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ANL-Gen-IV-061

Reactivity-Worth Estimates of the OSMOSE Samples in the MINERVE Reactor R1-UO2 Configuration

Topical Report

Nuclear Engineering Division

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by
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June 2005

Abstract

An initial series of calculations of the reactivity-worth of the OSMOSE samples in the MINERVE reactor with the R1-UO2 core configuration were completed. The reactor model was generated using the REBUS code developed at Argonne National Laboratory.

The calculations are based on the specifications for fabrication, so they are considered preliminary until sampling and analysis have been completed on the fabricated samples. The estimates indicate a range of reactivity effect from -22 pcm to +25 pcm compared to the natural U sample.

Introduction

The OSMOSE program (Oscillation in Minerve of isotopes in "Eupraxic" spectra) is a collaboration between the U.S. Department of Energy (DOE) and the Commissariat à l'Energie Atomique (CEA). It aims at measuring integral absorption rates of minor actinides by the oscillation technique in the MINERVE experimental facility located at the CEA Cadarache Research Center. The OSMOSE program also includes a complete analytical program to understand and resolve potential discrepancies between calculated and measured values. The OSMOSE program began in 2001 and will continue until 2013.

The Argonne National Laboratory has developed Monte Carlo and deterministic calculation models of the MINERVE facility to determine core and safety parameters and the reactivity worth of oscillated samples. Oscillation samples include calibration samples with different uranium enrichments and boron concentrations and the OSMOSE samples - separated actinides including ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{243}Am, ^{244}Cm and ^{245}Cm. Seven different neutron spectra will be created in the MINERVE facility: an overmoderated UO_2 matrix (representative of a fuel processing plant or flooded storage cask), a UO_2 matrix in water (representative of LWRs), a mixed oxide fuel matrix (representative of cores containing MOX fuels), two epithermal spectra (representative of under-moderated reactors), a moderated fast spectrum (representative of fast reactors which have some slowing down due to moderators such as lead-bismuth or sodium), and a very hard spectrum (representative of fast reactors with little moderation from reactor coolant). The different spectra are achieved by changing the experimental lattice within the MINERVE reactor.

The currently investigated core configuration, referred to as R1-UO2, is representative of a LWR loaded with UO_2 matrix. The goal of this report is to report on the results of the reactivity worth of the OSMOSE samples in the R1-UO2 configuration. The model of the samples is based on the specifications for fabrication of the samples. The analyses of the samples with as-built geometry and compositions will be performed after the samples have been fabricated and chemically analyzed.

Reactor Description

MINERVE is a zero power pool type experimental facility that is primarily used for neutronic studies. Built in the Nuclear Research Center of Fontenay-aux-Roses in 1959, it was transferred to the Nuclear Research Center (CEA) of Cadarache in 1977.

The maximum power of MINERVE is less than 100 W. Fuel elements are submerged under 3 meters of water. The driver fuel elements – made of highly enriched uranium plates – and the graphite reflector elements are mounted on 4 mobile grids to form the driver zone. In the center of the driver zone, an adjustable square cavity contains the experimental zone.

The experimental zone is subcritical and can be varied from one experiment to another. It is coupled to the driver zone and measurements are generally conducted in the center of the experimental zone.

The components of the control system – rods, automatic pilot rod, detectors – are located in the driver zone to avoid perturbations in the experimental zone. The automatic pilot rod maintains the power level in order to measure the reactivity change during oscillation measurements.

Reactor Model

The model of the reactor and samples are summarized in this report. The reactor is described is described in more detail in reference 1.

The deterministic model is based on the REBUS code system (ref. 2). REBUS has been used to solve the diffusion equation in XYZ geometry with the finite difference method. The self-shielded cross sections used in REBUS are provided by the one-dimensional-transport-code-system WIMS-ANL 5.07 (ref. 3).

The model describes the MINERVE core surrounded by at least 30 cm of water and/or structural material, resulting in a 271.5 cm by 271.5 cm by 220 cm region. The core can be schematically described as an experimental zone surrounded by a driver zone (in 4 quadrants). Fuel pins in the experimental zone are used to generate the appropriate flux spectrum in the center and the driver zone feeds the experimental zone with neutrons. The experimental fuel pin lattice is surrounded by an aluminum buffer within a chimney. The driver zone is located outside the chimney and graphite is used as reflector around it. Figure 1 and Figure 2 show radial and axial views of the complete geometry.

The number of mesh used in the R1UO2 and configuration is 190×190×116. In the XY plane, one mesh is used for each cell of the experimental fuel pin lattice (every 1.26 cm) and the mesh size is roughly the same in all the driver elements. The graphite blocks (large and medium) are mapped using a mesh every 2 cm in the X and Y dimension and an approximate 5cm-mesh-size is used for the surrounding water in the XY plan.

