.1% | -0.3% | -0.4% | -0.7% | 6.7% | 2.1% | 2.1% | 99.6% |
| Sm151 | 38.8% | 43.2% | 39.8% | 39.6% | 39.0% | 39.5% | 38.7% | 38.6% | 40.3% | 38.6% | 40.1% | 38.6% | 38.5% | 42.0% | 39.7% | 1.4% | 3.5% |
| Sm152 | -7.7% | -6.5% | -6.4% | -7.3% | -5.7% | -8.0% | -8.3% | -8.4% | -5.1% | -7.3% | -7.0% | -7.5% | -7.7% | -8.4% | -7.3% | 1.0% | -13.8% |
| Eu153 | 5.3% | 5.7% | 6.9% | 5.7% | 5.5% | 6.0% | 5.6% | 5.7% | 5.2% | 5.7% | 3.9% | 3.5% | 3.1% | 5.8% | 5.2% | 1.0% | 19.9% |

# Table 6.2. (Case 4/Case 3)-1

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -5.2% | -5.5% | -6.0% | -5.0% | -6.9% | -19.2% | -4.8% | -5.0% | -7.0% | -6.1% | -3.9% | -4.1% | -3.9% | -5.8% | -6.3% | 3.8% | -60.9% |
| U235 | 28.5% | 30.1% | 29.0% | 27.0% | 27.9% | 29.6% | 31.2% | 31.4% | 27.9% | 26.4% | 36.2% | 32.9% | 34.3% | 31.7% | 30.3% | 2.8% | 9.4% |
| U236 | -1.5% | -1.8% | -1.6% | -0.9% | -0.2% | -0.6% | -1.0% | -1.9% | -1.3% | 0.3% | -1.7% | -1.6% | -1.5% | -1.7% | -1.2% | 0.6% | -53.0% |
| U238 | -0.7% | -0.8% | -0.7% | -0.7% | -0.6% | -0.8% | -0.7% | -0.7% | -0.7% | -0.7% | -0.6% | -0.6% | -0.6% | -1.0% | -0.7% | 0.1% | -13.0% |
| Pu238 | 32.2% | 33.3% | 34.2% | 30.8% | 31.1% | 31.1% | 33.1% | 32.1% | 32.0% | 32.4% | 29.2% | 27.9% | 27.1% | 30.6% | 31.2% | 2.0% | 6.4% |
| Pu239 | 51.1% | 55.2% | 51.7% | 52.1% | 51.4% | 56.2% | 56.8% | 56.6% | 52.8% | 50.3% | 54.2% | 53.1% | 53.1% | 58.3% | 53.8% | 2.5% | 4.6% |
| Pu240 | 12.4% | 14.3% | 13.3% | 13.9% | 12.0% | 14.7% | 14.4% | 14.2% | 13.6% | 11.6% | 12.7% | 11.9% | 11.5% | 15.1% | 13.3% | 1.2% | 9.1% |
| Pu241 | 35.2% | 37.4% | 34.6% | 35.0% | 34.3% | 35.5% | 36.7% | 36.5% | 36.2% | 34.1% | 37.8% | 35.8% | 35.7% | 37.3% | 35.9% | 1.2% | 3.2% |
| Pu242 | -4.4% | -6.1% | -4.2% | -3.6% | -4.4% | -4.7% | -5.4% | -5.2% | -3.7% | -4.5% | -7.6% | -8.2% | -8.8% | -6.5% | -5.5% | 1.7% | -30.6% |
| Np237 | 21.8% | 24.0% | 22.5% | 20.9% | 21.8% | 21.3% | 22.2% | 21.4% | 22.0% | 22.8% | 21.6% | 20.9% | 20.4% | 21.7% | 21.8% | 0.9% | 4.1% |
| Am241 | 50.9% | 50.7% | 46.7% | 46.0% | 45.9% | 49.8% | 51.1% | 50.3% | 47.9% | 45.2% | 53.1% | 49.5% | 50.1% | 50.9% | 49.1% | 2.4% | 4.9% |
| Am243 | 11.0% | 10.2% | 13.2% | 13.0% | 11.0% | 8.1% | 9.9% | 9.4% | 12.6% | 11.1% | 5.5% | 5.4% | 4.3% | 9.6% | 9.6% | 2.8% | 29.7% |
| Rh103 | 4.3% | 5.7% | 3.9% | 4.5% | 3.8% | 6.4% | 6.1% | 6.0% | 4.6% | 4.3% | 4.9% | 4.3% | 4.1% | 4.7% | 4.8% | 0.9% | 18.0% |
| Cs133 | -2.5% | -2.3% | -2.9% | -2.3% | -2.7% | -1.7% | -2.1% | -2.0% | -2.8% | -2.1% | -3.0% | -3.3% | -3.5% | -2.9% | -2.6% | 0.5% | -20.1% |
| Nd143 | 7.0% | 8.1% | 7.5% | 6.8% | 6.7% | 7.7% | 7.5% | 7.5% | 6.9% | 6.4% | 7.9% | 6.8% | 6.9% | 7.5% | 7.2% | 0.5% | 7.1% |
| Nd145 | -2.4% | -1.9% | -3.1% | -2.1% | -2.3% | -1.0% | -1.9% | -1.8% | -2.3% | -2.4% | -3.1% | -3.3% | -3.5% | -2.1% | -2.4% | 0.7% | -28.9% |
| Gd155 | 138.2% | 161.6% | 116.2% | 149.8% | 86.4% | 53.7% | 102.3% | 102.4% | 94.4% | 92.2% | 100.3% | 98.1% | 97.8% | 121.4% | 108.2% | 27.7% | 25.6% |
| Mo95 | -2.6% | -2.4% | nodata | -2.7% | -2.4% | -2.2% | -2.8% | -2.8% | -2.7% | -2.5% | -3.8% | -4.0% | -4.2% | -2.4% | -2.9% | 0.7% | -23.6% |
| Tc99 | -2.1% | -1.7% | nodata | -1.7% | -2.6% | -1.0% | -1.6% | -1.5% | -2.2% | -2.0% | -3.0% | -3.2% | -3.4% | -1.6% | -2.1% | 0.7% | -33.6% |
| Ru101 | -0.7% | 0.0% | nodata | -0.4% | -0.8% | 0.2% | -0.4% | -0.4% | -0.5% | -0.9% | -2.0% | -2.3% | -2.6% | -0.4% | -0.9% | 0.9% | -99.2% |
| Ag109 | 4.3% | 3.8% | 0.6% | 5.1% | 10.5% | 6.8% | 7.1% | 6.9% | 4.6% | 6.1% | 56.7% | 0.0% | -0.5% | 7.6% | 8.5% | 14.2% | 166.4% |
| Sm147 | -8.2% | -9.9% | -9.9% | -10.6% | -11.0% | -10.0% | -9.7% | -9.7% | -11.7% | -10.0% | -10.0% | -10.3% | -10.3% | -14.8% | -10.4% | 1.5% | -14.2% |
| Sm149 | 67.2% | 75.4% | 72.2% | 69.5% | 66.9% | 81.9% | 75.6% | 75.4% | 68.8% | 67.3% | 71.5% | 70.8% | 70.5% | 85.7% | 72.8% | 5.6% | 7.7% |
| Sm150 | 0.4% | 2.2% | 3.1% | 1.4% | 1.1% | 6.2% | 2.3% | 2.3% | 0.7% | 0.5% | -0.9% | -0.8% | -1.2% | 7.5% | 1.8% | 2.5% | 142.1% |
| Sm151 | 51.7% | 56.8% | 53.6% | 52.6% | 52.2% | 51.5% | 50.3% | 50.0% | 53.9% | 51.4% | 52.5% | 50.9% | 50.6% | 55.0% | 52.4% | 1.9% | 3.6% |
| Sm152 | -9.0% | -7.6% | -7.5% | -8.5% | -6.7% | -9.7% | -10.5% | -10.6% | -6.1% | -8.6% | -8.2% | -8.6% | -8.8% | -9.8% | -8.6% | 1.3% | -15.4% |
| Eu153 | 1.9% | 2.1% | 4.8% | 2.2% | 2.5% | 2.7% | 2.3% | 2.4% | 2.0% | 2.4% | 1.0% | 0.7% | 0.2% | 1.9% | 2.1% | 1.1% | 51.0% |

## Table 6.3. (Case 5/Case 3)-1

*UOX 45 GWd/t, effect of 0-15 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -1.0% | -1.0% | -1.2% | -0.8% | -1.4% | -5.8% | -0.9% | -0.8% | -1.4% | -1.4% | -0.5% | -0.7% | -0.5% | -1.0% | -1.3% | 1.3% | -102.6% |
| U235 | 12.0% | 13.7% | 12.2% | 12.0% | 11.6% | 13.4% | 13.6% | 13.7% | 11.9% | 11.3% | 15.3% | 14.1% | 14.8% | 14.0% | 13.1% | 1.3% | 9.6% |
| U236 | 0.9% | 0.5% | 0.9% | 0.8% | 1.4% | 1.3% | 1.0% | 0.7% | 1.0% | 1.5% | 0.9% | 0.8% | 0.8% | 0.8% | 1.0% | 0.3% | 28.5% |
| U238 | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.1% | -0.1% | -0.5% | -0.2% | 0.1% | -40.3% |
| Pu238 | 6.3% | 7.3% | 6.8% | 6.5% | 6.1% | 7.0% | 7.3% | 7.0% | 6.3% | 7.1% | 5.7% | 5.8% | 5.2% | 6.5% | 6.5% | 0.6% | 9.7% |
| Pu239 | 5.5% | 6.2% | 5.6% | 5.8% | 5.4% | 6.0% | 6.1% | 6.3% | 5.6% | 5.5% | 5.5% | 5.6% | 5.6% | 6.3% | 5.8% | 0.3% | 5.8% |
| Pu240 | 5.7% | 6.5% | 5.8% | 6.1% | 5.5% | 6.5% | 6.5% | 6.5% | 5.9% | 5.7% | 5.6% | 5.7% | 5.4% | 6.5% | 6.0% | 0.4% | 7.1% |
| Pu241 | 7.8% | 8.7% | 8.0% | 8.2% | 7.6% | 8.2% | 8.5% | 8.8% | 8.2% | 7.8% | 8.0% | 7.9% | 7.8% | 8.8% | 8.2% | 0.4% | 4.7% |
| Pu242 | 3.3% | 3.5% | 3.2% | 3.5% | 3.3% | 3.4% | 3.4% | 3.4% | 3.6% | 3.4% | 2.9% | 2.8% | 2.4% | 3.3% | 3.2% | 0.3% | 10.3% |
| Np237 | 3.2% | 3.5% | 3.3% | 3.4% | 3.3% | 3.5% | 3.6% | 3.3% | 3.4% | 4.0% | 3.0% | 3.2% | 2.9% | 3.1% | 3.3% | 0.3% | 8.2% |
| Am241 | 15.2% | 16.8% | 15.6% | 16.0% | 15.0% | 16.2% | 17.1% | 17.2% | 16.0% | 15.1% | 16.1% | 15.4% | 15.4% | 17.3% | 16.0% | 0.8% | 4.9% |
| Am243 | 3.6% | 3.5% | 3.6% | 3.7% | 3.0% | 2.6% | 3.9% | 3.4% | 3.5% | 3.5% | 2.6% | 2.6% | 2.0% | 3.6% | 3.2% | 0.6% | 17.4% |
| Rh103 | 3.2% | 3.6% | 2.8% | 3.3% | 2.5% | 3.6% | 3.6% | 3.7% | 3.3% | 3.1% | 3.2% | 3.0% | 2.9% | 3.6% | 3.3% | 0.4% | 11.0% |
| Cs133 | 0.2% | 0.2% | 0.0% | 0.2% | 0.0% | 0.2% | 0.0% | 0.1% | 0.2% | 0.2% | -0.1% | -0.2% | -0.3% | 0.2% | 0.1% | 0.2% | 213.0% |
| Nd143 | 2.5% | 2.7% | 2.6% | 2.5% | 2.4% | 2.7% | 2.8% | 2.8% | 2.5% | 2.3% | 2.7% | 2.4% | 2.4% | 2.9% | 2.6% | 0.2% | 7.5% |
| Nd145 | -0.2% | -0.2% | -0.2% | -0.2% | -0.3% | -0.1% | -0.2% | -0.2% | -0.2% | -0.3% | -0.5% | -0.6% | -0.7% | -0.3% | -0.3% | 0.2% | -61.4% |
| Gd155 | 12.0% | 15.0% | 13.4% | 14.3% | 10.9% | 8.5% | 12.1% | 13.0% | 10.1% | 10.7% | 10.4% | 10.3% | 10.0% | 13.4% | 11.7% | 1.9% | 16.1% |
| Mo95 | -0.8% | -0.8% | nodata | -0.8% | -0.7% | -0.7% | -0.8% | -0.8% | -0.7% | -0.7% | -1.2% | -1.3% | -1.4% | -0.8% | -0.9% | 0.3% | -28.4% |
| Tc99 | 0.0% | 0.1% | nodata | 0.0% | 0.0% | 0.2% | 0.1% | 0.1% | 0.1% | 0.0% | -0.3% | -0.3% | -0.4% | 0.2% | 0.0% | 0.2% | -913.4% |
| Ru101 | 0.3% | 0.4% | nodata | 0.3% | 0.2% | 0.4% | 0.3% | 0.3% | 0.3% | 0.2% | -0.2% | -0.2% | -0.4% | 0.4% | 0.2% | 0.3% | 149.4% |
| Ag109 | 3.9% | 4.3% | 3.6% | 4.1% | 3.9% | 4.3% | 4.3% | 4.4% | 4.1% | 4.1% | 5.1% | 3.4% | 3.1% | 4.6% | 4.1% | 0.5% | 12.2% |
| Sm147 | 0.2% | 0.2% | -0.3% | 0.1% | -0.1% | 0.3% | 0.2% | 0.1% | 0.0% | 0.0% | -0.3% | -0.5% | -0.5% | -0.7% | -0.1% | 0.3% | -353.6% |
| Sm149 | 7.3% | 8.3% | 7.8% | 7.7% | 7.3% | 8.9% | 8.3% | 8.9% | 7.5% | 7.3% | 7.9% | 7.9% | 7.8% | 9.2% | 8.0% | 0.6% | 7.8% |
| Sm150 | 0.1% | 0.4% | 0.6% | 0.2% | 0.2% | 1.3% | 0.4% | 0.4% | 0.2% | 0.1% | -0.5% | -0.4% | -0.6% | 1.2% | 0.3% | 0.6% | 215.1% |
| Sm151 | 5.9% | 6.8% | 6.4% | 6.3% | 5.9% | 6.7% | 6.6% | 6.9% | 6.1% | 5.9% | 5.9% | 6.0% | 5.9% | 7.1% | 6.3% | 0.4% | 6.8% |
| Sm152 | 1.0% | 1.3% | 1.1% | 1.1% | 1.0% | 1.5% | 0.9% | 0.8% | 1.0% | 0.9% | 0.7% | 0.7% | 0.6% | 1.4% | 1.0% | 0.3% | 29.2% |
| Eu153 | 0.9% | 1.2% | 1.7% | 1.0% | 0.9% | 1.3% | 1.4% | 1.5% | 1.0% | 0.9% | 0.2% | 0.2% | 0.0% | 1.2% | 1.0% | 0.5% | 53.0% |

## Table 6.4. (Case 6/Case 3)-1

*UOX 45 GWd/t, effect of 15-30 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -1.4% | -1.5% | -1.7% | -1.4% | -1.9% | -6.9% | -1.1% | -1.3% | -2.0% | -1.7% | -0.8% | -1.0% | -0.9% | -1.5% | -1.8% | 1.5% | -83.8% |
| U235 | 11.2% | 12.3% | 11.4% | 10.7% | 11.1% | 11.8% | 12.3% | 12.4% | 11.1% | 10.5% | 14.6% | 12.2% | 13.3% | 12.9% | 12.0% | 1.1% | 9.4% |
| U236 | -0.9% | -1.3% | -1.0% | -0.8% | -0.5% | -0.7% | -0.9% | -1.2% | -0.9% | -0.4% | -1.2% | -1.1% | -1.1% | -0.8% | -0.9% | 0.3% | -27.7% |
| U238 | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.2% | -0.5% | -0.2% | 0.1% | -29.5% |
| Pu238 | 11.1% | 12.1% | 12.0% | 10.8% | 10.8% | 10.8% | 11.5% | 11.6% | 11.4% | 11.4% | 10.7% | 10.0% | 9.8% | 11.0% | 11.1% | 0.7% | 6.1% |
| Pu239 | 11.8% | 13.3% | 12.0% | 12.4% | 11.8% | 13.2% | 13.3% | 13.4% | 12.1% | 11.8% | 12.2% | 11.4% | 12.0% | 13.4% | 12.4% | 0.7% | 5.8% |
| Pu240 | 9.2% | 10.0% | 9.4% | 9.4% | 8.7% | 10.1% | 10.0% | 9.8% | 9.7% | 8.9% | 9.3% | 8.1% | 8.5% | 10.8% | 9.4% | 0.7% | 7.5% |
| Pu241 | 10.8% | 11.6% | 11.2% | 11.2% | 10.9% | 11.8% | 12.0% | 12.3% | 11.5% | 10.6% | 11.4% | 10.1% | 10.5% | 11.9% | 11.3% | 0.6% | 5.7% |
| Pu242 | -0.9% | -1.5% | -1.0% | -0.8% | -1.1% | -1.4% | -1.4% | -1.5% | -0.9% | -1.1% | -1.8% | -1.5% | -2.1% | -2.0% | -1.4% | 0.4% | -30.9% |
| Np237 | 6.8% | 8.0% | 7.1% | 7.0% | 6.9% | 7.0% | 7.1% | 7.1% | 7.2% | 7.5% | 7.0% | 6.4% | 6.5% | 7.0% | 7.0% | 0.4% | 5.4% |
| Am241 | 19.3% | 20.2% | 19.1% | 19.3% | 19.0% | 20.5% | 21.2% | 20.9% | 19.7% | 18.4% | 20.4% | 18.0% | 18.9% | 20.9% | 19.7% | 1.0% | 5.0% |
| Am243 | -0.8% | -1.5% | -0.6% | -0.6% | -1.1% | -2.6% | -1.7% | -1.6% | -0.5% | -1.1% | -2.5% | -1.6% | -2.6% | -1.6% | -1.5% | 0.7% | -49.6% |
| Rh103 | 2.7% | 3.2% | 2.5% | 2.9% | 2.7% | 3.6% | 3.4% | 3.5% | 3.0% | 2.8% | 2.9% | 2.4% | 2.5% | 3.3% | 3.0% | 0.4% | 13.4% |
| Cs133 | -0.6% | -0.6% | -0.8% | -0.5% | -0.7% | -0.4% | -0.6% | -0.6% | -0.7% | -0.5% | -0.9% | -0.8% | -1.0% | -0.7% | -0.7% | 0.2% | -23.0% |
| Nd143 | 3.4% | 3.6% | 3.6% | 3.3% | 3.3% | 3.7% | 3.7% | 3.7% | 3.4% | 3.2% | 3.7% | 3.1% | 3.2% | 3.8% | 3.5% | 0.2% | 6.7% |
| Nd145 | -0.6% | -0.6% | -0.9% | -0.6% | -0.7% | -0.2% | -0.5% | -0.5% | -0.6% | -0.7% | -1.0% | -1.0% | -1.1% | -0.6% | -0.7% | 0.2% | -33.1% |
| Gd155 | 19.8% | 23.6% | 21.7% | 22.8% | 18.3% | 10.8% | 19.0% | 20.0% | 16.2% | 17.6% | 17.8% | 16.4% | 16.9% | 21.0% | 18.7% | 3.3% | 17.4% |
| Mo95 | -1.0% | -0.8% | nodata | -0.9% | -0.8% | -0.7% | -0.9% | -0.9% | -0.9% | -0.9% | -1.4% | -1.4% | -1.5% | -0.8% | -1.0% | 0.3% | -27.1% |
| Tc99 | -0.5% | -0.5% | nodata | -0.5% | -0.8% | -0.3% | -0.3% | -0.3% | -0.6% | -0.5% | -0.9% | -0.9% | -1.0% | -0.4% | -0.6% | 0.2% | -41.7% |
| Ru101 | -0.1% | 0.1% | nodata | 0.0% | -0.2% | 0.1% | -0.1% | -0.1% | -0.1% | -0.2% | -0.6% | -0.6% | -0.8% | 0.0% | -0.2% | 0.3% | -140.2% |
| Ag109 | 3.1% | 3.1% | 2.3% | 3.3% | 5.0% | 3.8% | 4.0% | 3.8% | 3.3% | 3.3% | 12.8% | 1.9% | 1.6% | 4.0% | 4.0% | 2.7% | 68.1% |
| Sm147 | -2.9% | -3.7% | -3.7% | -3.7% | -3.9% | -3.3% | -3.1% | -3.4% | -4.2% | -3.4% | -3.8% | -3.7% | -3.8% | -6.0% | -3.8% | 0.7% | -19.4% |
| Sm149 | 10.0% | 11.2% | 10.5% | 10.5% | 10.1% | 12.5% | 11.7% | 11.8% | 10.2% | 10.0% | 10.6% | 9.7% | 10.1% | 11.2% | 10.7% | 0.8% | 7.9% |
| Sm150 | 0.3% | 0.9% | 1.2% | 0.7% | 0.6% | 2.5% | 0.9% | 1.0% | 0.4% | 0.3% | -0.2% | -0.1% | -0.3% | 2.5% | 0.8% | 0.9% | 113.7% |
| Sm151 | 9.2% | 10.5% | 10.0% | 9.8% | 9.3% | 10.9% | 10.4% | 10.5% | 9.5% | 9.2% | 9.4% | 8.7% | 9.0% | 11.3% | 9.8% | 0.8% | 8.0% |
| Sm152 | -0.1% | 0.4% | 0.3% | 0.0% | 0.0% | -0.5% | -0.8% | -1.1% | 0.3% | -0.2% | -0.4% | -0.4% | -0.6% | 0.0% | -0.2% | 0.5% | -203.0% |
| Eu153 | 0.0% | 0.1% | 1.2% | 0.1% | 0.4% | 0.3% | 0.1% | 0.1% | 0.3% | 0.1% | -0.4% | -0.4% | -0.6% | -0.2% | 0.1% | 0.4% | 619.0% |

# Table 6.5. (Case 7/Case 3)-1

*UOX 45 GWd/t, effect of 30-45 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -2.6% | -3.1% | -3.2% | -2.8% | -3.7% | -8.8% | -2.8% | -2.8% | -3.7% | -3.0% | -2.3% | -2.2% | -2.2% | -3.0% | -3.3% | 1.6% | -49.7% |
| U235 | 7.0% | 7.0% | 6.6% | 5.7% | 6.3% | 6.0% | 6.9% | 6.9% | 6.2% | 5.8% | 9.4% | 7.3% | 8.2% | 7.5% | 6.9% | 1.0% | 14.5% |
| U236 | -1.8% | -1.8% | -1.8% | -1.3% | -1.4% | -1.4% | -1.6% | -1.8% | -1.7% | -1.2% | -2.1% | -1.7% | -1.9% | -1.7% | -1.7% | 0.3% | -15.5% |
| U238 | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.3% | -0.2% | -0.2% | -0.5% | -0.3% | 0.1% | -18.6% |
| Pu238 | 14.7% | 15.1% | 16.3% | 14.1% | 14.7% | 13.8% | 14.7% | 14.8% | 15.2% | 14.7% | 14.1% | 13.1% | 13.0% | 13.8% | 14.4% | 0.9% | 6.0% |
| Pu239 | 34.5% | 35.2% | 33.1% | 33.0% | 33.3% | 35.4% | 36.4% | 36.1% | 34.0% | 32.5% | 36.3% | 29.6% | 32.5% | 37.8% | 34.3% | 2.1% | 6.2% |
| Pu240 | -0.2% | -0.1% | -0.2% | 0.2% | -0.5% | 1.1% | 0.1% | 0.1% | -0.2% | -1.2% | -0.3% | -2.7% | -1.6% | -0.3% | -0.4% | 0.9% | -215.0% |
| Pu241 | 18.8% | 19.0% | 18.1% | 18.2% | 18.3% | 18.0% | 18.7% | 18.7% | 18.9% | 18.1% | 20.1% | 18.7% | 18.8% | 20.1% | 18.8% | 0.7% | 3.5% |
| Pu242 | -7.8% | -8.1% | -7.2% | -6.7% | -7.4% | -7.4% | -8.2% | -8.0% | -7.0% | -7.6% | -9.1% | -7.3% | -8.7% | -9.2% | -7.8% | 0.7% | -9.5% |
| Np237 | 13.5% | 14.4% | 14.0% | 12.3% | 13.2% | 12.2% | 12.9% | 13.2% | 13.7% | 13.4% | 13.5% | 11.0% | 11.8% | 13.2% | 13.0% | 0.9% | 7.1% |
| Am241 | 19.3% | 15.0% | 15.1% | 14.0% | 14.9% | 14.9% | 16.4% | 15.5% | 15.3% | 14.6% | 17.8% | 14.9% | 16.0% | 16.4% | 15.7% | 1.4% | 8.9% |
| Am243 | 7.1% | 8.9% | 9.8% | 8.9% | 8.3% | 6.6% | 7.7% | 7.1% | 9.4% | 8.0% | 5.7% | 6.9% | 6.0% | 7.7% | 7.7% | 1.3% | 16.2% |
| Rh103 | -0.3% | -0.3% | -0.4% | -0.6% | -0.6% | 0.6% | 0.1% | 0.1% | -0.6% | -0.6% | -0.3% | -1.1% | -0.8% | -0.7% | -0.4% | 0.4% | -106.6% |
| Cs133 | -2.0% | -2.0% | -2.2% | -1.9% | -2.0% | -1.5% | -1.8% | -1.8% | -2.4% | -1.7% | -2.2% | -1.9% | -2.2% | -2.4% | -2.0% | 0.3% | -12.5% |
| Nd143 | 3.2% | 3.3% | 3.4% | 3.0% | 3.1% | 3.4% | 3.3% | 3.3% | 3.0% | 2.8% | 3.4% | 2.7% | 2.9% | 3.5% | 3.2% | 0.2% | 7.7% |
| Nd145 | -1.3% | -1.3% | -1.9% | -1.2% | -1.3% | -0.5% | -1.0% | -1.0% | -1.4% | -1.3% | -1.7% | -1.5% | -1.7% | -1.2% | -1.3% | 0.3% | -26.4% |
| Gd155 | 96.4% | 100.4% | 73.5% | 97.5% | 54.6% | 33.4% | 65.3% | 65.0% | 63.0% | 59.5% | 64.3% | 52.2% | 58.1% | 78.6% | 68.7% | 19.0% | 27.7% |
| Mo95 | -0.7% | -1.0% | nodata | -1.1% | -0.9% | -0.8% | -1.1% | -1.1% | -1.1% | -0.9% | -1.4% | -1.2% | -1.4% | -1.0% | -1.1% | 0.2% | -18.7% |
| Tc99 | -1.4% | -1.4% | nodata | -1.3% | -1.9% | -0.8% | -1.2% | -1.2% | -1.7% | -1.5% | -2.0% | -1.7% | -2.0% | -1.3% | -1.5% | 0.3% | -23.0% |
| Ru101 | -0.8% | -0.5% | nodata | -0.7% | -0.8% | -0.3% | -0.7% | -0.7% | -0.8% | -0.9% | -1.3% | -1.1% | -1.4% | -0.7% | -0.8% | 0.3% | -36.8% |
| Ag109 | -1.9% | -2.6% | -4.7% | -1.6% | 2.3% | -0.2% | -0.5% | -0.7% | -2.1% | -0.7% | 33.2% | -3.4% | -4.2% | -0.2% | 0.9% | 9.5% | 1045.8% |
| Sm147 | -5.0% | -7.3% | -6.3% | -7.5% | -7.4% | -7.2% | -6.9% | -6.9% | -8.0% | -6.9% | -6.8% | -6.1% | -6.4% | -9.2% | -7.0% | 1.0% | -13.7% |
| Sm149 | 48.7% | 52.5% | 49.7% | 48.1% | 46.7% | 54.8% | 51.9% | 51.0% | 48.0% | 47.5% | 50.8% | 44.2% | 47.0% | 59.2% | 50.0% | 3.8% | 7.6% |
| Sm150 | 0.6% | 1.5% | 1.9% | 1.1% | 0.9% | 3.5% | 1.6% | 1.6% | 0.8% | 0.6% | 0.2% | 0.4% | 0.1% | 4.3% | 1.4% | 1.2% | 89.9% |
| Sm151 | 37.5% | 38.4% | 36.4% | 36.0% | 36.8% | 32.3% | 32.3% | 32.2% | 38.2% | 36.5% | 37.3% | 31.6% | 33.9% | 35.7% | 35.4% | 2.4% | 6.8% |
| Sm152 | -9.9% | -9.7% | -9.4% | -10.2% | -8.0% | -11.2% | -12.1% | -12.3% | -7.7% | -9.9% | -8.9% | -8.4% | -8.9% | -12.0% | -9.9% | 1.5% | -15.3% |
| Eu153 | 1.4% | 1.2% | 2.8% | 1.6% | 1.8% | 1.6% | 2.0% | 2.0% | 1.1% | 1.9% | 1.4% | 1.3% | 1.1% | 1.2% | 1.6% | 0.5% | 29.4% |

# Table 6.6. (Case 8/Case 3)-1

*UOX 45 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -2.5% | -2.6% | -3.0% | -2.3% | -3.4% | -12.1% | -2.1% | -2.2% | -3.5% | -3.2% | -1.5% | -1.8% | -1.6% | -2.5% | -3.2% | 2.6% | -83.5% |
| U235 | 22.7% | 24.9% | 23.2% | 22.2% | 22.3% | 24.7% | 25.4% | 25.5% | 22.5% | 21.3% | 28.8% | 26.3% | 27.5% | 25.8% | 24.5% | 2.2% | 9.0% |
| U236 | 0.0% | -0.6% | -0.1% | 0.1% | 0.9% | 0.5% | 0.1% | -0.5% | 0.1% | 1.1% | -0.2% | -0.2% | -0.2% | 0.0% | 0.1% | 0.5% | 667.5% |
| U238 | -0.4% | -0.5% | -0.4% | -0.4% | -0.4% | -0.5% | -0.4% | -0.4% | -0.4% | -0.4% | -0.4% | -0.4% | -0.3% | -0.5% | -0.4% | 0.0% | -10.5% |
| Pu238 | 17.8% | 19.1% | 18.6% | 17.2% | 17.1% | 17.8% | 19.1% | 18.3% | 17.5% | 18.4% | 16.1% | 15.6% | 14.9% | 17.3% | 17.5% | 1.2% | 7.1% |
| Pu239 | 18.0% | 20.4% | 18.4% | 19.1% | 18.0% | 20.4% | 20.5% | 20.2% | 18.6% | 18.1% | 18.5% | 18.9% | 18.9% | 20.5% | 19.2% | 1.0% | 5.2% |
| Pu240 | 14.7% | 16.2% | 15.0% | 15.3% | 14.0% | 16.2% | 16.1% | 15.9% | 15.4% | 14.3% | 14.7% | 14.4% | 14.1% | 16.4% | 15.2% | 0.8% | 5.6% |
| Pu241 | 18.3% | 19.9% | 18.8% | 19.0% | 18.2% | 19.5% | 20.5% | 20.3% | 19.4% | 18.1% | 19.2% | 18.5% | 18.3% | 20.3% | 19.2% | 0.9% | 4.5% |
| Pu242 | 2.1% | 1.4% | 1.9% | 2.3% | 1.9% | 1.6% | 1.5% | 1.6% | 2.3% | 1.9% | 0.6% | 0.1% | -0.4% | 1.3% | 1.4% | 0.8% | 56.3% |
| Np237 | 10.1% | 11.3% | 10.3% | 10.2% | 10.1% | 10.4% | 10.9% | 10.1% | 10.4% | 11.2% | 9.9% | 9.8% | 9.4% | 10.1% | 10.3% | 0.5% | 5.2% |
| Am241 | 34.6% | 37.3% | 34.5% | 35.0% | 33.8% | 37.0% | 38.2% | 37.7% | 35.6% | 33.3% | 36.8% | 34.6% | 34.9% | 38.2% | 35.8% | 1.7% | 4.7% |
| Am243 | 3.0% | 1.8% | 3.3% | 3.5% | 2.3% | 0.5% | 2.5% | 1.8% | 3.2% | 2.7% | 0.0% | -0.1% | -1.0% | 1.9% | 1.8% | 1.4% | 78.1% |
| Rh103 | 5.5% | 6.5% | 4.9% | 5.8% | 4.9% | 6.7% | 6.6% | 6.7% | 5.9% | 5.5% | 5.7% | 5.3% | 5.2% | 6.6% | 5.8% | 0.7% | 11.4% |
| Cs133 | -0.5% | -0.4% | -0.8% | -0.4% | -0.7% | -0.2% | -0.3% | -0.3% | -0.5% | -0.4% | -1.0% | -1.1% | -1.3% | -0.7% | -0.6% | 0.3% | -54.3% |
| Nd143 | 5.2% | 5.8% | 5.5% | 5.1% | 5.0% | 5.8% | 5.7% | 5.7% | 5.2% | 4.8% | 5.7% | 5.0% | 5.0% | 5.6% | 5.4% | 0.3% | 6.5% |
| Nd145 | -0.9% | -0.8% | -1.2% | -0.9% | -1.0% | -0.4% | -0.8% | -0.8% | -0.9% | -1.0% | -1.5% | -1.7% | -1.8% | -0.9% | -1.0% | 0.4% | -38.2% |
| Gd155 | 33.3% | 40.8% | 36.6% | 39.1% | 29.9% | 19.6% | 32.8% | 32.4% | 27.1% | 28.9% | 28.9% | 28.4% | 28.1% | 35.3% | 31.5% | 5.5% | 17.3% |
| Mo95 | -1.8% | -1.5% | nodata | -1.6% | -1.5% | -1.3% | -1.7% | -1.7% | -1.6% | -1.6% | -2.6% | -2.7% | -2.9% | -1.6% | -1.9% | 0.5% | -28.1% |
| Tc99 | -0.6% | -0.4% | nodata | -0.5% | -0.8% | -0.1% | -0.3% | -0.3% | -0.6% | -0.5% | -1.2% | -1.3% | -1.5% | -0.4% | -0.7% | 0.4% | -63.9% |
| Ru101 | 0.2% | 0.5% | nodata | 0.2% | 0.0% | 0.5% | 0.2% | 0.2% | 0.2% | -0.1% | -0.8% | -0.9% | -1.2% | 0.2% | -0.1% | 0.5% | -930.4% |
| Ag109 | 6.7% | 6.9% | 5.5% | 7.1% | 8.7% | 7.7% | 8.1% | 8.0% | 7.1% | 7.1% | 18.9% | 4.8% | 4.4% | 8.2% | 7.8% | 3.4% | 44.0% |
| Sm147 | -2.9% | -3.4% | -4.1% | -3.7% | -4.1% | -3.2% | -3.2% | -3.3% | -4.3% | -3.6% | -4.0% | -4.4% | -4.3% | -6.4% | -3.9% | 0.9% | -21.8% |
| Sm149 | 17.5% | 19.7% | 18.6% | 18.4% | 17.6% | 21.7% | 20.8% | 20.6% | 18.0% | 17.4% | 18.6% | 18.5% | 18.3% | 21.4% | 19.1% | 1.5% | 7.7% |
| Sm150 | 0.3% | 1.1% | 1.7% | 0.8% | 0.7% | 3.5% | 1.3% | 1.2% | 0.4% | 0.3% | -0.7% | -0.7% | -1.0% | 3.7% | 0.9% | 1.4% | 158.6% |
| Sm151 | 15.2% | 17.6% | 16.6% | 16.4% | 15.4% | 18.0% | 17.7% | 17.3% | 15.8% | 15.2% | 15.5% | 15.5% | 15.2% | 18.3% | 16.4% | 1.2% | 7.1% |
| Sm152 | 0.8% | 1.7% | 1.4% | 1.1% | 0.9% | 1.2% | 0.2% | 0.3% | 1.3% | 0.6% | 0.3% | 0.1% | -0.1% | 1.4% | 0.8% | 0.6% | 71.0% |
| Eu153 | 0.8% | 1.2% | 2.7% | 1.0% | 1.2% | 1.4% | 1.2% | 1.0% | 1.2% | 0.8% | -0.2% | -0.4% | -0.7% | 1.1% | 0.9% | 0.8% | 95.7% |

