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ANALYSIS OF THE SAMPLE OSCILLATION MEASUREMENTS IN THE STEK-FACILITY USING JEF-2.2 DATA

Andreas Meister

CEA/DRN/DER/SPRC, CE Cadarache
13108 Saint-Paul lez Durance Cedex, France

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The fission product sample reactivity worth measurements performed at the STEK-facility provide a valuable data base for the assessment of reactor calculations and the validation and improvement of the neutron data libraries. The STEK-facility was a fast-thermal coupled critical system built in RCN Petten in the framework of the Fast Breeder Reactor development. The STEK-facility was used during the 1969 to 1973 period for performing integral measurements from which information on fission product cross sections could be inferred. The central reactivity worths of 102 sample substances were determined using the sample oscillation technique in the centre of the fast zone. Five different cores were used (STEK-4000, STEK-3000, STEK-2000, STEK-1000, STEK-500) providing central neutron spectra of different hardness [1, 2].

Most of the samples were fission product isotopes. There were also a few structural materials, standard materials, and actinides. The samples were made of metals or chemical compounds with either an enrichment in one special isotope or the natural isotope mixture. Samples of different masses and dimensions were used, mostly 2 or 3, in a few cases only 1 sample, and some substances were measured with up to 9 samples.

The NEANSC Working Party on the International Evaluation Co-operation in the OECD countries has recommended the use of the STEK measurements as a data base for validation of the nuclear data libraries [3].

In the present work the STEK measurements have been analysed using the modern deterministic programs of the ECCO / ERANOS code system for reactor calculations and the JEF-2.2 based ECCO group cross library.

The reactor calculations have been performed with the S_n transport program BISTRO in two-dimensional RZ geometry and a model of the STEK reactors consisting of 15 regions of different compositions. Figure 1 shows the geometric representation used for the transport calculations. Particular attention has been paid to the modelling of the sample surrounding. The cell code ECCO has been used to provide the broad group constants for the various reactor regions with calculations performed for heterogeneous structures and macrocells to precisely treat the heterogeneity effects. With this data as input for the transport code BISTRO, the neutron flux and the adjoint neutron flux were determined for the sample position. Details of the reactor calculations are described in Reference [4]. The resulting neutron flux spectra and adjoint fluxes for the five STEK cores are shown in Figure 2. The STEK-500 core has the hardest neutron spectrum. The spectra in the other STEK cores become softer and softer.

The reactivity worths of all isotopes forming a sample have been determined by perturbation calculations with a special module of the ERANOS code system [4]. This module calculates the following perturbation integral:

$$\delta\rho = -\delta\left(\frac{1}{k_{eff}}\right) = \frac{1}{NI}\cdot\left\langle \phi^{*}(E,\mathbf{r}), \left(\frac{1}{k_{eff}}\delta F - \delta A\right)\cdot\phi'(E,\mathbf{r})\right\rangle,$$

where $\left(\frac{1}{k_{eff}}\delta F - \delta A\right)$ is the operator describing the perturbation of the system with δF characterising the fission sources and δA characterising the removal of neutrons from a certain energy. This removal may be caused by an absorption or a scattering process in the sample. ϕ' is the perturbed neutron flux, ϕ^* is the adjoint flux, and k_{eff} is the multiplication factor of the system. The brackets stand for energy and space integration over the sample region. The normalisation integral NI in the denominator is:

$$NI = \left\langle \phi^{*}(E,\mathbf{r}), F'\cdot\phi'(E,\mathbf{r})\right\rangle$$

with F' being the operator of the perturbed fission sources, and the integration covers the whole reactor volume.

The perturbation calculation with a deterministic reactor code has advantages for the simulation of small (infinite diluted) samples. However, it is not well adapted for analysing measurements with samples of significant size. In the case of the STEK experiments the sample size effects reduce the apparent reactivity worth for many samples

by a factor of two and, for a few samples, to one tenth of the reactivity effect of an infinite diluted sample. Therefore, it is very important to take account of the sample size effects with great care. In the present work, three independent methods have been used to tackle this problem.

The first method consists in a recalculation of the perturbation integral for the real sample with an exact geometric modelling in shape and size. The Monte Carlo method is used for the integration over the angular coordinates and deterministic integration is used for the neutron path coordinate and the energy coordinate. Flux attenuation and up to five successive multiple collisions have been considered. The calculation starts from pointwise cross sections derived from JEF-2.2 [5]. The spectrum of neutrons entering the sample has been taken from the S_n calculations. The model and the computer code developed for that purpose have been tested with the measurements of some substances providing typical effects as resonance absorption, 1/v absorption, multiple scattering, resonance scattering, inelastic scattering, the shielding of resonances by the fine structure flux, a test of the sample position, and sample shape effects. The net sample size effect is calculated with a precision on the order of 1% up to a few per cent for most of the samples. This method is preferable because calculations may be performed for the various individual samples with variations of the geometry and other parameters. Figures 3 and 4 show the results for the Rh-103 and the Cs-133 samples. A full documentation of this approach and the complete results of the analysis are given in a CEA Report [6].