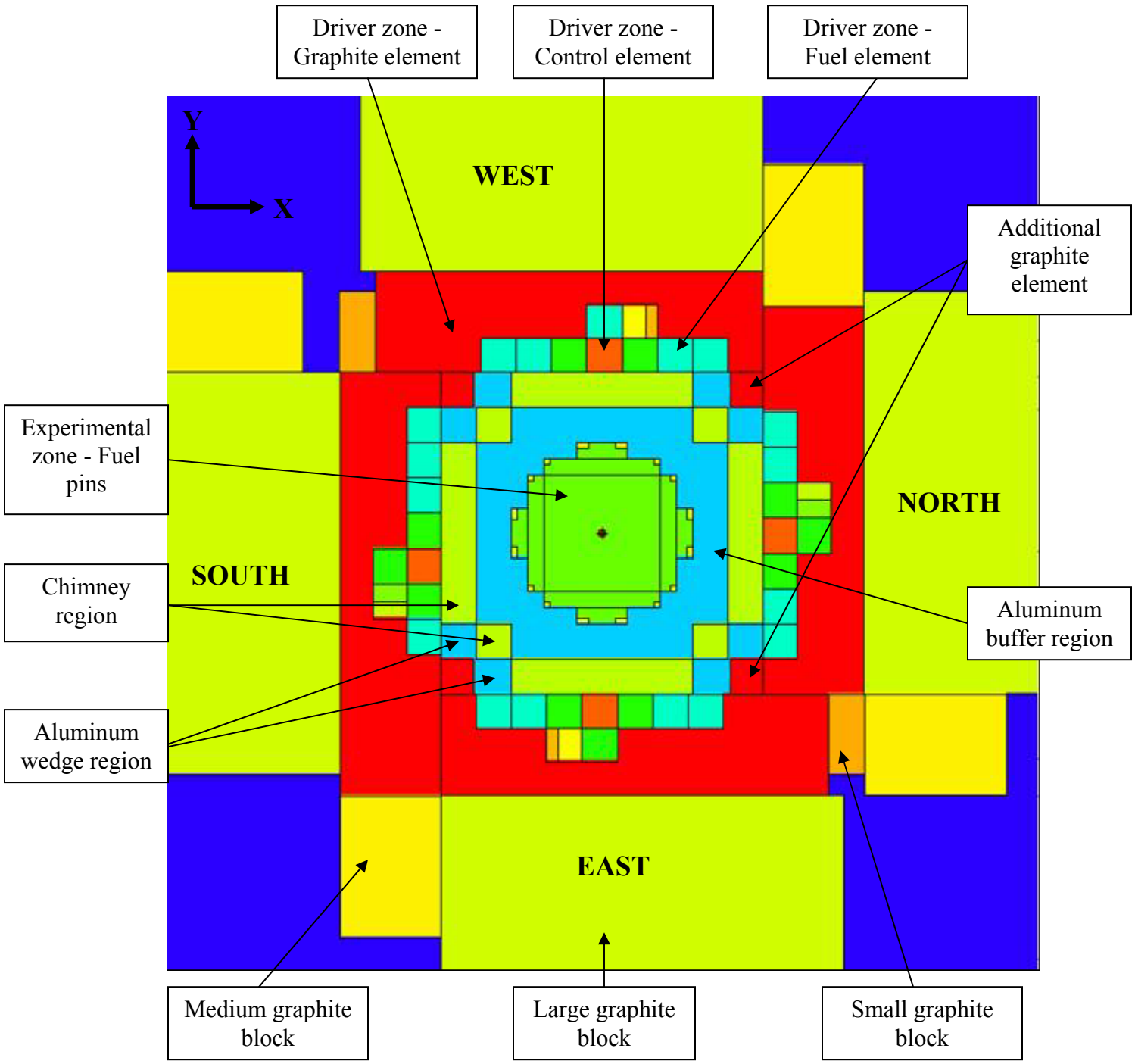

Figure 1: Radial view of the REBUS model in the R1UO2 configuration

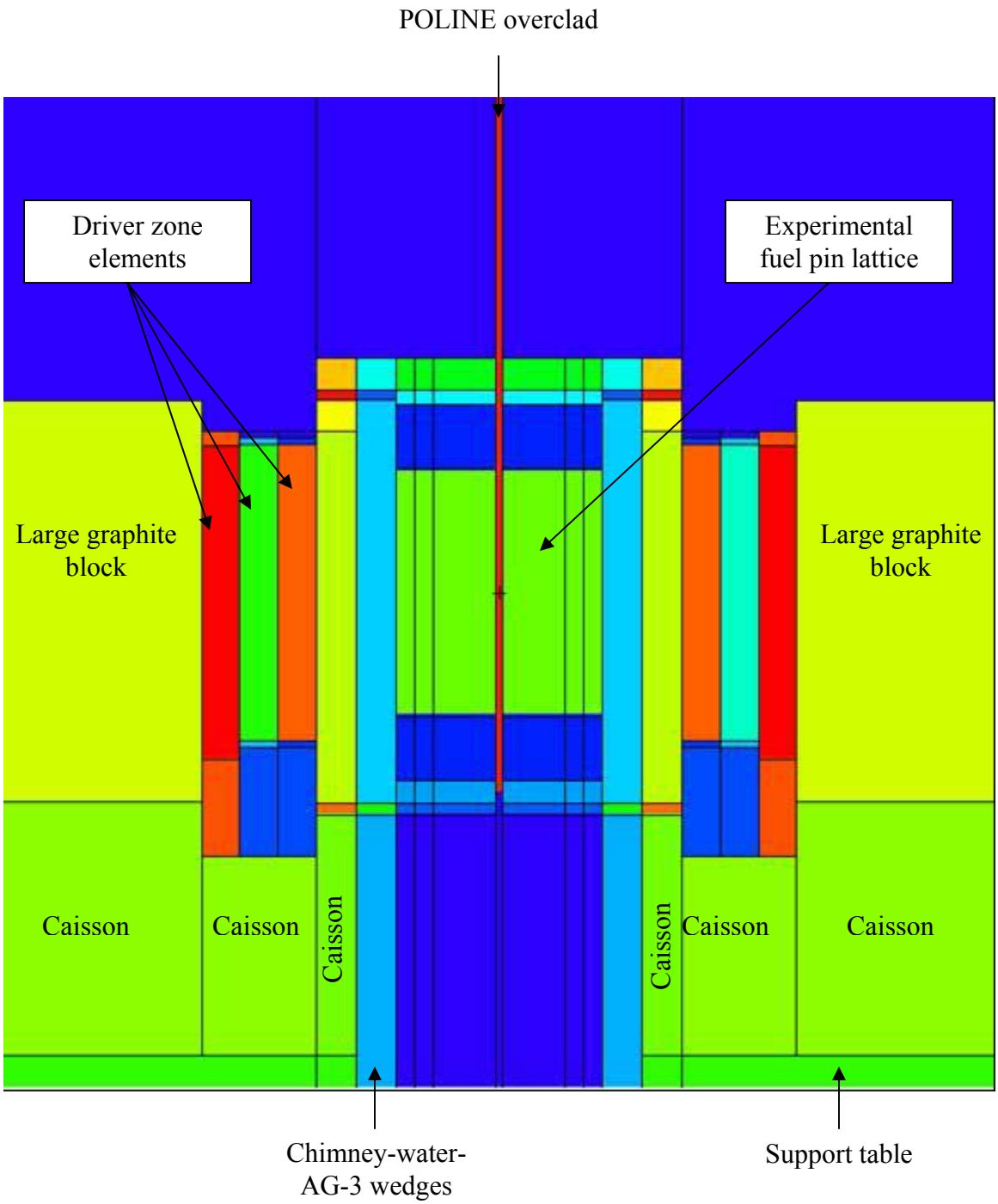

Figure 2: Axial view of the REBUS model in the R1UO2 configuration

Axially, the mesh size is defined by the fuel elements and pins of the geometry. The surrounding water is mapped with a 10 cm mesh size, the structural material around the fuel (grid plate of the driver regions, lower and upper end plug and stainless steel spacers) is mapped using a 1-2 cm mesh size, and the fuel and the Plexiglas spacers of the experimental zone are mapped with a 1 cm mesh size.

Microscopic cross sections for the different homogenized regions have been calculated using the one-dimensional-transport-code-system WIMS-ANL 5.07. The starting 69 group structure of the ENDFB-VI library was collapsed to 7 groups (Table 1).

Table 1: REBUS group structure

Group	Energy
1	500 keV – 10 MeV
2	9.118 keV – 500 keV
3	1.123 eV – 9.118 keV
4	0.4 eV – 1.123 eV
5	0.14 eV – 0.4 eV
6	0.05 eV – 0.4 eV
7	0.00001 eV - 0.05 eV

The cross sections used in the REBUS code for the materials are calculated in two steps. First microscopic cross sections for different elements (such as Al-27, U-235, Fe-54…) are calculated using WIMS. The macroscopic cross sections of the materials are then generated in REBUS from the microscopic cross sections and the atom densities of the different elements.

Because the self shielding of the microscopic cross sections is performed in WIMS, it is often necessary to define different sets of cross sections for a given element. It is particularly important for the constituents of the fuel and the absorber. For a detailed description of the cross-sections and methods used to generate the macroscopic cross-sections for the models see Reference 1.

Oscillation Samples

There are several different kinds of oscillation samples: uranium calibration samples, boron loaded calibration samples, OSMOSE separated actinide samples, and absorber samples.

The samples are composed of fuel pellets (height~9.35 cm, diameter ~ 0.81cm) clad with zircomium-4 (inner diameter = 0.836, outer diameter = 0.956 cm) and terminated by two zirconium-4 end plugs (same outer diameter, height of 0.2 cm). The sample has a second clad (inner diameter = 1.02 cm, outer diameter = 1.06 cm) with a lower end plug of 0.2 cm height and two upper end plug of 0.2 cm height. The external diameter of the entire sample is 1.06 cm with a total height of 10.35 cm (ref. 4).