# Table 6.7. (Case 10/Case 9)-1

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 5 years*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -4.3% | -4.5% | -4.6% | -4.1% | -5.3% | -13.0% | -4.1% | -4.2% | -5.4% | -5.3% | -3.7% | -3.7% | -3.6% | -4.6% | -5.0% | 2.4% | -47.0% |
| U235 | 11.0% | 12.0% | 11.0% | 10.5% | 10.3% | 11.5% | 12.2% | 12.3% | 10.5% | 10.0% | 14.3% | 13.5% | 13.9% | 12.2% | 11.8% | 1.4% | 11.6% |
| U236 | -0.5% | -1.0% | -0.6% | 0.0% | 0.7% | 0.2% | -0.3% | -1.1% | -0.1% | 1.1% | -1.3% | -1.1% | -1.3% | -0.7% | -0.4% | 0.7% | -178.2% |
| U238 | -0.5% | -0.5% | -0.5% | -0.5% | -0.5% | -0.6% | -0.5% | -0.5% | -0.5% | -0.5% | -0.5% | -0.4% | -0.5% | -0.9% | -0.5% | 0.1% | -24.4% |
| Pu238 | 35.4% | 37.3% | 38.1% | 34.4% | 34.7% | 35.5% | 37.4% | 36.7% | 36.3% | 36.0% | 32.7% | 30.9% | 30.0% | 34.6% | 35.0% | 2.4% | 6.8% |
| Pu239 | 39.3% | 43.2% | 39.7% | 40.6% | 39.4% | 44.0% | 44.6% | 44.3% | 40.5% | 39.0% | 42.6% | 41.7% | 41.7% | 45.2% | 41.8% | 2.2% | 5.2% |
| Pu240 | 11.1% | 12.9% | 11.6% | 12.6% | 10.8% | 13.1% | 12.8% | 12.7% | 12.3% | 10.6% | 11.3% | 10.5% | 10.0% | 13.2% | 11.8% | 1.1% | 9.3% |
| Pu241 | 28.7% | 31.1% | 27.7% | 29.1% | 27.8% | 28.7% | 30.3% | 30.4% | 29.1% | 28.1% | 30.4% | 28.7% | 28.4% | 30.7% | 29.2% | 1.1% | 3.9% |
| Pu242 | 3.4% | 1.8% | 3.7% | 4.6% | 3.6% | 2.9% | 2.7% | 2.7% | 4.4% | 3.6% | -0.5% | -1.7% | -2.2% | 2.0% | 2.2% | 2.2% | 98.2% |
| Np237 | 24.2% | 27.0% | 26.0% | 23.4% | 24.6% | 25.1% | 25.9% | 25.3% | 24.5% | 25.5% | 24.5% | 23.4% | 22.8% | 24.8% | 24.8% | 1.1% | 4.6% |
| Am241 | 29.5% | 31.8% | 28.2% | 29.5% | 28.2% | 29.3% | 30.9% | 30.9% | 29.5% | 28.5% | 31.0% | 29.4% | 29.1% | 31.7% | 29.8% | 1.2% | 4.1% |
| Am243 | 24.6% | 23.7% | 26.6% | 27.3% | 24.9% | 22.7% | 24.8% | 24.0% | 26.7% | 25.1% | 17.3% | 15.9% | 15.0% | 23.0% | 23.0% | 4.0% | 17.4% |
| Rh103 | 2.6% | 4.1% | 2.1% | 3.2% | 2.7% | 4.7% | 4.3% | 4.2% | 3.2% | 3.1% | 3.0% | 2.6% | 2.2% | 3.1% | 3.2% | 0.8% | 24.8% |
| Cs133 | -2.2% | -1.9% | -2.5% | -1.9% | -2.2% | -1.5% | -1.8% | -1.8% | -2.2% | -1.8% | -3.0% | -3.3% | -3.5% | -2.4% | -2.3% | 0.6% | -26.1% |
| Nd143 | 1.7% | 2.6% | 2.2% | 1.9% | 1.6% | 2.4% | 2.0% | 2.0% | 1.8% | 1.5% | 1.4% | 1.0% | 0.8% | 2.0% | 1.8% | 0.5% | 27.5% |
| Nd145 | -2.4% | -2.0% | -2.8% | -2.1% | -2.3% | -1.3% | -2.1% | -2.0% | -2.2% | -2.3% | -3.4% | -3.7% | -3.9% | -2.5% | -2.5% | 0.7% | -28.1% |
| Gd155 | 41.5% | 44.7% | 24.3% | 42.7% | 11.2% | -4.6% | 11.6% | 11.6% | 18.2% | 11.0% | 9.6% | 9.4% | 8.9% | 10.9% | 17.9% | 14.9% | 83.1% |
| Mo95 | -2.6% | -2.2% | nodata | -2.3% | -2.0% | -1.8% | -2.5% | -2.5% | -2.3% | -2.2% | -3.7% | -3.9% | -4.1% | -2.2% | -2.6% | 0.8% | -28.5% |
| Tc99 | -1.9% | -1.5% | nodata | -1.5% | -2.1% | -0.8% | -1.5% | -1.4% | -1.8% | -1.7% | -2.9% | -3.1% | -3.4% | -1.5% | -1.9% | 0.8% | -39.2% |
| Ru101 | -0.3% | 0.4% | nodata | 0.0% | -0.3% | 0.6% | 0.0% | 0.0% | 0.0% | -0.4% | -1.6% | -2.0% | -2.2% | 0.0% | -0.5% | 0.9% | -189.8% |
| Ag109 | 8.2% | 8.3% | 5.9% | 9.2% | 14.1% | 10.0% | 10.5% | 10.4% | 8.8% | 9.8% | 42.6% | 4.7% | 4.2% | 11.2% | 11.3% | 9.4% | 83.3% |
| Sm147 | -6.7% | -6.7% | -7.3% | -6.9% | -7.5% | -6.4% | -6.4% | -6.4% | -7.8% | -6.5% | -7.7% | -7.9% | -8.0% | -11.6% | -7.4% | 1.3% | -18.2% |
| Sm149 | 31.7% | 37.9% | 37.0% | 34.7% | 34.0% | 41.5% | 36.5% | 36.6% | 33.0% | 33.7% | 33.6% | 34.8% | 34.1% | 45.4% | 36.0% | 3.6% | 10.1% |
| Sm150 | 1.1% | 2.7% | 3.6% | 2.0% | 1.8% | 5.3% | 2.3% | 2.2% | 1.7% | 1.1% | -0.3% | -0.4% | -0.7% | 6.7% | 2.1% | 2.1% | 99.7% |
| Sm151 | 38.1% | 42.4% | 39.8% | 39.0% | 38.4% | 38.7% | 37.9% | 37.9% | 39.1% | 37.9% | 39.4% | 38.0% | 37.8% | 41.3% | 39.0% | 1.4% | 3.5% |
| Sm152 | -7.7% | -6.5% | -6.4% | -7.3% | -5.7% | -8.0% | -8.3% | -8.4% | -5.1% | -7.3% | -7.0% | -7.5% | -7.7% | -8.2% | -7.2% | 1.0% | -13.7% |
| Eu153 | 5.3% | 5.7% | 6.9% | 5.7% | 5.5% | 6.0% | 5.6% | 5.7% | 5.2% | 5.7% | 4.0% | 3.5% | 3.1% | 5.5% | 5.2% | 1.0% | 19.6% |

## Table 6.8. (Case 12/Case 11)-1

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 5 years*

| | FRANCE | UK BNFL | FINLAND | UK SERCO | KOREA | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U234 | -3.2% | -3.7% | -3.9% | -3.4% | -4.8% | -16.1% | -2.9% | -3.2% | -4.9% | -6.1% | -2.2% | -2.5% | -2.2% | -3.6% | -4.5% | 3.5% | -78.5% |
| U235 | 28.5% | 29.8% | 29.0% | 27.0% | 27.9% | 29.6% | 31.1% | 31.4% | 27.8% | 26.4% | 36.2% | 32.9% | 34.2% | 31.7% | 30.3% | 2.8% | 9.4% |
| U236 | -1.5% | -1.8% | -1.6% | -0.9% | -0.2% | -0.6% | -1.0% | -1.8% | -1.2% | 0.3% | -1.7% | -1.6% | -1.6% | -1.7% | -1.2% | 0.6% | -53.0% |
| U238 | -0.7% | -0.7% | -0.7% | -0.7% | -0.6% | -0.8% | -0.7% | -0.7% | -0.7% | -0.7% | -0.6% | -0.6% | -0.6% | -1.0% | -0.7% | 0.1% | -13.0% |
| Pu238 | 31.1% | 31.9% | 32.9% | 29.7% | 30.0% | 29.8% | 31.7% | 30.8% | 31.5% | 31.1% | 28.1% | 26.9% | 26.2% | 29.3% | 30.1% | 1.9% | 6.4% |
| Pu239 | 50.4% | 53.5% | 51.0% | 51.5% | 50.8% | 55.5% | 56.1% | 55.9% | 51.8% | 49.6% | 53.2% | 52.4% | 52.3% | 57.4% | 53.0% | 2.4% | 4.5% |
| Pu240 | 12.5% | 13.9% | 13.3% | 13.9% | 12.1% | 14.7% | 14.5% | 14.2% | 13.7% | 11.6% | 12.7% | 11.9% | 11.5% | 15.0% | 13.3% | 1.2% | 9.0% |
| Pu241 | 35.2% | 37.2% | 34.7% | 35.0% | 34.3% | 35.6% | 36.7% | 36.5% | 35.9% | 34.1% | 37.8% | 35.8% | 35.7% | 37.4% | 35.9% | 1.2% | 3.2% |
| Pu242 | -4.4% | -5.8% | -4.2% | -3.6% | -4.4% | -4.7% | -5.4% | -5.2% | -3.7% | -4.5% | -7.6% | -8.2% | -8.8% | -6.5% | -5.5% | 1.7% | -30.6% |
| Np237 | 21.7% | 23.4% | 22.5% | 20.7% | 21.8% | 21.3% | 22.1% | 21.4% | 21.8% | 22.7% | 21.5% | 20.8% | 20.4% | 22.0% | 21.7% | 0.8% | 3.8% |
| Am241 | 37.2% | 38.9% | 36.1% | 36.4% | 35.8% | 37.3% | 38.5% | 38.3% | 37.3% | 35.5% | 39.7% | 37.5% | 37.6% | 39.0% | 37.5% | 1.3% | 3.4% |
| Am243 | 11.0% | 10.5% | 13.2% | 13.0% | 11.0% | 8.1% | 9.9% | 9.4% | 12.4% | 11.1% | 5.5% | 5.4% | 4.3% | 9.6% | 9.6% | 2.8% | 29.6% |
| Rh103 | 3.8% | 5.3% | 3.9% | 4.3% | 3.8% | 6.1% | 5.7% | 5.7% | 4.4% | 4.1% | 4.4% | 3.9% | 3.7% | 4.3% | 4.5% | 0.8% | 18.2% |
| Cs133 | -2.5% | -2.2% | -2.9% | -2.2% | -2.7% | -1.7% | -2.1% | -2.0% | -2.8% | -2.0% | -3.0% | -3.2% | -3.5% | -2.9% | -2.6% | 0.5% | -20.6% |
| Nd143 | 6.7% | 7.9% | 7.5% | 6.6% | 6.6% | 7.5% | 7.3% | 7.3% | 6.7% | 6.2% | 7.6% | 6.6% | 6.7% | 7.0% | 7.0% | 0.5% | 7.1% |
| Nd145 | -2.4% | -1.9% | -3.1% | -2.1% | -2.3% | -1.0% | -1.9% | -1.8% | -2.3% | -2.4% | -3.1% | -3.3% | -3.6% | -2.1% | -2.4% | 0.7% | -29.1% |
| Gd155 | 45.1% | 47.6% | 27.0% | 46.1% | 10.1% | -11.9% | 10.4% | 10.5% | 15.3% | 9.5% | 8.6% | 8.9% | 8.1% | 10.1% | 17.5% | 17.4% | 99.6% |
| Mo95 | -2.8% | -2.2% | nodata | -2.5% | -2.2% | -2.0% | -2.6% | -2.6% | -2.5% | -2.4% | -3.7% | -3.8% | -4.0% | -2.3% | -2.7% | 0.7% | -24.4% |
| Tc99 | -2.1% | -1.7% | nodata | -1.7% | -2.6% | -0.9% | -1.6% | -1.5% | -2.2% | -2.0% | -3.0% | -3.2% | -3.4% | -1.6% | -2.1% | 0.7% | -34.4% |
| Ru101 | -0.7% | 0.0% | nodata | -0.4% | -0.8% | 0.2% | -0.4% | -0.4% | -0.5% | -0.9% | -2.0% | -2.3% | -2.6% | -0.4% | -0.9% | 0.9% | -99.4% |
| Ag109 | 4.3% | 3.8% | 0.6% | 5.1% | 10.5% | 6.8% | 7.1% | 6.9% | 4.6% | 6.1% | 56.5% | 0.0% | -0.5% | 7.6% | 8.5% | 14.2% | 165.9% |
| Sm147 | -6.7% | -6.8% | -7.6% | -7.2% | -8.1% | -6.3% | -6.2% | -6.3% | -8.3% | -6.8% | -7.1% | -7.5% | -7.6% | -11.7% | -7.5% | 1.4% | -18.6% |
| Sm149 | 39.1% | 45.6% | 45.1% | 42.6% | 42.1% | 52.1% | 45.7% | 45.9% | 40.5% | 41.6% | 40.5% | 42.2% | 41.3% | 54.1% | 44.2% | 4.4% | 9.9% |
| Sm150 | 0.4% | 2.2% | 3.1% | 1.4% | 1.1% | 6.2% | 2.3% | 2.3% | 0.7% | 0.5% | -0.9% | -0.8% | -1.2% | 7.5% | 1.8% | 2.5% | 142.1% |
| Sm151 | 50.7% | 54.9% | 53.6% | 51.9% | 51.4% | 50.5% | 49.3% | 49.0% | 52.3% | 50.6% | 51.6% | 50.1% | 49.8% | 54.1% | 51.4% | 1.8% | 3.5% |
| Sm152 | -9.0% | -7.5% | -7.5% | -8.5% | -6.7% | -9.7% | -10.5% | -10.6% | -6.0% | -8.6% | -8.1% | -8.6% | -8.8% | -10.0% | -8.6% | 1.4% | -15.7% |
| Eu153 | 1.8% | 2.1% | 4.8% | 2.2% | 2.5% | 2.7% | 2.3% | 2.4% | 2.0% | 2.3% | 1.0% | 0.7% | 0.2% | 2.3% | 2.1% | 1.1% | 51.4% |

**Figure 6.1. Effect of CR insertion on actinide concentrations**

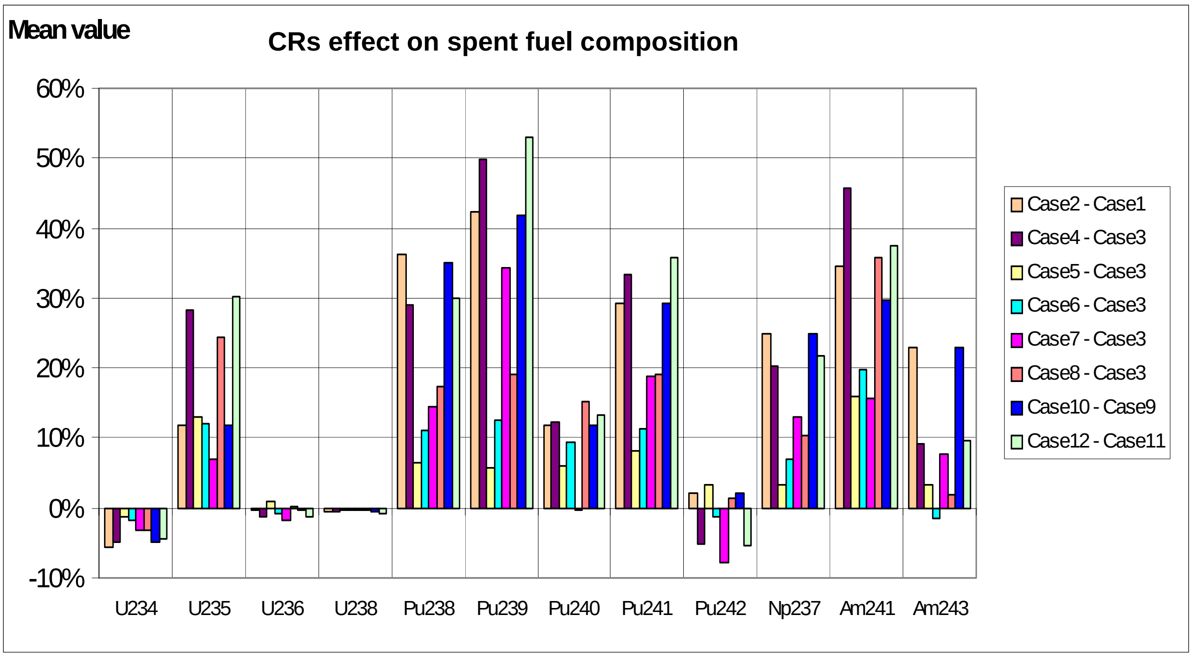



**Figure 6.2. Effect of CR insertion on fission product concentrations**

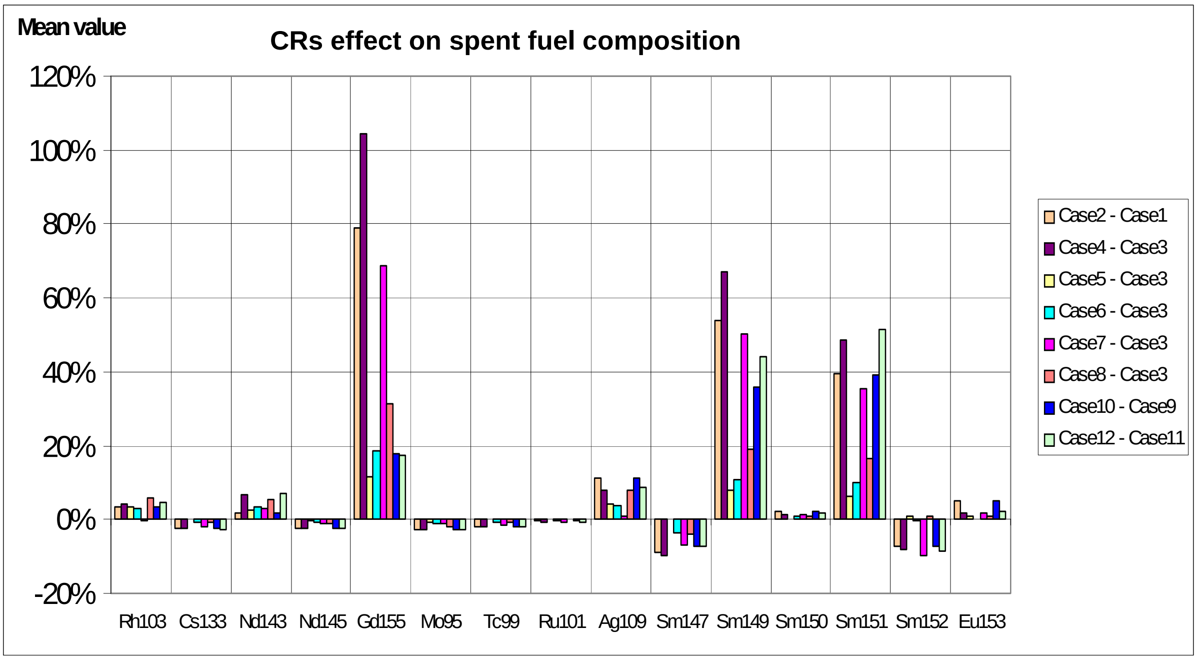


**Figure 6.3. (Case 2/Case 1)-1**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

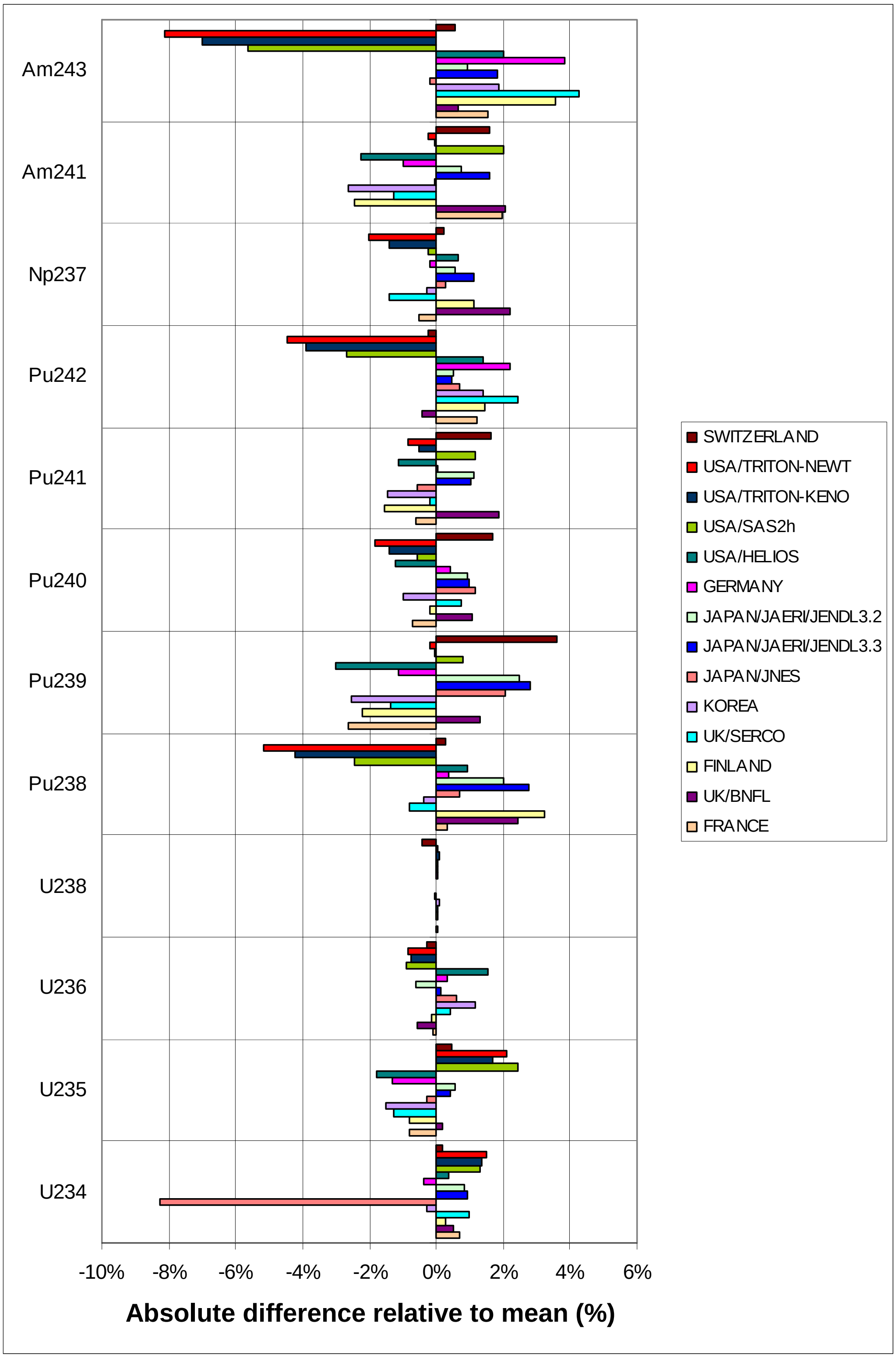


**Figure 6.4. (Case 2/Case 1)-1**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

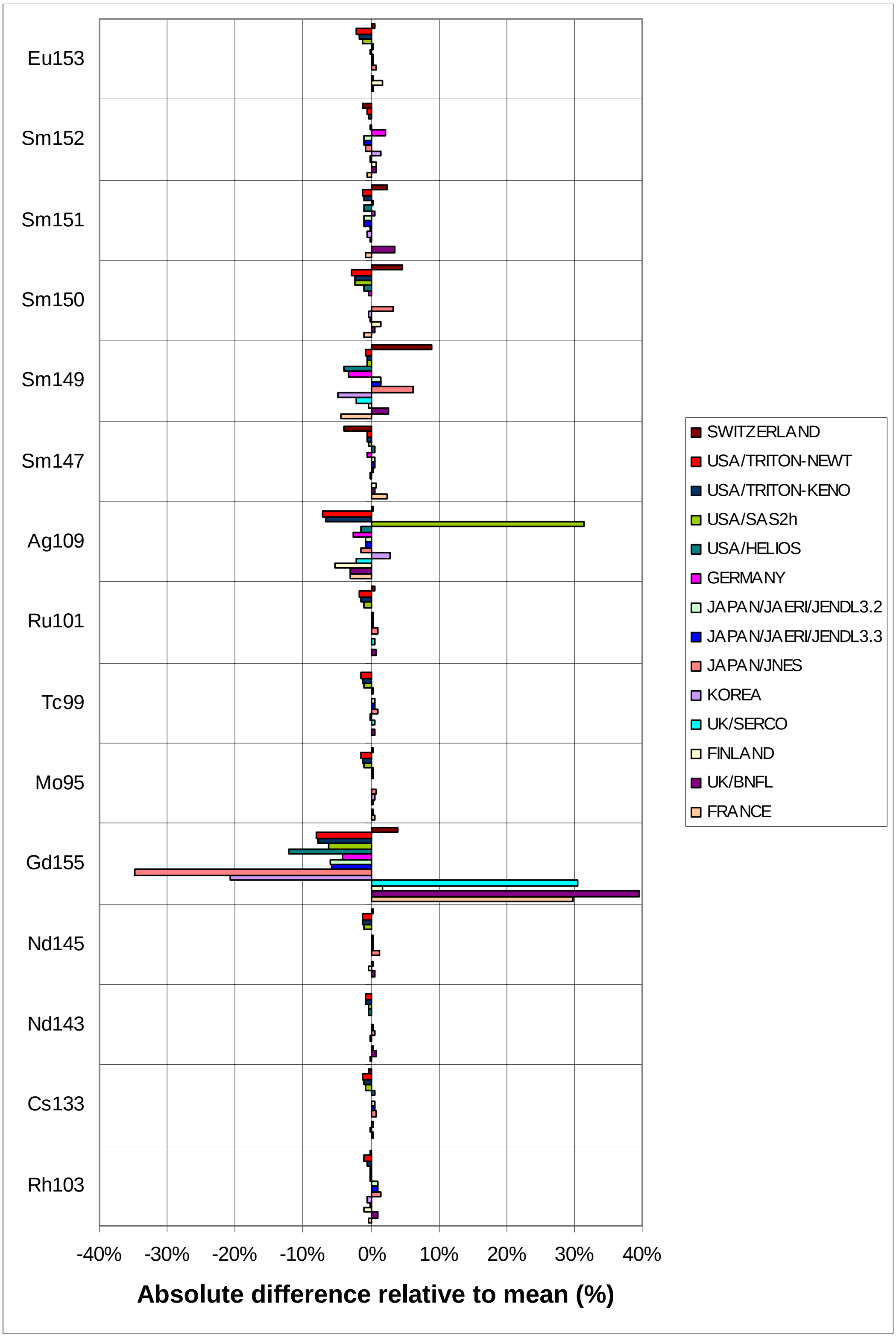


**Figure 6.5. (Case 4/Case 3)-1**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

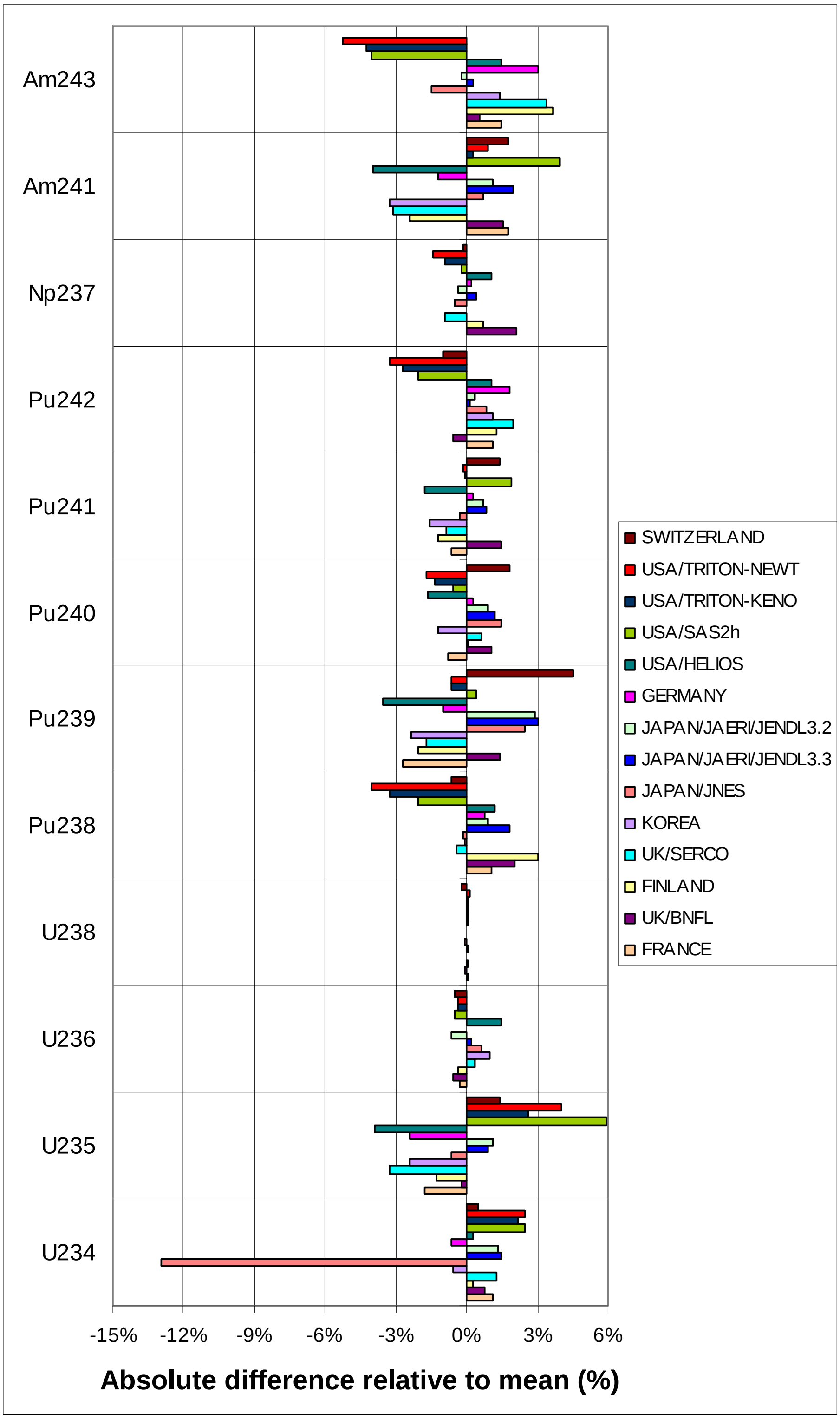


**Figure 6.6. (Case 4/Case 3)-1**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

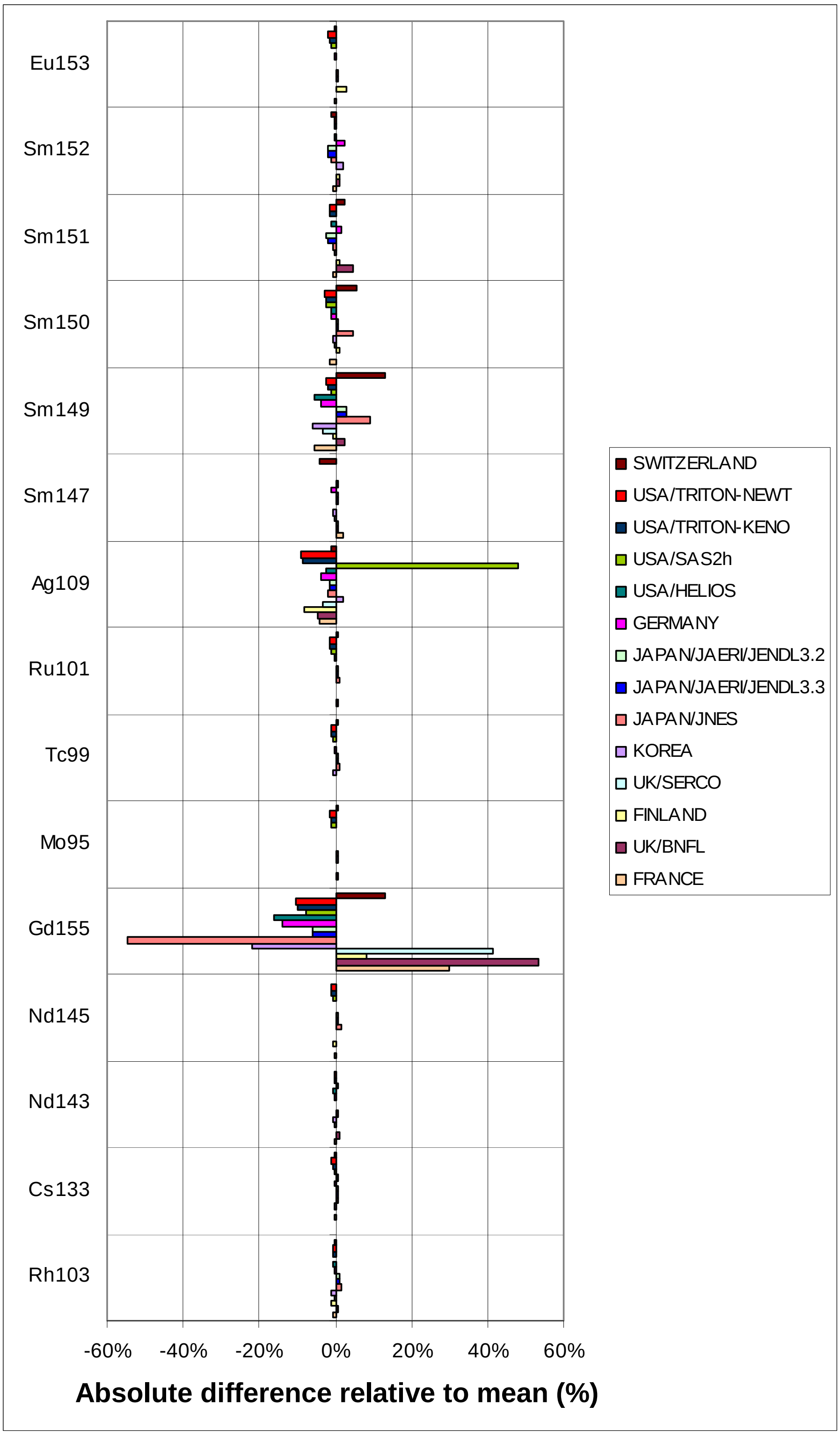


**Figure 6.7. (Case 5/Case 3)-1**

*UOX 45 GWd/t, effect of 0-15 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

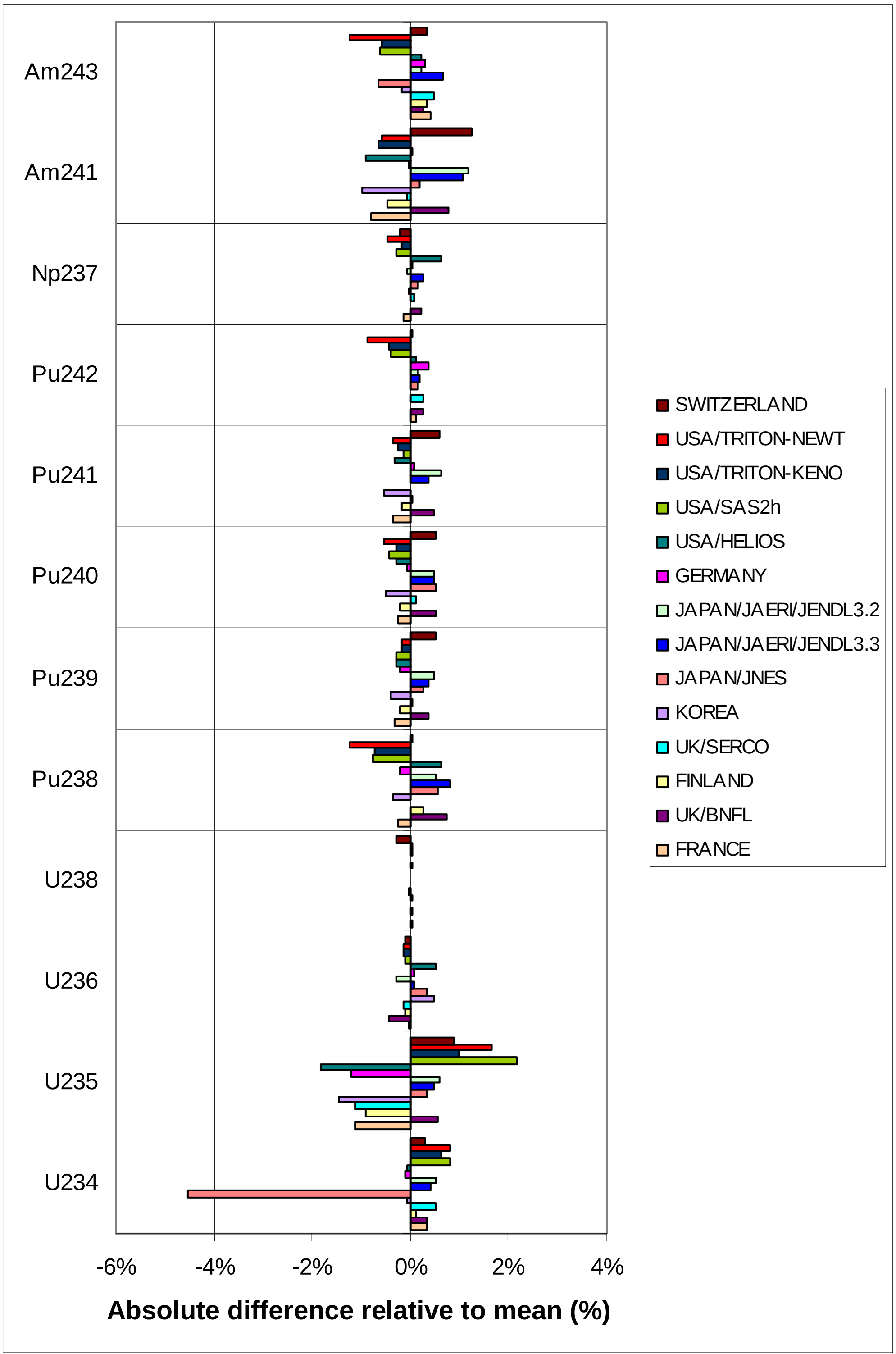


**Figure 6.8. (Case 5/Case 3)-1**

*UOX 45 GWd/t, effect of 0-15 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