The differences between the calculated and experimental values are shown in Figures 5 to 9 for all five STEK cores. The values in these figures are averaged for all measurements of a sample substance, and the error bars refer to the total error, which is the sum of (i) the statistical errors of the sample measurements, (ii) the statistical errors for the Boron reference measurements, and (iii) the systematic normalisation error.

The self shielding effect is generally strong in the region of strong resonances and it normally becomes small in the high energy region above a few keV if the sample is not very thick. The self shielding has also been estimated for the unresolved resonance region for a few samples, and this region normally provides less than 1% of the net self shielding effect. In the case of the Sm-149 samples however, the self shielding is very strong, and it could not really be determined with a high accuracy, therefore the Sm-149 results are not very accurate for the harder spectra. For Sm-149 the resolved resonance region provided by JEF-2.2 ends at 1.5 keV. At this energy the self shielding still reduces the spectral effect by a factor of 0.4.

In a previous analysis of the STEK measurements in Reference [7] the capture reactivity was calculated for the real thick samples with the JEF-1 cross sections and with

an improved version of the code TRIX [8]. This data, which includes the self shielding, has also been used here. The elastic and inelastic scattering components have been assumed to be independent from the sample size. For this application, the ECCO / ERANOS results for infinite diluted substances were split into a scattering part and a capture part, and a self shielding factor f_s was used to reduce the capture part. The self shielding factor f_s has been determined from the following relation:

$$f_s = \frac{\rho_{tot} - \rho_c + \rho_c \cdot \frac{\rho^{ECN}_{c,Sample}}{\rho^{ECN}_{c,infinite}}}{\rho_{tot}},$$

where the quantities labelled "ECN" are from Reference [7] and the unlabelled ones from ECCO / ERANOS. The advantage of this second approach is that it enables comparisons with published results which were determined with standard routines of reactor calculations.

The third approach finally consists in extrapolating the experimental data from samples of different sizes to zero sample size using an exponential or a linear expression. Figures 10 and 11 show these results for the Rh-103 and the Cs-133 samples. This method is preferable in the sense that it uses only the experimental values without further data and further model assumptions. It however has serious disadvantages in the case of scarce experimental data, which tends to be the case for most of the measurements in STEK. Then the extrapolation becomes unreliable. This analysis is documented in a CEA Report [9].

The analysis has been performed for 89 sample substances and altogether about 300 samples in each of the five STEK cores. For most of the samples all three methods have been used. The calculated sample reactivity worth values agree with the experimental values for most of the substances within about 0.03pcm (per 1g of sample substance), which is close to the experimental accuracy. This can be seen from Figures 5 to 9. There however is a significant number of substances for which the calculated values tend to a stronger absorption than it is observed in the experiment. The deviation into the opposite direction occurs very seldom.

The three approaches give consistent results in most cases. This can be seen from Table 1, where the C/E ratios from the present analysis are compiled. The C/E ratios are for the real samples which are generally not pure, and they are for the net reactivity worth including the capture, scattering, and fission contributions. The main isotopes of the samples are quoted. The error values given in the table refer to the total experimental uncertainty, except for Boron, where only the statistical errors are given.

The agreement between the calculation and the experiment is within the experimental uncertainty of about 5% (the accuracy is different for the different substances, the best values are 3%) for:

H, C, O, Al, Cs-133, U-235, Pu-239.

The reactivity of natural Boron has been used for the normalisation. There is no hint of a bias in the boron data.

The following samples have an experimental accuracy of better than 10% in all STEK-cores and are also reproduced within about 10% by the calculation:

Nb, Mo, Tc-99, Rh-103, Pd, Pd-105, Pd-106, Pd-107, In, I-127, Cs-135, Sm-150, Eu, Pb.

There are significant discrepancies which are greater than 20% for the following samples:

Zr-90, Zr-93, Zr-96, Mo-95, Mo-97, Mo-98, Mo-100, Ru-102, Ru-104, Cd-111, La-139, Pr-141, Nd-143, Nd-145, Nd-148, Pm-147, Sm-147, Sm-149, Gd-157, Hf.

The other substances are reproduced within 10% to 20%, or they have a low experimental precision.