The total height of the fuel pellets is often larger than 9.35 cm. In order to keep the total height constant (10.35 cm) the upper end plug of the outer clad was modeled with a smaller height to accommodate the different fuel pellet heights.

The characteristics of the U-235 calibration sample fuel pellets are listed in ref. 6 and are reported in Table 2. The number density of the U-235 calibration samples have been deduced from measurements in ref. 5 and are reported in Table 3.

Table 2: Geometry and material specification of the U-235 calibration sample

Sample	F0025	F0050	N0071	S0100	S0200	S0300	S0400	S0495
U235 enrichment (%)	0.25	0.49	0.71	1.00	2.01	3.01	4.00	4.93
Height (mm)	94.08	94.1	94.06	94.04	94.1	94.08	94.06	94.1
Diameter (mm)	8.0943	8.0946	8.0943	8.1114	8.0986	8.1032	8.0999	8.1036
Density (g/cc)	10.442	10.464	10.515	10.594	10.606	10.62	10.629	10.648

Table 3: Number density of the U-235 calibration samples

Isotope	Sample identification							
	F0025 (0.25%)	F0050 (0.49%)	N0071 (0.71%)	S0100 (1.00%)	S0200 (2.01%)	S0300 (3.01%)	S0400 (4.00%)	S0495 (4.93%)
U-234	2.328E-07	7.933E-07	1.290E-06	1.913E-06	4.258E-06	6.513E-06	8.773E-06	1.093E-05
U-235	5.849E-05	1.154E-04	1.666E-04	2.367E-04	4.745E-04	7.124E-04	9.479E-04	1.171E-03
U-236	6.985E-08	7.000E-08	1.172E-07	1.181E-07	1.183E-07	9.474E-08	1.186E-07	1.188E-07
U-238	2.322E-02	2.322E-02	2.328E-02	2.338E-02	2.317E-02	2.297E-02	2.276E-02	2.257E-02
O	4.663E-02	4.672E-02	4.695E-02	4.734E-02	4.736E-02	4.747E-02	4.747E-02	4.762E-02
total	**6.991E-02**	**7.006E-02**	**7.039E-02**	**7.096E-02**	**7.101E-02**	**7.116E-02**	**7.118E-02**	**7.137E-02**

The characteristics of the borated UO_2 calibration sample fuel pellets are reported in Table 4. On the contrary to the U-235 calibration samples, the number density of the borated calibration sample has not been measured. The number density of the borated calibration samples are reported in Table 5 and were calculated using the total density, geometry and boron enrichment of the sample from ref. 6.