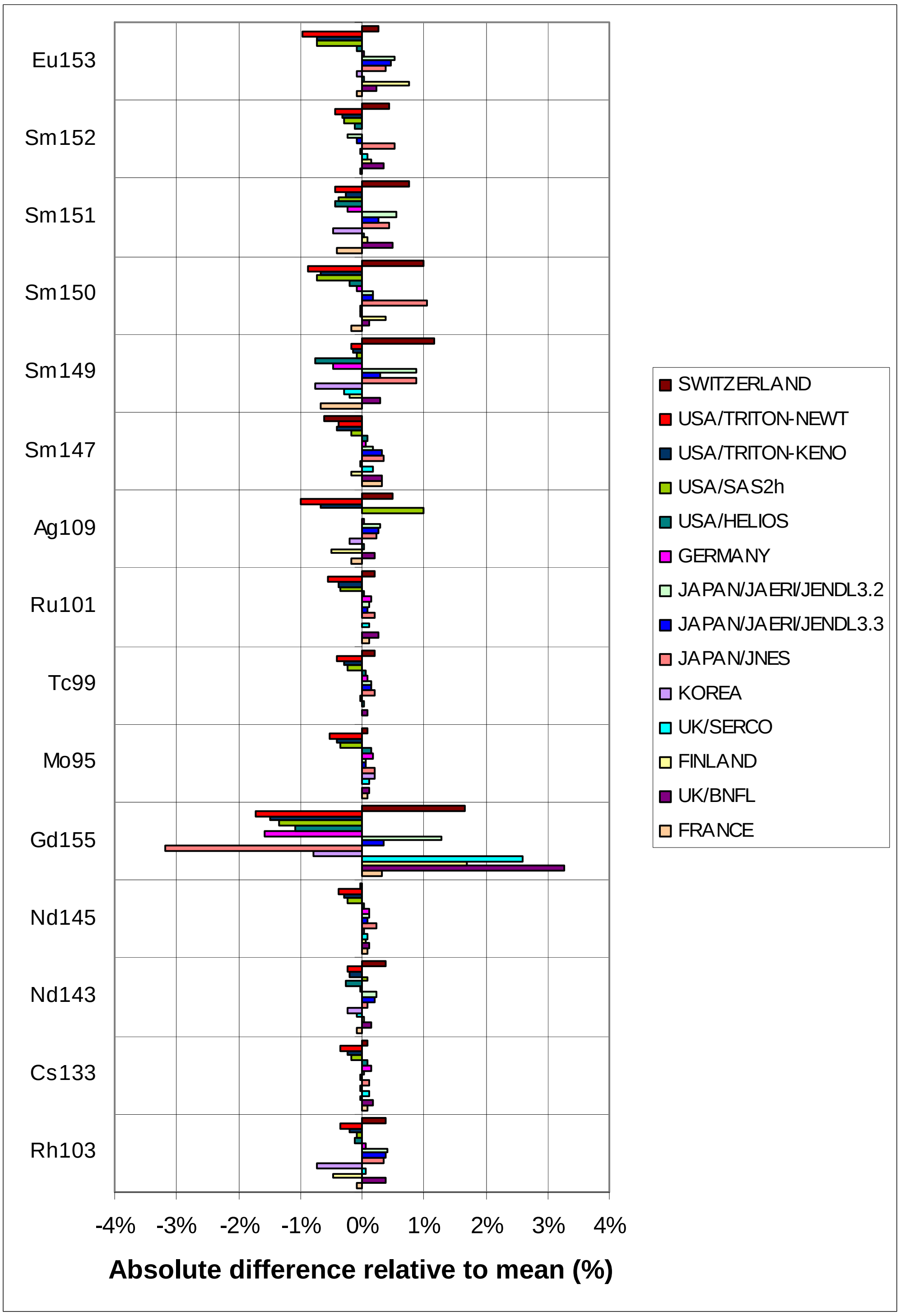


**Figure 6.9. (Case 6/Case 3)-1**

*UOX 45 GWd/t, effect of 15-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

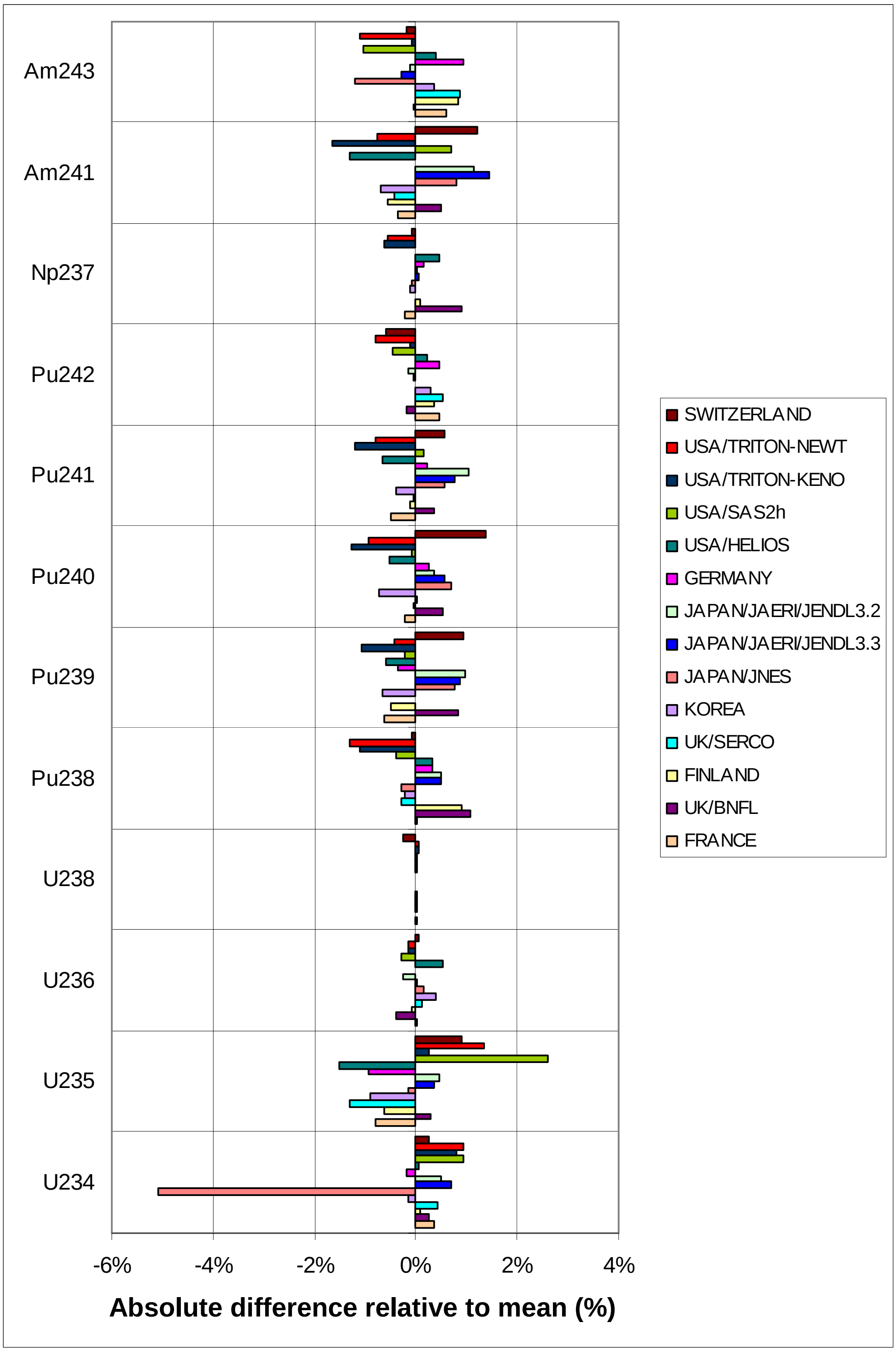


**Figure 6.10. (Case 6/Case 3)-1**

*UOX 45 GWd/t, effect of 15-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

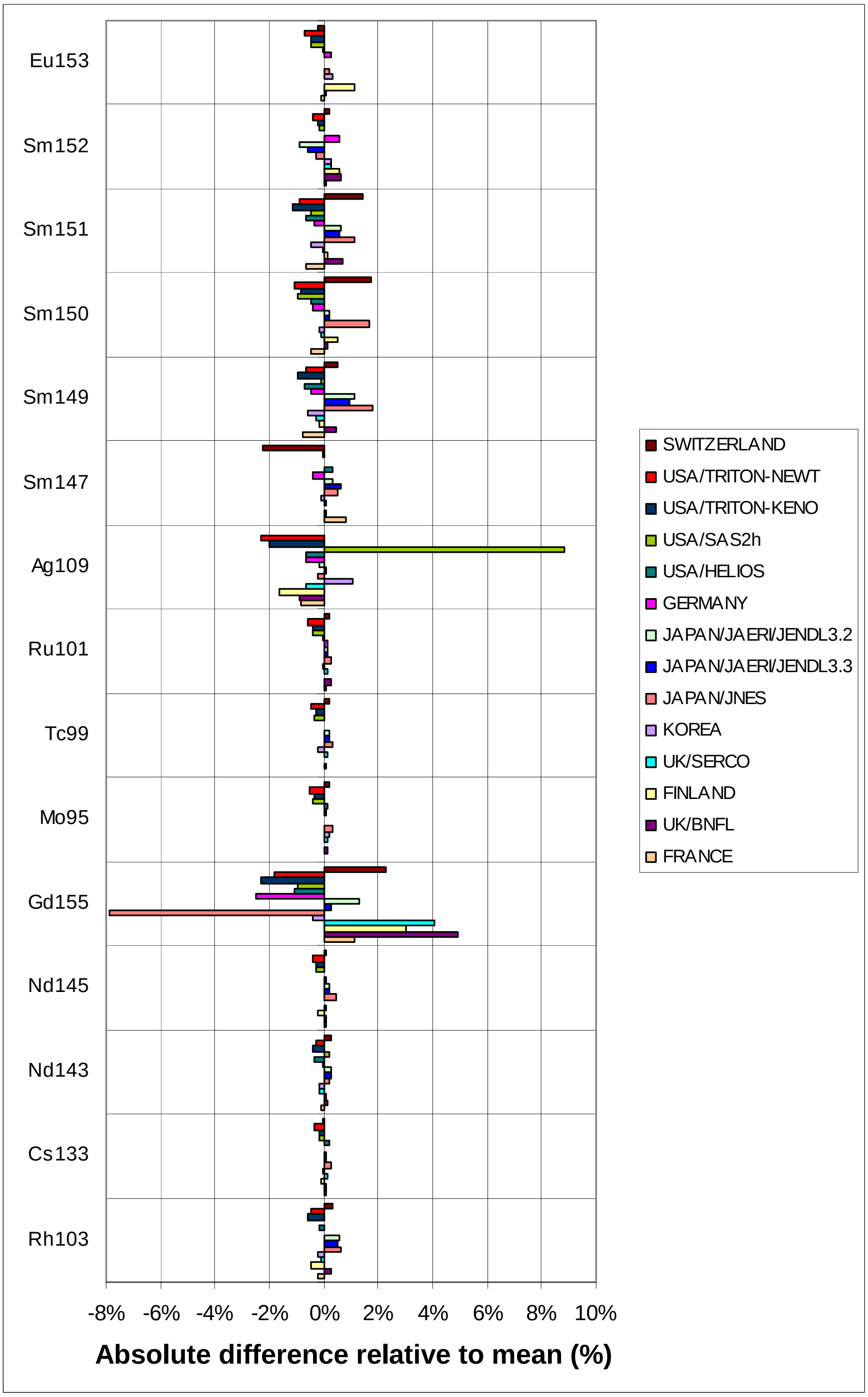


**Figure 6.11. (Case 7/Case 3)-1**

*UOX 45 GWd/t, effect of 30-45 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

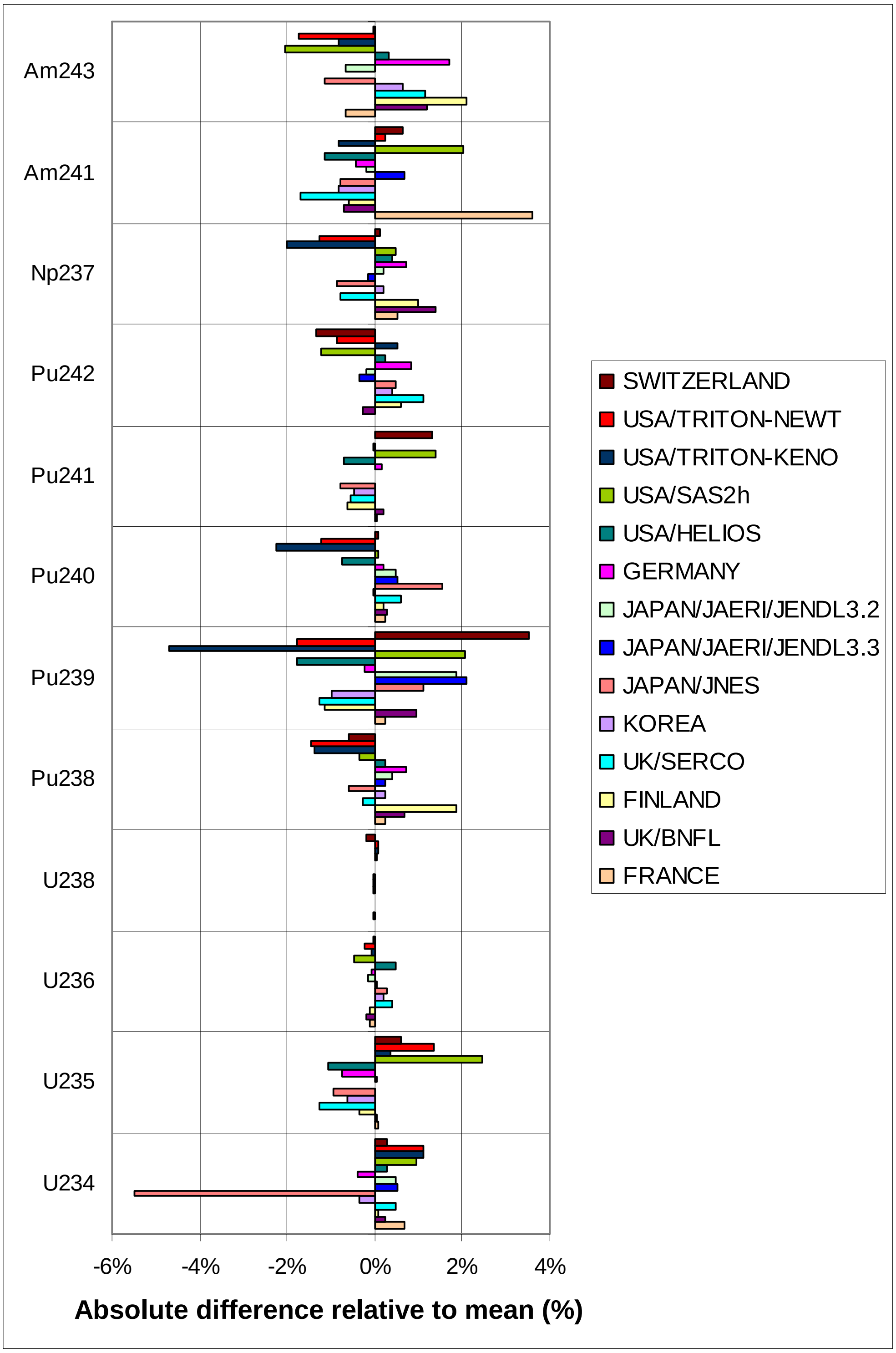


**Figure 6.12. (Case 7/Case 3)-1**

*UOX 45 GWd/t, effect of 30-45 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

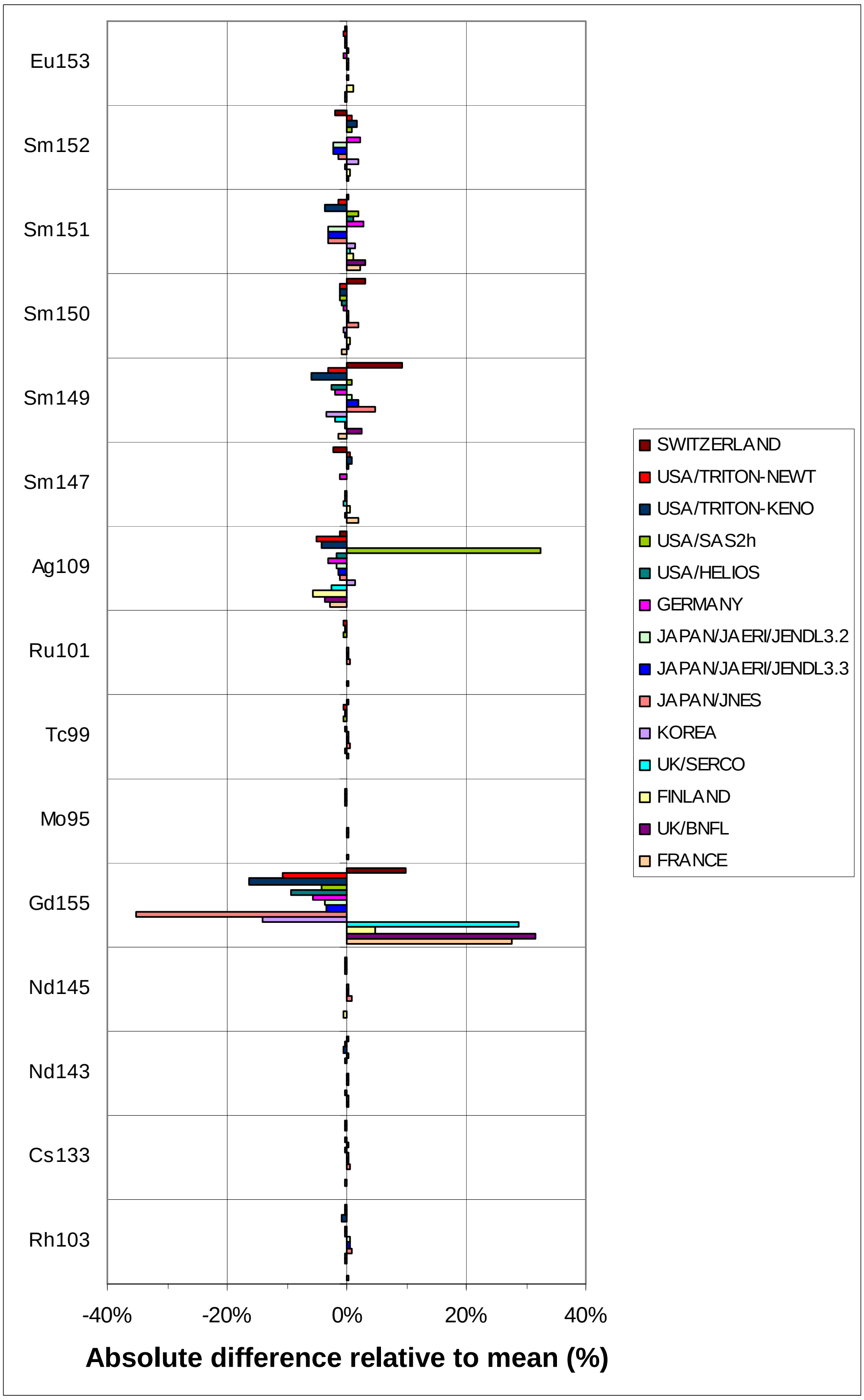


**Figure 6.13. (Case 8/Case 3)-1**

*UOX 45 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on actinide concentrations*

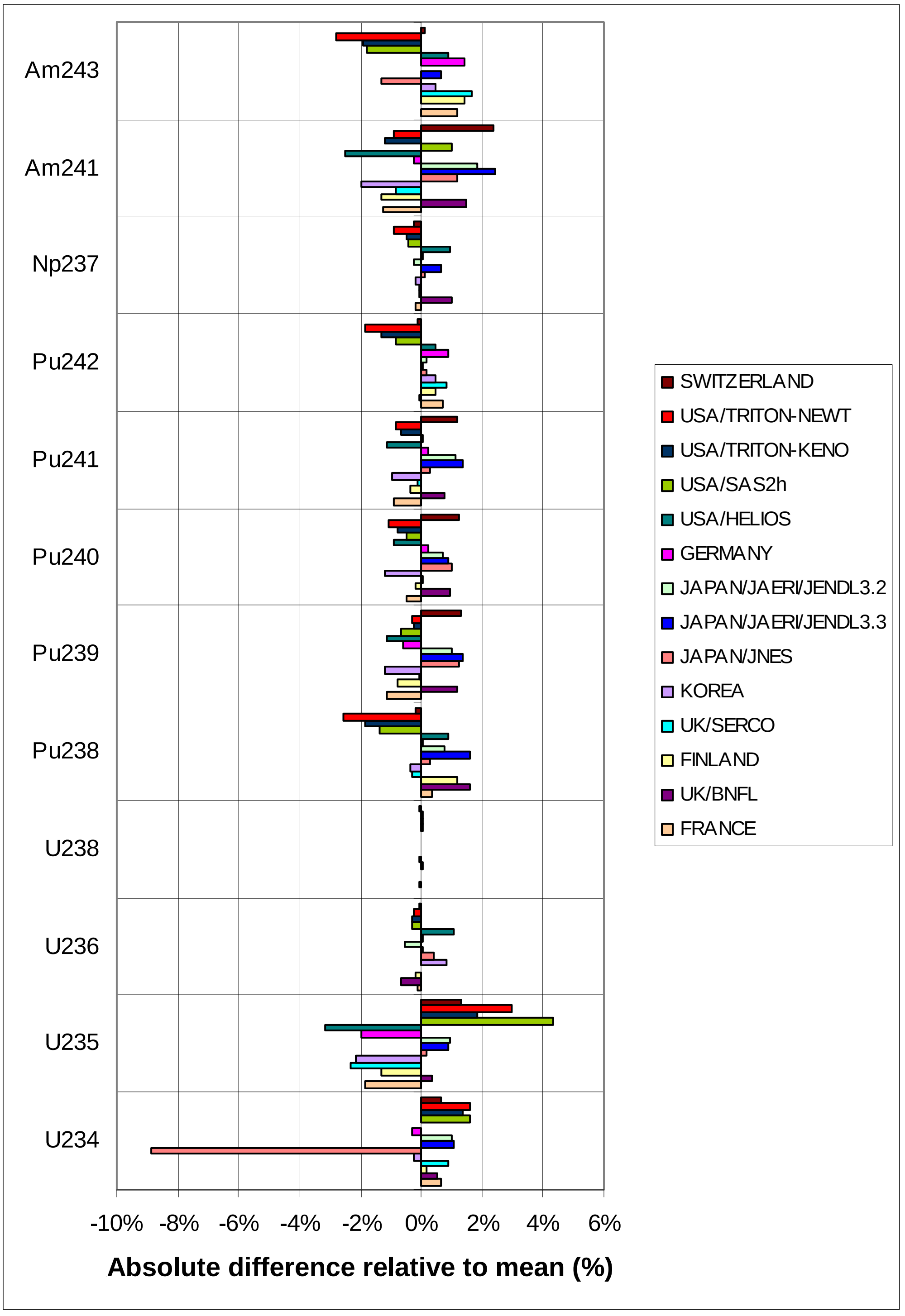


**Figure 6.14. (Case 8/Case 3)-1**

*UOX 45 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days*
*Absolute difference on fission product concentrations*

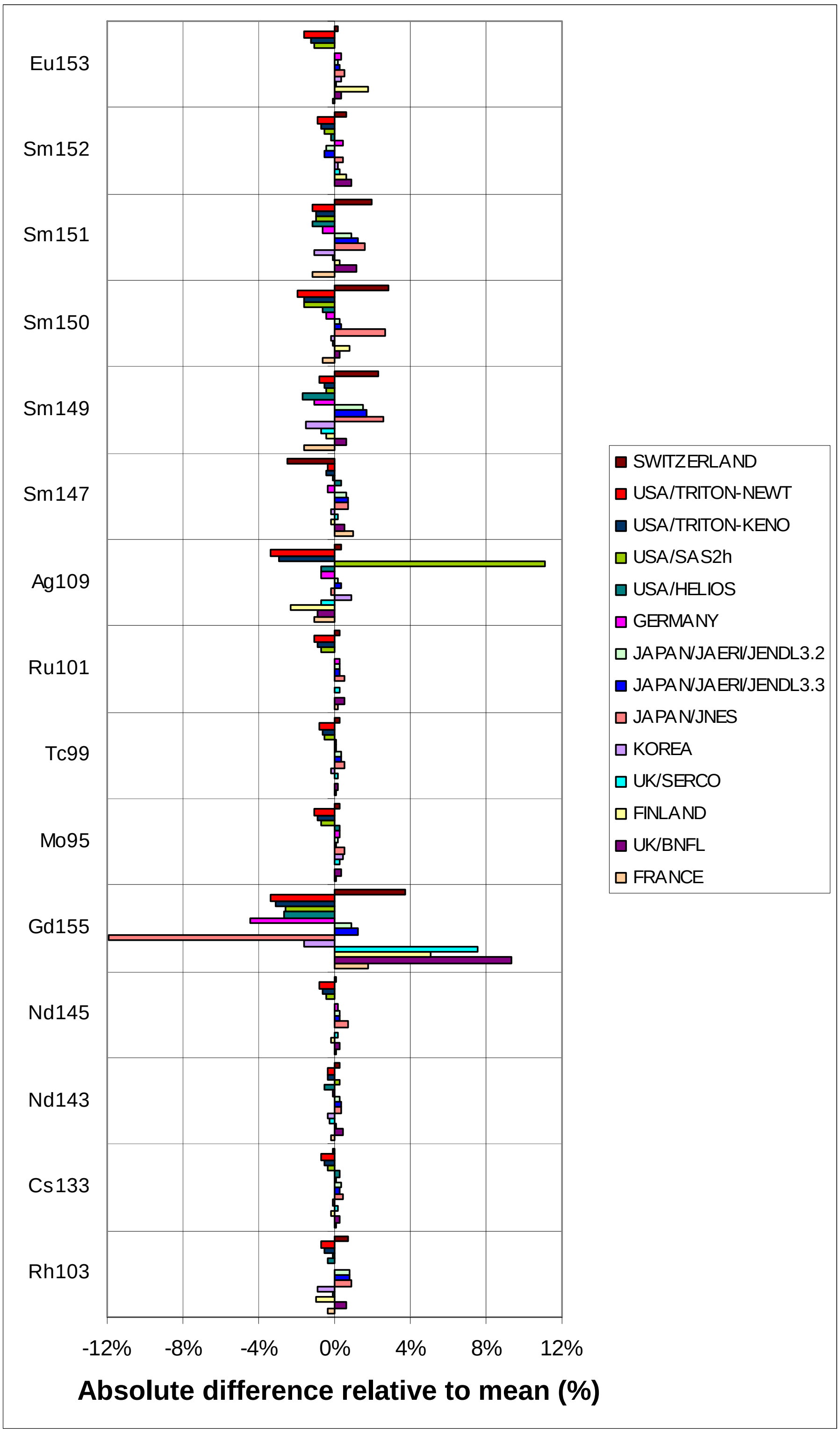


**Figure 6.15. (Case 10/Case 9)-1**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 5 years*
*Absolute difference on actinide concentrations*

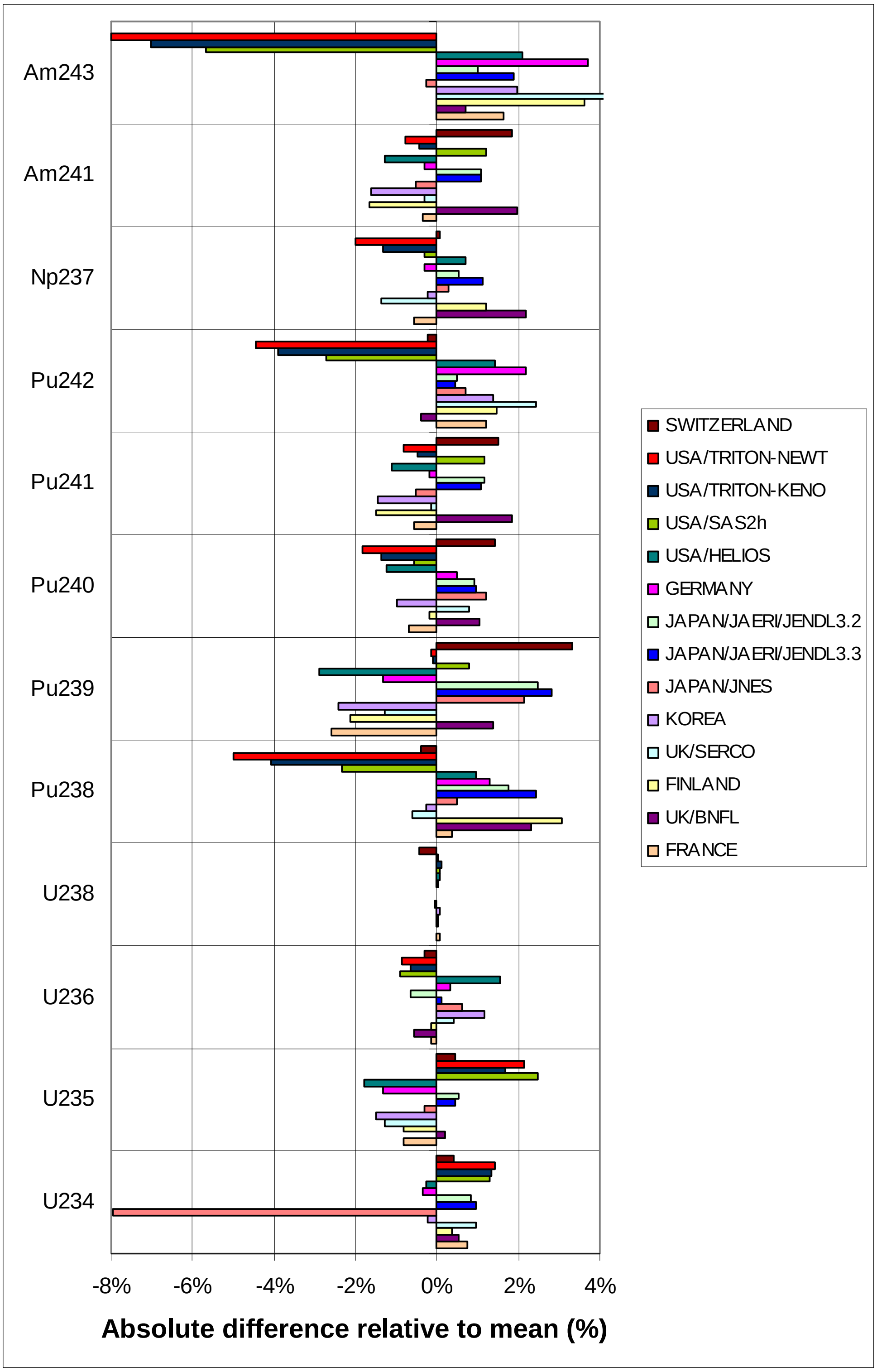


**Figure 6.16. (Case 10/Case 9)-1**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 5 years*
*Absolute difference on fission product concentrations*

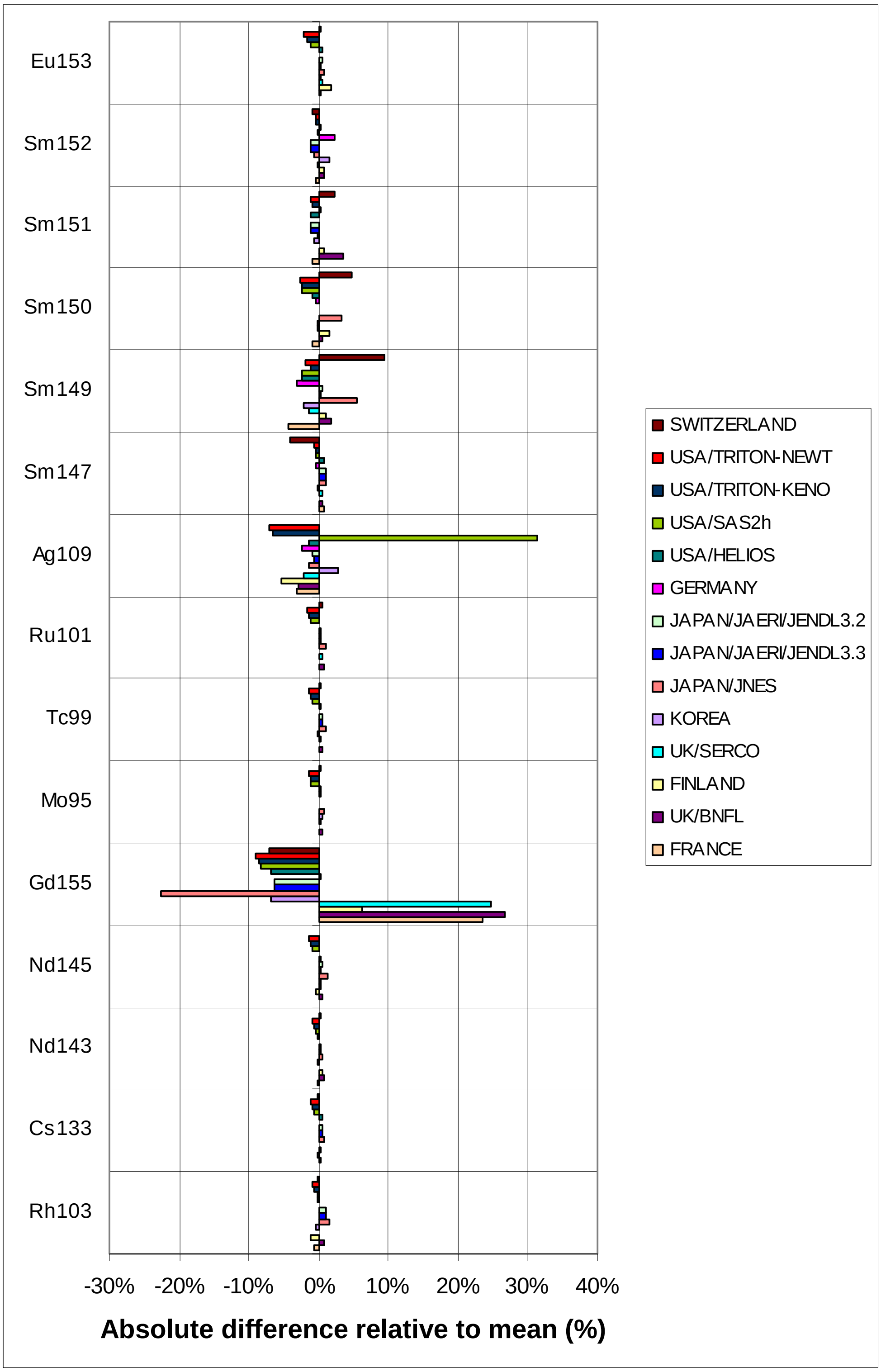


**Figure 6.17. (Case 12/Case 10)-1**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 5 years*
*Absolute difference on actinide concentrations*

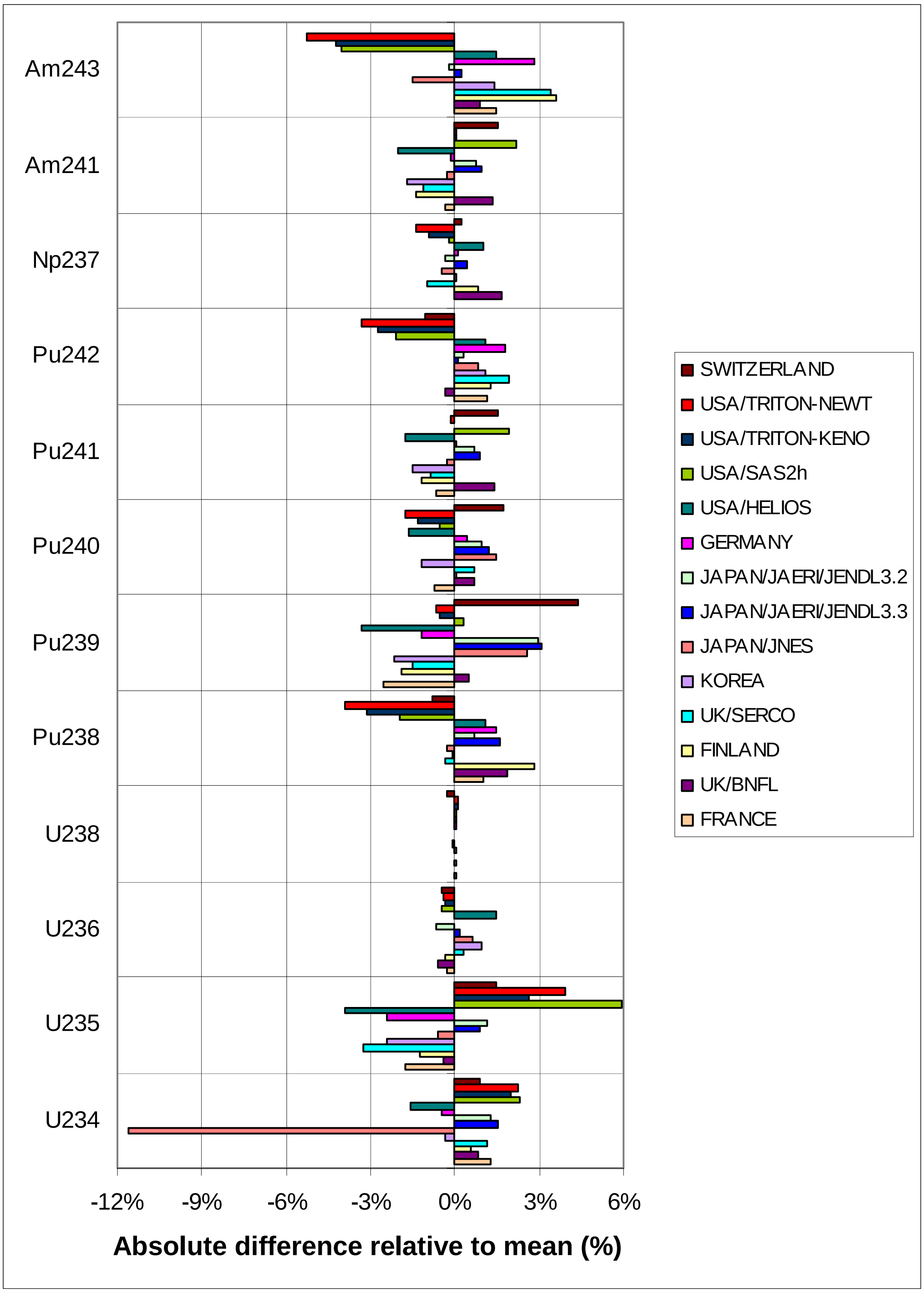
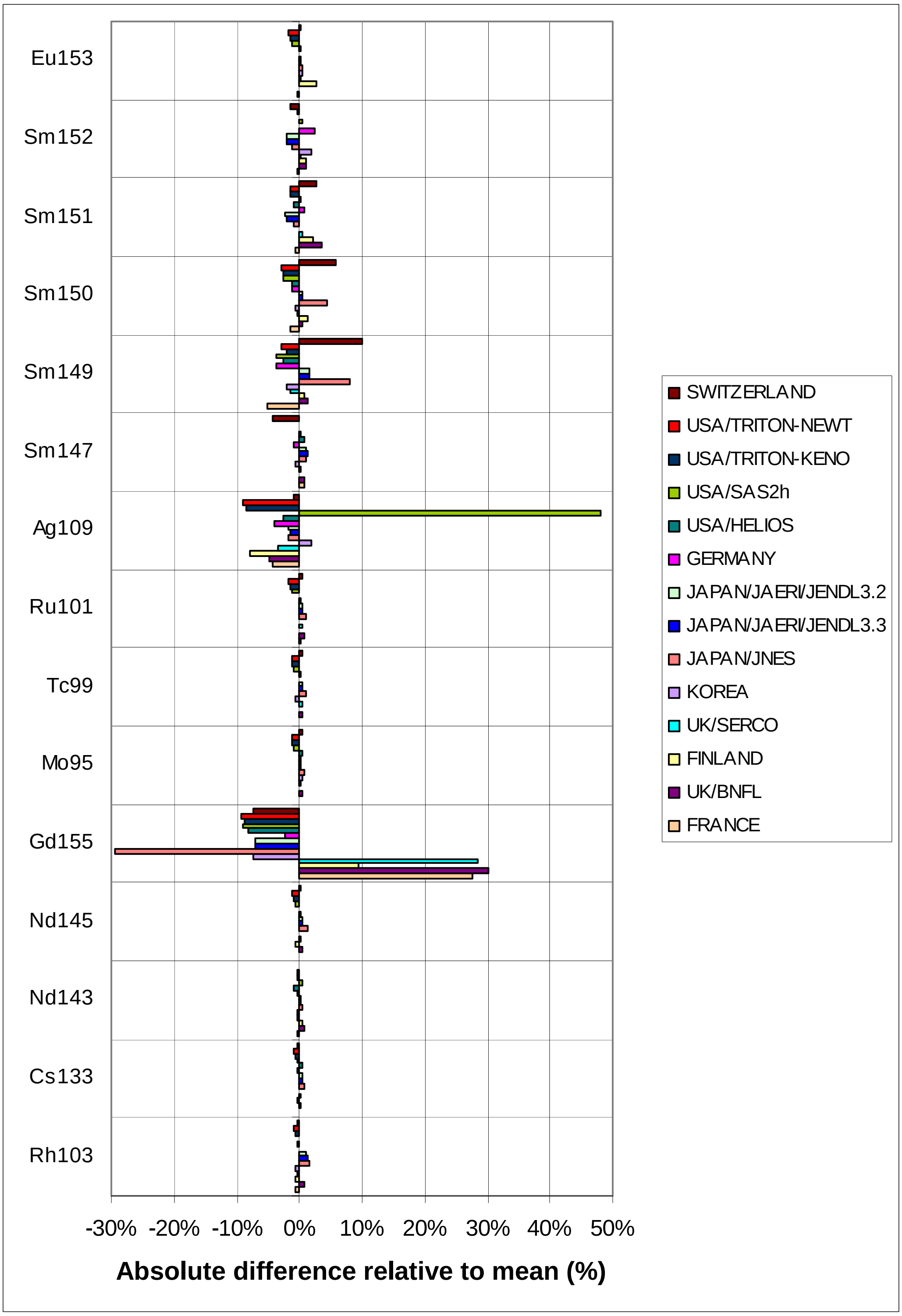


**Figure 6.18. (Case 12/Case 10)-1**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 5 years*
*Absolute difference on fission product concentrations*



## *Chapter 7*

# REACTIVITY EFFECT OF CONTROL ROD INSERTION

## 7.1 Results

The Kinf effect of control rod (CR) insertion, deduced from the neutron multiplication factor calculated by each participant (Table 4.1) is given in pcm in Table 7.1, and expressed in % in Table 7.2. The Kinf effect, expressed in pcm, is graphically presented in Figures 7.1 to 7.12.