The analysis of the STEK measurements has been discussed in detail for each sample substance in Reference [6], and the main components of the reactivity worth have been specified for the single substances. Deviations of the calculation from the experiment are discussed in terms of the cross section, and the possible reasons for the deviations are given. Because of the broad energy resolution of the present integral method of cross section measurement, the energy range can normally be specified only approximately. However, there are strong discrepancies evidently caused by the capture cross section, and the relative discrepancy is greater at high neutron energies (keV region to the region of unresolved resonances) than at low neutron energies (eV region). The STEK experiments were not designed to distinguish between the capture effect and the scattering (slowing down) effect in the reactivity worth, and the measured effect is a superposition of both. Therefore, in the case of weak absorbing isotopes, there remain ambiguities concerning the type of the reaction which causes the discrepancy.

The capture reactivity worth calculated for infinite diluted sample substance with the JEF-2.2 / ECCO / ERANOS scheme appears to be systematically greater than the value determined by the analysis using adjusted fluxes and cross sections from the JEF-1.1 library in Reference [7]. The difference is about 10% in the softer spectrum (STEK-4000) and about 20% in the harder spectrum (STEK-500); Figure 12 shows the results for the STEK-4000 and STEK-1000 cores. It seems that there also is a systematic trend, and that the relative deviation slightly increases with the mass number of the isotope. There are stronger deviations for Zr-93.

The STEK experiments have been analysed recently at JAERI [10] using the JENDL-3.2 cross section library, which includes more recent experimental data from ORNL and JAERI. These additional data are not used for the JEF-2.2 library. The newer experiments have a tendency to yield smaller capture cross sections, e.g. for Sm-149 and Ag-109. The C/E ratio of that analysis based on JENDL-3.2 is less than 1 for many isotopes. Also, for the isotopes for which RCN data adjusted to the STEK experiments were taken for JEF-2.2, there exists a correlation of the C/E ratio with the cross section in such way that the JEF-2.2 capture cross section is systematically greater than the JENDL-3.2 cross section. The present analysis of the STEK experiments with ECCO / ERANOS shows that the JEF-2.2 capture cross section should be reduced for many isotopes to reproduce the experimental STEK data.

For a certain number of isotopes, sample worth data also exist from the SEG-facility with similar neutron spectra as in STEK. These measurements were analysed at Cadarache with the same programs of the ECCO / ERANOS system and with the JEF-2.2 cross sections, see Reference [11]. The results of that analysis are in agreement with the present one for:

Nb, Mo-95, Pd-106, Nd-145, Sm-149 (strongly discrepant), Eu-153, W, U-235.

For some isotopes, however, discrepancies exist between the SEG and STEK results (Mo-97, Mo-98, Mo-100, Rh-103, Ag-109 and Nd-143).

The fission product isotope samples measured in STEK represent a total of about 75% of the cumulative yield of all fission products. The sum of the weighted infinite reactivity worths of these isotopes is important for evaluating the reactor poisoning by the fission products. It has been calculated from JEF-2.2 and compared with the value deduced from the STEK experiments. The calculated value in the STEK-4000 to STEK-2000 spectra is 10% higher than that from the experiment, and in STEK-1000 and STEK-500 it is about 20% higher. The precision of the basic information from the STEK experiments and of the fission product yields provides a 4% to 6% accuracy of the weighted fission product reactivity sum.

The most important gain in confidence and accuracy of the fission product reactivity could be achieved if the discrepancies between the calculation and the STEK experiments were eliminated or reduced for the following isotopes (in order of decreasing importance):

Sm-149
Sm-147
Zr-93, Pm-147
Mo-95, M0-96, Nd-143, Nd-145
Mo-97, Mo-98, Ru-101, Sm-151, Eu-153.

Because the absolute deviation normalised to the U-235 value becomes stronger in the softer STEK cores, the inclusion of experimental data from more thermalised spectra would be useful. The Sm-149 result is of poor quality because of the strong self shielding effect and the lack of cross section data for calculating a correction.