Table 4: Geometry and material specification of the borated UO_2 calibration sample

Sample	1B0000	1B0071	1B0150	1B0419	2B0000	2B0333	2B1062	2B2360
U235 enrichment (%)	0.25	0.25	0.25	0.25	0.53	0.53	0.53	0.53
Boron fraction (ppm)	0	71	150	419	0	333	1062	2360
Height (mm)	99.96	100	99.98	99.82	99.7	99.5	99.62	98.7
Diameter (mm)	8.079	8.08	8.106	8.084	8.203	8.2	8.202	8.2
Density (g/cc)	9.551	9.545	9.380	9.523	2.854	9.801	9.701	9.504

Table 5: Number density of the Boron calibration samples								
Iso-tope	Sample identification							
	1B0000 (0 ppm)	1B0071 (71 ppm)	1B0150 (150 ppm)	1B0419 (419 ppm)	2B0000 (0 ppm)	2B0333 (333 ppm)	2B1062 (1062 ppm)	2B2360 (2360 ppm)
U-235	5.393E-05	5.389E-05	5.356E-05	5.375E-05	1.180E-04	1.173E-04	1.160E-04	1.135E-04
U-238	2.125E-02	2.123E-02	2.110E-02	2.117E-02	2.186E-02	2.173E-02	2.150E-02	2.103E-02
O	4.260E-02	4.257E-02	4.231E-02	4.246E-02	4.395E-02	4.370E-02	4.322E-02	4.229E-02
B-10	-	7.513E-06	1.578E-05	4.423E-05	-	3.618E-05	1.142E-04	2.486E-04
B-11	-	3.024E-05	6.350E-05	1.780E-04	-	1.456E-04	4.597E-04	1.001E-03
total	**6.390E-02**	**6.389E-02**	**6.354E-02**	**6.391E-02**	**6.593E-02**	**6.573E-02**	**6.541E-02**	**6.468E-02**

The masses of the studied isotope in each of the OSMOSE samples are reported in Table 6. Depending on the studied isotope, the samples may contain other isotopes as a result on contaminants in the feed stock or the inability to complete separate the actinides. Detailed compositions and number densities for the samples are shown in Appendix 1. These masses and compositions are based on a sample mass (mass of the fuel pellets in the sample) of 50.3 grams. The compositions of the constituents used in the analysis are based on the isotopic information available for the feedstock materials and the specifications for fabrication of the sample pellets.

Table 6: Mass of Studied Isotopes in OSMOSE Samples		
Sample	Studied Isotope	Isotope Mass (g)
1	Th-232 (1)	44.2
2	Th-232 (2)	2.1
3	U-233	0.5
4	U-234	0.32
5	URE	0.4*
6	U-nat	44.3
7	Np-237 (1)	0.1
8	Np-237 (2)	0.6
9	Pu-238	0.4
10	Pu-239	0.6
11	Pu-240	0.16
12	Pu-241	0.08
13	Pu-242	0.5
14	Am-241 (1)	0.06
15	Am-241 (2)	0.2
16	Am-243	0.1

*This is the mass of U-236 in the sample.

Results

The samples listed in the section above were run to calculate a steady-state eigenvalue for k-effective using the REBUS code as described previously. The results of the calculations are shown in Table 7 and graphically in Figures 3 and 4. The results for the reactivity-worth of the samples are compared to the natural uranium sample by

subtracting the nat. U sample value from the OSMOSE sample value. In this manner, the nat. U sample shows a zero value for the reactivity-worth. The samples that show a positive reactivity-worth have a larger reactivity effect than natural uranium. Samples that have a negative reactivity-worth have a larger integrated absorption cross-section or a smaller fission cross-section than natural uranium (i.e. a larger value of Σ_a-$\upsilon\Sigma_f$).

Table 7: Reactivity Worth of OSMOSE samples

Sample	Isotope Mass (g)	Keff	Reactivity (pcm)	Reactivity-worth (pcm)
Th-232 (1)	44.2	1.000528	52.8	-28.3
Th-232 (2)	2.1	1.000798	79.8	-1.3
U-233	0.5	1.000945	94.5	13.3
U-234	0.32	1.000788	78.8	-2.4
URE	0.4*	1.001001	100.0	18.9
U-nat	44.3	1.000812	81.2	0
Np-237 (1)	0.1	1.000786	78.6	-2.6
Np-237 (2)	0.6	1.000688	68.8	-12.3
Pu-238	0.4	1.000701	70.1	-11.0
Pu-239	0.6	1.000939	93.9	12.7
Pu-240	0.16	1.000723	72.3	-8.9
Pu-241	0.08	1.000840	84.0	2.9
Pu-242	0.5	1.000784	78.4	-2.7
Am-241 (1)	0.06	1.000755	75.4	-5.7
Am-241 (2)	0.2	1.000663	66.3	-14.8
Am-243	0.1	1.000789	78.9	-2.3

*This is the mass of U-236 in the sample.