The Kinf effect of CR insertion, expressed in pcm, is defined as follows:

$$(\text{Kinf effect})_i = \Delta\text{Kinf}_i = (\text{Kinf}_i\ (\text{with CRs}) - \text{Kinf}_i\ (\text{no CRs})) \times 10^5$$

The Kinf effect of CR insertion, expressed in %, is defined as follows:

$$(\text{Kinf effect})_i = \Delta\text{Kinf}_i/\text{Kinf}_i\ (\text{no CRs}) = [\text{Kinf}_i\ (\text{with CRs})/\text{Kinf}_i\ (\text{no CRs}) - 1] \times 100$$

$\text{Kinf}_i$ is the neutron multiplication factor calculated by participant i.

In addition to this, the tables also present the mean calculated effects of CR insertion, the standard deviation (SD) from the 13 individual contributions and the relative standard deviation (RSD). The average, standard deviation and relative standard deviation are defined in § 3.1.

Figure 7.14 presents the percentage differences of the Kinf effects relative to the mean and Figure 7.15 the relative standard deviation.

## 7.2 Effect of CR insertion

Tables 7.1 and 7.2, and Figure 7.13, show the Kinf increase with CR insertion, due to the neutron spectrum hardening, which enhances a reduced $^{235}U$ depletion, a higher production of fissile plutonium isotopes and an increased plutonium fission (see § 6.2). The maximum increase (9 000 pcm) is obtained when the CRs are inserted from 0 to 45 GWd/t. The minimum (2 200 pcm) is obtained when CRs are inserted from 0 to 15 GWd/t.

The Kinf effect is smaller when FPs are taken into account in the calculations, due to the increase of some FP concentration when CRs are inserted. This induces a higher Kinf decrease (the Kinf decreases when you take into account FPs in addition to actinides) compared to the case where the CRs are not inserted, and hence a lower Kinf effect of CR insertion (see Table 7.1).

On the other hand, when you consider only actinides, there is no significant difference between the Kinf effect without considering cooling time and the Kinf effect with a cooling time of five years. The difference we can observe at 45 GWd/t when we take into account FPs (about 800 pcm) is mainly due to the $^{155}Gd$ concentration. When the cooling time increases, the increase of $^{155}Gd$ concentration due to the insertion of the CRs is less significant (see § 6.2) and results in an increase of the Kinf effect on CR insertion.

Table 5.1 suggests that the effect of CR insertion for a cask will be very similar to the array. Hence, there is no need to analyse in detail the effect of CR insertion on a cask.

## 7.3 Comparison of the calculated effect

Figure 7.14 shows the percentage differences relative to the mean for each participant. These values are due to the absolute difference relative to the mean observed in calculated CR effect on fuel inventories. Thanks to the sensitivity calculations (see § 5), it is easy to link differences in calculated ΔN with differences in calculated ΔKinf.

*$^{234}U$*. The high JNES effects of CR insertion observed in § 6.3 (the absolute difference from the mean value reaches 13% maximum, corresponding to the case when CRs are inserted from 0 to 45 GWd/t) have no impact on ΔKinf values because of the low sensitivity of this nuclide on the Kinf (~ -1 pcm/%).

*$^{235}U$*. The percentage differences relative to the mean obtained from the SAS2h fuel inventory range between +10% to +15%. This is mainly due to the great effect of CR insertion on $^{235}$U concentration compared to the mean value, ranging from 2% to 6% (see § 6.3), which has a significant impact on the Kinf with regard to the sensitivity calculations (about +130 pcm/%).

*$^{243}Am$*. The low USA effects of CR insertion observed in § 6.3 (the absolute difference from the mean value is of -8% at 30 GWd/t) have no impact on ΔKinf values because of the low sensitivity of this nuclide on the Kinf (< -2 pcm/%).

*$^{155}Gd$*. The big disagreement between participants has no impact on ΔKinf values when there is no cooling time because of the low sensitivity of this nuclide on the Kinf (< -0.5 pcm/%). But as this sensitivity increases with the cooling time to reach -15 pcm/%, the impact on ΔKinf is then more important: -500 pcm for France and the UK, and +500 pcm for JNES.

*$^{109}Ag$*. The high USA effects of CR insertion observed in § 6.3 (the absolute difference from the mean value reaches +40% when CRs are inserted from 0 to 45 GWd/t) have a low impact on ΔKinf values (maximum -90 pcm) because of the low sensitivity of this nuclide on the Kinf (< -2 pcm/%).

*$^{239}Pu$*. Because of the high sensitivity of the $^{239}$Pu concentration on the Kinf (about +140 pcm/%), the impact on ΔKinf of differences in the CR effect on the $^{239}$Pu concentration can reach ±500 pcm.

The addition of all these effects on ΔKinf induces percentage differences of the Kinf effect of CR insertion relative to the mean ranging between -10% and +10%.

The RSD on the Kinf effect of CR insertion is graphically presented in Figure 7.15. The RSD lies between 5 and 8%, which corresponds to about 300 pcm.

## 7.4 Prospect

The large effect of CR insertion (9 000 pcm when CRs are inserted from 0 to 45 GWd/t) is due in part to the fact that the CR are axially fully inserted in this benchmark. A more "typical" CR insertion profile will not consider CRs fully inserted during all the irradiation, and particularly over three cycles. A further benchmark (Phase II-E) has been initiated to study the effect of CR insertion with partial axial CR insertion and axial burn-up profile [3].

# Table 7.1. Kinf effect of CR insertion (in pcm)

| ΔK | FRANCE | UK BNFL | FINLAND | UK SERCO | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2a-1a** | 4961 | 5180 | 5006 | 4870 | 5288 | 5415 | 5403 | 4882 | 4754 | 5715 | 5355 | 5665 | 5460 | 5227 | 311 | 5.96% |
| **2b-1b** | 4745 | 4900 | 4493 | 4660 | 4999 | 5185 | 5172 | 4644 | 4475 | 5462 | 5256 | 5387 | 5020 | 4954 | 331 | 6.68% |
| **4a-3a** | 9091 | 9370 | 9027 | 8710 | 9435 | 9564 | 9575 | 9137 | 8700 | 10237 | 9610 | 9782 | 9750 | 9384 | 441 | 4.70% |
| **4b-3b** | 8825 | 9020 | 8595 | 8520 | 9081 | 9368 | 9395 | 8825 | 8382 | 9852 | 9368 | 9515 | 9360 | 9085 | 438 | 4.82% |
| **5b-3b** | 2107 | 2280 | 2156 | 2090 | 2240 | 2284 | 2348 | 2115 | 1968 | 2600 | 2260 | 2355 | 2410 | 2247 | 164 | 7.31% |
| **6b-3b** | 2773 | 3120 | 2977 | 2730 | 3024 | 3109 | 3142 | 2887 | 2701 | 3369 | 2888 | 2998 | 3080 | 2984 | 188 | 6.31% |
| **7b-3b** | 5464 | 5520 | 5204 | 5040 | 5376 | 5667 | 5624 | 5315 | 5087 | 6080 | 5072 | 5511 | 5700 | 5435 | 299 | 5.49% |
| **8b-3b** | 4673 | 5000 | 4662 | 4690 | 4913 | 5107 | 5107 | 4780 | 4436 | 5431 | 5114 | 5214 | 5190 | 4947 | 283 | 5.71% |
| **10a-9a** | 4769 | 4990 | 4706 | 4730 | 5078 | 5275 | 5254 | 4719 | 4579 | 5542 | 5247 | 5446 | 5340 | 5052 | 323 | 6.39% |
| **10b-9b** | 4472 | 4750 | 4299 | 4470 | 5024 | 5277 | 5203 | 4541 | 4552 | 5415 | 5229 | 5373 | 5010 | 4893 | 394 | 8.05% |
| **12a-11a** | 8927 | 9000 | 8853 | 8450 | 9163 | 9375 | 9419 | 8846 | 8602 | 9927 | 9428 | 9627 | 9570 | 9168 | 433 | 4.72% |
| **12b-11b** | 8553 | 8660 | 8370 | 8230 | 9445 | 9618 | 9528 | 8852 | 8441 | 9924 | 9603 | 9677 | 9450 | 9104 | 594 | 6.53% |

# Table 7.2. Kinf effect of CR insertion (%)

| ΔK/K (%) | FRANCE | UK BNFL | FINLAND | UK SERCO | JAPAN JNES | JAPAN JAERI JENDL3.3 | JAPAN JAERI JENDL3.2 | GERMANY | USA HELIOS | USA SAS2h | USA TRITON-KENO | USA TRITON-NEWT | SWITZERLAND | Average | SD | RSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2a-1a** | 4.2% | 4.4% | 4.3% | 4.1% | 4.5% | 4.6% | 4.6% | 4.2% | 4.0% | 4.9% | 4.6% | 4.9% | 4.7% | 4.5% | 0.3% | 6.32% |
| **2b-1b** | 4.3% | 4.4% | 4.1% | 4.2% | 4.5% | 4.7% | 4.7% | 4.2% | 4.1% | 5.1% | 4.8% | 4.9% | 4.6% | 4.5% | 0.3% | 7.10% |
| **4a-3a** | 8.5% | 8.6% | 8.4% | 8.0% | 8.7% | 8.8% | 8.8% | 8.4% | 8.0% | 9.7% | 8.9% | 9.1% | 9.0% | 8.7% | 0.5% | 5.34% |
| **4b-3b** | 9.0% | 9.0% | 8.7% | 8.5% | 9.1% | 9.4% | 9.4% | 8.9% | 8.4% | 10.2% | 9.5% | 9.7% | 9.5% | 9.2% | 0.5% | 5.53% |
| **5b-3b** | 2.1% | 2.3% | 2.2% | 2.1% | 2.3% | 2.3% | 2.4% | 2.1% | 2.0% | 2.7% | 2.3% | 2.4% | 2.4% | 2.3% | 0.2% | 8.02% |
| **6b-3b** | 2.8% | 3.1% | 3.0% | 2.7% | 3.0% | 3.1% | 3.1% | 2.9% | 2.7% | 3.5% | 2.9% | 3.1% | 3.1% | 3.0% | 0.2% | 6.81% |
| **7b-3b** | 5.6% | 5.5% | 5.3% | 5.0% | 5.4% | 5.7% | 5.6% | 5.4% | 5.1% | 6.3% | 5.2% | 5.6% | 5.8% | 5.5% | 0.3% | 6.15% |
| **8b-3b** | 4.8% | 5.0% | 4.7% | 4.7% | 4.9% | 5.1% | 5.1% | 4.8% | 4.5% | 5.6% | 5.2% | 5.3% | 5.3% | 5.0% | 0.3% | 6.36% |
| **10a-9a** | 4.8% | 5.0% | 4.7% | 4.7% | 5.1% | 5.3% | 5.3% | 4.7% | 4.6% | 5.5% | 5.2% | 5.4% | 5.3% | 5.1% | 0.3% | 6.39% |
| **10b-9b** | 4.5% | 4.8% | 4.3% | 4.5% | 5.0% | 5.3% | 5.2% | 4.5% | 4.6% | 5.4% | 5.2% | 5.4% | 5.0% | 4.9% | 0.4% | 8.05% |
| **12a-11a** | 8.9% | 9.0% | 8.9% | 8.5% | 9.2% | 9.4% | 9.4% | 8.8% | 8.6% | 9.9% | 9.4% | 9.6% | 9.6% | 9.2% | 0.4% | 4.72% |
| **12b-11b** | 8.6% | 8.7% | 8.4% | 8.2% | 9.4% | 9.6% | 9.5% | 8.9% | 8.4% | 9.9% | 9.6% | 9.7% | 9.5% | 9.1% | 0.6% | 6.53% |

**Figure 7.1. Kinf effect of CR insertion (pcm) – Case 2a/Case 1a**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days, no FPs*

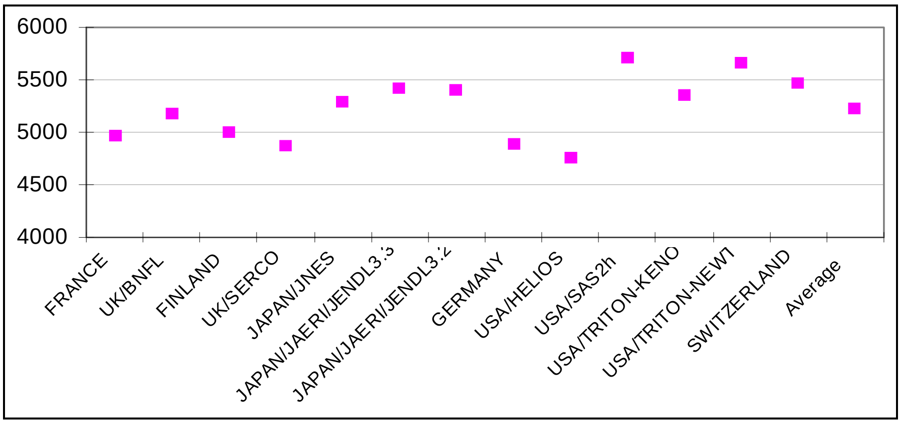



**Figure 7.2. Kinf effect of CR insertion (pcm) – Case 2b/Case 1b**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days, with FPs*

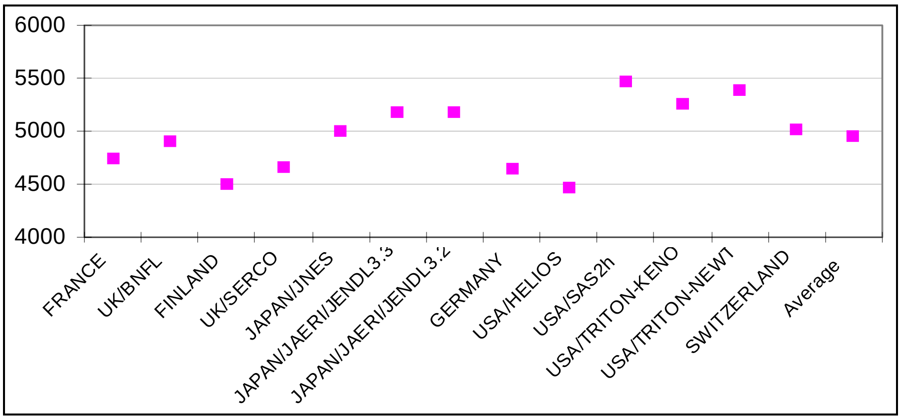



**Figure 7.3. Kinf effect of CR insertion (pcm) – Case 4a/Case 3a**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 0 days, no FPs*

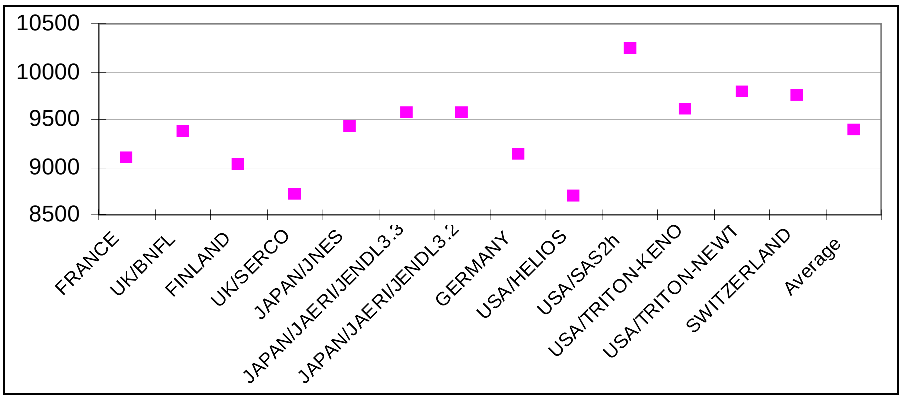


**Figure 7.4. Kinf effect of CR insertion (pcm) – Case 4b/Case 3b**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 0 days, with FPs*

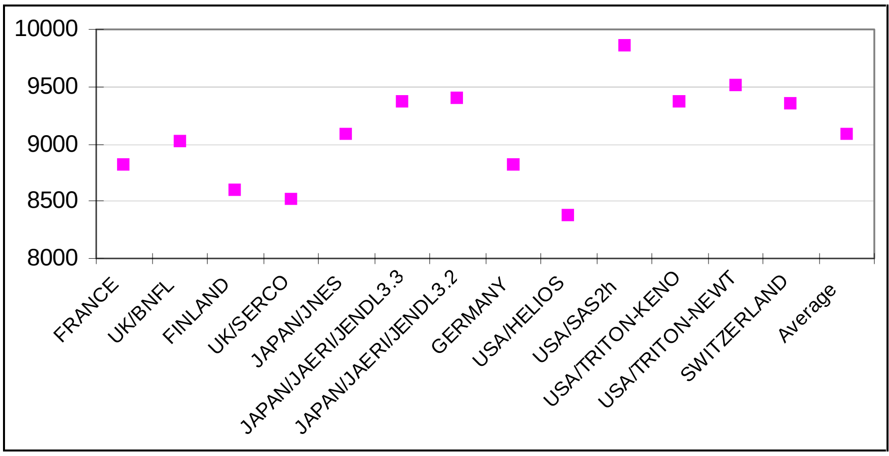



**Figure 7.5. Kinf effect of CR insertion (pcm) – Case 5b/Case 3b**

*UOX 45 GWd/t, effect of 0-15 GWd/t CR insertion, Ctime = 0 days, with FPs*

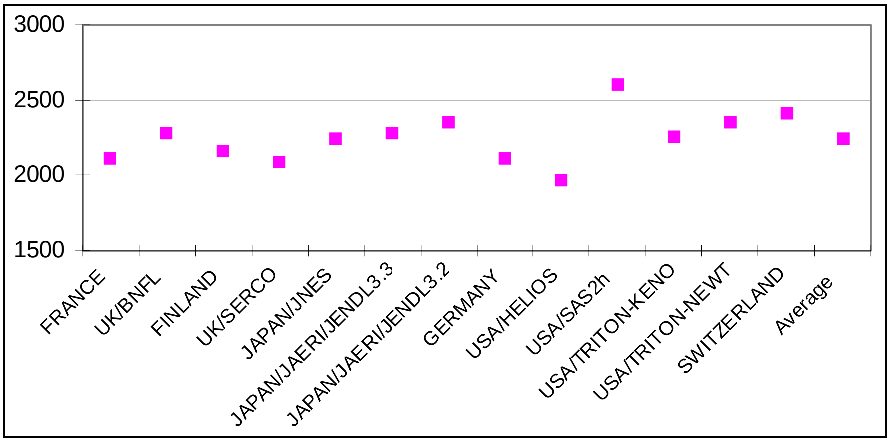



**Figure 7.6. Kinf effect of CR insertion (pcm) – Case 6b/Case 3b**

*UOX 45 GWd/t, effect of 15-30 GWd/t CR insertion, Ctime = 0 days, with FPs*

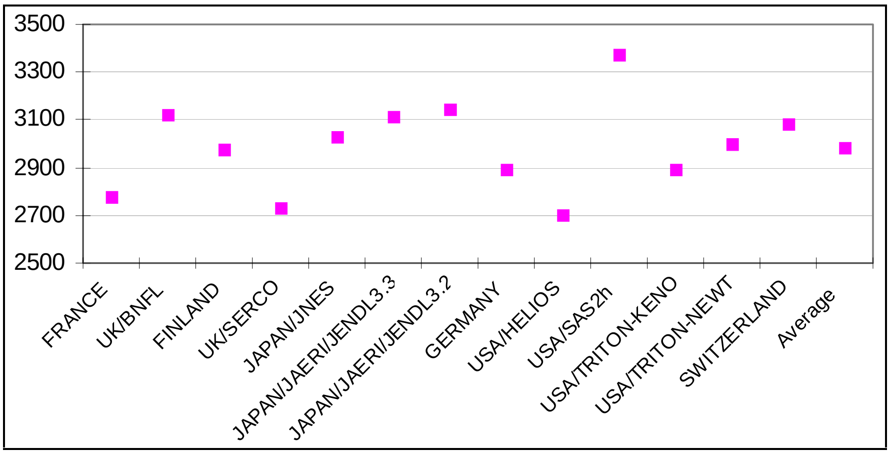


**Figure 7.7. Kinf effect of CR insertion (pcm) – Case 7b/Case 3b**

*UOX 45 GWd/t, effect of 30-45 GWd/t CR insertion, Ctime = 0 days, with FPs*

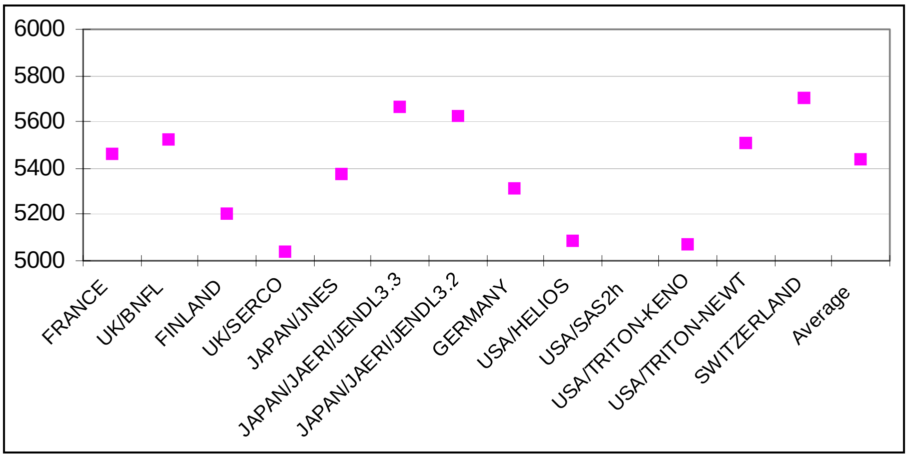



**Figure 7.8. Kinf effect of CR insertion (pcm) – Case 8b/Case 3b**

*UOX 45 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 0 days, with FPs*

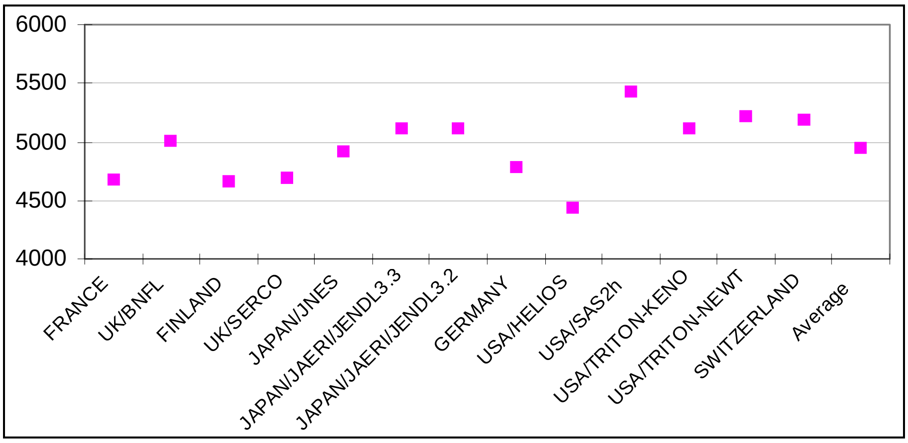



**Figure 7.9. Kinf effect of CR insertion (pcm) – Case 10a/Case 9a**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 5 years, no FPs*

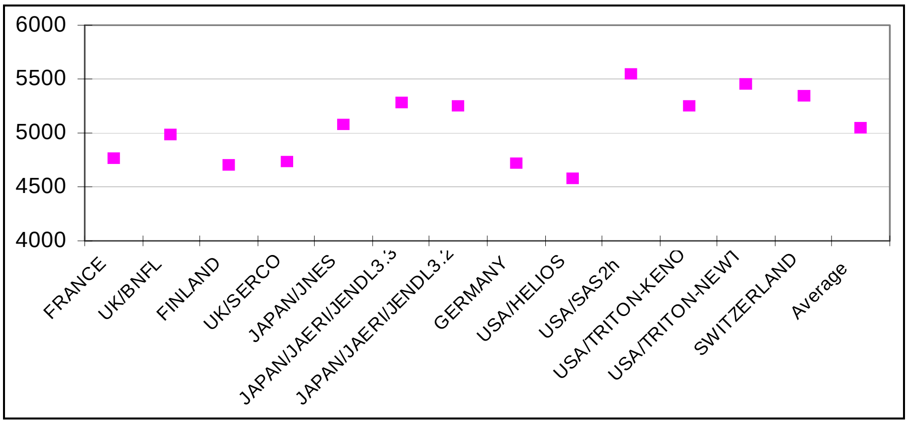


**Figure 7.10. Kinf effect of CR insertion (pcm) – Case 10b/Case 9b**

*UOX 30 GWd/t, effect of 0-30 GWd/t CR insertion, Ctime = 5 years, with FPs*

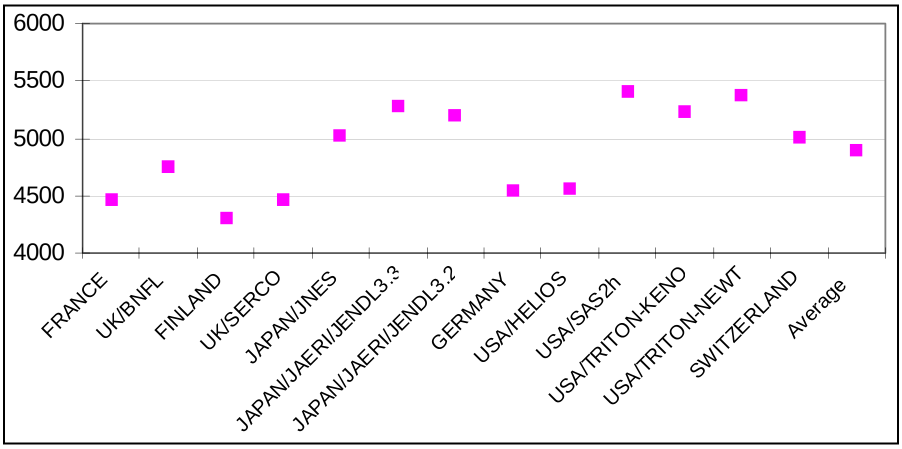



**Figure 7.11. Kinf effect of CR insertion (pcm) – Case 12a/Case 11a**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 5 years, no FPs*

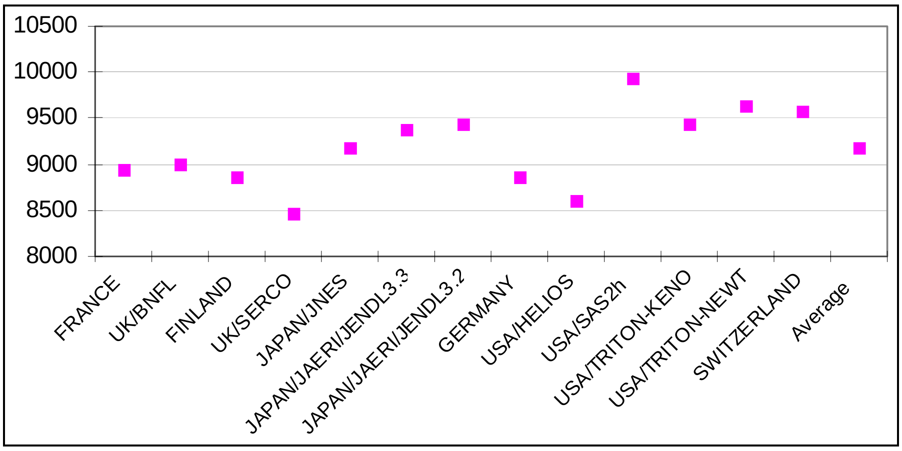



**Figure 7.12. Kinf effect of CR insertion (pcm) – Case 12b/Case 11b**

*UOX 45 GWd/t, effect of 0-45 GWd/t CR insertion, Ctime = 5 years, with FPs*

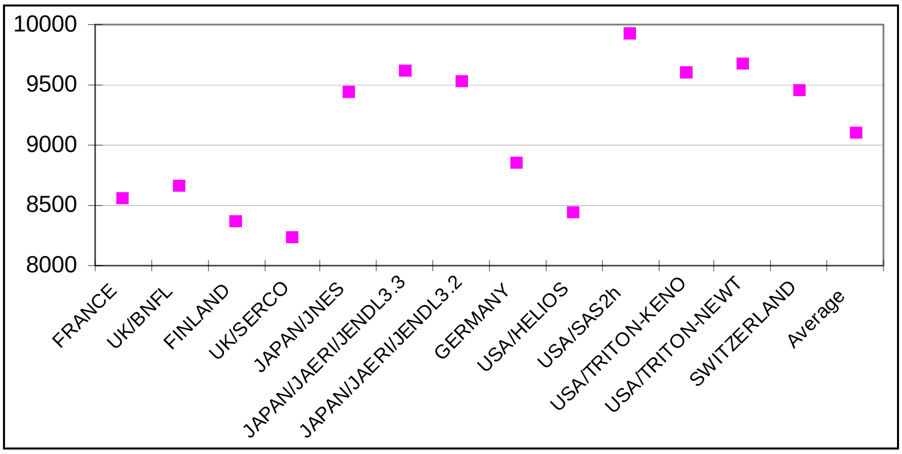


**Figure 7.13. Mean Kinf effect of CR insertion (in pcm)**

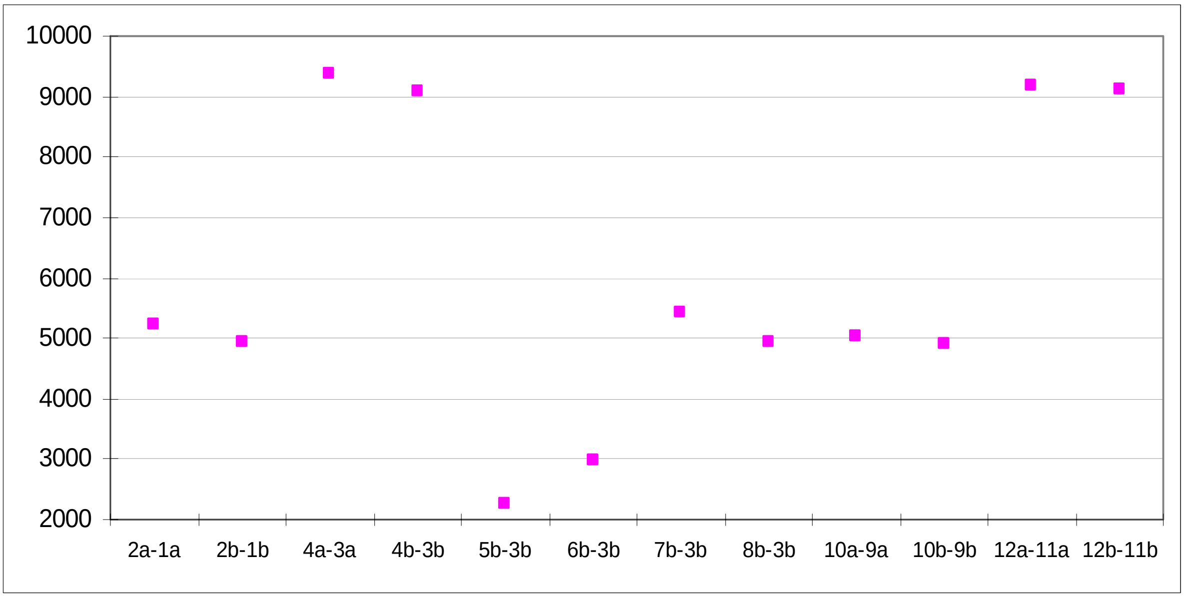



**Figure 7.14. Kinf effect of CR insertion**

*Percentage difference relative to the mean*

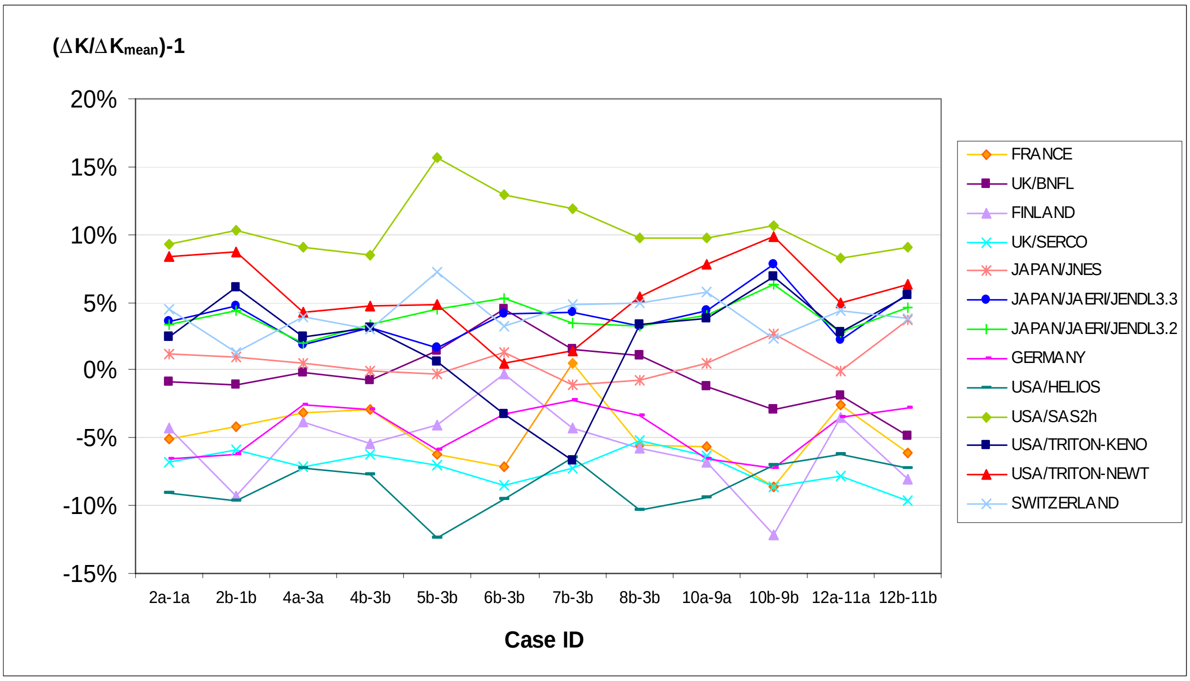
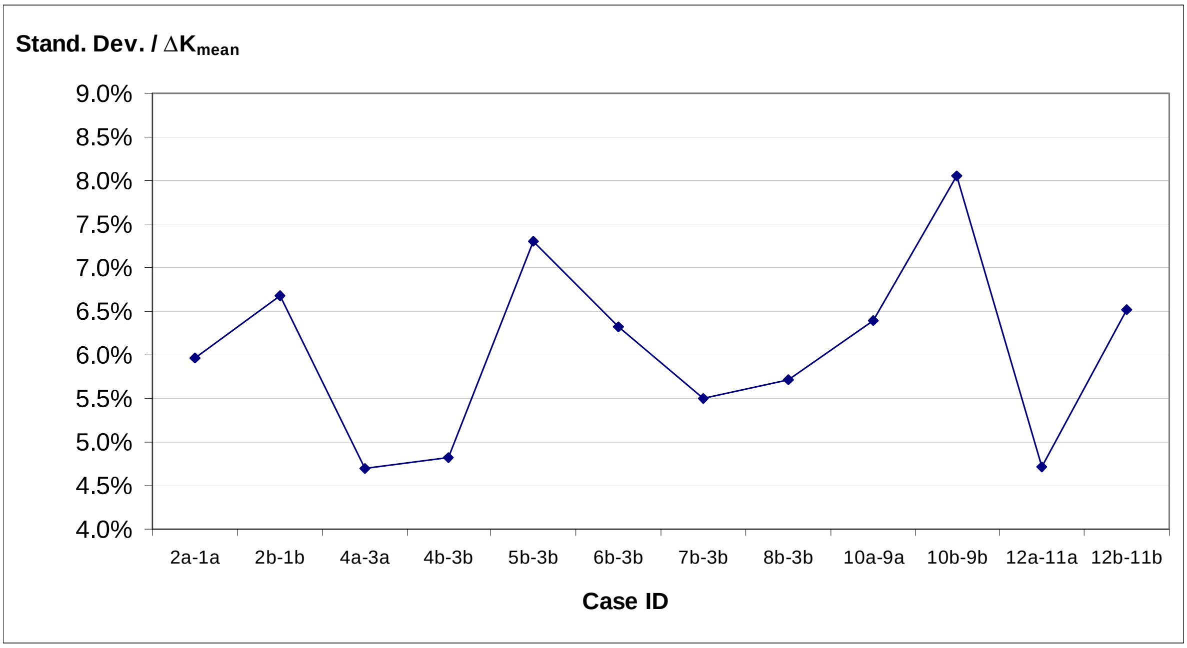


**Figure 7.15. Relative standard deviation on Kinf effect of CR insertion**



## *Chapter 8*

## CONCLUSION

The OECD/NEA Expert Group on Burn-up Credit Criticality Safety has produced this benchmark with the intention of undertaking an initial investigation into the effects of CR insertion observed with $UO_2$ fuel for combinations of computer codes and data libraries currently being used around the world.