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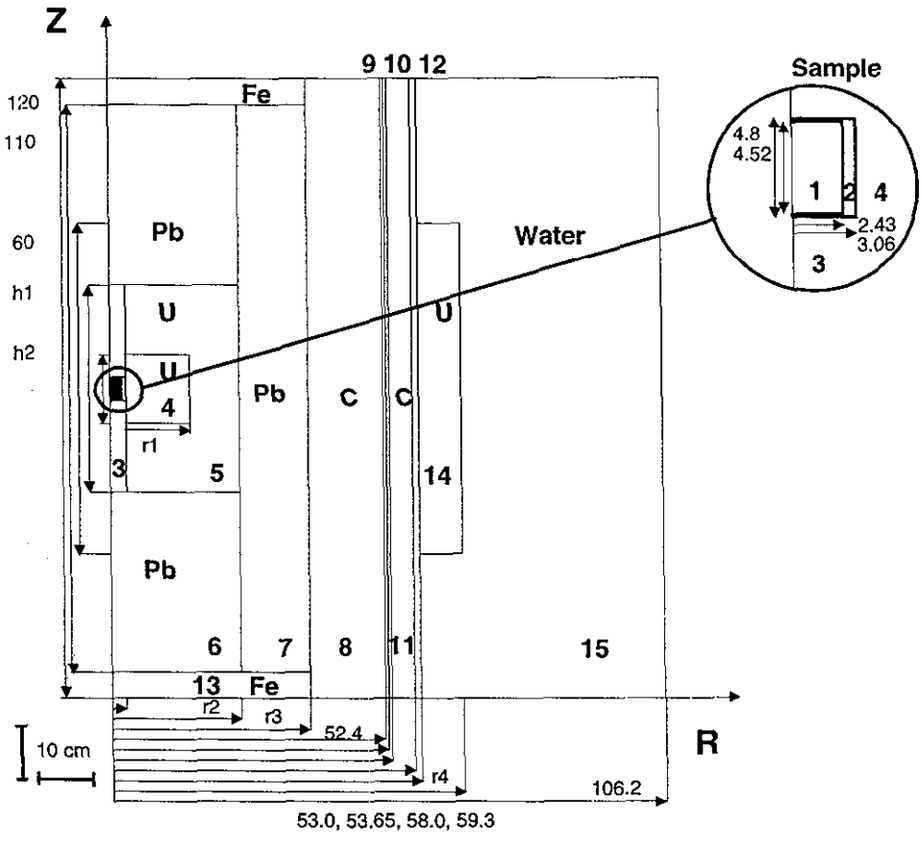
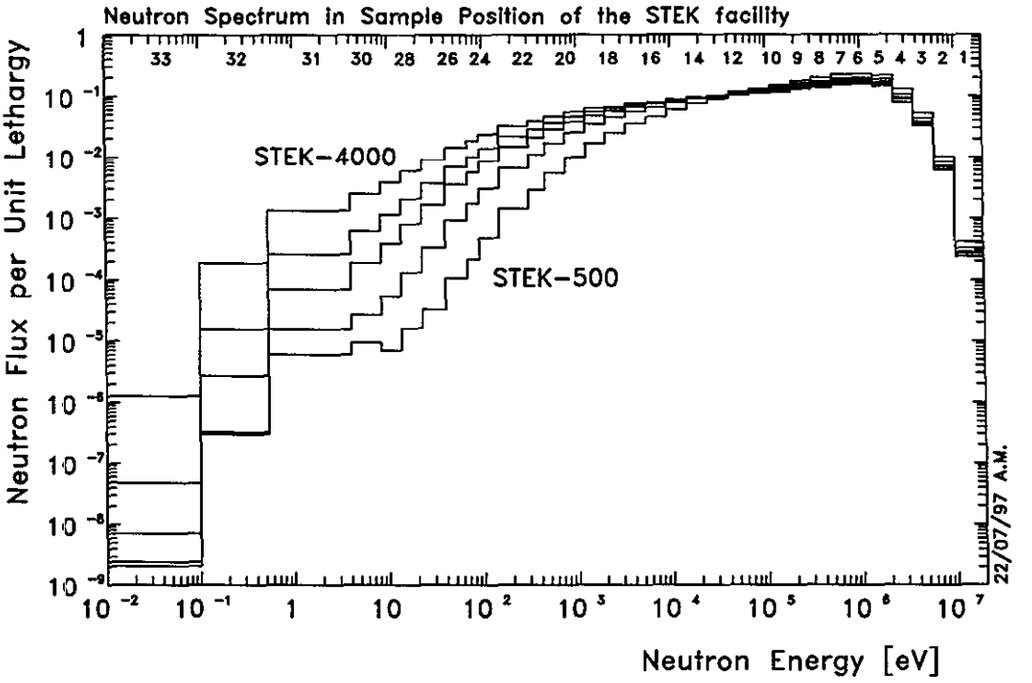


Figure 1:
STEK core lay-out model for calculation in RZ symmetry. The dimensions are given in cm units, the region numbers are indicated, for more details see Reference [4].

The following 15 regions / cells were considered:

1. Sample volume (macrocell calculation)
2. Sample surrounding (homogeneous)
3. Fast core, oscillator element (calculation for heterogeneous geometry)
4. Fast core, inner region (calculation for heterogeneous geometry)
5. Fast core, outer region (calculation for heterogeneous geometry)
6. Axial Lead reflector (homogeneous)
7. Lead reflector (homogeneous)
8. Graphite reflector (homogeneous)
9. Aluminium tank, fast zone (homogeneous)
10. Boral control plates (homogeneous)
11. Outer graphite layer (homogeneous)
12. Aluminium tank, thermal zone (homogeneous)
13. Stainless steel slabs (homogeneous)
14. Thermal zone (calculation for heterogeneous geometry)
15. Water (homogeneous).