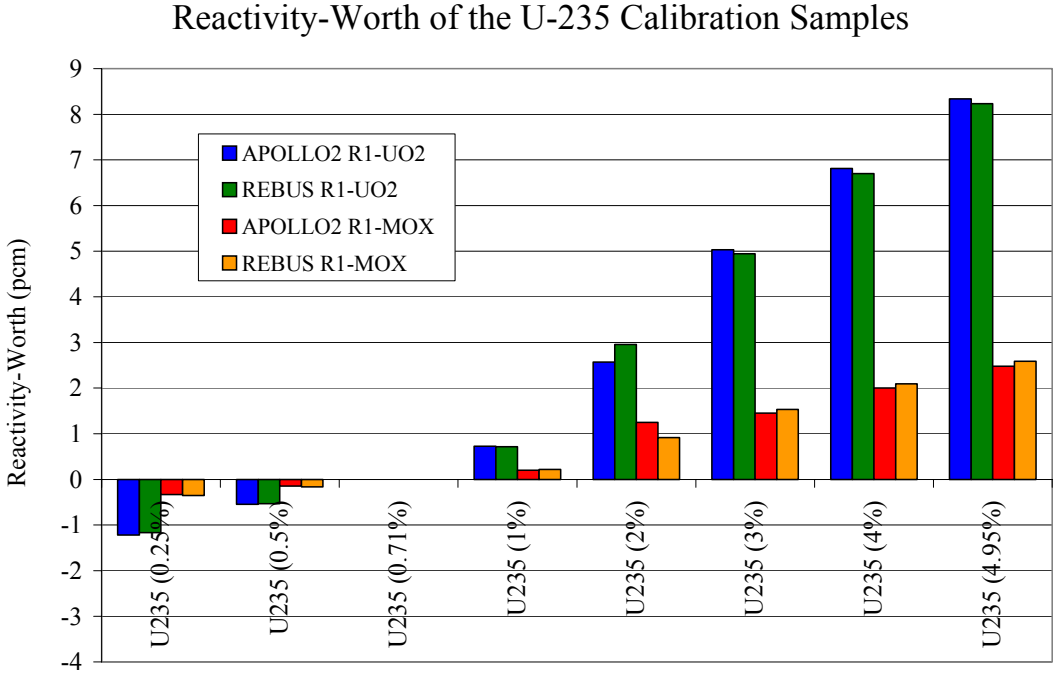

Figure 3

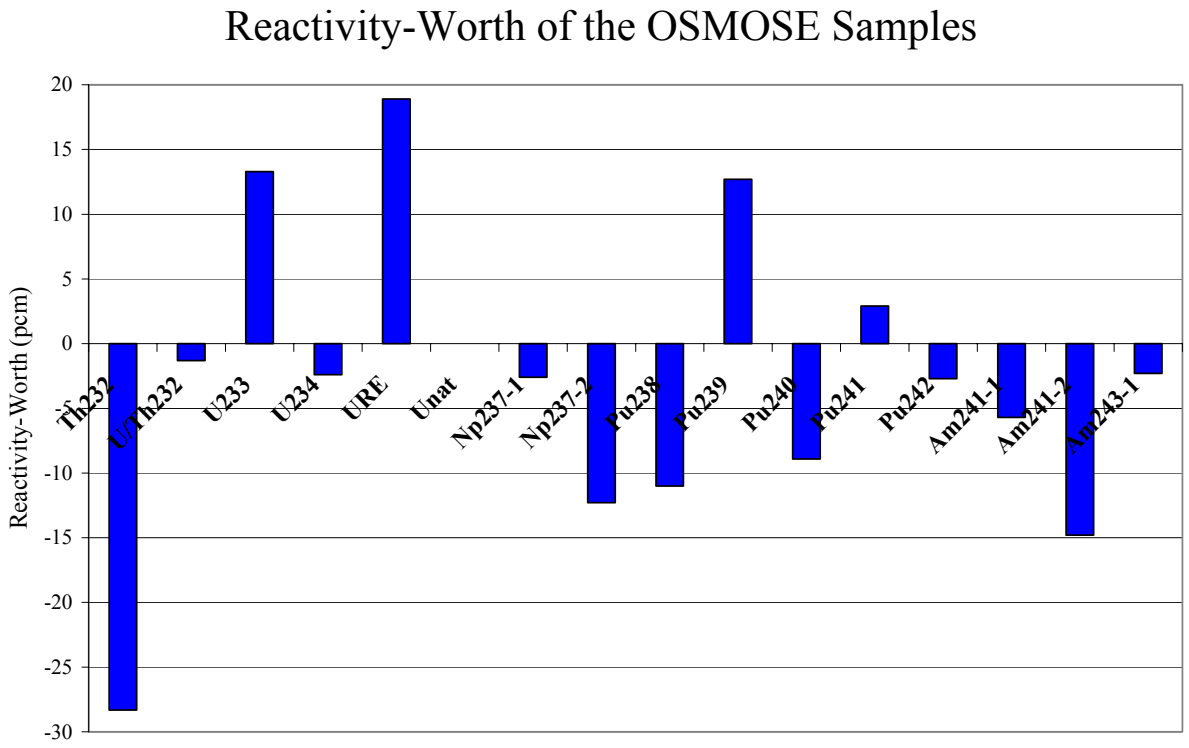

Figure 4

Conclusions

Initial estimates of the reactivity worth of the OSMOSE samples have been calculated for the R1-UO2 configuration.

Since the neutron spectrum in the R1-UO2 configuration is considered primarily thermal, the results are consistent with analytic results and what one would expect for a thermal spectrum. The samples containing isotopes of fissile materials with a fission cross-section at thermal energies have a reactivity worth larger than the natural uranium sample. Isotopes that do not fission at thermal energies have a lower reactivity worth than the natural uranium sample.