For this purpose, a range of CR insertion profiles during irradiation have been defined and participants were asked to calculate the spent fuel inventory and the neutron multiplication factor for each case.

To assist in the evaluation of the benchmark results, the sensitivity of the neutron multiplication factor to a variation of isotope concentrations have been performed by a limited number of participants.

In total, 14 contributions submitted results to the Phase II-D benchmark exercise, coming from ten different companies/organisations from eight countries around the world, including one which has not performed neutron multiplication factors, and four which have made in addition to this, the sensitivity exercise.

Analysis of the nuclide concentration effect of CR insertion shows good agreement between participants except for the $^{155}$Gd nuclide: the absolute difference from the mean value is less than 10%, but reaches 50% for the $^{155}$Gd.

Analysis of the Kinf effect of CR insertion shows a good agreement between participants. The relative standard deviation is about 6%, which corresponds to 300 pcm. The percentage differences relative to the mean value lie between -15% and +15%. Most of the participants are in the range of ±5%.

Analysis of the sensitivity exercises shows that the nuclides which have the most important effect on Kinf or Keff are the $^{235}$U (+140 pcm/%), $^{238}$U (-120 pcm/%), $^{239}$Pu (+140 pcm/%), $^{240}$Pu (-40 pcm/%) and $^{241}$Pu (+50 pcm/%). The effect of other nuclides is less than 20 pcm/%, with most contributing less than 5 pcm/%.

The large effect of CR insertion (9 000 pcm when CRs are inserted from 0 to 45 GWd/t) is due in part to the fact that the CR are axially fully inserted in this benchmark. A more “typical” CR insertion profile will not consider CRs fully inserted during all the irradiation, particularly over three cycles. A further benchmark has been initiated to study the effect of CR insertion considering partial axial CR insertion and an axial burn-up profile.

## REFERENCES


[1] Venard, C., B. Camous, S. Mengelle, H. Toubon, "Contribution of the Experimental Validation of the French Criticality-Safety Package CRISTAL V1: APOLLO2 SN Route", *ICNC2003*, Tokai, Japan, 20-24 October 2003.

[2] Dehart, M.D., M.C. Brady, C.V. Parks, *OECD/NEA Burn-up Credit Calculational Criticality Benchmark Phase-IB, Isotopic Prediction: Final Report*, ORNL-6901, NEA/NSC/DOC(1996)6, June 1996.

[3] Working Party on Nuclear Criticality Safety Expert Group on Burn-up Credit Criticality, *Summary Record of the Thirteenth Meeting*, Prague, Czech Republic, 2 September 2004, NEA/NSC/WPNCS/DOC(2004)8.

[4] Roque, B., A. Santamarina, N. Thiollay, "Burn-up Credit Calculation Route for PWR MOX Assemblies and Experimental Validation in MINERVE R1-MOX and SLB1 P.I.E.", *IAEA Technical Committee Meeting on the Requirements, Practices and Developments in Burn-up Credit Applications*, Madrid, Spain, April 2002.

# *Appendix A*

## PROBLEM SPECIFICATION FOR THE NEA NUCLEAR SCIENCE COMMITTEE BURN-UP CREDIT BENCHMARK PHASE II-D

*Study of Control Rod Effects*


*A. Barreau*
CEA, France

*J. Gulliford*
BNFL, United Kingdom

*J.C. Wagner*
ORNL, United States

## 1. Introduction

Taking credit for changes to fuel composition during irradiation in spent fuel criticality analyses (BUC) normally requires that a depletion calculation is made. Some depletion parameters have an important effect on nuclide concentration, and hence on spent fuel reactivity. This benchmark proposes a study of the effect of control rod (CR) modelling on calculated spent fuel composition.

The presence of control rods during the depletion of a $UO_2$ assembly results in hardening of the irradiation neutron spectrum (due to the removal of thermal neutrons by capture and by displacement of moderator). This in turn leads to an increased production rate of fissile plutonium isotopes and a decrease in $^{235}U$ fission rate. An assembly that experienced CR insertion during irradiation can therefore have a higher reactivity than a similar assembly that had not been exposed to CRs.

This main part of this benchmark is divided into two sets of calculations:

- depletion calculations for a $UO_2$ assembly;
- Kinf calculations on an infinite array of irradiated $UO_2$ assemblies in cold water.

The depletion calculations are made for two levels of burnup, (30 GWd/tU and 45 GWd/tU), and two cooling times, (zero and five years). A range of CR insertion profiles during irradiation is defined and participants are asked to calculate the spent fuel inventory in each case. The Kinf values for the infinite array provide a simple means of assessing the impact of differences in calculated inventory on neutron multiplication factors for spent fuel.

To facilitate more detailed analysis of the effects of differences in calculated inventories, further calculations will be made by a limited number of participants. These will provide sensitivity coefficients, $\left(\frac{\delta K}{\delta n}\right)_i$, by isotope for both the infinite array and for a spent fuel cask environment. These calculations are specified in Annexes 1 and 2. It is anticipated that two or three sets of results will be submitted for this part of the benchmark.

## 2. Depletion calculation

### *2.1 Geometry data*

We propose to model a $UO_2$ $17 \times 17$ assembly, as shown in Figure 1 (translational boundary conditions). In some cases, (see Table 2), the 24 guide tubes will contain control rods during all or part of the irradiation. The central guide tube is always “un-rodded”. Un-rodded guide tubes contain water.

The geometry of the various cells is defined in Figure 2.

### *2.2 $UO_2$ fuel composition (concentrations in atom/barn.cm)*

The $UO_2$ fuel has an initial enrichment of 4 wt.% $^{235}U$:

$^{234}U$ 7.834E-06
$^{235}U$ 9.097E-04
$^{236}U$ 2.967E-06
$^{238}U$ 2.155E-02
$^{16}O$ 4.493E-02

### 2.3 *Non-fissile material composition (concentrations in atom/barn.cm)*

| ***Fuel clad*** | ***Moderator*** (456 ppm of bore) | ***Guide tube*** | ***Absorber*** | ***Absorber clad*** |
|---|---|---|---|---|
| Fe 1.383E-04<br>Cr 7.073E-05<br>O 2.874E-04<br>Zr 3.956E-02 | H 4.860E-02<br>O 2.430E-02<br>$^{10}$B 3.692E-06<br>$^{11}$B 1.477E-05 | Fe 1.476E-04<br>Cr 7.549E-05<br>O 3.067E-04<br>Zr 4.222E-02 | Ag 4.491E-02<br>Cd 2.624E-03<br>$^{115}$In 7.574E-03 | Fe 5.565E-02<br>Ni 7.500E-03<br>Cr 1.524E-02<br>Mn 8.013E-04<br>Si 6.269E-04 |

### 2.4 *Parameters for depletion calculation*

| **Fuel temperature** | **Clad temperature** | **Moderator temperature** | **Power concentration** |
|---|---|---|---|
| 873 K | 673 K | 573 K | 38 W/gU |

### 2.5 *Irradiation histories*

The requested calculations must be performed to attain a total burn-up for the $UO_2$ assembly of 30 GWd/tU and 45 GWd/tU. The irradiation is continuous, with a power concentration of 38 W/gU.

The inventory is calculated at discharge (zero cooling) and for a cooling time of five years.

## 3. Kinf calculation

### 3.1 *Geometry data*

The Kinf calculations are to be performed on an infinite array of $UO_2$ assemblies in cold water (293 K). The $17 \times 17$ $UO_2$ assemblies include 25 guide tubes full of water (the CRs are removed at discharge). The water gap between each assembly is of 4 cm (see Figure 1).

### 3.2 *Material compositions (concentrations in atom/barn.cm)*

| **Spent fuel** | **Fuel clad** | **Guide tube** | **Water** |
|---|---|---|---|
| See § 3.3 | Fe 1.383E-04<br>Cr 7.073E-05<br>O 2.874E-04<br>Zr 3.956E-02 | Fe 1.476E-04<br>Cr 7.549E-05<br>O 3.067E-04<br>Zr 4.222E-02 | H 6.662E-02<br>O 3.331E-02 |

### 3.3 *Spent fuel composition*

The Kinf calculations use either the spent fuel inventories from depletion calculations (see § 2), or the spent fuel inventories given in Table 1. No burn-up profile is considered. Depending on the case number (see Table 3), the fuel inventory is composed of:

- either actinides only: $^{234}U$, $^{235}U$, $^{236}U$, $^{238}U$, $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Pu$, $^{242}Pu$, $^{237}Np$, $^{241}Am$, $^{243}Am$ and $^{16}O$;

- or actinides + FPs: $^{234}U$, $^{235}U$, $^{236}U$, $^{238}U$, $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Pu$, $^{242}Pu$, $^{237}Np$, $^{241}Am$, $^{243}Am$, $^{103}Rh$, $^{133}Cs$, $^{143}Nd$, $^{145}Nd$, $^{155}Gd$, $^{95}Mo$, $^{99}Tc$, $^{101}Ru$, $^{109}Ag$, $^{147}Sm$, $^{149}Sm$, $^{150}Sm$, $^{151}Sm$, $^{152}Sm$, $^{153}Eu$ and $^{16}O$.

## 4. Parameters required and case number

### *4.1 Fuel inventory*

Twelve cases of fuel inventory calculation are requested (see Table 2). In the reference cases, the $UO_2$ assembly has no CRs inserted (Cases 1, 3, 9, 11). Some cases consider CRs present in the $UO_2$ assembly during all the depletion (Cases 2, 4, 10, 12), others during part of the depletion (Cases 5, 6, 7, 8). For example, in Case 6, the period of CR insertion is from 15 to 30 GWd/tU. Here the guide tubes are full of water from 0 to 15 GWd/tU, then with CRs (except the central guide tube) from 15 to 30 GWd/tU, and finally back to water from 30 to 45 GWd/tU.

The fuel inventory is calculated on the $UO_2$ average assembly and concerns the 27 BUC nuclides:

- Actinides: $^{234}U$, $^{235}U$, $^{236}U$, $^{238}U$, $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Pu$, $^{242}Pu$, $^{237}Np$, $^{241}Am$, $^{243}Am$.

- FPs: $^{103}Rh$, $^{133}Cs$, $^{143}Nd$, $^{145}Nd$, $^{155}Gd$, $^{95}Mo$, $^{99}Tc$, $^{101}Ru$, $^{109}Ag$, $^{147}Sm$, $^{149}Sm$, $^{150}Sm$, $^{151}Sm$, $^{152}Sm$, $^{153}Eu$.

### *4.2 Kinf calculation*

Twenty-three cases of Kinf calculation are specified (see Table 3). Cases 1 to 12 use the spent fuel inventory cases defined in Table 2, Cases 13 and 14 use the spent fuel inventories given in Table 1, and Case 15 uses the fresh fuel composition. Cases 1, 2, 3, 4, 9, 10, 11 and 12 consider either actinides only (symbolised by the letter “a”), or actinides + FPs (symbolised by the letter “b”).

## 5. Requested information and results

Please forward the results by an electronic mail to A. Barreau at CEA (barreaua@drncad.cea.fr). E-mail is the preferred way for us to receive your data. If possible, please avoid sending the results by diskette as this may cause compatibility problems. This electronic mail must be composed of two files:

1. Fuel inventory results.

2. Kinf results.

### *5.1 Fuel inventory results*

The “Fuel inventory results” file must be composed as follows:

| Line No. | Contents |
|---|---|
| 1 | “Fuel inventory calculation” |
| 2 | Date |
| 3 | Institute |
| 4 | Contact person |
| 5 | E-mail address or telefax number of the contact person |
| 6 | Computer code |
| 7 | *Case 1* |
| 8 | Nuclide concentration (atom/barn.cm) of $^{234}$U |
| 9 | Nuclide concentration (atom/barn.cm) of $^{235}$U |
| 10 | Nuclide concentration (atom/barn.cm) of $^{236}$U |
| 11 | Nuclide concentration (atom/barn.cm) of $^{238}$U |
| 12 | Nuclide concentration (atom/barn.cm) of $^{238}$Pu |
| 13 | Nuclide concentration (atom/barn.cm) of $^{239}$Pu |
| 14 | Nuclide concentration (atom/barn.cm) of $^{240}$Pu |
| 15 | Nuclide concentration (atom/barn.cm) of $^{241}$Pu |
| 16 | Nuclide concentration (atom/barn.cm) of $^{242}$Pu |
| 17 | Nuclide concentration (atom/barn.cm) of $^{237}$Np |
| 18 | Nuclide concentration (atom/barn.cm) of $^{241}$Am |
| 19 | Nuclide concentration (atom/barn.cm) of $^{243}$Am |
| 20 | Nuclide concentration (atom/barn.cm) of $^{103}$Rh |
| 21 | Nuclide concentration (atom/barn.cm) of $^{133}$Cs |
| 22 | Nuclide concentration (atom/barn.cm) of $^{143}$Nd |
| 23 | Nuclide concentration (atom/barn.cm) of $^{145}$Nd |
| 24 | Nuclide concentration (atom/barn.cm) of $^{55}$Gd |
| 25 | Nuclide concentration (atom/barn.cm) of $^{95}$Mo |
| 26 | Nuclide concentration (atom/barn.cm) of $^{99}$Tc |
| 27 | Nuclide concentration (atom/barn.cm) of $^{101}$Ru |
| 28 | Nuclide concentration (atom/barn.cm) of $^{109}$Ag |
| 29 | Nuclide concentration (atom/barn.cm) of $^{147}$Sm |
| 30 | Nuclide concentration (atom/barn.cm) of $^{149}$Sm |
| 31 | Nuclide concentration (atom/barn.cm) of $^{150}$Sm |
| 32 | Nuclide concentration (atom/barn.cm) of $^{151}$Sm |
| 33 | Nuclide concentration (atom/barn.cm) of $^{152}$Sm |
| 34 | Nuclide concentration (atom/barn.cm) of $^{153}$Eu |
| 35 | *Case 2* |
| 36 to 62 | As for items 8 to 34 |
| 63 | *Case 3* |
| 64 to 90 | As for items 8 to 34 |
| 91 | *Case 4* |
| 92 to 118 | As for items 8 to 34 |
| 119 | *Case 5* |
| 120 to 146 | As for items 8 to 34 |
| 147 | *Case 6* |
| 148 to 174 | As for items 8 to 34 |
| 175 | *Case 7* |
| 176 to 202 | As for items 8 to 34 |
| 203 | *Case 8* |
| 204 to 230 | As for items 8 to 34 |
| 231 | *Case 9* |
| 232 to 258 | As for items 8 to 34 |

| | |
|---|---|
| 259 | *Case 10* |
| 260 to 286 | As for items 8 to 34 |
| 287 | *Case 11* |
| 288 to 314 | As for items 8 to 34 |
| 315 | *Case 12* |
| 316 to 342 | As for items 8 to 34 |
| 343~ | Please describe your analysis environment here. It will be included in phase IID report. The description should include:<br>Institute and country<br>Participants<br>Neutron data library<br>Neutron data processing code or method<br>Neutron energy groups<br>Description of your code system<br>Geometry modelling (3-D, 2-D, etc.)<br>Omitted nuclides if any<br>Omitted cases if any<br>Other related information |

### *5.2 Kinf results*

The "Kinf results" file must be composed as follows:

| Line No. | Contents |
|---|---|
| 1 | "Kinf calculation" |
| 2 | Date |
| 3 | Institute |
| 4 | Contact person |
| 5 | E-mail address or telefax number of the contact person |
| 6 | Computer code |
| 7 to 29 | Kinf of Cases 1a, 1b, 2a, 2b, 3a, 3b, 4a, 4b, 5b, 6b, 7b, 8b, 9a, 9b, 10a, 10b, 11a, 11b, 12a, 12b, 13b, 14b, 15 |
| 30~ | Please describe your analysis environment here. It will be included in phase IID report. The description should include:<br>Institute and country<br>Participants<br>Neutron data library<br>Neutron data processing code or method<br>Neutron energy groups<br>Description of your code system<br>Geometry modelling (3-D , 2-D, etc.)<br>Omitted nuclides if any<br>Omitted cases if any<br>Other related information |

**Table 1. Spent fuel composition for Kinf calculation***

| Isotopes | Average BU = 45 GWd/tU Cooling time five years Assembly without CRs | Average BU = 45 GWd/tU Cooling time five years Assembly with CRs |
|---|---|---|
| $^{234}U$ | 4.191E-06 | 4.081E-06 |
| $^{235}U$ | 1.844E-04 | 2.404E-04 |
| $^{236}U$ | 1.184E-04 | 1.163E-04 |
| $^{238}U$ | 2.084E-02 | 2.070E-02 |
| $^{237}Np$ | 1.373E-05 | 1.675E-05 |
| $^{238}Pu$ | 5.796E-06 | 7.543E-06 |
| $^{239}Pu$ | 1.291E-04 | 1.974E-04 |
| $^{240}Pu$ | 5.893E-05 | 6.690E-05 |
| $^{241}Pu$ | 2.772E-05 | 3.760E-05 |
| $^{242}Pu$ | 1.603E-05 | 1.517E-05 |
| $^{241}Am$ | 8.573E-06 | 1.176E-05 |
| $^{243}Am$ | 3.473E-06 | 3.790E-06 |
| $^{95}Mo$ | 5.729E-05 | 5.587E-05 |
| $^{99}Tc$ | 5.706E-05 | 5.606E-05 |
| $^{101}Ru$ | 5.587E-05 | 5.566E-05 |
| $^{103}Rh$ | 3.086E-05 | 3.229E-05 |
| $^{109}Ag$ | 4.870E-06 | 5.102E-06 |
| $^{133}Cs$ | 5.868E-05 | 5.743E-05 |
| $^{143}Nd$ | 3.836E-05 | 4.114E-05 |
| $^{145}Nd$ | 3.287E-05 | 3.221E-05 |
| $^{147}Sm$ | 9.240E-06 | 8.672E-06 |
| $^{149}Sm$ | 1.511E-07 | 2.154E-07 |
| $^{150}Sm$ | 1.429E-05 | 1.445E-05 |
| $^{151}Sm$ | 5.450E-07 | 8.359E-07 |
| $^{152}Sm$ | 5.045E-06 | 4.642E-06 |
| $^{153}Eu$ | 6.050E-06 | 6.180E-06 |
| $^{155}Gd$ | 2.152E-07 | 3.139E-07 |
| $^{16}O$ | 4.493E-02 | 4.493E-02 |

* For Cases 13b and 14b, see Table 3.

**Table 2. Parameters and case number for fuel inventory**

| Cooling time | CRs | Period of CR insertion | Fuel inventory burn-up | Case number |
|---|---|---|---|---|
| 0 day (end of irradiation) | No | – | 30 GWd/tU | 1 |
| | Yes | 0-30 GWd/tU | 30 GWd/tU | 2 |
| | No | – | 45 GWd/tU | 3 |
| | Yes | 0-45 GWd/tU | 45 GWd/tU | 4 |
| | Yes | 0-15 GWd/tU | 45 GWd/tU | 5 |
| | Yes | 15-30 GWd/tU | 45 GWd/tU | 6 |
| | Yes | 30-45 GWd/tU | 45 GWd/tU | 7 |
| | Yes | 0-30 GWd/tU | 45 GWd/tU | 8 |
| Five years | No | – | 30 GWd/tU | 9 |
| | Yes | 0-30 GWd/tU | 30 GWd/tU | 10 |
| | No | – | 45 GWd/tU | 11 |
| | Yes | 0-45 GWd/tU | 45 GWd/tU | 12 |

**Table 3. Parameters and case number for Kinf calculation**

| Fuel inventory case number (BU, C time, CR) | FPs | Kinf calculation case no. | Fuel inventory Case number (BU, C time, CR) | FPs | Kinf calculation case no. |
|---|---|---|---|---|---|
| 1 (30, 0 d, no) | No | 1a | 9 (30, 5 y, no) | No | 9a |
| | Yes | 1b | | Yes | 9b |
| 2 (30, 0 d, yes) | No | 2a | 10 (30, 5 y, yes) | No | 10a |
| | Yes | 2b | | Yes | 10b |
| 3 (45, 0 d, no) | No | 3a | 11 (45, 5 y, no) | No | 11a |
| | Yes | 3b | | Yes | 11b |
| 4 (45, 0 d, yes) | No | 4a | 12 (45, 5 y, yes) | No | 12a |
| | Yes | 4b | | Yes | 12b |
| 5 (45, 0 d, yes) | Yes | 5b | See Table 1 Ass. without CRs | Yes | 13b |
| 6 (45, 0 d, yes) | Yes | 6b | See Table 1 Ass. with CRs | Yes | 14b |
| 7 (45, 0 d, yes) | Yes | 7b | Fresh fuel | – | 15 |
| 8 (45, 0 d, yes) | Yes | 8b | | | |

**Figure 1. $UO_2$ assembly geometry**

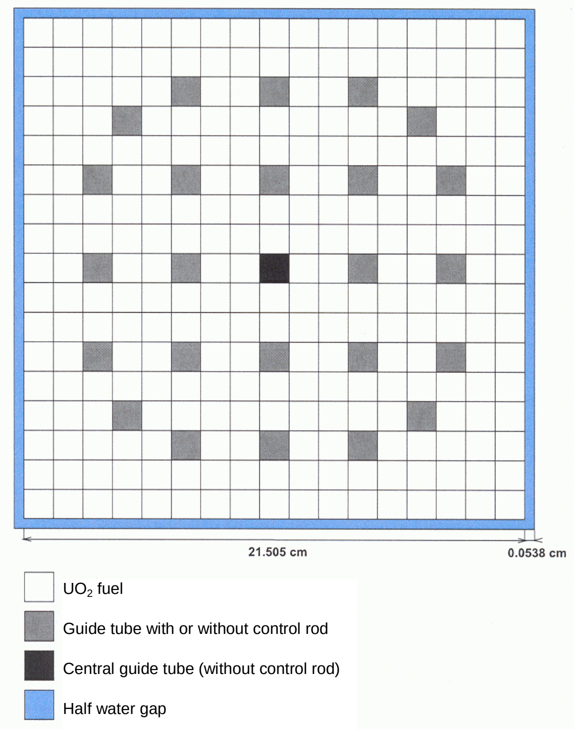



**Figure 2. Fuel cell geometry**

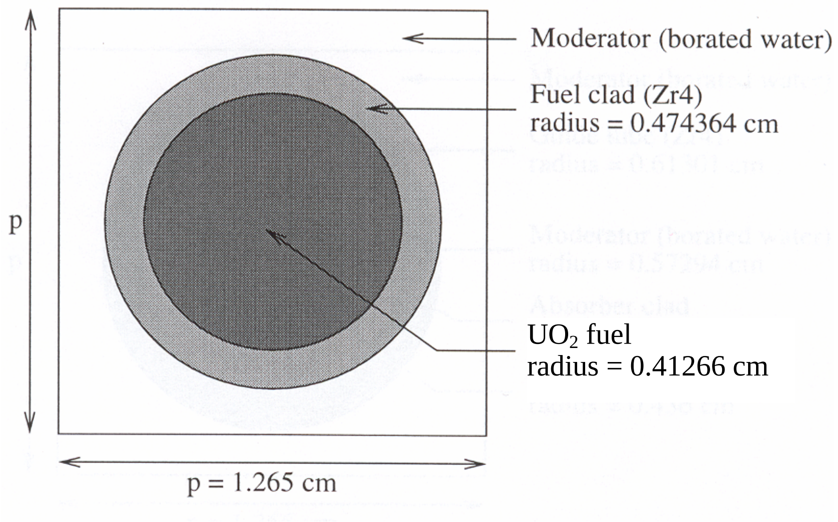


**Figure 3. Guide tube cell geometry without control rod**

*Central guide tube cell geometry*

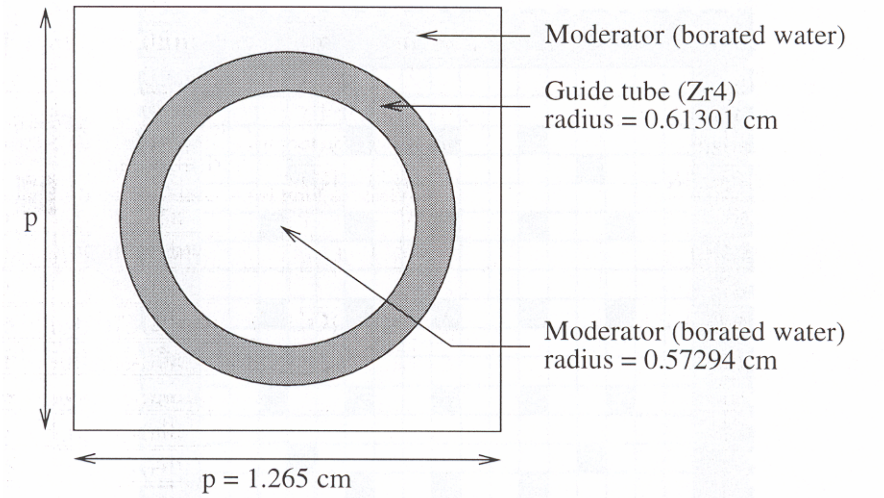



**Figure 4. Guide tube cell geometry with control rod**

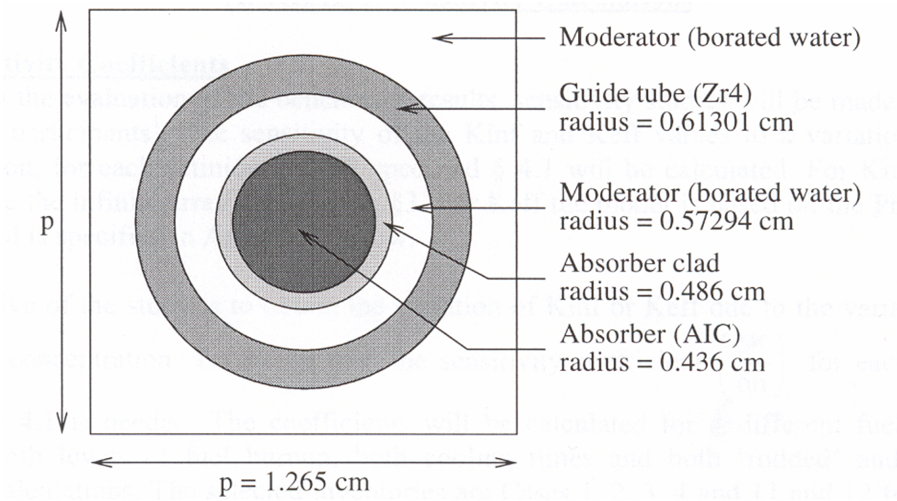
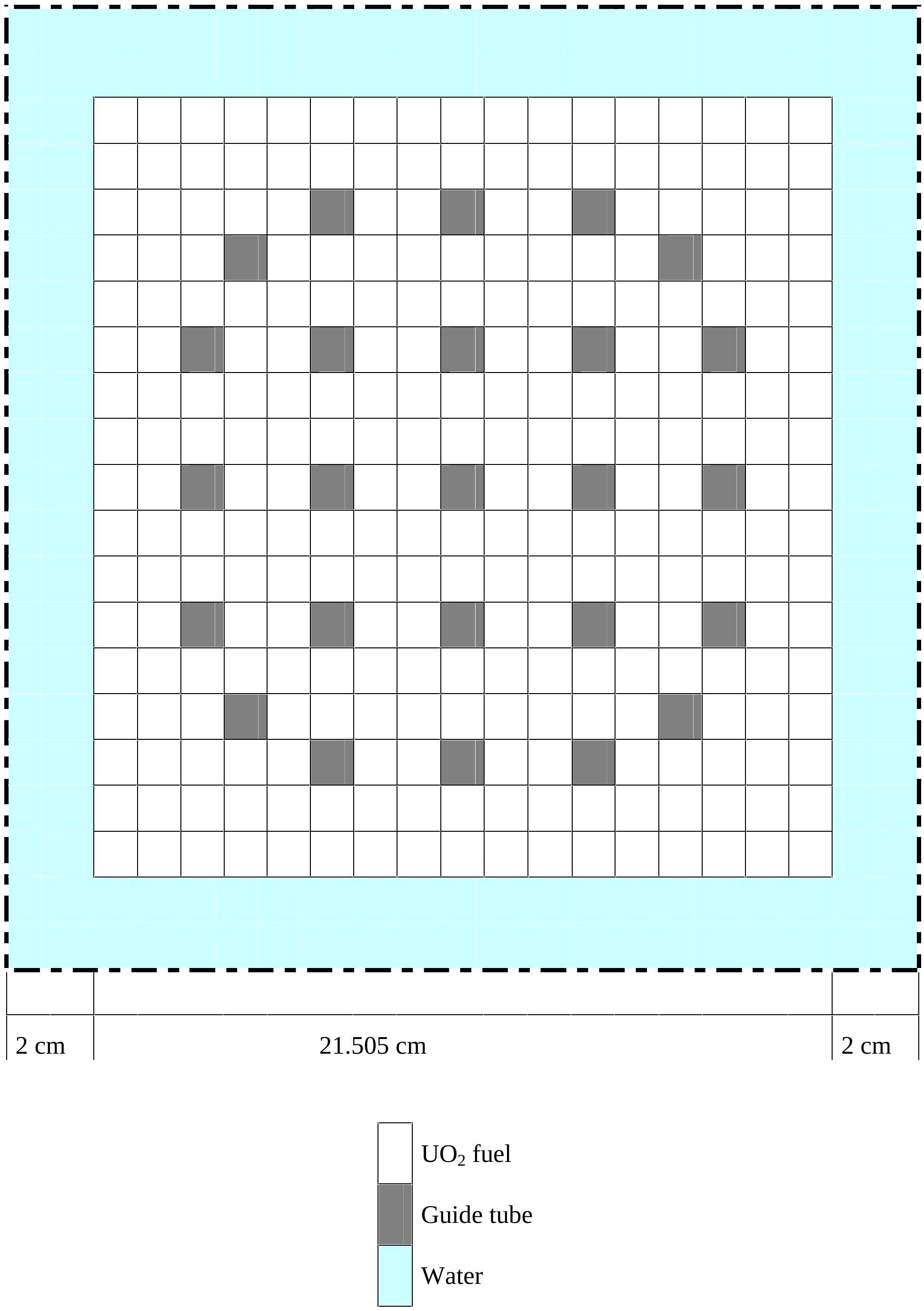


**Figure 5. Infinite array mesh**



## *Annex 1*

## SENSITIVITY CALCULATIONS

### A1.1 Sensitivity coefficients

To assist in the evaluation of the benchmark results, sensitivity studies will be made by a limited number of participants.[1] The sensitivity of the Kinf and Keff values to a variation of isotope concentration, for each actinide and FP specified § 4.1 will be calculated. For Kinf the model used will be the infinite array specified in §3. For Keff the model is based on the Phase II-B cask scenario and is specified in Annex 2, below.

The objective of the study is to obtain the variation of Kinf or Keff due to the variation of each isotope (i) concentration. To realise this, the sensitivity coefficient $\left(\frac{\delta K}{\delta n}\right)_i$ for each isotope (i) specified § 4.1 is needed. The coefficients will be calculated for 4 different fuel inventories covering both levels of fuel burn-up, both cooling times and both "rodded" and "un-rodded" depletion calculations. The selected inventories are Cases 1, 2, 3, 4 and 11 and 12 from Table 2. These will be calculated for both the infinite array and cask models, giving a total of eight sets of coefficients.

### A1.2 Required information

The "Sensitivity Coefficient" files (twelve files in all) must be composed of:

| Line no. | Contents |
|---|---|
| 1 | "Sensitivity Coefficients" |
| 2 | Date |
| 3 | Institute |
| 4 | Contact person |
| 5 | E-mail address or telefax number of the contact person |
| 6 | Computer code |
| 7 | Model (i.e. "infinite array" or "cask") |
| 8 | Inventory case number (i.e. 1, 2, 3, 4, 11 or 12) |
| 9 | Kinf or Keff value |
| 10 to 36 | $\left(\frac{\delta K}{\delta n}\right)_i$ |

[1] As minimum these calculations will be made by Oak Ridge National Laboratories (using SCALE/KENO) and by Serco Assurance (using MONK). Further contributions are welcome, but not mandatory.

for i = $^{234}U$
$^{235}U$
$^{236}U$
$^{238}U$
$^{238}Pu$
$^{239}Pu$
$^{240}Pu$
$^{241}Pu$
$^{242}Pu$
$^{237}Np$
$^{241}Am$
$^{243}Am$
$^{103}Rh$
$^{133}Cs$
$^{143}Nd$
$^{145}Nd$
$^{55}Gd$
$^{95}Mo$
$^{99}Tc$
$^{101}Ru$
$^{109}Ag$
$^{147}Sm$
$^{149}Sm$
$^{150}Sm$
$^{151}Sm$
$^{152}Sm$
$^{153}Eu$

*Annex 2*

# CASK MODEL

The cask environment consists of the cask model described in the Phase II-B specification, i.e. a configuration of 21 PWR spent fuel assemblies in a stainless steel transport flask. However, for this study, the 17 × 17 assemblies have to be modelled with guide tubes full of water. A borated stainless steel basket centred in the flask separates the assemblies. The basket 5 × 5 array with the four corner positions removed) is fully flooded with water.