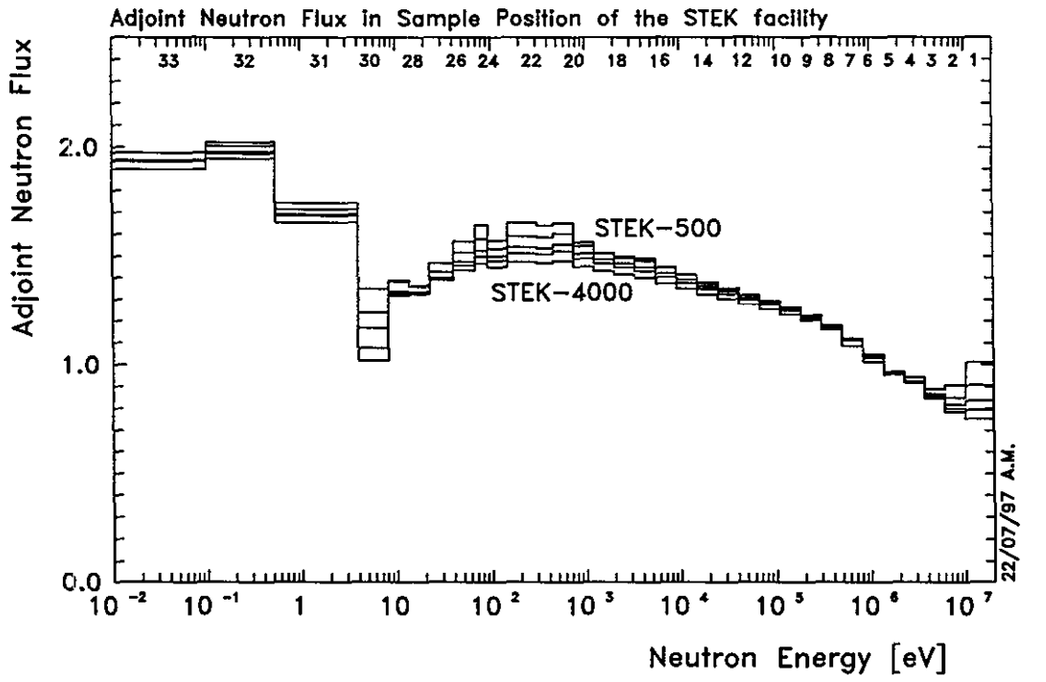


Figure 2:
Neutron flux densities and adjoint fluxes calculated for the sample position in the five STEK cores with the S_n code BISTRO.