The reactivity effect cannot be directly related to only the absorption cross-section of the studied isotopes because natural uranium contains ~0.72 percent U-235 – so thermal neutron fission does still occur in the reference sample). In addition, the neutron spectrum is not completely thermal and therefore there is still a contribution from fission at higher neutron energies.

However, the results are still consistent in that the U-233, URE, Pu-239, and Pu-241 samples all have a positive reactivity effect with respect to the natural uranium reference sample. Note that the URE sample is primarily U-236, however, there is still more U-235 in the URE sample than U-235 in the reference sample.

References

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6. J. P. Hudelot, Personal Communication.

Appendix 1
Compositions of the OSMOSE Samples

Avogadro 0.602214

Mean hypothesis

mass (g)	50.30
height (mm)	93.75
diameter (mm)	8.1
volume (mm3)	4831
density (g/cm3)	10.41

Matrix UnatO2
O/U 2 (between 2.15 and 2.2)

Sample Unat

	mass	molar mass	atom frac.	number density (at)	at/bcm
UO2 nat	50.298				
Unat	44.335	238.0288959		1.122E-01	2.322E-02
U-234		234.041	0.0055%	6.169E-06	**1.277E-06**
U-235		235.0392	0.720%	8.076E-04	**1.672E-04**
U-238		238.0508	99.2745%	1.114E-01	**2.305E-02**
O	5.960	15.9994		2.243E-01	**4.644E-02**
sum	50.295				

Sample Np37/1

	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	50.193					
Unat	44.25		238.0288959		1.120E-01	2.317E-02
U-234			234.041	0.0055%	6.157E-06	**1.275E-06**
U-235			235.0392	0.720%	8.061E-04	**1.669E-04**
U-238			238.0508	99.2745%	1.111E-01	**2.301E-02**
O	5.949		15.9994		2.239E-01	**4.635E-02**
sum	50.199					
Dopping	0.11		236.9969956		2.684E-04	5.556E-05
Np-237	0.1046	99.00%	237.048167		2.657E-04	**5.499E-05**
Th-232	0.0011	1.00%	232.0381		2.741E-06	**5.675E-07**

Sample Np37/2

	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	49.698					
Unat	43.8		238.0288959		1.108E-01	2.294E-02
U-234			234.041	0.0055%	6.095E-06	**1.262E-06**
U-235			235.0392	0.720%	7.979E-04	**1.652E-04**
U-238			238.0508	99.2745%	1.100E-01	**2.277E-02**
O	5.888		15.9994		2.216E-01	**4.588E-02**
sum	49.688					
Dopping	0.60		236.9969956		1.525E-03	3.156E-04
Np-237	0.5940	99.00%	237.048167		1.509E-03	**3.124E-04**
Th-232	0.0060	1.00%	232.0381		1.557E-05	**3.223E-06**

Sample	**UTh2**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	48.201					
Unat	42.49		238.0288959		1.075E-01	2.225E-02
U-234			234.041	0.0055%	5.912E-06	**1.224E-06**
U-235			235.0392	0.720%	7.740E-04	**1.602E-04**
U-238			238.0508	99.2745%	1.067E-01	**2.209E-02**
O	5.712		15.9994		2.150E-01	**4.450E-02**
sum	48.202					
Dopping	2.10		232.0381		5.444E-03	1.127E-03
Th-232	2.0974	100.00%	232.0381		5.444E-03	**1.127E-03**

Sample	**U233**							
	mass	weight frac.	molar mass	atom frac.	number density			
Sample	50.30							
Matrix	49.775							
Unat	43.875		238.0288959		1.110E-01	sum	number de	at/bcm
U-234			234.041	0.0055%	6.105E-06	U-233	1.303E-03	**2.698E-04**
U-235			235.0392	0.720%	7.992E-04	U-234	3.572E-05	**7.393E-06**
U-238			238.0508	99.2745%	1.102E-01	U-235	8.006E-04	**1.657E-04**
O	5.898		15.9994		2.220E-01	U-238	1.102E-01	**2.282E-02**
sum	49.773					O	2.220E-01	**4.596E-02**
Dopping	0.52		232.1839		1.357E-03	2.808E-04		
U-233	0.5022	96.01%	232.0381		1.303E-03	2.698E-04		
U-234	0.0115	2.20%	234.041		2.961E-05	6.130E-06		
U-235	0.0005	0.10%	235.0392		1.340E-06	2.774E-07		
U-238	0.0088	1.69%	238.0508		2.236E-05	4.629E-06		

Sample	**U234**							
	mass	weight frac.	molar mass	atom frac.	number density			
Sample	50.30							
Matrix	49.981							
Unat	44.06		238.0288959		1.115E-01	sum	number de	at/bcm
U-234			234.041	0.0055%	6.131E-06	U-233	8.224E-08	**1.702E-08**
U-235			235.0392	0.720%	8.026E-04	U-234	8.208E-04	**1.699E-04**
U-238			238.0508	99.2745%	1.107E-01	U-235	8.029E-04	**1.662E-04**
O	5.923		15.9994		2.229E-01	U-236	8.084E-08	**1.673E-08**
sum	49.983					U-238	1.107E-01	**2.291E-02**
Dopping	0.32		234.0422		8.154E-04	O	2.229E-01	**4.615E-02**
U-233	0.0000	0.01%	232.0381		8.224E-08			
U-234	0.3166	99.92%	234.041		8.147E-04			
U-235	0.0001	0.04%	235.0392		3.248E-07			
U-236	0.0000	0.01%	236.04556		8.084E-08			
U-238	0.0001	0.02%	238.0508		1.603E-07			