## Material and geometrical description

### Fuel assembly

#### *Rod data*

| | |
|---|---|
| Rod length | 365.7 cm (fuel or guide tube) |
| End plug material | Zircaloy |
| End plug height | 1.75 cm |
| Full rod length | 369.2 cm (fuel or guide tube + 2 end plugs) |
| Upper hardware | 30.0 cm |
| Lower hardware | 10.0 cm |
| Upper water region | 7.0 cm |
| Lower water region | 0.0 cm |

#### *Assembly data*

| | |
|---|---|
| Lattice | 17 × 17 (264 fuel rods, 25 guide tubes) |
| Dimensions | 21.505 × 21.505 × 409.2 $cm^3$ |
| Pitch | 1.265 cm |
| Moderator | Water |
| Upper and lower end Hardware | 50% stainless steel, 50% $H_2O$ (by volume)<br>Note: rather than attempt to model the detail of the assembly end hardware, it has been chosen to mock up the hardware as a region of smeared water and stainless steel. Other hardware (e.g. grid spacers) is ignored. |

### Cask

#### *Cask shell*

| | |
|---|---|
| Inner diameter | 136.0 cm |
| Outside diameter | 196.0 cm |
| Material | Stainless steel (SS304) |
| Height (outside) | 476.2 cm |
| Height (inner cavity) | 416.2 cm |

***Assembly basket***

| | |
|---|---|
| Inner basket compartment dimensions | 22 cm × 22 cm × 416.2 cm (per assembly position) |
| Material | Borated stainless steel (1 wt.% boron) |
| Basket wall thickness | 1 cm |

***Configuration***

21 assemblies positioned in a 5 × 5 array (without assembly in corner)
Fuel assemblies are centred within basket region
Cask is completely flooded with water

**Material compositions (concentrations in atom/barn.cm)**

| | | |
|---|---|---|
| **Spent fuel** | See § A.1.1 | |
| **Fuel clad** | Fe | 1.383E-04 |
| | Cr | 7.073E-05 |
| | O | 2.874E-04 |
| | Zr | 3.956E-02 |
| **End plug** | Cr | 7.589E-05 |
| | Fe | 1.484E-04 |
| | Zr | 4.298E-02 |
| **Guide tube** | Fe | 1.476E-04 |
| | Cr | 7.549E-05 |
| | O | 3.067E-04 |
| | Zr | 4.222E-02 |
| **Water (moderator)** | H | 6.662E-02 |
| | O | 3.331E-02 |
| **Stainless steel** | Cr | 1.743E-02 |
| | Mn | 1.736E-03 |
| | Fe | 5.936E-02 |
| | Ni | 7.721E-03 |
| **Borated (1 wt.%) stainless steel** | Cr | 1.691E-02 |
| | Mn | 1.684E-03 |
| | Fe | 5.758E-02 |
| | Ni | 7.489E-03 |
| | $^{10}B$ | 7.836E-04 |
| | $^{11}B$ | 3.181E-03 |
| **50/50 stainless steel/ water mixture** | Cr | 8.714E-03 |
| | Mn | 8.682E-04 |
| | Fe | 2.968E-02 |
| | Ni | 3.860E-03 |
| | H | 3.338E-02 |
| | O | 1.669E-02 |

**Figure 6. Cask model (top view)**

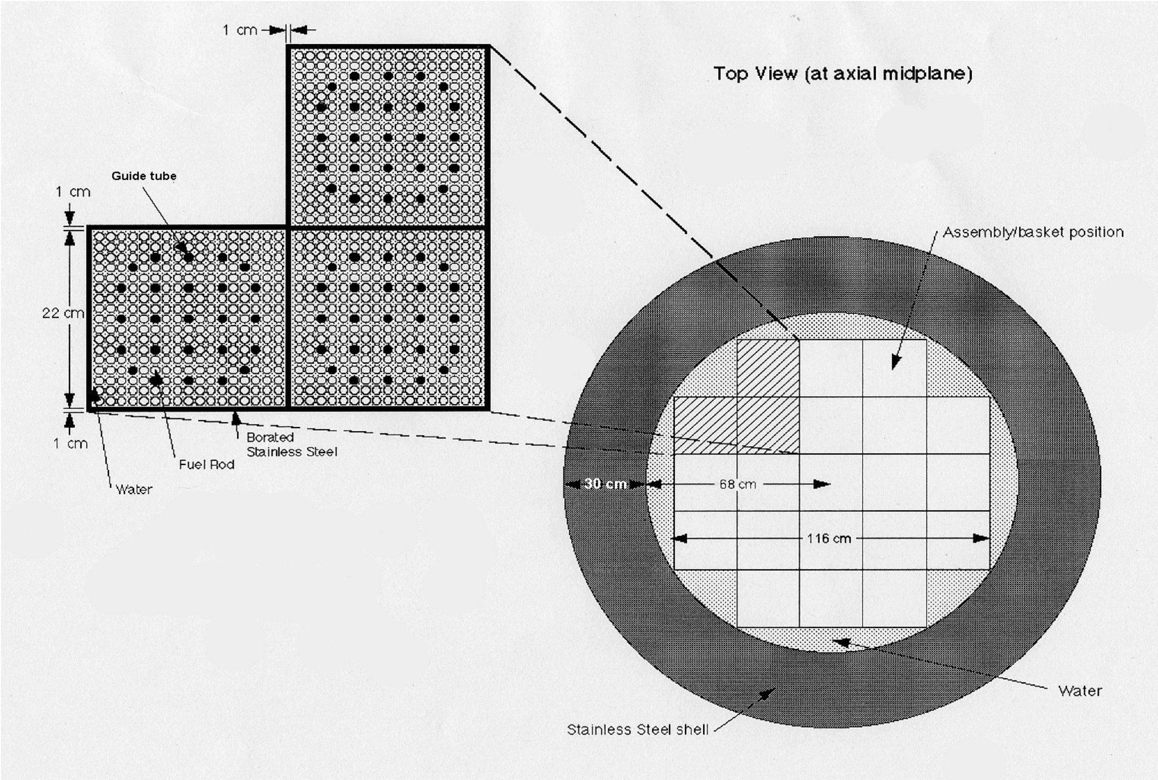


**Figure 7. Cask model (side view)**

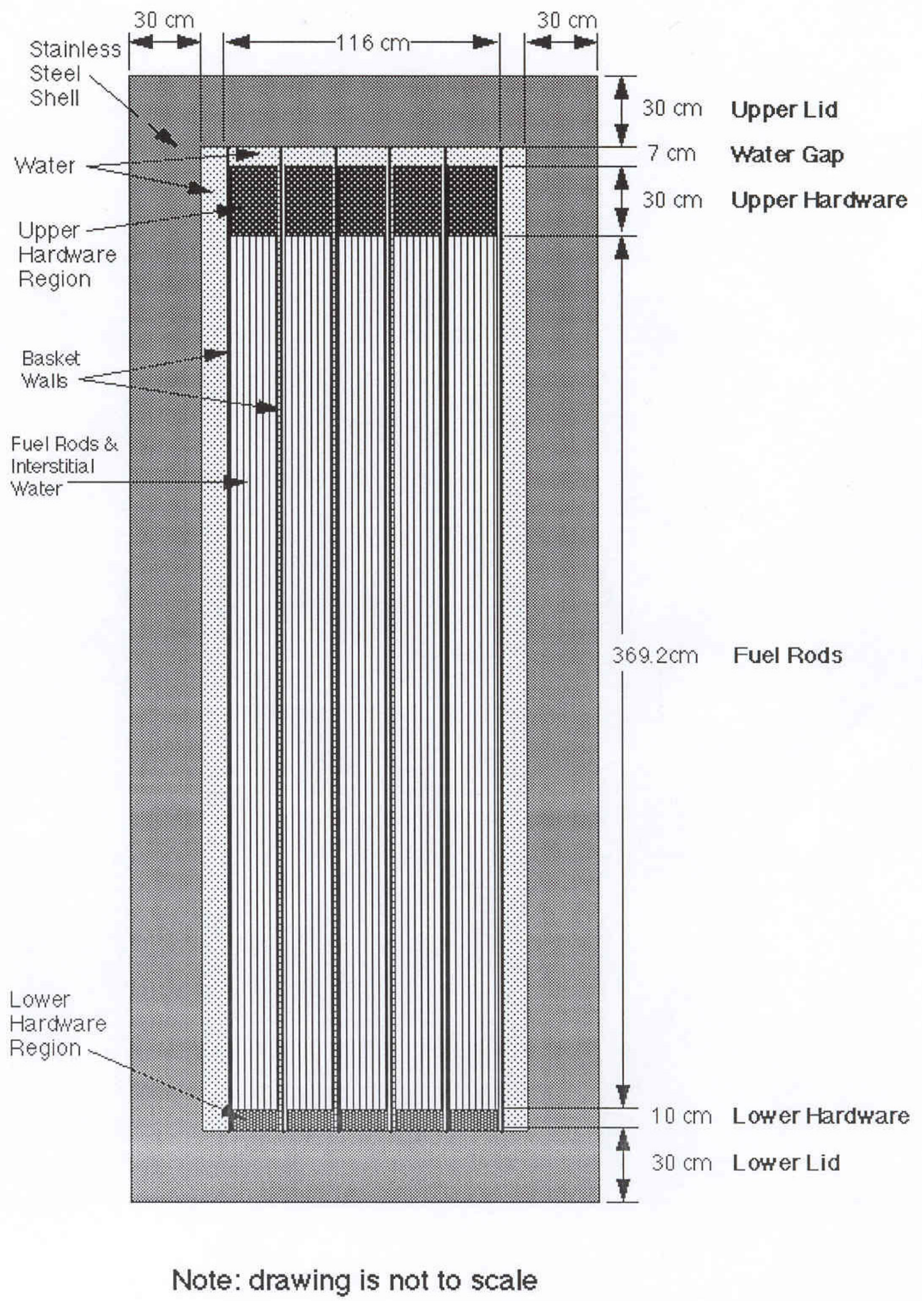
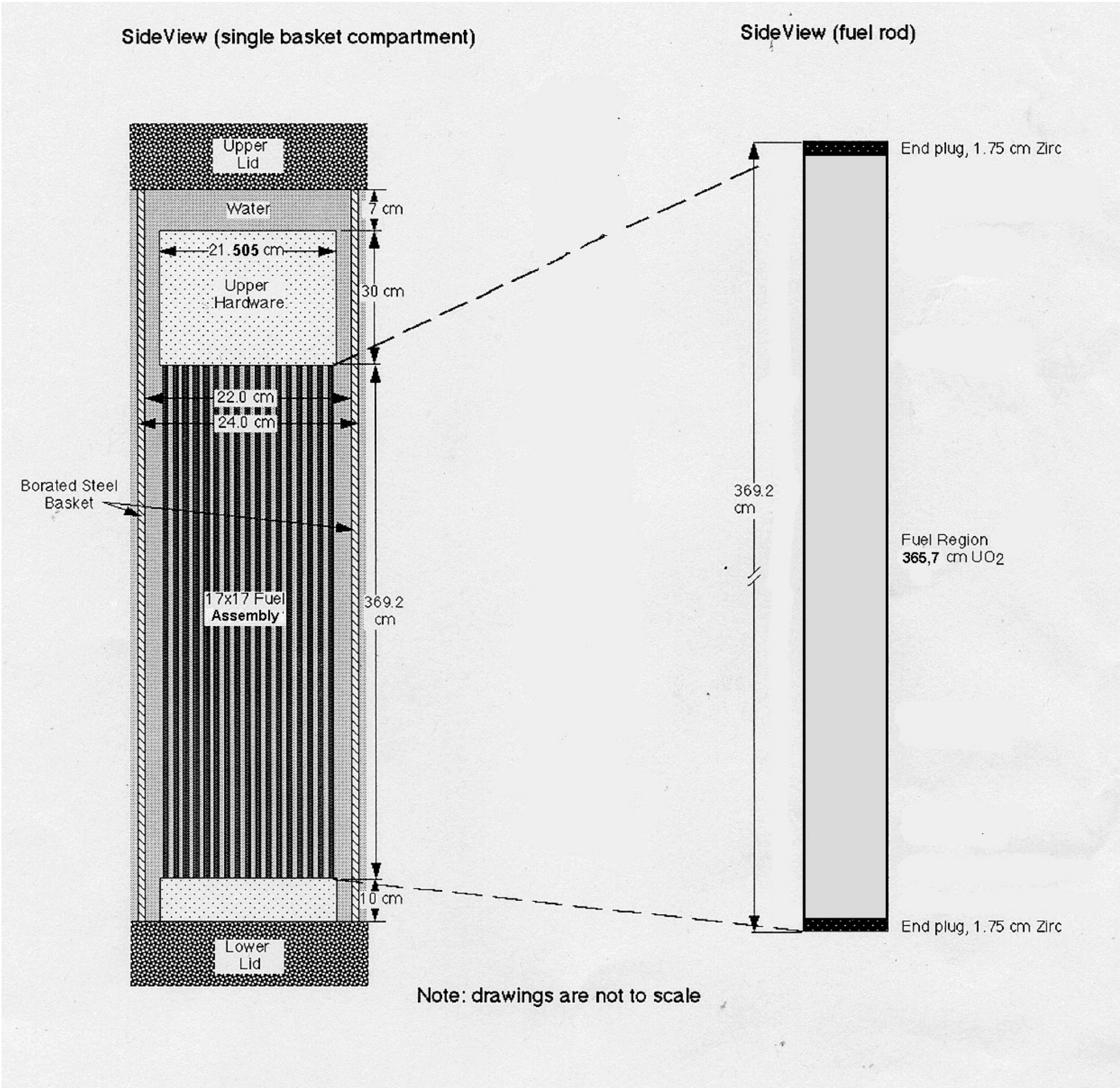


**Figure 8. Single basket compartment**



## *Appendix B*

# PARTICIPANTS AND ANALYSIS METHODS

# A. FUEL INVENTORY CALCULATION

## 1. PSI, Switzerland

### 1. Institute

Paul Scherrer Institute

### 2. Participants

A.V. Vasiliev, J.R. Lebenhaft

### 3. Computer code

Monteburns-2.0/MCNPX-2.4.0/ORIGEN-2.1

### 4. Data library

| | |
|---|---|
| Actinide and fission products: | ENDF/B-VI.8 processed for 870K |
| Water, clad, guide tube: | JEF2.2NEA.BOLIB, mixed temperatures |
| Absorber isotopes (Ag, Cd, In): | MCNPDATA DLC-200 (ENDF60;ENDL92; 300K) |

### 5. Neutron data processing code or method

Not used (previously available neutron data libraries were used).

### 6. Neutron energy groups

Continuous energy.

### 7. Geometry modelling

3-D pin-wise model of fuel assembly with reflecting boundary conditions; no radial discretisation of fuel-single fuel material per single fuel rod.

### 8. Description of the code system

Monteburns-2.0/MCNPX-2.4.0/ORIGEN-2.1 coupled-code system.

## 2. JNES, Japan

### 1. Institute

Japan Nuclear Energy Safety Organisation

### 2. Participants

Tetsuo Nakata, Hiroki Sakamoto, Susumu Mitake

### 3. Computer code

MVP-ORBURN

### 4. Data library

JENDL-3.3

### 5. Neutron data processing code or method

ART [1] is used to make temperature.

### 6. Neutron energy groups

Continuous energy.

### 7. Geometry modelling

For MVP, the fuel assembly is modelled in 3-D. Burn-up calculations are conducted in a 0-D model by ORIGEN.

### 8. Description of your code system

MVP-ORBURN is an integrated burn-up code system composed of continuous-energy Monte Carlo code MVP 2.0 [2] and point depletion code ORIGEN 2.1 [3]. In the MVP-ORBURN calculations, the effective cross-sections for each fuel in a fuel assembly are evaluated at every burn-up time steps using neutron flux distributions and neutron energy spectra calculated by the MVP code. The depletion and decay-chain calculations are performed by the ORIGEN code.

The main advantages of the MVP-ORBURN system are as follows:

(a) Wide and precise depletion analyses are performed with the ORIGEN code and its libraries.

(b) Fine and localised effects in a fuel assembly are evaluated by the MVP code.

(c) Many characteristics of spent fuel are available, i.e. cooling effect, radioactivity, source strength, heat generation rates, etc.

## 9. Omitted nuclide

In the MVP calculations, total number of the nuclides are limited to about 50, including those important to neutron balance calculations.

## 10. Other information

Non-uniform 21 steps: "0.0, 0.2, 1.0, 3.0, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, 20.0, 22.5, 25.0, 27.5, 30.0, 32.5, 35.0, 37.5,40.0, 42.5, 45.0 GWd/t, nearly 2.5 GWd/t per step."
Employed convergence limit: None.
Neutron history: 5 000 history/cycle, 110 cycles, 10 cycles skip.

## References


[1] Mori, T.,, *et al.*, *Proc. Int. Conf. on Mathematics and Computation (M&C'99)*, Madrid, Spain, Vol. 2, p. 987 (1999).

[2] Mori, T., M. Nakagawa: *MVP/GMVP: General Purpose Monte Carlo Codes for Neutron and Photon Transport Calculations Based on Continuous Energy and Multigroup Methods*, JAERI-Data/Code 94-007 (1994).

[3] Croff, A.G., "ORIGEN2 Code Package CCC-371", Informal Notes (Oct. 1981).

## 3. JAERI, Japan

### 1. Institute

Japan Atomic Energy Research Institute

### 2. Participants

Kenya Suyama, Hiroshi Okuno, Yoshinori Miyoshi (JAERI), Hiroki Mochizuki (JRI)

### 3. Computer code

SWAT2

### 4. Data library

JENDL-3.2 and JENDL-3.3

### 5. Neutron data processing code or method

For MVP, ART [1] is used to make temperature-dependent libraries. SWAT library: LINEAR, RECENT, SIGMA1 [2] and CRECTJ5 [3].

### 6. Neutron energy groups

Continuous-energy neutron transport calculation by MVP. 147-group flux is obtained and one-group effective cross-section is prepared for point burn-up calculation.

### 7. Geometry modelling

2-D

### 8. Description of your code system

SWAT2 [4] drives a continuous-energy Monte Carlo Code MVP [5]. For each burn-up step, the neutron spectrum and effective multi group cross-section are evaluated by MVP, then tally file of MVP calculation is read and the one-group cross-section data file for the ORIGEN2.1 [6] is prepared. For cross-section data that are not included MVP library, infinite dilution cross-sections stored in the SWAT library are collapsed by the neutron flux of MVP. Fission yield data of $^{233}$U, $^{235}$U, $^{239}$Pu and $^{241}$Pu for thermal neutrons, decay constants and branching ratios for FP are taken from JNDC FP library second version. Using the prepared library, a one-step burn-up calculation by ORIGEN2.1 is carried out. Then, input files for MVP or SRAC95 and ORIGEN2.1 using the geometry data and burn-up calculation results are generated. Up to the final burn-up, that procedure is repeated in every burn-up step.

### 9. Other information

Neutron history data for a burn-up step: cycle number: 120, skip cycle: 20, neutrons/cycle: 6 000, total history number: 600 000, MVP calculation is called for each 2 000MWd/t burn-up step.

## References

[1] Mori, T., *et al.*, *Proc. Int. Conf. on Mathematics and Computation (M&C'99)*, Madrid, Spain, Vol. 2, p. 987 (1999).

[2] Cullen, D., UCRL-50400, Vol. 17, Part B (1979).

[3] Nakagawa, T., JAERI Data/Code 99-41(2000).

[4] Suyama, Kenya, Hiroki Mochizuki, Hiroshi Okuno, Yoshinori Miyoshi, *Proceedings of PHYSOR-2004*, Chicago, USA, 25-29 April 2004.

[5] Mori, T., M. Nakagawa, JAERI-Data/Code 94-007 (1994).

[6] Notz, K.J., CCC-371:200-08, RSICC (1991).

[7] Tasaka, K., J. Katakura, H. Ihara, *et al*., JAERI 1320, Japan Atomic Energy Research Institute (1990).

## 4. KAERI, Korea

### 1. Institute

Korea Atomic Energy Research Institute

### 2. Participants

Kang-Seog Kim, Chung Chan Lee

### 3. Computer code

LIBERTE

### 4. Data library

ENDF/B-VI

### 5. Neutron data processing code or method

NJOY, RABBLE

### 6. Neutron energy groups

35 groups

### 7. Geometry modelling

2-D rectangular geometry

### 8. Description of your code system

Spatial discretisation = characteristics method
Resonance treatment = subgroup method
Depletion calculation = matrix exponential method
Criticality spectrum = B-1 approximation

## 5. SERCO ASSURANCE, United Kingdom

**1. Institute**

Serco Assurance

**2. Participant**

David Hanlon

**3. Computer code**

WIMS8

**4. Data library**

JEF-2.2

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

172 groups

**7. Geometry modelling**

2-D

**8. Description of your code system**

The WIMS8 calculations employed a subgroup resonance treatment along with differential burn-up. The spectrum calculation used a multi-cell collision probability treatment, which was used to condense from the library 172 groups to 12 fewgroups. The fewgroup flux solution calculation employed the method of characteristics (CACTUS) in two dimensions.

## 6. BNFL, United Kingdom

**1. Institute**

British Nuclear Fuels

**2. Participants**

Andrew Maunder, Jim Gulliford

**3. Computer code**

WIMS8A

**4. Data library**

JEF-2.2

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

172 groups

**7. Geometry modelling**

2-D

**8. Description of your code system**

None.

## 7. VTT, Finland

### 1. Institute

Technical Reasearch Centre of Finland

### 2. Participants

Anssu Ranta-aho, Markku Anttila

### 3. Computer code

CASMO-4

### 4. Data library

E4LBL70, based mainly on ENDF/B-IV

### 5. Neutron data processing code or method

CASLIB

### 6. Neutron energy groups

70 groups cover the range 0 to 10 MeV

### 7. Geometry modelling

A fully heterogeneous description of the fuel assembly with the reflective boundary conditions is used in the final two-dimensional calculation.

### 8. Description of your code system

CASMO-4 is a multi-group two-dimensional transport-theory code for burn-up calculations on BWR and PWR fuel assemblies. The two-dimensional flux calculation performed normally in eight energy groups is based on the method of characteristics. In the depletion calculations a predictor-corrector method is applied.

### 9. Omitted nuclide

$^{95}$Mo, $^{99}$Tc, $^{101}$Ru

## 8. AREVA, Germany

**1. Institute**

Framatome-ANP

**2. Participant**

Jens-Christian Neuber

**3. Computer code**

CASMO-4

**4. Data library**

JEF-2.2

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

70 groups

**7. Geometry modelling**

2-D

**8. Description of your code system**

CASMO-4 is a multi-group 2-D transport theory code for burn-up calculations on BWR and PWR assemblies or simple pin cells. Accordingly, the code is capable of handling a geometry consisting of cylindrical fuel rods of varying composition in a square pitch array with allowance for cluster control rods.

## 9. CEA, France

### 1. Institute

Commissariat à l'énergie atomique

### 2. Participant

A. Barreau

### 3. Computer code

APOLLO2.5

### 4. Data library

CEA93, based on JEF-2.2.

### 5. Neutron data processing code or method

NJOY

### 6. Neutron energy groups

172 groups

### 7. Geometry modelling

2-D

### 8. Description of your code system

APOLLO2 is a modular code which solves both the Boltzmann integral equation and the integro-differential equation ($S_n$ method). APOLLO2 allows the use of several collision probability methods to solve the integral equation: exact 2-D $P_{ij}$, multi-cell $P_{ij}$ based on the interface current method. The one used for the benchmark is the exact 2-D $P_{ij}$ method. In our calculations, the UOX fuel pin is divided into four concentric zones. Self-shielded cross-sections are calculated for $^{238}$U in each concentric zone; an accurate "background matrix" formalism is used for resonant reaction rate calculation, allowing space-dependent resonance self-shielding and rim effect modelling. For the other actinides, $^{240}$Pu, $^{239}$Pu, $^{241}$Pu, $^{242}$Pu, $^{238}$Pu, $^{241}$Am, $^{235}$U, $^{236}$U, Zr, Ag and In, we used an "average" self-shielding formalism.

## 10. ORNL, United States

**1. Institute**

Oak Ridge National Laboratory

**2. Participants**

John C. Wagner, Jonathon Waldes

**3. Computer code**

HELIOS

**4. Data library**

ENDF/B-V library (distributed with HELIOS)

**5. Neutron data processing code or method**

**6. Neutron energy groups**

45-group structure

**7. Geometry modelling**

2-D

**8. Description of your code system**

HELIOS-1.6 is a 2-D transport theory based on the method of collision probabilities with current coupling.

**9. Other information**

Burn-up steps of 1 GWd/MTU were used.

## 11. ORNL, United States

### 1. Institute

Oak Ridge National Laboratory

### 2. Participants

John C. Wagner, Jonathon Waldes

### 3. Computer code

SAS2H

### 4. Data library

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

### 5. Neutron data processing code or method

BONAMI/NITAWL (SCALE 5)

### 6. Neutron energy groups

44-group structure

### 7. Geometry modelling

A SAS2H model of a fuel assembly is limited to a 1-D radial model with a single smeared fuel region. Geometric modelling approximations are made in an effort to achieve a reasonable assembly-averaged neutron spectrum.

### 8. Description of your code system

SAS2H uses XSDRNPM for 1-D discrete ordinates transport calculations coupled with ORIGEN-S for independent depletion of each fuel region.

### 9. Other information

Burn-up steps of 1 GWd/MTU were used.
Comparison of the SAS2H results to results from other codes revealed that the $^{109}$Ag composition was being over-estimated by SAS2H. It was found that the presence of the $^{109}$Ag in the control rods was leading to poor $^{109}$Ag cross-sections throughout the fuel. This is an inherent problem with the 1-D calculation approach, where cross-sections are calculated by cell weighting based on the flux through the material – in this case the $^{109}$Ag cross-sections were calculated based on the extremely low flux in the control rod region. The lower $^{109}$Ag cross-sections result in less destruction of $^{109}$Ag in the fuel region as it is being produced, and hence explains the over-estimated final concentration. This problem will be present in any case where control rods contain a fission product of interest. This problem could be solved by calculating unique cross-sections in each radial region in the SAS2H Path-B model (i.e. separate $^{109}$Ag cross-sections for the fuel and control rod regions). However, that would be a deviation from what is done in the standard version of SAS2H – the results reported herein are based on the standard version of SAS2H distributed in SCALE 5 and are included here to help inform users of this limitation.

## 12. ORNL, United States

### 1. Institute

Oak Ridge National Laboratory

### 2. Participants

John C. Wagner, Jonathon Waldes

### 3. Computer code

TRITON/KENO

### 4. Data library

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

### 5. Neutron data processing code or method

BONAMI/NITAWL (SCALE 5)

### 6. Neutron energy groups

44-group structure

### 7. Geometry modelling

3-D

### 8. Description of your code system

TRITON/KENO is a 3-D depletion sequence developed for a future release of SCALE (it is not a part of SCALE 5). TRITON used KENO V.a for 3-D Monte Carlo transport calculations coupled with ORIGEN-S for independent depletion of each fuel region.

### 9. Other information

Burn-up steps of 1 GWd/MTU were used. Results at each burn-up step are based on 2 000 active generations, 100 skipped generations, and 1 000 neutron histories per generation.

## 13. ORNL, United States

### 1. Institute

Oak Ridge National Laboratory

### 2. Participants

John C. Wagner, Jonathon Waldes

### 3. Computer code

TRITON/NEWT

### 4. Data library

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

### 5. Neutron data processing code or method

BONAMI/NITAWL (SCALE 5)

### 6. Neutron energy groups

44-group structure

### 7. Geometry modelling

NEWT employs arbitrary-polygon computational cells; all curved surfaces were approximated by high-order polygons (10 or more sides) with volumes conserved. A quarter-assembly model (with reflective boundary conditions) was constructed and used.

### 8. Description of your code system

TRITON/NEWT is a 2-D depletion sequence in SCALE 5. TRITON used NEWT for 2-D transport calculations coupled with ORIGEN-S for independent depletion of each fuel region. NEWT is a generalised-geometry discrete ordinates solver.

### 9. Other information

Burn-up steps of 1 GWd/MTU were used. Results at each burn-up step are based on 2 000 active generation, 100 skipped generations, and 1 000 neutron histories per generation.

## B. KINF CALCULATION

### 1. PSI, Switzerland

**1. Institute**

Paul Scherrer Institute

**2. Participants**

A.V. Vasiliev, J.R. Lebenhaft

**3. Computer code**

MCNPX-2.4.0

**4. Data library**

| | |
|---|---|
| Actinides and fission products: | ENDF/B-VI.8 processed for 870K |
| Water, clad, guide tube: | JEF2.2NEA.BOLIB, mixed temperatures |
| Absorber isotopes (Ag, Cd, In): | MCNPDATA DLC-200 (ENDF60; ENDL92; 300K) |

**5. Neutron data processing code or method**

Not used (previously available neutron data libraries were used)

**6. Neutron energy groups**

Continuous energy

**7. Geometry modelling**

3-D model of fuel assembly with reflecting boundary conditions; no burn-up.

**8. Description of your code system**

None.

**9. Other information**

Estimated standard deviations for presented Kinf are 0.0002.

## 2. JNES, Japan

### 1. Institute

Japan Nuclear Energy Safety Organisation

### 2. Participants

Tetsuo Nakata, Hiroki Sakamoto, Susumu Mitake

### 3. Computer code

MVP 2.0

### 4. Data library

JENDL-3.3

### 5. Neutron data processing code or method

ART [1] is used to make temperature-dependent libraries.

### 6. Neutron energy groups

Continuous energy

### 7. Geometry modelling

3-D

### 8. Description of your code system

MVP 2.0 [2] is a continuous-energy Monte Carlo code developed at JAERI.

### 9. Other information

Employed convergence limit: None.
Neutron history: 10 000 history/cycle, 210 cycles, 10 cycles skip.

### References


[1] Mori, T., *et al.*, *Proc. Int. Conf. on Mathematics and Computation (M&C'99)*, Madrid, Spain, Vol. 2, p. 987 (1999).

[2] Mori, T., M. Nakagawa, *MVP/GMVP: General Purpose Monte Carlo Codes for Neutron and Photon Transport Calculations Based on Continuous Energy and Multigroup Methods*, JAERI-Data/Code 94-007 (1994).

## 3. JAERI, Japan

### 1. Institute

Japan Atomic Energy Research Institute

### 2. Participants

Kenya Suyama, Hiroshi Okuno, Yoshinori Miyoshi (JAERI), Hiroki Mochizuki (JRI)

### 3. Computer code

SWAT2

### 4. Data library

JENDL-3.2, JENDL-3.3

### 5. Neutron data processing code or method

ART [1] is used to make temperature-dependent libraries.

### 6. Neutron energy groups

Continuous energy for neutron transport calculation.

### 7. Geometry modelling

2-D

### 8. Description of your code system

A continuous-energy Monte Carlo Code MVP [2] is used.

### 9. Other information

Cycle number: 550, skip cycle: 50.
Neutrons/cycle: 10 000, total history number: 5 000 000.
One-standard deviation of neutron multiplication factor is approximately 2.5E-4 [%].

### References


[3] Mori, T., *et al.*, *Proc. Int. Conf. on Mathematics and Computation (M&C'99)*, Madrid, Spain, Vol. 2, p. 987 (1999).

[4] Mori, T., M. Nakagawa, *MVP/GMVP: General Purpose Monte Carlo Codes for Neutron and Photon Transport Calculations Based on Continuous Energy and Multigroup Methods,* JAERI-Data/Code 94-007 (1994).

## 4. SERCO ASSURANCE, United Kingdom

### 1. Institute

Serco Assurance

### 2. Participant

David Hanlon

### 3. Computer code

MONK8B

### 4. Data library

JEF-2.2

### 5. Neutron data processing code or method

NJOY

### 6. Neutron energy groups

13 193 hyper-fine group structure.

### 7. Geometry modelling

3-D with a nominal length and full specular reflection on all outer surfaces.

### 8. Description of your code system

The calculations used the Monte Carlo criticality code MONK8B with its associated JEF-2.2 based library. The library was generated during 1997 using NJOY and has a 13 193 hyper-fine group structure. This library, together with the point-energy collision processing algorithms, provide a very detailed model of the physics, so the ultimate accuracy of the MONK code largely depends on the numerical accuracy of the basic nuclear data.

## 6. BNFL, United Kingdom

**1. Institute**

British Nuclear Fuels

**2. Participants**

Andrew Maunder, Jim Gulliford

**3. Computer code**

MONK8B

**4. Data library**

JEF-2.2

**5. Neutron data processing code or method**

Dice

**6. Neutron energy groups**

13 193-group

**7. Geometry modelling**

3-D

**8. Description of your code system**

None.

## 7. VTT, Finland

### 1. Institute

Technical Research Centre of Finland

### 2. Participants

Anssu Ranta-aho, Markku Anttila

### 3. Computer code

MCNP4C

### 4. Data library

ENDF/B-6.8

### 5. Neutron data processing code or method

NJOY

### 6. Neutron energy groups

Continuous energy

### 7. Geometry modelling

1/2 assembly with reflective boundary conditions.

### 8. Description of your code system

MCNP4C is a Monte Carlo code for calculating particle transport in exact geometry.

### 9. Omitted nuclide

$^{95}Mo$, $^{99}Tc$, $^{101}Ru$

## 8. AREVA, Germany

**1. Institute**

Framatome-ANP

**2. Participant**

Jens-Christian Neuber

**3. Computer code**

KENO V.a / SCALE 4.4a

**4. Data library**

ENDF/B-V

**5. Neutron data processing code or method**

CSAS25: AMPEX/SCALE 4.4a, KENO V.a

**6. Neutron energy groups**

44 energy groups

**7. Geometry modelling**

3-D

**8. Description of your code system**

The criticality calculation modules of the SCALE-4.4 package are used by applying the Criticality Safety Analysis Sequence CSAS25 of that package together with the 44-group ENDF/B-V derived cross-section library 44GROUPNDF5.The sequence CSAS25 executes successively the modules BONAMI-S, NITAWL-II, and the Monte Carlo code KENO V.a. BONAMI-S performs resonance shielding through the application of the Bondarenko shielding factor method, and NITAWL-II carries out resonance shielding by use of the Nordheim integral technique. The KENO V.a code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first-degree surfaces and some special second-degree surfaces. It solves the multi-energy group form of the neutron transport equation as an eigenvalue problem through employment of Monte Carlo techniques. The results given above are based on three calculation runs with 1 200 neutron batches each. For each batch 2 000 neutrons were employed. The initial 200 batches are skipped (not used for calculating the final kinf mean value).

## 9. CEA, France

### 1. Institute

Commissariat à l'énergie atomique

### 2. Participants

A. Barreau, C. Venard

### 3. Computer code

CRISTAL V1

### 4. Data library

CEA93, based on JEF-2.2

### 5. Neutron data processing code or method

NJOY

### 6. Neutron energy groups

20 groups

### 7. Geometry modelling

2-D

### 8. Description of your code system

The CRISTAL package used here includes the Sn route. This route is based on APOLLO2, a user oriented, modular code. APOLLO2 solves the integral form of the Boltzmann equation through the collision probability method (Pij method), and/or the integro-differential transport equation, using the discrete ordinates method. The Sn modules were developed to perform large 2-D geometry calculations; methods such as the Sn-nodal technique were implemented.

## 10. ORNL, United States

### 1. Institute

Oak Ridge National Laboratory

### 2. Participants

John C. Wagner, Jonathon Waldes

### 3. Computer code

KENO V.a

### 4. Data library

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

### 5. Neutron data processing code or method

BONAMI/NITAWL (SCALE 5)

### 6. Neutron energy groups

238-group structure

### 7. Geometry modelling

3-D

### 8. Description of your code system

KENO V.a is a 3-D Monte Carlo criticality code in SCALE 5.

### 9. Omitted nuclides

### 10. Other information

Standard deviations for the kinf values.

| Case | Standard deviations |
|---|---|
| 1a | 0.00043 |
| 1b | 0.0004 |
| 2a | 0.00044 |
| 2b | 0.00039 |
| 3a | 0.0004 |
| 3b | 0.00039 |
| 4a | 0.00044 |
| 4b | 0.0004 |
| 5b | 0.00036 |
| 6b | 0.00037 |
| 7b | 0.00036 |
| 8b | 0.00037 |
| 9a | 0.00039 |
| 9b | 0.00037 |
| 10a | 0.00047 |
| 10b | 0.00038 |
| 11a | 0.00038 |
| 11b | 0.00039 |
| 12a | 0.0004 |
| 12b | 0.00039 |
| 13b | 0.00033 |
| 14b | 0.00038 |
| 15 | 0.00045 |

## 11. ORNL, United States

**1. Institute**

Oak Ridge National Laboratory

**2. Participants**

John C. Wagner, Jonathon Waldes

**3. Computer code**

KENO V.a

**4. Data library**

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

**5. Neutron data processing code or method**

BONAMI/NITAWL (SCALE 5)

**6. Neutron energy groups**

238-group structure

**7. Geometry modelling**

3-D

**8. Description of your code system**

KENO V.a is a 3-D Monte Carlo criticality code in SCALE 5.

**9. Omitted nuclides**

**10. Other information**

Standard deviations for the kinf values.

| Case | Standard deviations |
|---|---|
| 1a | 0.00042 |
| 1b | 0.00038 |
| 2a | 0.00043 |
| 2b | 0.00039 |
| 3a | 0.00036 |
| 3b | 0.00035 |
| 4a | 0.0004 |
| 4b | 0.00038 |
| 5b | 0.00037 |
| 6b | 0.00036 |
| 7b | 0.00037 |
| 8b | 0.00037 |
| 9a | 0.0004 |
| 9b | 0.00037 |
| 10a | 0.0004 |
| 10b | 0.00038 |
| 11a | 0.00038 |
| 11b | 0.00035 |
| 12a | 0.00038 |
| 12b | 0.00036 |
| 13b | 0.00033 |
| 14b | 0.00038 |
| 15 | 0.00045 |

## 12. ORNL, United States

**1. Institute**

Oak Ridge National Laboratory

**2. Participants**

John C. Wagner, Jonathon Waldes

**3. Computer code**

KENO V.a

**4. Data library**

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

**5. Neutron data processing code or method**

BONAMI/NITAWL (SCALE 5)

**6. Neutron energy groups**

238-group structure

**7. Geometry modelling**

3-D

**8. Description of your code system**

KENO V.a is a 3-D Monte Carlo criticality code in SCALE 5.

**9. Omitted nuclides**

**10. Other information**

Standard deviations for the kinf values.

| Case | Standard deviations |
|---|---|
| 1a | 0.00042 |
| 1b | 0.00038 |
| 2a | 0.00041 |
| 2b | 0.00037 |
| 3a | 0.00036 |
| 3b | 0.00036 |
| 4a | 0.00039 |
| 4b | 0.00037 |
| 5b | 0.00035 |
| 6b | 0.00035 |
| 7b | 0.00039 |
| 8b | 0.00036 |
| 9a | 0.0004 |
| 9b | 0.00041 |
| 10a | 0.00038 |
| 10b | 0.00037 |
| 11a | 0.00043 |
| 11b | 0.00037 |
| 12a | 0.0004 |
| 12b | 0.00038 |
| 13b | 0.00033 |
| 14b | 0.00038 |
| 15 | 0.00045 |

## 13. ORNL, United States

**1. Institute**

Oak Ridge National Laboratory

**2. Participants**

John C. Wagner, Jonathon Waldes

**3. Computer code**

KENO V.a

**4. Data library**

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

**5. Neutron data processing code or method**

BONAMI/NITAWL (SCALE 5)

**6. Neutron energy groups**

238-group structure

**7. Geometry modelling**

3-D

**8. Description of your code system**

KENO V.a is a 3-D Monte Carlo criticality code in SCALE 5.

**9. Omitted nuclides**

**10. Other information**

Standard deviations for the kinf values.

| Case | Standard deviations |
|---|---|
| 1a | 0.00039 |
| 1b | 0.00042 |
| 2a | 0.00043 |
| 2b | 0.0004 |
| 3a | 0.00038 |
| 3b | 0.00034 |
| 4a | 0.0004 |
| 4b | 0.00037 |
| 5b | 0.00037 |
| 6b | 0.00037 |
| 7b | 0.00038 |
| 8b | 0.00036 |
| 9a | 0.00041 |
| 9b | 0.00035 |
| 10a | 0.0004 |
| 10b | 0.00038 |
| 11a | 0.00037 |
| 11b | 0.00036 |
| 12a | 0.00039 |
| 12b | 0.00035 |
| 13b | 0.00033 |
| 14b | 0.00038 |
| 15 | 0.00045 |

## C. SENSITIVITY CALCULATION ON INFINITE ARRAY

### 1. SERCO ASSURANCE, United Kingdom

**1. Institute**

Serco Assurance

**2. Participant**

David Hanlon

**3. Computer code**

MONK8B

**4. Data library**

JEF-2.2.

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

13 193 hyper-fine group structure

**7. Geometry modelling**

3-D with a nominal length and full specular reflection on all outer surfaces.

**8. Description of your code system**

The calculations used the Monte Carlo criticality code MONK8B with its associated JEF-2.2 based library. The library was generated during 1997 using NJOY and has a 13 193 hyper-fine group structure. This library, together with the point-energy collision processing algorithms, provide a very detailed model of the physics, so the ultimate accuracy of the MONK code largely depends on the numerical accuracy of the basic nuclear data.

## 2. VTT, Finland

**1. Institute**

Technical Research Centre of Finland

**2. Participants**

Anssu Ranta-aho, Markku Anttila

**3. Computer code**

MCNP4C

**4. Data library**

ENDF/B-6.8

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

Continuous energy

**7. Geometry modelling**

1/2 assembly with reflective boundary conditions

**8. Description of your code system**

MCNP4C is a Monte Carlo code for calculating particle transport in exact geometry.