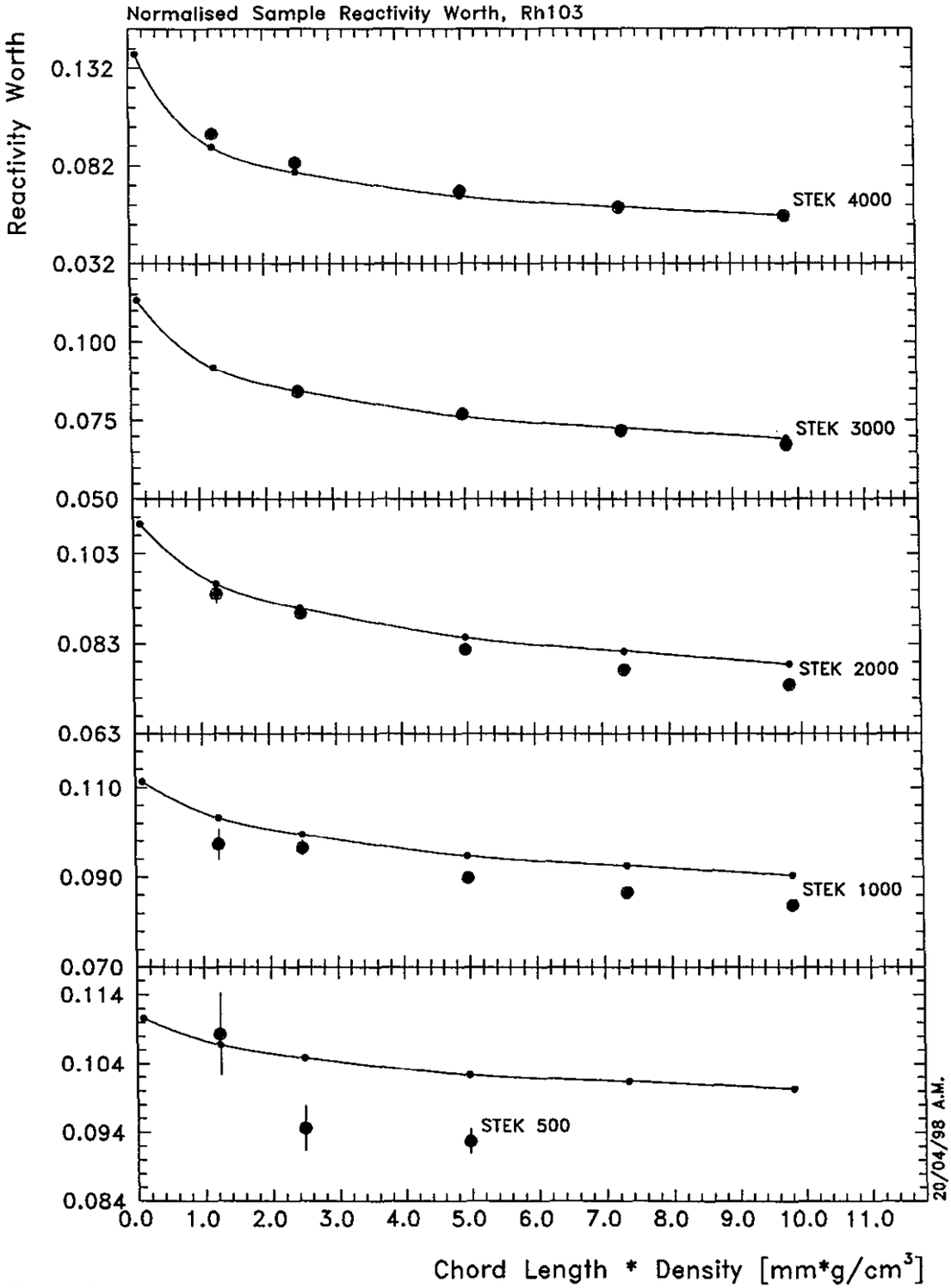


Figure 3:
Analysis of the Rh-103 measurements in the five STEK cores (dots with indication of the statistical errors of the sample reactivity measurements) with the geometry model for calculating the sample size effect and the ECCO / ERANOS calculation for infinite diluted sample substance (small dots on the full curves). The reactivity data is for 1g of the sample substance and normalised to the infinite diluted value of 1g of Boron.