Sample	**Am41/1**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	50.233					
Unat	44.28		238.0288959		1.120E-01	2.319E-02
U-234			234.041	0.0055%	6.162E-06	**1.275E-06**
U-235			235.0392	0.720%	8.066E-04	**1.670E-04**
U-238			238.0508	99.2745%	1.112E-01	**2.302E-02**
O	5.953		15.9994		2.241E-01	**4.638E-02**
sum	50.233					
Dopping	0.07		240.9997633		1.634E-04	3.382E-05
Np-237	0.0009	1.40%	237.048167		2.326E-06	**4.814E-07**
Am-241	0.0645	98.60%	241.05682		1.611E-04	**3.334E-05**

Sample	**Am41/2**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	50.098					
Unat	44.16		238.0288959		1.117E-01	2.313E-02
U-234			234.041	0.0055%	6.145E-06	**1.272E-06**
U-235			235.0392	0.720%	8.044E-04	**1.665E-04**
U-238			238.0508	99.2745%	1.109E-01	**2.296E-02**
O	5.937		15.9994		2.234E-01	**4.625E-02**
sum	50.097					
Dopping	0.20		240.9997633		4.998E-04	1.035E-04
Np-237	0.0028	1.40%	237.048167		7.113E-06	**1.472E-06**
Am-241	0.1972	98.60%	241.05682		4.926E-04	**1.020E-04**

Sample	**Cm244**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	48.201					
Unat	42.49		238.0288959		1.075E-01	2.225E-02
U-234			234.041	0.0055%	5.912E-06	**1.224E-06**
U-235			235.0392	0.720%	7.740E-04	**1.602E-04**
U-238			238.0508	99.2745%	1.067E-01	**2.209E-02**
O	5.712		15.9994		2.150E-01	**4.450E-02**
sum	48.202					
Dopping	2.10		244.2017		5.172E-03	1.071E-03
Cm-242	0.0044	0.21%	242.0588		1.096E-05	**2.268E-06**
Cm-243	0.0036	0.17%	243.0614		8.834E-06	**1.829E-06**
Cm-244	1.8975	90.47%	244.0627		4.682E-03	**9.692E-04**
Cm-245	0.0787	3.75%	245.0655		1.933E-04	**4.001E-05**
Cm-246	0.1133	5.40%	246.0672		2.772E-04	**5.738E-05**

Sample	**Cm244+Cm245**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	49.252					
Unat	43.415		238.0289		1.098E-01	2.274E-02
U-234			234.0410	0.0055%	6.041E-06	**1.251E-06**
U-235			235.0392	0.720%	7.908E-04	**1.637E-04**
U-238			238.0508	99.2745%	1.090E-01	**2.257E-02**
O	5.836		15.9994		2.197E-01	**4.547E-02**
sum	49.251					
Dopping	1.05		244.2837		2.579E-03	5.339E-04
Cm-242	0.0078	0.75%	242.0588		1.952E-05	**4.041E-06**
Cm-243	0.0085	0.81%	243.0614		2.100E-05	**4.346E-06**
Cm-244	0.8596	82.16%	244.0627		2.121E-03	**4.390E-04**
Cm-245	0.0842	8.05%	245.0655		2.070E-04	**4.284E-05**
Cm-246	0.0861	8.23%	246.0672		2.107E-04	**4.362E-05**

Sample	**Pu38**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	49.876					
Unat	43.965		238.0289		1.112E-01	2.302E-02
U-234			234.0410	0.0055%	6.118E-06	**1.266E-06**
U-235			235.0392	0.720%	8.009E-04	**1.658E-04**
U-238			238.0508	99.2745%	1.104E-01	**2.286E-02**
O	5.910		15.9994		2.225E-01	**4.605E-02**
sum	49.875					
Dopping	0.42		238.2008		1.068E-03	2.211E-04
Pu-238	0.4009	94.89%	238.04955		1.014E-03	**2.099E-04**
Pu-239	0.0195	4.61%	239.05216		4.907E-05	**1.016E-05**
Pu-240	0.0016	0.39%	240.05381		4.134E-06	**8.557E-07**
Pu-241	0.0003	0.06%	241.05685		6.333E-07	**1.311E-07**
Pu-242	0.0000	0.01%	242.05874		1.051E-07	**2.176E-08**

Sample	**Pu39**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	49.664					
Unat	43.78		238.0289		1.108E-01	2.293E-02
U-234			234.0410	0.0055%	6.092E-06	**1.261E-06**
U-235			235.0392	0.720%	7.975E-04	**1.651E-04**
U-238			238.0508	99.2745%	1.100E-01	**2.276E-02**
O	5.885		15.9994		2.215E-01	**4.586E-02**
sum	49.665					
Dopping	0.63		239.0755		1.596E-03	3.305E-04
Pu-238	0.0000	0.00%	238.04955		0.000E+00	
Pu-239	0.6194	97.74%	239.05216		1.560E-03	**3.230E-04**
Pu-240	0.0139	2.19%	240.05381		3.482E-05	**7.207E-06**
Pu-241	0.0004	0.06%	241.05685		9.500E-07	**1.966E-07**
Pu-242	0.0001	0.01%	242.05874		1.577E-07	**3.264E-08**