**9. Omitted nuclides**

$^{95}Mo$, $^{99}Tc$, $^{101}Ru$

## 3. CEA, France

### 1. Institute

Commissariat à l’énergie atomique

### 2. Participants

A. Barreau, C. Venard

### 3. Computer code

CRISTAL V1

### 4. Data library

CEA93, based on JEF-2.2

### 5. Neutron data processing code or method

NJOY

### 6. Neutron energy groups

20 groups

### 7. Geometry modelling

2-D

### 8. Description of your code system

The CRISTAL package used here includes the Sn route, based on APOLLO2, a user-oriented, modular code. APOLLO2 solves the integral form of the Boltzmann equation through the collision probability method (Pij method), and/or the integro-differential transport equation, using the discrete ordinates method. To perform sensitivity calculation, an exact perturbation method is used; the integral form of the Boltzmann equation is solved through the collision probability method (Pij method).

The CRISTAL package used here includes the Sn route, based on APOLLO2, a user oriented, modular code. APOLLO2 solves the integral form of the Boltzmann equation through the collision probability method (Pij method), and/or the integro-differential transport equation, using the discrete ordinates method. The Sn modules were developed to perform large 2-D-geometry calculations; methods such as the Sn-nodal technique were implemented.

## 4. ORNL, United States

**1. Institute**

Oak Ridge National Laboratory

**2. Participants**

John C. Wagner, Jonathon Waldes

**3. Computer code**

TSUNAMI-3D

**4. Data library**

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

**5. Neutron data processing code or method**

BONAMI/NITAWL (SCALE 5)

**6. Neutron energy groups**

238-group structure

**7. Geometry modelling**

3-D

**8. Description of your code system**

TSUNAMI-3D is a computational sequence in SCALE 5 that computes the sensitivity of keff to cross-section data for explicit 3-D system models. The KENO V.a module is used to produce forward and adjoint neutron transport solutions and the SAMS module is used to produce sensitivity coefficients. The BONAMIST and NITAWLST modules are used to produce the sensitivity of the resonance self-shielded multi-group cross-section data to input data for the unresolved and resolved resonance regions, respectively.

The input for TSUNAMI-3D is similar to that used for the CSAS25 3-D criticality safety analysis sequence of SCALE, with some additional input requirements. TSUNAMI-3D produces a sensitivity data file that contains the sensitivity of $k_{eff}$ to each reaction of each nuclide on a group-wise basis.

**9. Other information**

Standard deviations for the sensitivity values can be seen in the following table.

| Case | 1 | 2 | 3 | 4 | 11 | 12 |
|---|---|---|---|---|---|---|
| $^{234}U$ | 6.57E-07 | 6.48E-07 | 4.84E-07 | 5.12E-07 | 5.13E-07 | 5.25E-07 |
| $^{235}U$ | 9.50E-05 | 1.03E-04 | 5.20E-05 | 6.50E-05 | 5.18E-05 | 6.39E-05 |
| $^{236}U$ | 3.16E-06 | 3.28E-06 | 3.25E-06 | 3.62E-06 | 3.31E-06 | 3.50E-06 |
| $^{238}U$ | 1.14E-04 | 1.16E-04 | 1.09E-04 | 1.15E-04 | 1.09E-04 | 1.13E-04 |
| $^{238}Pu$ | 5.19E-07 | 6.46E-07 | 1.38E-06 | 1.64E-06 | 1.42E-06 | 1.66E-06 |
| $^{239}Pu$ | 5.99E-05 | 8.13E-05 | 6.32E-05 | 9.11E-05 | 6.42E-05 | 9.03E-05 |
| $^{240}Pu$ | 1.44E-05 | 1.53E-05 | 1.55E-05 | 1.73E-05 | 1.59E-05 | 1.66E-05 |
| $^{241}Pu$ | 1.45E-05 | 1.78E-05 | 2.15E-05 | 2.72E-05 | 1.68E-05 | 2.10E-05 |
| $^{242}Pu$ | 1.82E-06 | 1.88E-06 | 3.62E-06 | 3.74E-06 | 3.73E-06 | 3.62E-06 |
| $^{237}Np$ | 8.46E-07 | 1.02E-06 | 1.40E-06 | 1.65E-06 | 1.42E-06 | 1.65E-06 |
| $^{241}Am$ | 1.79E-07 | 2.33E-07 | 3.27E-07 | 4.68E-07 | 2.52E-06 | 3.25E-06 |
| $^{243}Am$ | 2.52E-07 | 3.03E-07 | 8.37E-07 | 9.71E-07 | 8.36E-07 | 9.18E-07 |
| $^{103}Rh$ | 2.36E-06 | 2.45E-06 | 3.12E-06 | 3.38E-06 | 3.39E-06 | 3.52E-06 |
| $^{133}Cs$ | 1.69E-06 | 1.70E-06 | 2.14E-06 | 2.27E-06 | 2.18E-06 | 2.22E-06 |
| $^{143}Nd$ | 4.66E-06 | 4.51E-06 | 5.94E-06 | 5.99E-06 | 6.02E-06 | 6.01E-06 |
| $^{145}Nd$ | 1.60E-06 | 1.60E-06 | 1.99E-06 | 2.14E-06 | 2.03E-06 | 2.08E-06 |
| $^{155}Gd$ | 2.52E-08 | 4.09E-08 | 4.73E-08 | 8.64E-08 | 3.29E-06 | 3.27E-06 |
| $^{95}Mo$ | 1.65E-06 | 1.65E-06 | 2.18E-06 | 2.36E-06 | 2.45E-06 | 2.49E-06 |
| $^{99}Tc$ | 1.62E-06 | 1.64E-06 | 2.04E-06 | 2.20E-06 | 2.08E-06 | 2.14E-06 |
| $^{101}Ru$ | 4.37E-07 | 4.40E-07 | 6.13E-07 | 6.30E-07 | 6.22E-07 | 6.18E-07 |
| $^{109}Ag$ | 6.84E-07 | 7.39E-07 | 1.14E-06 | 1.27E-06 | 1.14E-06 | 1.21E-06 |
| $^{147}Sm$ | 2.41E-07 | 2.24E-07 | 3.55E-07 | 3.52E-07 | 9.25E-07 | 9.03E-07 |
| $^{149}Sm$ | 3.02E-06 | 4.50E-06 | 2.84E-06 | 4.63E-06 | 4.59E-06 | 6.17E-06 |
| $^{150}Sm$ | 5.28E-07 | 5.32E-07 | 8.04E-07 | 8.01E-07 | 8.05E-07 | 7.80E-07 |
| $^{151}Sm$ | 3.53E-06 | 4.61E-06 | 4.19E-06 | 5.77E-06 | 4.04E-06 | 5.51E-06 |
| $^{152}Sm$ | 3.00E-06 | 2.93E-06 | 3.79E-06 | 3.94E-06 | 3.87E-06 | 3.83E-06 |
| $^{153}Eu$ | 5.19E-07 | 5.31E-07 | 8.90E-07 | 8.88E-07 | 8.91E-07 | 8.71E-07 |

## D. SENSITIVITY CALCULATION ON CASK

### 1. SERCO ASSURANCE, United Kingdom

**1. Institute**

Serco Assurance

**2. Participant**

David Hanlon

**3. Computer code**

MONK8B

**4. Data library**

JEF-2.2

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

13 193 hyper-fine group structure

**7. Geometry modelling**

3-D with a nominal length and full specular reflection on all outer surfaces.

**8. Description of your code system**

The calculations used the Monte Carlo criticality code MONK8B with its associated JEF-2.2 based library. The library was generated during 1997 using NJOY and has a 13 193 hyper-fine group structure. This library, together with the point-energy collision processing algorithms, provide a very detailed model of the physics, so the ultimate accuracy of the MONK code largely depends on the numerical accuracy of the basic nuclear data.

## 2. VTT, Finland

**1. Institute**

Technical Research Centre of Finland

**2. Participants**

Anssu Ranta-aho, Markku Anttila

**3. Computer code**

MCNP4C

**4. Data library**

ENDF/B-6.8

**5. Neutron data processing code or method**

NJOY

**6. Neutron energy groups**

Continuous energy

**7. Geometry modelling**

1/2 assembly with reflective boundary conditions.

**8. Description of your code system**

MCNP4C is a Monte Carlo code for calculating particle transport in exact geometry.

**10. Omitted nuclides**

$^{95}$Mo, $^{99}$Tc, $^{101}$Ru

## 3. ORNL, United States

### 1. Institute

Oak Ridge National Laboratory

### 2. Participants

John C. Wagner, Jonathon Waldes

### 3. Computer code

TSUNAMI-3-D

### 4. Data library

ENDF/B-V library (contains ENDF/B-VI evaluations for O, N, and Eu)

### 5. Neutron data processing code or method

BONAMI/NITAWL (SCALE 5)

### 6. Neutron energy groups

238-group structure

### 7. Geometry modelling

3-D

### 8. Description of your code system

TSUNAMI-3D is a computational sequence in SCALE 5 that computes the sensitivity of keff to cross-section data for explicit 3-D system models. The KENO V.a module is used to produce forward and adjoint neutron transport solutions and the SAMS module is used to produce sensitivity coefficients. The BONAMIST and NITAWLST modules are used to produce the sensitivity of the resonance self-shielded multi-group cross-section data to input data for the unresolved and resolved resonance regions, respectively.

The input for TSUNAMI-3D is similar to that used for the CSAS25 3-D criticality safety analysis sequence of SCALE, with some additional input requirements. TSUNAMI-3D produces a sensitivity data file that contains the sensitivity of keff to each reaction of each nuclide on a group-wise basis.

### 9. Other information

Standard deviations for the sensitivity values are shown in the following table.

| Case | 1 | 2 | 3 | 4 | 11 | 12 |
|---|---|---|---|---|---|---|
| $^{234}U$ | 2.50E-06 | 2.77E-06 | 1.95E-06 | 2.04E-06 | 1.91E-06 | 2.16E-06 |
| $^{235}U$ | 1.07E-04 | 1.19E-04 | 6.55E-05 | 7.49E-05 | 6.21E-05 | 7.48E-05 |
| $^{236}U$ | 1.24E-05 | 1.39E-05 | 1.35E-05 | 1.46E-05 | 1.30E-05 | 1.43E-05 |
| $^{238}U$ | 4.34E-04 | 4.96E-04 | 4.41E-04 | 4.77E-04 | 4.17E-04 | 4.68E-04 |
| $^{238}Pu$ | 6.03E-07 | 7.71E-07 | 1.78E-06 | 1.94E-06 | 1.73E-06 | 2.02E-06 |
| $^{239}Pu$ | 1.02E-04 | 1.43E-04 | 1.15E-04 | 1.55E-04 | 1.11E-04 | 1.56E-04 |
| $^{240}Pu$ | 3.82E-05 | 4.38E-05 | 4.26E-05 | 4.56E-05 | 3.98E-05 | 4.53E-05 |
| $^{241}Pu$ | 1.88E-05 | 2.38E-05 | 3.05E-05 | 3.58E-05 | 2.28E-05 | 2.82E-05 |
| $^{242}Pu$ | 7.53E-06 | 8.58E-06 | 1.57E-05 | 1.61E-05 | 1.49E-05 | 1.56E-05 |
| $^{237}Np$ | 2.17E-06 | 2.93E-06 | 3.74E-06 | 4.55E-06 | 3.58E-06 | 4.57E-06 |
| $^{241}Am$ | 3.96E-07 | 5.61E-07 | 7.54E-07 | 1.07E-06 | 5.44E-06 | 7.43E-06 |
| $^{243}Am$ | 1.04E-06 | 1.33E-06 | 3.63E-06 | 3.98E-06 | 3.35E-06 | 3.80E-06 |
| $^{103}Rh$ | 8.08E-06 | 9.26E-06 | 1.09E-05 | 1.16E-05 | 1.09E-05 | 1.22E-05 |
| $^{133}Cs$ | 6.12E-06 | 6.66E-06 | 8.04E-06 | 8.47E-06 | 7.82E-06 | 8.36E-06 |
| $^{143}Nd$ | 6.59E-06 | 6.89E-06 | 9.04E-06 | 8.93E-06 | 8.70E-06 | 9.10E-06 |
| $^{145}Nd$ | 6.68E-06 | 7.42E-06 | 9.08E-06 | 9.46E-06 | 8.68E-06 | 9.36E-06 |
| $^{155}Gd$ | 2.75E-08 | 4.48E-08 | 5.75E-08 | 9.43E-08 | 3.82E-06 | 3.72E-06 |
| $^{95}Mo$ | 6.94E-06 | 7.47E-06 | 9.86E-06 | 1.00E-05 | 9.97E-06 | 1.09E-05 |
| $^{99}Tc$ | 5.95E-06 | 6.48E-06 | 7.80E-06 | 8.26E-06 | 7.59E-06 | 8.11E-06 |
| $^{101}Ru$ | 1.86E-06 | 2.08E-06 | 2.82E-06 | 2.89E-06 | 2.64E-06 | 2.90E-06 |
| $^{109}Ag$ | 2.73E-06 | 3.29E-06 | 4.85E-06 | 5.26E-06 | 4.49E-06 | 5.19E-06 |
| $^{147}Sm$ | 1.09E-06 | 1.13E-06 | 1.75E-06 | 1.68E-06 | 4.21E-06 | 4.38E-06 |
| $^{149}Sm$ | 4.16E-06 | 6.32E-06 | 4.28E-06 | 6.44E-06 | 6.61E-06 | 8.89E-06 |
| $^{150}Sm$ | 1.27E-06 | 1.45E-06 | 2.00E-06 | 2.02E-06 | 1.89E-06 | 2.03E-06 |
| $^{151}Sm$ | 3.88E-06 | 5.06E-06 | 5.15E-06 | 6.35E-06 | 4.73E-06 | 6.29E-06 |
| $^{152}Sm$ | 1.37E-05 | 1.44E-05 | 1.82E-05 | 1.83E-05 | 1.74E-05 | 1.78E-05 |
| $^{153}Eu$ | 1.43E-06 | 1.62E-06 | 2.51E-06 | 2.67E-06 | 2.40E-06 | 2.63E-06 |

## *Appendix C**

# PSI RESULTS OF CALCULATIONS FOR THE NEA PHASE II-D BURN-UP CREDIT BENCHMARK WITH THE MONTEBURNS 2.0/MCNPX 2.4.0/ORIGEN 2.1 CODE SYSTEM

*A.V. Vasiliev, J.R. Lebenhaft*
Paul Scherrer Institut

* Transparencies presented by A.V. Vasiliev in the meeting of WPNCS Expert Group on Burn-up Credit Criticality Safety, having taken place on 2 September 2004, in Prague.

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## DESCRIPTION OF THE COMPUTATIONAL MODEL

### Pin-wise fuel assembly model without radial discretization of fuel

### Neutron data libraries:

- actinides and fission products: ENDF/B-VI.5 files processed for 870K (generated by H.R. Trellue, LANL);
- water, clad, guide tube: JEF22NEA.BOLIB, mixed temperatures;
- absorber isotopes (Ag, Cd, In-115): MCNPDATA DLC-200 (ENDF60;ENDL92; 300K)

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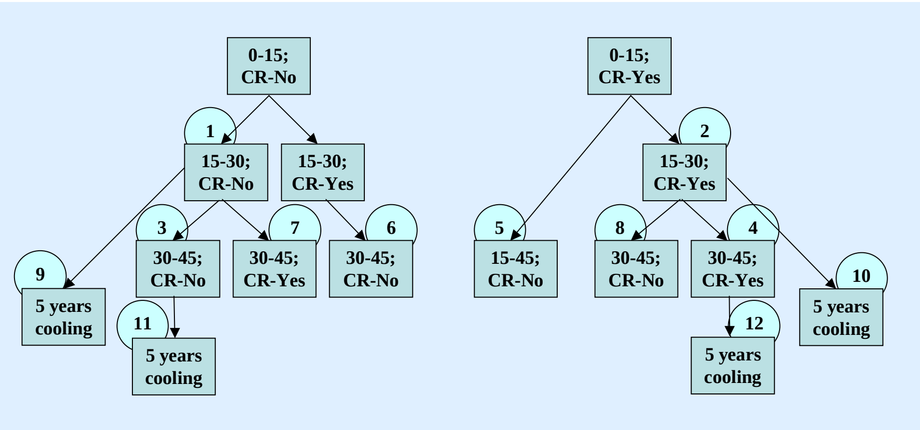
### Burnup calculation flowchart

(Values in circles – benchmark case number)



## Modeling details

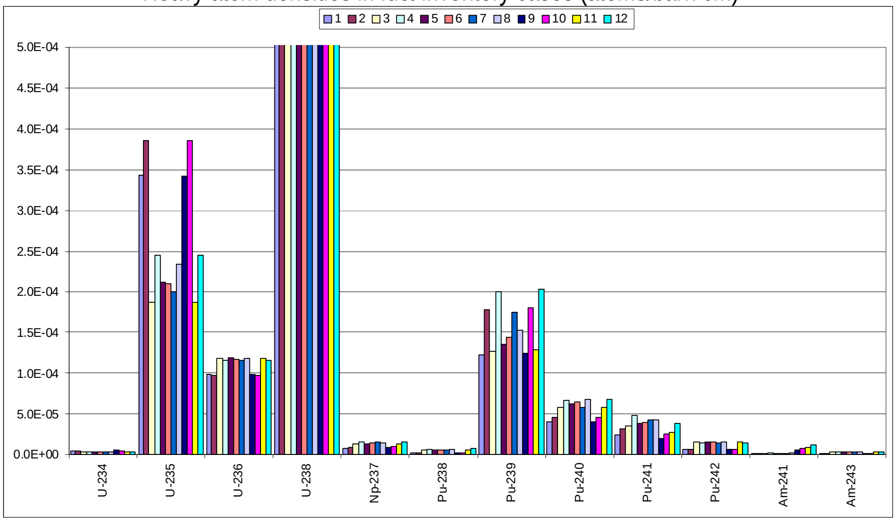
- Number of neutron histories per cycle = 5000;
  Number of neutron cycles = 110, 10 inactive cycles;
- Lengths of burnup steps (days):
  0.10; 2.50; 5.00; 10.00; 26.35; 43.85;
  all subsequent time steps are 43.85 days (1.67 GWd/tU )
- $^{235}Q_{fis}$ =201.7 MeV; ($^{239}Q_{fis}$ =210.5 MeV)
- Actinides and fission products tracked in the MCNPX cross-sections recalculations:

  U-234, U-235, U-236, U-238, Np-237, Np-239, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-242m, Am-243, Cm-244, Cm-245;

  Sr-90, Zr-93, Mo-95, Tc-99, Ru-101, Ru-103, Ru-106, Rh-103, Pd-105, Pd-106, Ag-109, Cd-113, I-129, Xe-131, Xe-132, Xe-134, Xe-135, Xe-136, Cs-133, Cs-134, Cs-135, Cs-137, Ba-138, Ce-144, Pr-141, Nd-143, Nd-144, Nd-145, Nd-146, Nd-148, Nd-150, Pm-147, Pm-148, Sm-147, Sm-148, Sm-149, Sm-150, Sm-151, Sm-152, Eu-153, Eu-154, Eu-155, Gd-155, Gd-156, Gd-157.

**Calculation results:**

Heavy atom densities in fuel inventory cases (atoms/barn·cm)



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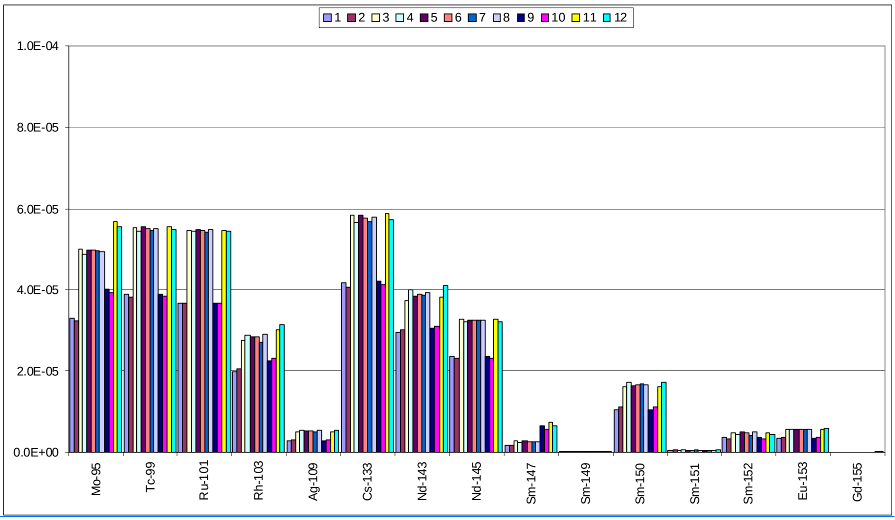
## Calculation results:

Fission-product atomic densities in fuel inventory cases (atoms/barn·cm)

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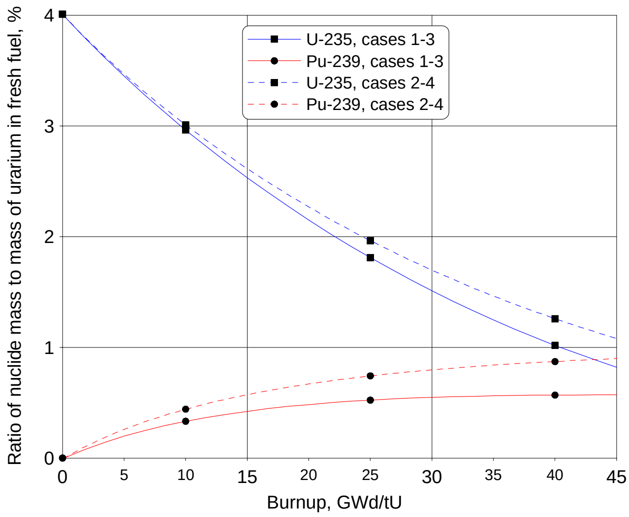
Variation in U-235 and Pu-239 masses with burnup

for cases 1-3 and 2-4



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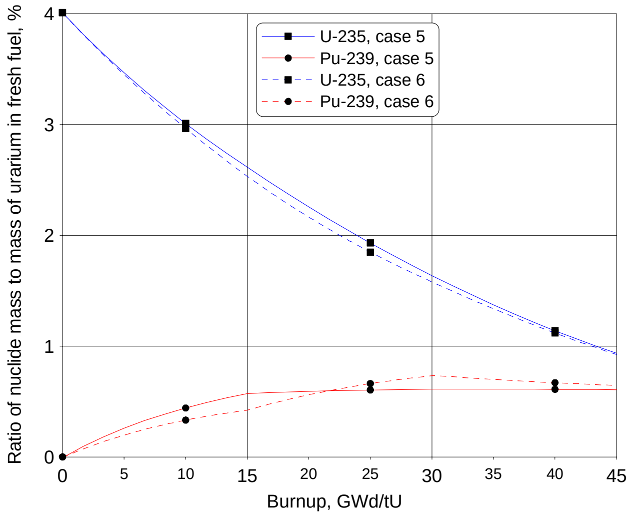
Variation in U-235 and Pu-239 masses with burnup
for cases 5 and 6

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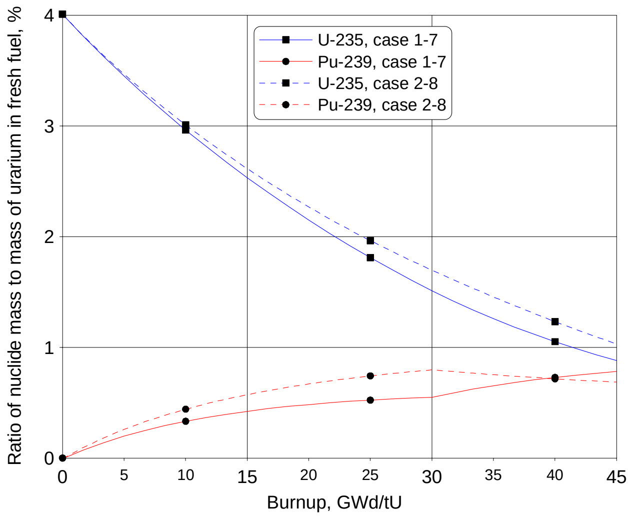
Variation in U-235 and Pu-239 masses with burnup
for cases 7 and 8



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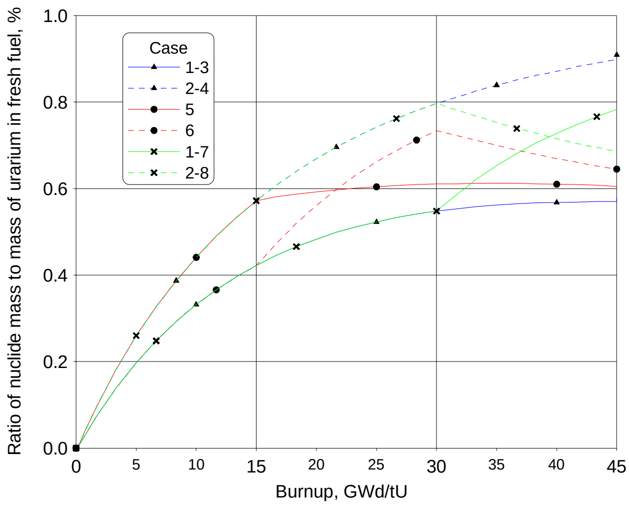
Variation in Pu-239 mass with burnup

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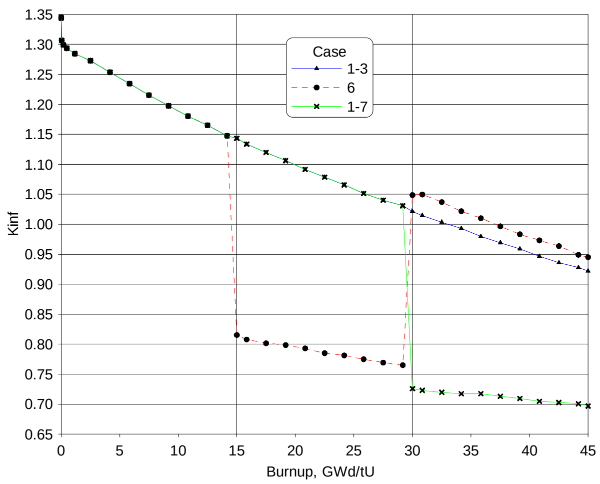
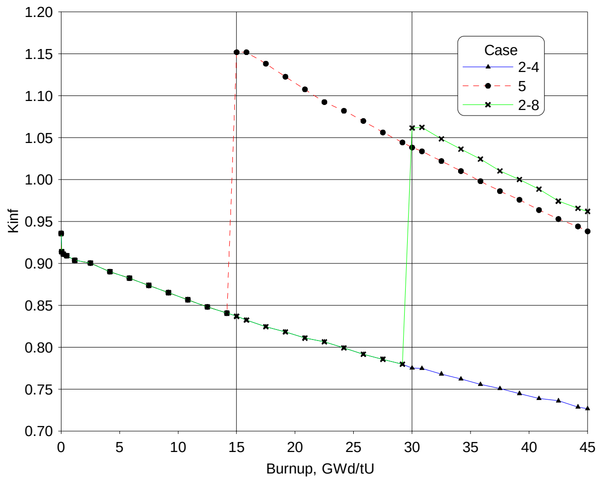
Variation in k-inf with burnup without CR inserted at BOC

(Monteburns-MCNPX results at burnup step midpoints)



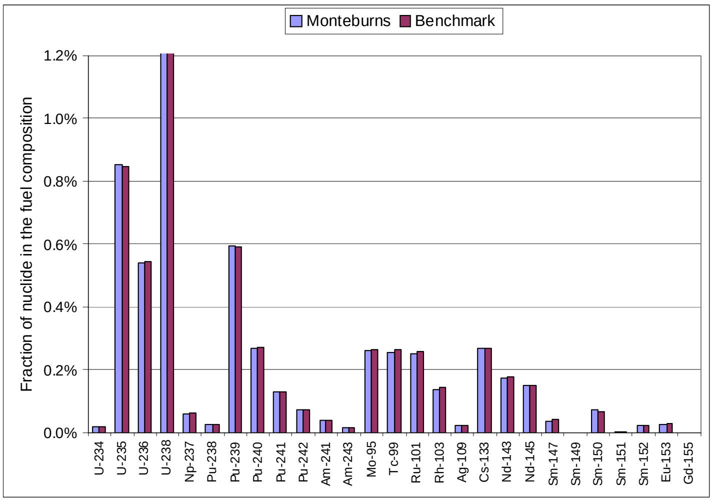
Variation in k-inf with burnup with CR inserted at BOC
(Monteburns-MCNPX results at burnup step midpoints)




## k-inf results (σ=0.0002)

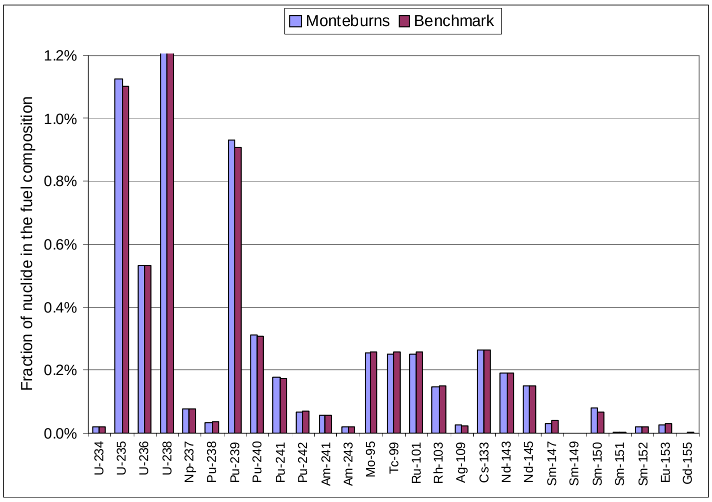
| Fuel inventory case (BU, cooling time) | k-inf Without FP | k-inf With FP |
|---|---|---|
| 1 (30; 0) | 1.1686 | 1.0942 |
| 2 (30; 0) | 1.2232 | 1.1444 |
| 3 (45; 0) | 1.0798 | 0.9862 |
| 4 (45; 0) | 1.1773 | 1.0798 |
| 5 (45; 0) | not required | 1.0103 |
| 6 (45; 0) | not required | 1.0170 |
| 7 (45; 0) | not required | 1.0432 |
| 8 (45; 0) | not required | 1.0381 |
| 9 (30; 5y) | 1.1537 | 1.0649 |
| 10 (30; 5y) | 1.2071 | 1.1150 |
| 11 (45; 5y) | 1.0551 | 0.9433 |
| 12 (45; 5y) | 1.1508 | 1.0378 |
| *13 (45; 5y)* | *not required* | *0.9358* |
| *14 (45; 5y)* | *not required* | *1.0231* |
| 15 (fresh fuel) | 1.3407 | - |

Spent-fuel composition. Average BU=45 GWd/tU;
cooling time= 5 years; burnup of FA without CR






Spent-fuel composition. Average BU=45 GWd/tU;
cooling time= 5 years; burnup of FA with CR



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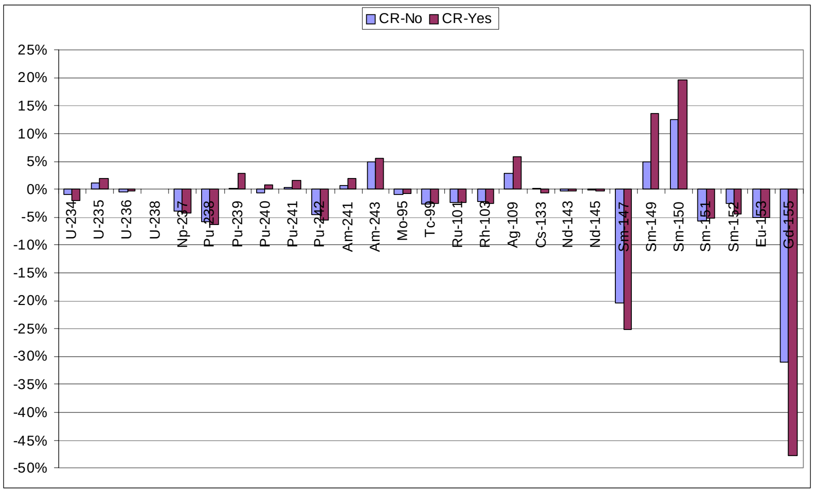
Relative difference between calculated PSI and specified benchmark spent-fuel compositions.

Average BU=45 GWd/tU; cooling time= 5years

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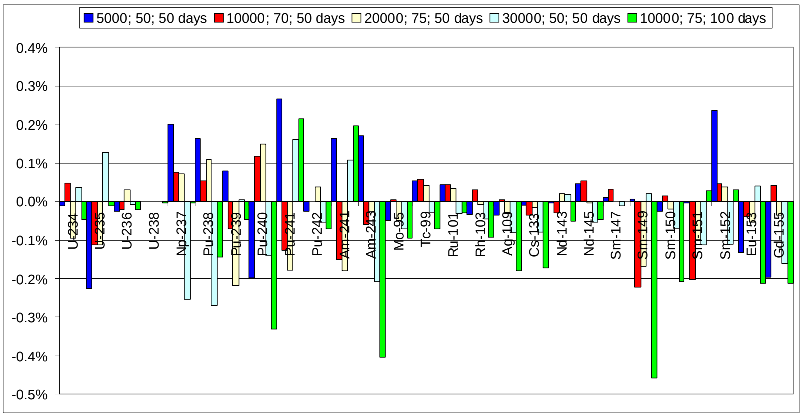
**Sensitivity studies and discussion**

***Effect of the MCNPX statistical accuracy and frequency of the flux and cross-section recalculations***




**Dependence of the fuel inventory results on the number of neutron histories used in MCNPX and on the duration of the burnup step.**
**Reference case: 100,000 neutron histories per cycle; 70 active cycles; burnup step 50 days**

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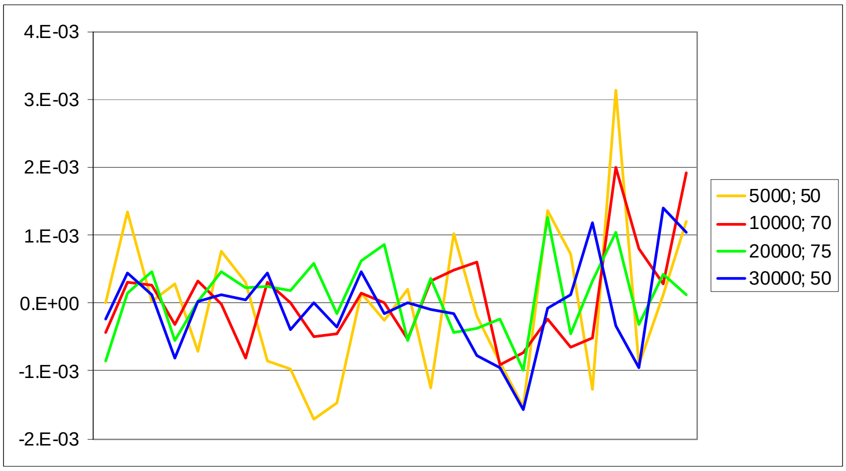
*Deviation of k-inf between calculations with different numbers of neutron histories and reference case during burnup*

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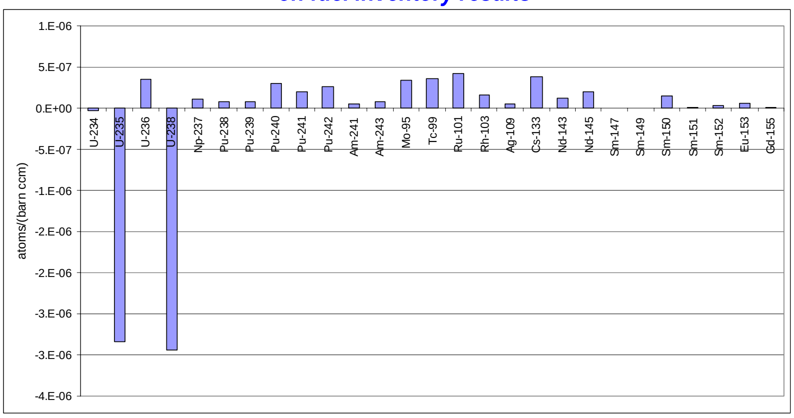
***Effect of the choice of recoverable fission energy value for flux normalization on fuel inventory results***




Absolute difference in spent-fuel nuclide densities calculated by Monteburns with ${}^{235}Q_{fis}$ values of 201.7 and 200 MeV; (reference case: 201.7 MeV)
FA without CR; burnup = 45 GWd/tU

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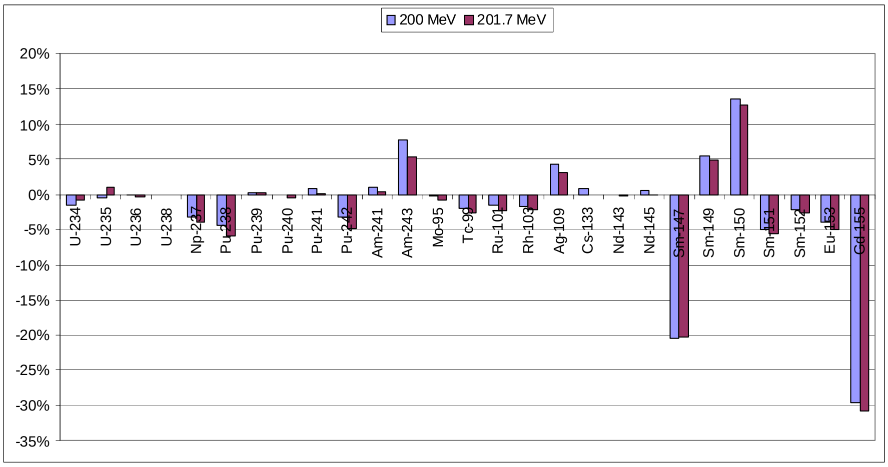
## Relative difference of PSI results and benchmark definition of spent fuel composition

Average BU = 45 GWd/tU, cooling time = 5 years, burnup of FA without CR

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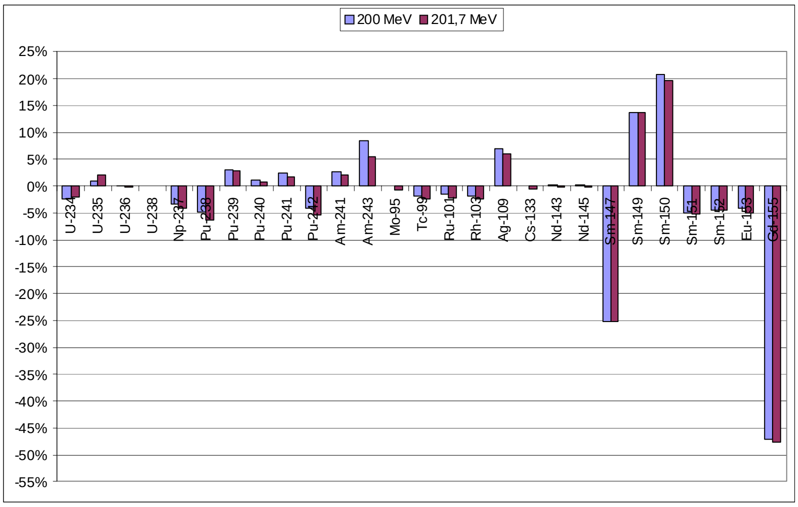
## Relative difference of PSI results and benchmark definition of spent fuel composition

Average BU = 45 GWd/tU, cooling time = 5 years, burnup of FA with CR



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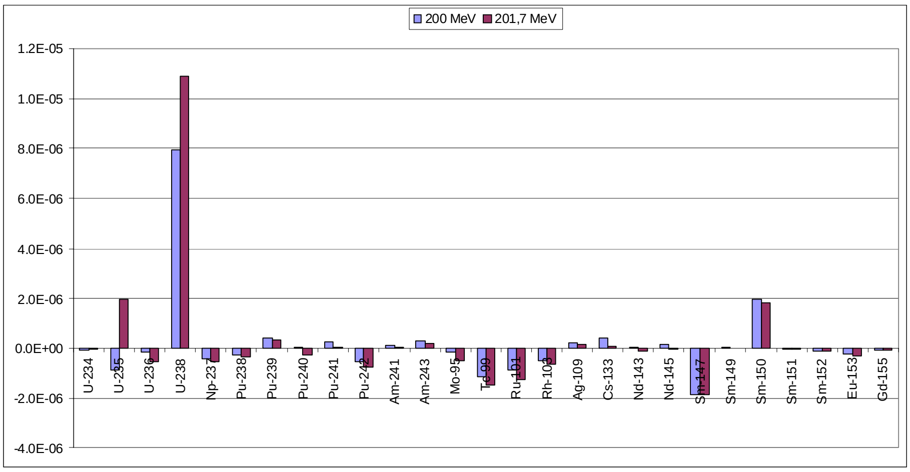
## Absolute difference of PSI results and benchmark definition of spent fuel composition

Average BU = 45 GWd/tU, cooling time = 5 years, burnup of FA without CR

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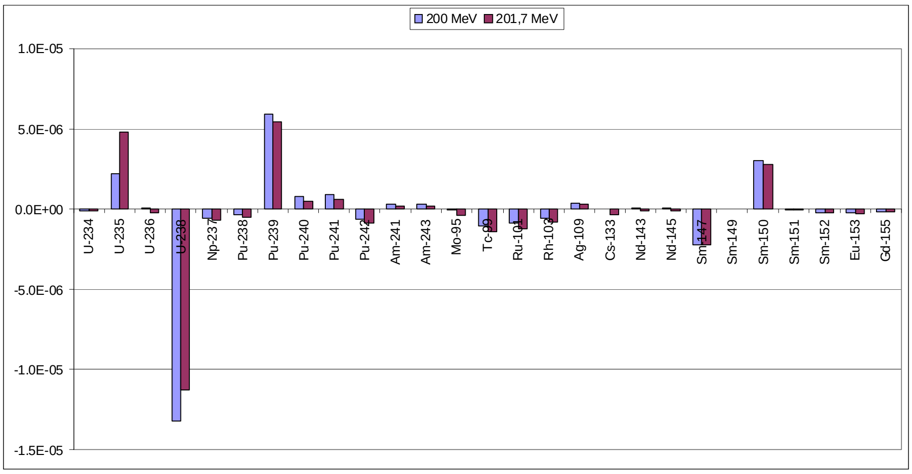
## Absolute difference of PSI results and benchmark definition of spent fuel composition

Average BU = 45 GWd/tU, cooling time = 5 years, burnup of FA with CR



## Fuel burnup in heavy atoms, %

| CR presence during irradiation | Monteburns, $^{235}Q_{fis}$ =200 MeV | Monteburns, $^{235}Q_{fis}$ =201.7 MeV | Benchmark definition |
|---|---|---|---|
| No | 4.69 | 4.67 | 4.72 |
| Yes | 4.70 | 4.69 | 4.69 |

The corresponding differences in the k-eff values that resulted from a change in the $^{235}Q_{fis}$ value from 201.7 to 200 MeV were -0.26% and -0.14%, respectively, for the burnup cases of a fuel assembly without and with control rods (σ = 0.0002).