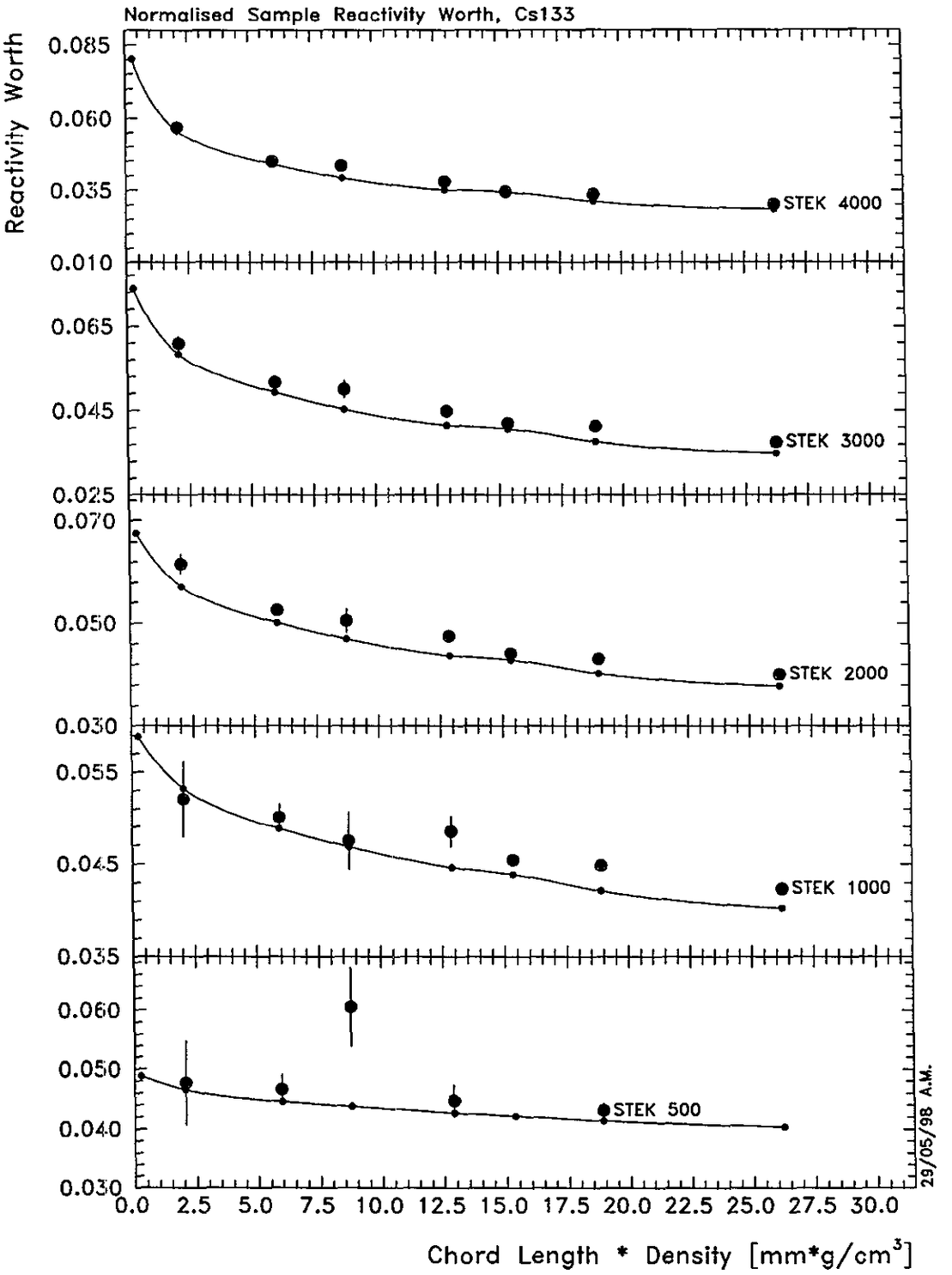


Figure 4:
Analysis of the Cs-133 measurements in the five STEK cores (dots with indication of the statistical errors of the sample reactivity measurements) with the geometry model for calculating the sample size effect and the ECCO / ERANOS calculation for infinite diluted sample substance (small dots on the full curves).