Sample	**Pu40**						
	mass	weight frac.	molar mass	atom frac.	number density		at/bcm
Sample	50.30						
Matrix	50.140						
Unat	44.2		238.0289		1.118E-01		2.315E-02
U-234			234.0410	0.0055%	6.150E-06	**6.158E-06**	**1.275E-06**
U-235			235.0392	0.720%	8.051E-04		**1.667E-04**
U-238			238.0508	99.2745%	1.110E-01		**2.298E-02**
O	5.942		15.9994		2.237E-01		**4.630E-02**
sum	50.142						
Dopping	0.16		240.0580		3.975E-04		8.227E-05
Pu-238	0.0000	0.01%	238.04955		2.778E-08		**5.751E-09**
Pu-239	0.0012	0.73%	239.05216		2.898E-06		**5.998E-07**
Pu-240	0.1558	98.30%	240.05381		3.907E-04		**8.088E-05**
Pu-241	0.0002	0.15%	241.05685		5.767E-07		**1.194E-07**
Pu-242	0.0004	0.28%	242.05874		1.113E-06		**2.304E-07**
Am-241	0.0008	0.52%	241.05682		2.048E-06		**4.239E-07**
Np-237	0.0000	0.02%	237.048167		6.638E-08		**1.374E-08**
U-234	0.0000	0.00%	234.0410		7.990E-09		1.654E-09

Sample	**Pu41**						
	mass	weight frac.	molar mass	atom frac.	number density		at/bcm
Sample	50.30						
Matrix	50.193						
Unat	44.245		238.0289		1.119E-01		2.317E-02
U-234			234.0410	0.0055%	6.157E-06	6.161E-06	**1.275E-06**
U-235			235.0392	0.720%	8.060E-04		**1.668E-04**
U-238			238.0508	99.2745%	1.111E-01		**2.300E-02**
O	5.948		15.9994		2.239E-01		**4.634E-02**
sum	50.193						
Dopping	0.11		240.9594		2.640E-04		5.464E-05
Pu-238	0.0000	0.04%	238.04955		1.187E-07		**2.458E-08**
Pu-239	0.0033	3.10%	239.05216		8.241E-06		**1.706E-06**
Pu-240	0.0127	12.01%	240.05381		3.183E-05		**6.589E-06**
Pu-241	0.0801	75.80%	241.05685		2.000E-04		**4.141E-05**
Pu-242	0.0095	8.99%	242.05874		2.362E-05		**4.889E-06**
Am-241	0.0000	0.00%	241.05682		0.000E+00		
Np-237	0.0001	0.05%	237.048167		1.403E-07		**2.904E-08**
U-234	0.0000	0.00%	234.0410		3.812E-09		7.890E-10

Sample	**Pu42**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	49.775					
Unat	43.875		238.0289		1.110E-01	
U-234			234.0410	0.0055%	6.105E-06	
U-235			235.0392	0.720%	7.992E-04	**1.654E-04**
U-238			238.0508	99.2745%	1.102E-01	**2.281E-02**
O	5.898		15.9994		2.220E-01	**4.596E-02**
sum	49.773					
Dopping	0.52		242.0576		1.301E-03	
Pu-238	0.0000	0.00%	238.04955		4.273E-08	**8.844E-09**
Pu-239	0.0000	0.00%	239.05216		6.507E-08	**1.347E-08**
Pu-240	0.0001	0.02%	240.05381		2.863E-07	**5.927E-08**
Pu-241	0.0001	0.01%	241.05685		1.367E-07	**2.830E-08**
Pu-242	0.5227	99.93%	242.05874		1.301E-03	**2.692E-04**
Am-241	0.0001	0.02%	241.05682		3.112E-07	**6.443E-08**
Np-237	0.0000	0.00%	237.048167		7.532E-09	**1.559E-09**
U-234	0.0000	0.00%	234.0410		9.329E-09	1.931E-09
Pu-244	0.0000	0.00%	244.06419		2.603E-08	**5.388E-09**

Sample	**Am43**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
Matrix	50.193					
Unat	44.245		238.0289		1.119E-01	
U-234			234.0410	0.0055%	6.157E-06	**1.274E-06**
U-235			235.0392	0.720%	8.060E-04	**1.668E-04**
U-238			238.0508	99.2745%	1.111E-01	**2.300E-02**
O	5.948		15.9994		2.239E-01	**4.634E-02**
sum	50.193					
Dopping	0.11		243.0611		2.617E-04	
Pu-238	0.0000	0.00%	238.04955		0.000E+00	
Pu-239	0.0000	0.00%	239.05216		0.000E+00	
Pu-240	0.0000	0.00%	240.05381		0.000E+00	
Pu-241	0.0000	0.00%	241.05685		0.000E+00	
Pu-242	0.0000	0.00%	242.05874		0.000E+00	
Am-241	0.0000	0.01%	241.05682		3.007E-08	**6.225E-09**
Np-237	0.0000	0.00%	237.048167		0.000E+00	
U-234	0.0000	0.00%	234.0410		0.000E+00	
Am-243	0.1056	99.99%	243.0613709		2.617E-04	**5.417E-05**

Sample	**Th32**					
	mass	weight frac.	molar mass	atom frac.	number density	at/bcm
Sample	50.30					
ThO2	50.298					
Th-232	44.2		232.0381		1.147E-01	**2.375E-02**
O	6.095		15.9994		2.294E-01	**4.749E-02**
sum	50.295					

Sample	**URE**				
	mass	weight frac.	molar mass	atom frac.	number density	
Sample	50.298					
Unat	44.335		237.9092		1.122E-01	
U-234	0.0319	0.07%	234.041		8.214E-05	**1.700E-05**
U-235	1.7539	3.96%	235.0392		4.494E-03	**9.302E-04**
U-238	42.1519	95.08%	238.0508		1.066E-01	**2.207E-02**
U-236	0.3972	0.90%	236.04556		1.013E-03	**2.098E-04**
O	5.963		15.9994		2.244E-01	**4.646E-02**
sum	50.298					

Data extracted from file "Probleme du calcul des isotopes"
Data extracted from file "Cahier des specifications et clauses techniques"
Data extracted from file " Besoins en analyse isotopique, chimique …"

No element with absorbing cross section (Gd-157 equivalent) are included in the samples

To be updated

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