## *Influence of FA geometry modeling on fuel inventory results*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 1.08 |
| | | | | | | | 1.07 | 1.07 |
| | | | | | | 1.02 | 1.05 | 1.06 |
| | | | | | | 1.00 | 1.03 | 1.05 |
| | | | | 0.97 | 0.97 | 0.98 | 1.02 | 1.03 |
| | | | | 0.96 | 0.96 | | 1.00 | 1.02 |
| | | 0.97 | 0.96 | 0.97 | 0.98 | 0.98 | 1.01 | 1.03 |
| | 0.97 | 0.97 | 0.96 | 0.98 | 0.98 | 0.98 | 1.00 | 1.02 |
| | 0.96 | 0.96 | | 0.96 | 0.97 | | 1.00 | 1.02 |

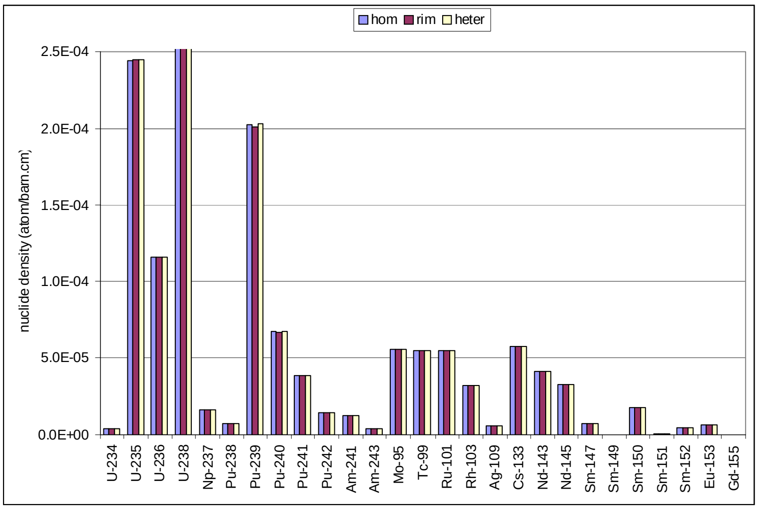
(a)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.80 |
| | | | | | | | 0.85 | 0.82 |
| | | | | | | 0.94 | 0.87 | 0.85 |
| | | | | | | 1.03 | 0.91 | 0.87 |
| | | | | 1.13 | 1.16 | 1.09 | 0.97 | 0.91 |
| | | | | 1.15 | 1.15 | | 1.02 | 0.92 |
| | | 1.03 | 1.11 | 1.07 | 1.06 | 1.08 | 0.98 | 0.92 |
| | 0.94 | 1.00 | 1.09 | 1.05 | 1.06 | 1.08 | 0.98 | 0.92 |
| | 0.91 | 1.02 | | 1.10 | 1.11 | | 1.02 | 0.92 |

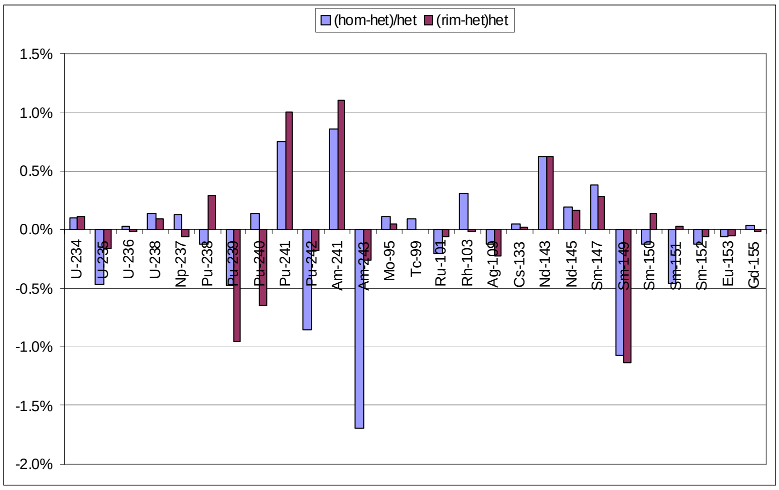
(b)

Relative pin-wise plutonium distribution
generated during the fuel cycle.

Case (a) FA without CR; case (b) FA with CR; burnup = 45 GWd/tU




Nuclide densities for the fuel inventory case for different FA models with CR; burnup of 45 GWd/tU followed by 5 years of cooling




Relative differences in nuclide densities for the fuel inventory case for different FA models with CR; burnup of 45 GWd/tU followed by 5 years of cooling

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k-inf sensitivity study

| Spent fuel composition | k-inf calculation case BU=45GWd/tU | |
|---|---|---|
| | FA without CR | FA with CR |
| Benchmark definition (cases 13,14) | 0.9358 | 1.0231 |
| Monteburns result (cases 11,12) | 0.9433 (0.80%) | 1.0378 (1.43%) |
| Monteburns result for actinides, benchmark definition for FP | 0.9385 (0.29%) | 1.0306 (0.73%) |
| Monteburns result, Gd-155 from benchmark definition | 0.9390 (0.34%) | 1.0292 (0.59%) |

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## Conclusions

- The discrepancies in the spent-fuel isotopic composition between the results obtained and the benchmark data for heavy atoms are generally within ~5% for the fuel depletion cases considered
- The deviations in the fission-product densities are much higher, the maximum being for Gd-155, approximately 30% to 45% for the corresponding cases
- The disagreements in the fuel assembly k-inf values between spent-fuel compositions obtained during the present study and those specified in the benchmark are about 0.8% and 1.4%, respectively, for fuel assemblies without and with control rods. Such large discrepancies can be attributed mainly to differences in the Gd-155 nuclide densities

# *Appendix D*

## COMPARISON OF JAERI/JNES RESULTS

*T. Nkata*
Japan Nuclear Energy Safety Organisation

In comparison with JAERI, our results show slightly more accumulation of $^{239}Pu$ and more consumption of $^{235}U$ than JAERI by spectrum hardening owing to CR insertion. But these differences are not so great.

In comparison with JAERI, our results show good agreement with JAERI without $^{234}U$ and $^{155}Gd$.

**$^{155}$Gd**

$^{155}Gd$ is almost produced from $^{155}Eu$ beta-decay (a half-life is 4.9 y) and by fission directly (a total fission yield is 0.025%).

***Cause and comment***

$^{155}Gd$ amount with BU should be changed by using different cross-section, fission yield, decay constant, flux level. Although, fission yield, decay constant are correct because of using same values in un-rodded burn-up and showing good agreement. Thus, the differences derive from cross-section or flux level.

One of the possible causes could be that the $^{155}Gd$ cross-section of ORIGEN is not correctly changed along with spectrum hardening by any program error. But there is no different procedure on $^{155}Gd$ and other nuclides in one rod. There is no difference between with CR calculation and without CR calculation.

- We made ORIGEN micro cross-section by using a MVP macro cross-section and a nuclide density in preceding step. It is one of a possible cause that $^{155}Gd$ macro cross-section in MVP is probably fluctuate along with BU because of very small number density and then low statistical accuracy.

- And also it is one of a possible cause (main cause?) that $^{155}Eu$ micro cross-section is constant against a changing of $^{155}Gd$ cross-section along with BU because we did not include $^{155}Eu$ in this MVP calculation. Therefore, this $^{155}Eu$ absorption cross-section will become relatively greater by CR insertion than without condition. As $^{155}Eu$ which is mother nuclide of $^{155}Gd$ will decrease faster, $^{155}Gd$ will accumulate slower.

- Burn-up flux level is 5% higher than JAERI's, because of using new Q-value. It means 10% or higher under CR inserted condition. For this reason, under without CR condition, $^{235}U$ consumptions are slightly larger and total plutonium amount are greater than JAERI. If this reason is a real cause, it will be the feature of our system. For this benchmark it is not so adequate but the difference is not so bad because the cause is clear.

In these calculations, absolute values of $^{155}Gd$ are very small (10-9). These small values and its ratio have usually large uncertainties. Of course, $^{155}Gd$ is important nuclide as absorber materials but in Phase II-D calculations $^{155}Gd$ is only one of a FP nuclide. If Gd fuel or BP rods are provided, our system could prepare a special procedure and calculate detailed burn-up properties. If we have any problem as above, these are only affecting to a FP nuclide in a fuel and these are not affecting to the absorber materials.

**Figure 1. Comparison of final nuclide number density ratio at 30 GWd/t**

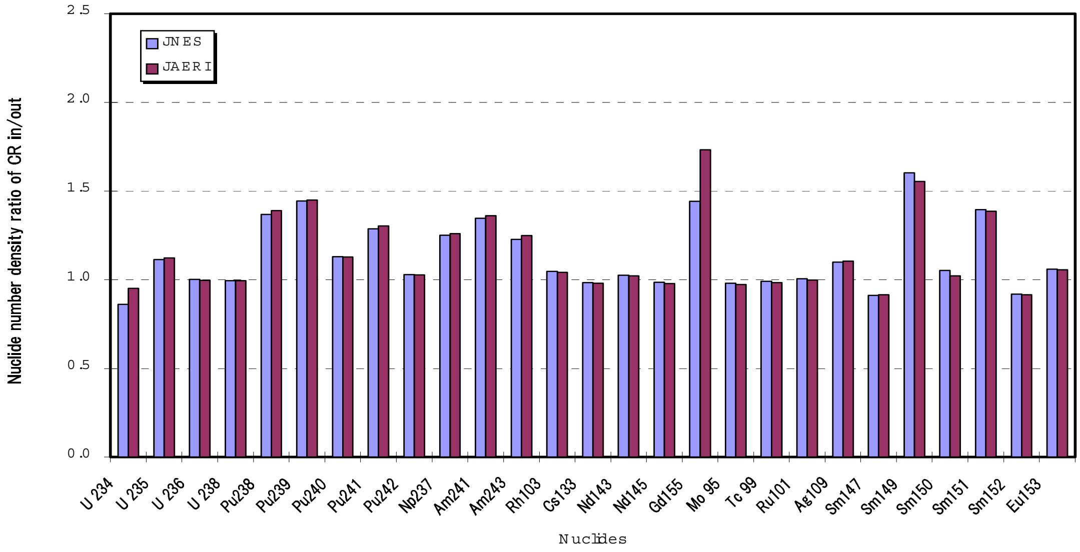


**Figure 2. Comparison of final nuclide number density ratio at 45 GWd/t**

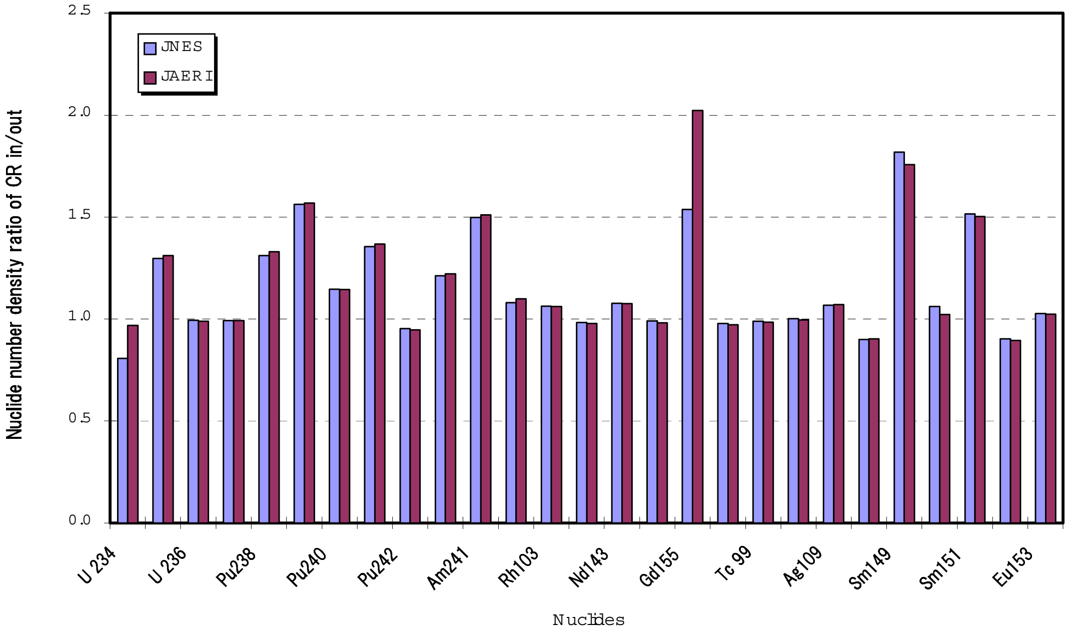

**Figure 3. Comparison of nuclide number density changing ratio of 30 GWd/t by 45 GWd/t**

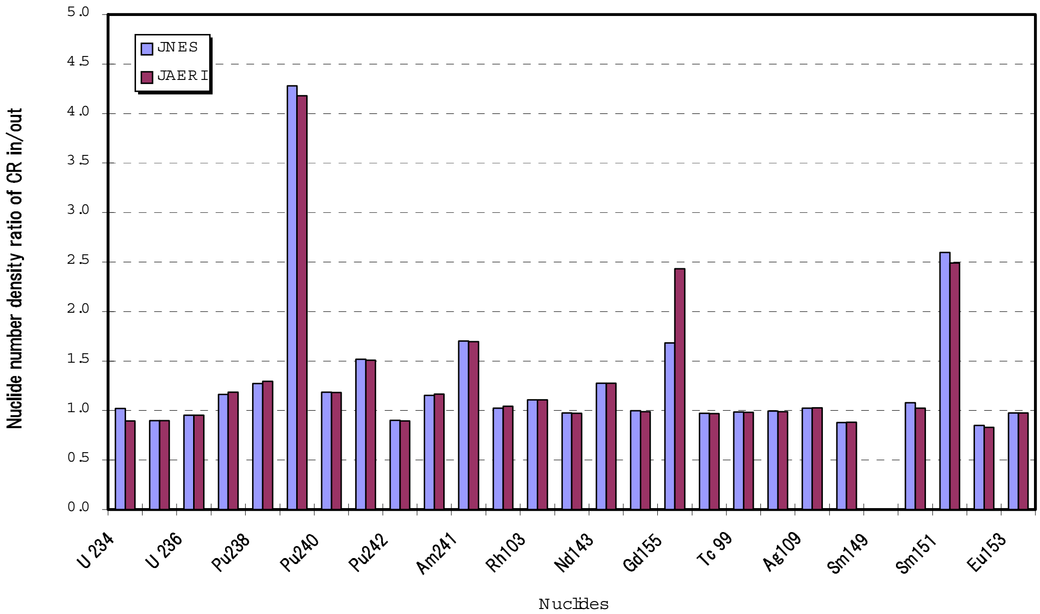


**Table 1. Comparison with JAERI on final number densities at 30 GWd/t**

| BU | 30GWd/t | | | | | | | | Comparison | |
|---|---|---|---|---|---|---|---|---|---|---|
| items | JNES | | | | JAERI | | | | IN/OUT ratio | IN-OUT difference |
| Nuclide | CR-OUT | CR-IN | IN/OUT | IN-OUT | CR-OUT | CR-IN | IN/OUT | IN-OUT | JNES/JAERI | JNES-JAERI |
| **U 234** | **4.867E-06** | **4.188E-06** | **0.861** | **-6.786E-07** | **5.203E-06** | **4.957E-06** | **0.953** | **-2.460E-07** | **0.903** | **-4.326E-07** |
| U 235 | 3.367E-04 | 3.754E-04 | 1.115 | 3.868E-05 | 3.411E-04 | 3.828E-04 | 1.122 | 4.170E-05 | 0.993 | -3.024E-06 |
| U 236 | 1.028E-04 | 1.030E-04 | 1.002 | 2.492E-07 | 1.010E-04 | 1.007E-04 | 0.997 | -3.000E-07 | 1.005 | 5.492E-07 |
| U 238 | 2.110E-02 | 2.098E-02 | 0.994 | -1.168E-04 | 2.111E-02 | 2.100E-02 | 0.995 | -1.100E-04 | 1.000 | -6.811E-06 |
| Pu238 | 2.255E-06 | 3.089E-06 | 1.370 | 8.334E-07 | 1.981E-06 | 2.755E-06 | 1.391 | 7.740E-07 | 0.985 | 5.940E-08 |
| Pu239 | 1.267E-04 | 1.829E-04 | 1.444 | 5.621E-05 | 1.245E-04 | 1.806E-04 | 1.451 | 5.610E-05 | 0.995 | 1.149E-07 |
| Pu240 | 4.150E-05 | 4.689E-05 | 1.130 | 5.391E-06 | 4.068E-05 | 4.588E-05 | 1.128 | 5.200E-06 | 1.002 | 1.909E-07 |
| Pu241 | 2.620E-05 | 3.372E-05 | 1.287 | 7.520E-06 | 2.515E-05 | 3.277E-05 | 1.303 | 7.620E-06 | 0.988 | -9.962E-08 |
| Pu242 | 6.855E-06 | 7.054E-06 | 1.029 | 1.988E-07 | 6.415E-06 | 6.587E-06 | 1.027 | 1.720E-07 | 1.002 | 2.683E-08 |
| Np237 | 8.541E-06 | 1.069E-05 | 1.251 | 2.148E-06 | 8.011E-06 | 1.009E-05 | 1.260 | 2.079E-06 | 0.994 | 6.856E-08 |
| Am241 | 6.294E-07 | 8.474E-07 | 1.346 | 2.181E-07 | 6.091E-07 | 8.299E-07 | 1.363 | 2.208E-07 | 0.988 | -2.731E-09 |
| Am243 | 1.107E-06 | 1.360E-06 | 1.228 | 2.526E-07 | 9.471E-07 | 1.183E-06 | 1.249 | 2.359E-07 | 0.983 | 1.668E-08 |
| Rh103 | 2.063E-05 | 2.159E-05 | 1.047 | 9.603E-07 | 2.021E-05 | 2.106E-05 | 1.042 | 8.500E-07 | 1.004 | 1.103E-07 |
| Cs133 | 4.277E-05 | 4.213E-05 | 0.985 | -6.432E-07 | 4.351E-05 | 4.271E-05 | 0.982 | -8.000E-07 | 1.003 | 1.568E-07 |
| Nd143 | 2.990E-05 | 3.065E-05 | 1.025 | 7.477E-07 | 2.958E-05 | 3.022E-05 | 1.022 | 6.400E-07 | 1.003 | 1.077E-07 |
| Nd145 | 2.408E-05 | 2.376E-05 | 0.987 | -3.134E-07 | 2.378E-05 | 2.328E-05 | 0.979 | -5.000E-07 | 1.008 | 1.866E-07 |
| **Gd155** | **1.576E-09** | **2.275E-09** | **1.443** | **6.988E-10** | **1.571E-09** | **2.722E-09** | **1.733** | **1.151E-09** | **0.833** | **-4.522E-10** |
| Mo95 | 3.372E-05 | 3.305E-05 | 0.980 | -6.641E-07 | 3.324E-05 | 3.238E-05 | 0.974 | -8.600E-07 | 1.006 | 1.959E-07 |
| Tc99 | 4.063E-05 | 4.029E-05 | 0.992 | -3.402E-07 | 4.060E-05 | 4.000E-05 | 0.985 | -6.000E-07 | 1.007 | 2.598E-07 |
| Ru101 | 3.775E-05 | 3.795E-05 | 1.005 | 2.064E-07 | 3.672E-05 | 3.671E-05 | 1.000 | -1.000E-08 | 1.006 | 2.164E-07 |
| Ag109 | 3.454E-06 | 3.797E-06 | 1.100 | 3.438E-07 | 3.278E-06 | 3.623E-06 | 1.105 | 3.450E-07 | 0.995 | -1.166E-09 |
| Sm147 | 2.162E-06 | 1.973E-06 | 0.913 | -1.888E-07 | 2.203E-06 | 2.016E-06 | 0.915 | -1.870E-07 | 0.997 | -1.759E-09 |
| Sm149 | 9.103E-08 | 1.459E-07 | 1.602 | 5.483E-08 | 9.270E-08 | 1.441E-07 | 1.554 | 5.140E-08 | 1.031 | 3.427E-09 |
| Sm150 | 9.028E-06 | 9.506E-06 | 1.053 | 4.776E-07 | 9.150E-06 | 9.357E-06 | 1.023 | 2.070E-07 | 1.030 | 2.706E-07 |
| Sm151 | 4.482E-07 | 6.253E-07 | 1.395 | 1.770E-07 | 4.356E-07 | 6.041E-07 | 1.387 | 1.685E-07 | 1.006 | 8.531E-09 |
| Sm152 | 3.640E-06 | 3.350E-06 | 0.920 | -2.909E-07 | 3.650E-06 | 3.346E-06 | 0.917 | -3.040E-07 | 1.004 | 1.312E-08 |
| Eu153 | 3.426E-06 | 3.631E-06 | 1.060 | 2.044E-07 | 3.282E-06 | 3.465E-06 | 1.056 | 1.830E-07 | 1.004 | 2.142E-08 |

## Table 2. Comparison with JAERI on final number densities at 45 GWd/t

| BU | 45GWd/t | | | | | | | | Comparison | |
|---|---|---|---|---|---|---|---|---|---|---|
| item s | JNES | | | | JAERI | | | | IN/OUT ratio | IN-OUT difference |
| Nuclide | CR-OUT | CR-N | IN/OUT | IN-OUT | CR-OUT | CR-N | IN/OUT | IN-OUT | JNES/JAERI | JNES-JAERI |
| **U 234** | **3.658E-06** | **2.954E-06** | **0.808** | **-7.037E-07** | **4.092E-06** | **3.964E-06** | **0.969** | **-1.280E-07** | **0.834** | **-5.757E-07** |
| U 235 | 1.825E-04 | 2.366E-04 | 1.297 | 5.415E-05 | 1.856E-04 | 2.434E-04 | 1.311 | 5.780E-05 | 0.989 | -3.654E-06 |
| U 236 | 1.226E-04 | 1.219E-04 | 0.994 | -7.249E-07 | 1.213E-04 | 1.200E-04 | 0.989 | -1.300E-06 | 1.005 | 5.751E-07 |
| U 238 | 2.082E-02 | 2.066E-02 | 0.992 | -1.617E-04 | 2.084E-02 | 2.068E-02 | 0.992 | -1.600E-04 | 1.000 | -1.738E-06 |
| Pu238 | 5.908E-06 | 7.743E-06 | 1.311 | 1.835E-06 | 5.304E-06 | 7.058E-06 | 1.331 | 1.754E-06 | 0.985 | 8.128E-08 |
| Pu239 | 1.323E-04 | 2.067E-04 | 1.562 | 7.440E-05 | 1.301E-04 | 2.040E-04 | 1.568 | 7.390E-05 | 0.996 | 5.015E-07 |
| Pu240 | 5.952E-05 | 6.828E-05 | 1.147 | 8.755E-06 | 5.824E-05 | 6.664E-05 | 1.144 | 8.400E-06 | 1.002 | 3.546E-07 |
| Pu241 | 3.725E-05 | 5.049E-05 | 1.356 | 1.324E-05 | 3.655E-05 | 4.997E-05 | 1.367 | 1.342E-05 | 0.992 | -1.761E-07 |
| Pu242 | 1.684E-05 | 1.605E-05 | 0.953 | -7.931E-07 | 1.627E-05 | 1.539E-05 | 0.946 | -8.800E-07 | 1.007 | 8.688E-08 |
| Np237 | 1.407E-05 | 1.707E-05 | 1.213 | 3.000E-06 | 1.341E-05 | 1.639E-05 | 1.222 | 2.980E-06 | 0.993 | 2.027E-08 |
| Am241 | 1.098E-06 | 1.645E-06 | 1.498 | 5.468E-07 | 1.097E-06 | 1.657E-06 | 1.510 | 5.600E-07 | 0.992 | -1.316E-08 |
| Am243 | 4.000E-06 | 4.323E-06 | 1.081 | 3.234E-07 | 3.572E-06 | 3.924E-06 | 1.099 | 3.520E-07 | 0.984 | -2.858E-08 |
| Rh103 | 2.856E-05 | 3.039E-05 | 1.064 | 1.827E-06 | 2.825E-05 | 2.996E-05 | 1.061 | 1.710E-06 | 1.003 | 1.171E-07 |
| Cs133 | 6.002E-05 | 5.897E-05 | 0.983 | -1.045E-06 | 6.124E-05 | 5.996E-05 | 0.979 | -1.280E-06 | 1.004 | 2.348E-07 |
| Nd143 | 3.772E-05 | 4.064E-05 | 1.077 | 2.916E-06 | 3.739E-05 | 4.020E-05 | 1.075 | 2.810E-06 | 1.002 | 1.062E-07 |
| Nd145 | 3.342E-05 | 3.310E-05 | 0.990 | -3.245E-07 | 3.309E-05 | 3.247E-05 | 0.981 | -6.200E-07 | 1.009 | 2.955E-07 |
| **Gd155** | **2.577E-09** | **3.960E-09** | **1.537** | **1.383E-09** | **2.680E-09** | **5.420E-09** | **2.022** | **2.740E-09** | **0.760** | **-1.357E-09** |
| Mo95 | 5.082E-05 | 4.969E-05 | 0.978 | -1.131E-06 | 5.025E-05 | 4.885E-05 | 0.972 | -1.400E-06 | 1.006 | 2.688E-07 |
| Tc99 | 5.789E-05 | 5.730E-05 | 0.990 | -5.940E-07 | 5.793E-05 | 5.701E-05 | 0.984 | -9.200E-07 | 1.006 | 3.260E-07 |
| Ru101 | 5.611E-05 | 5.622E-05 | 1.002 | 1.059E-07 | 5.466E-05 | 5.444E-05 | 0.996 | -2.200E-07 | 1.006 | 3.259E-07 |
| Ag109 | 6.018E-06 | 6.425E-06 | 1.068 | 4.071E-07 | 5.832E-06 | 6.246E-06 | 1.071 | 4.140E-07 | 0.997 | -6.893E-09 |
| Sm147 | 3.408E-06 | 3.067E-06 | 0.900 | -3.404E-07 | 3.521E-06 | 3.179E-06 | 0.903 | -3.420E-07 | 0.997 | 1.580E-09 |
| Sm149 | 8.407E-08 | 1.529E-07 | 1.819 | 6.886E-08 | 8.631E-08 | 1.516E-07 | 1.756 | 6.529E-08 | 1.036 | 3.567E-09 |
| Sm150 | 1.381E-05 | 1.467E-05 | 1.062 | 8.590E-07 | 1.415E-05 | 1.448E-05 | 1.023 | 3.300E-07 | 1.038 | 5.290E-07 |
| Sm151 | 4.982E-07 | 7.549E-07 | 1.515 | 2.567E-07 | 4.870E-07 | 7.320E-07 | 1.503 | 2.450E-07 | 1.008 | 1.170E-08 |
| Sm152 | 4.770E-06 | 4.309E-06 | 0.903 | -4.608E-07 | 4.861E-06 | 4.349E-06 | 0.895 | -5.120E-07 | 1.010 | 5.123E-08 |
| Eu153 | 5.580E-06 | 5.731E-06 | 1.027 | 1.503E-07 | 5.448E-06 | 5.576E-06 | 1.023 | 1.280E-07 | 1.003 | 2.226E-08 |

## Table 3. Comparison with JAERI on burn-up differences of number densities

| BU | 45-30 GWd/t | | | | | | | | Comparison | |
|---|---|---|---|---|---|---|---|---|---|---|
| item s | JNES | | | | JAERI | | | | IN/OUT ratio | IN-OUT difference |
| Nuclide | CR-OUT | CR-N | IN/OUT | IN-OUT | CR-OUT | CR-N | IN/OUT | IN-OUT | JNES/JAERI | JNES-JAERI |
| **U 234** | **-1.209E-06** | **-1.234E-06** | **1.021** | **-2.513E-08** | **-1.111E-06** | **-9.930E-07** | **0.894** | **1.180E-07** | **1.142** | **-1.431E-07** |
| U 235 | -1.542E-04 | -1.388E-04 | 0.900 | 1.547E-05 | -1.555E-04 | -1.394E-04 | 0.896 | 1.610E-05 | 1.004 | -6.297E-07 |
| U 236 | 1.987E-05 | 1.889E-05 | 0.951 | -9.741E-07 | 2.030E-05 | 1.930E-05 | 0.951 | -1.000E-06 | 1.000 | 2.588E-08 |
| U 238 | -2.785E-04 | -3.235E-04 | 1.161 | -4.493E-05 | -2.700E-04 | -3.200E-04 | 1.185 | -5.000E-05 | 0.980 | 5.073E-06 |
| Pu238 | 3.653E-06 | 4.654E-06 | 1.274 | 1.002E-06 | 3.323E-06 | 4.303E-06 | 1.295 | 9.800E-07 | 0.984 | 2.188E-08 |
| Pu239 | 5.548E-06 | 2.373E-05 | 4.278 | 1.819E-05 | 5.600E-06 | 2.340E-05 | 4.179 | 1.780E-05 | 1.024 | 3.865E-07 |
| Pu240 | 1.802E-05 | 2.139E-05 | 1.187 | 3.364E-06 | 1.756E-05 | 2.076E-05 | 1.182 | 3.200E-06 | 1.004 | 1.637E-07 |
| Pu241 | 1.105E-05 | 1.677E-05 | 1.518 | 5.723E-06 | 1.140E-05 | 1.720E-05 | 1.509 | 5.800E-06 | 1.006 | -7.652E-08 |
| Pu242 | 9.984E-06 | 8.992E-06 | 0.901 | -9.919E-07 | 9.855E-06 | 8.803E-06 | 0.893 | -1.052E-06 | 1.008 | 6.005E-08 |
| Np237 | 5.525E-06 | 6.377E-06 | 1.154 | 8.527E-07 | 5.399E-06 | 6.300E-06 | 1.167 | 9.010E-07 | 0.989 | -4.829E-08 |
| Am241 | 4.683E-07 | 7.971E-07 | 1.702 | 3.288E-07 | 4.879E-07 | 8.271E-07 | 1.695 | 3.392E-07 | 1.004 | -1.043E-08 |
| Am243 | 2.893E-06 | 2.963E-06 | 1.024 | 7.084E-08 | 2.625E-06 | 2.741E-06 | 1.044 | 1.161E-07 | 0.981 | -4.526E-08 |
| Rh103 | 7.936E-06 | 8.803E-06 | 1.109 | 8.668E-07 | 8.040E-06 | 8.900E-06 | 1.107 | 8.600E-07 | 1.002 | 6.835E-09 |
| Cs133 | 1.724E-05 | 1.684E-05 | 0.977 | -4.020E-07 | 1.773E-05 | 1.725E-05 | 0.973 | -4.800E-07 | 1.004 | 7.802E-08 |
| Nd143 | 7.825E-06 | 9.994E-06 | 1.277 | 2.168E-06 | 7.810E-06 | 9.980E-06 | 1.278 | 2.170E-06 | 0.999 | -1.551E-09 |
| Nd145 | 9.343E-06 | 9.332E-06 | 0.999 | -1.106E-08 | 9.310E-06 | 9.190E-06 | 0.987 | -1.200E-07 | 1.012 | 1.089E-07 |
| **Gd155** | **1.000E-09** | **1.685E-09** | **1.684** | **6.843E-10** | **1.109E-09** | **2.698E-09** | **2.433** | **1.589E-09** | **0.692** | **-9.047E-10** |
| Mo95 | 1.711E-05 | 1.664E-05 | 0.973 | -4.671E-07 | 1.701E-05 | 1.647E-05 | 0.968 | -5.400E-07 | 1.005 | 7.290E-08 |
| Tc99 | 1.726E-05 | 1.701E-05 | 0.985 | -2.538E-07 | 1.733E-05 | 1.701E-05 | 0.982 | -3.200E-07 | 1.004 | 6.618E-08 |
| Ru101 | 1.836E-05 | 1.826E-05 | 0.995 | -1.006E-07 | 1.794E-05 | 1.773E-05 | 0.988 | -2.100E-07 | 1.006 | 1.094E-07 |
| Ag109 | 2.565E-06 | 2.628E-06 | 1.025 | 6.327E-08 | 2.554E-06 | 2.623E-06 | 1.027 | 6.900E-08 | 0.998 | -5.727E-09 |
| Sm147 | 1.246E-06 | 1.094E-06 | 0.878 | -1.517E-07 | 1.318E-06 | 1.163E-06 | 0.882 | -1.550E-07 | 0.995 | 3.338E-09 |
| Sm149 | -6.961E-09 | 7.069E-09 | -1.015 | 1.403E-08 | -6.390E-09 | 7.500E-09 | -1.174 | 1.389E-08 | 0.865 | 1.397E-10 |
| Sm150 | 4.787E-06 | 5.168E-06 | 1.080 | 3.814E-07 | 5.000E-06 | 5.123E-06 | 1.025 | 1.230E-07 | 1.054 | 2.584E-07 |
| Sm151 | 4.992E-08 | 1.296E-07 | 2.596 | 7.966E-08 | 5.140E-08 | 1.279E-07 | 2.488 | 7.650E-08 | 1.043 | 3.164E-09 |
| Sm152 | 1.129E-06 | 9.592E-07 | 0.850 | -1.699E-07 | 1.211E-06 | 1.003E-06 | 0.828 | -2.080E-07 | 1.026 | 3.811E-08 |
| Eu153 | 2.154E-06 | 2.100E-06 | 0.975 | -5.416E-08 | 2.166E-06 | 2.111E-06 | 0.975 | -5.500E-08 | 1.000 | 8.377E-10 |

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