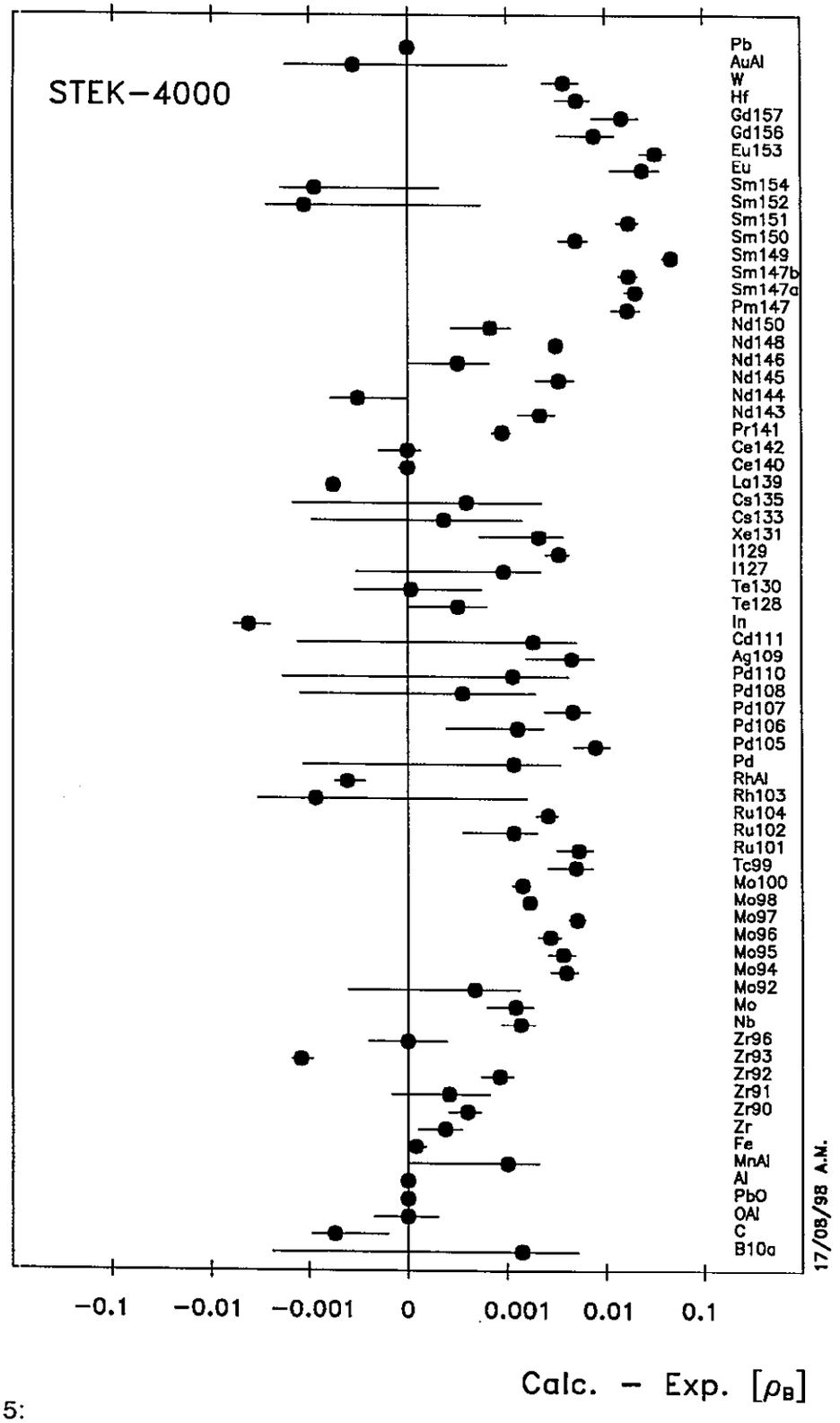


Figure 5:
Differences between the calculated and experimental reactivity worths measured in STEK-4000. The error bars refer to the total error of the experimental data. The reactivity worth is for 1g of sample substance and it is normalised to the value of 1g Boron (about 13 pcm).

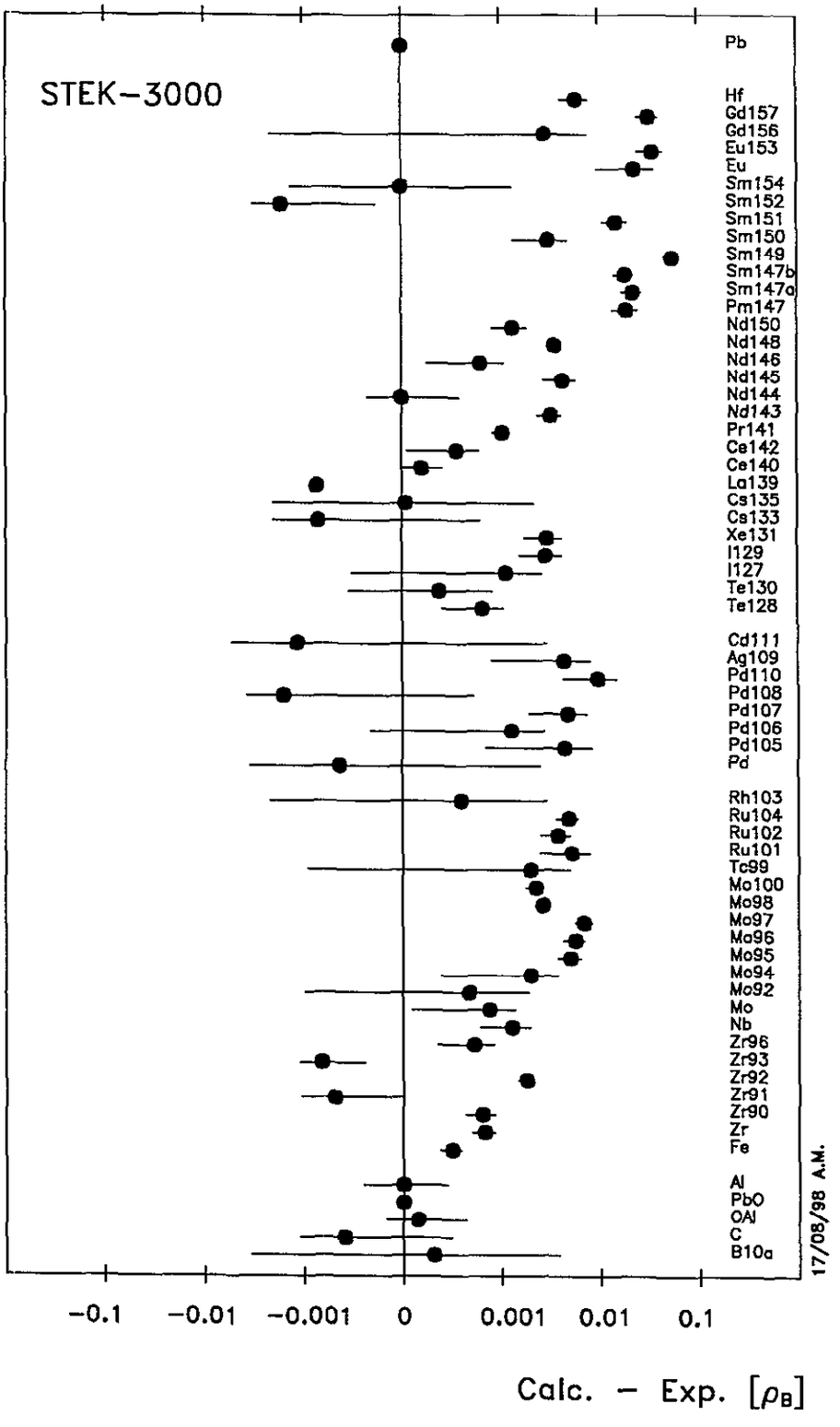


Figure 6:
Differences between the calculated and experimental reactivity worths measured in STEK-3000. 1g of Boron has a reactivity worth of about 8 pcm.

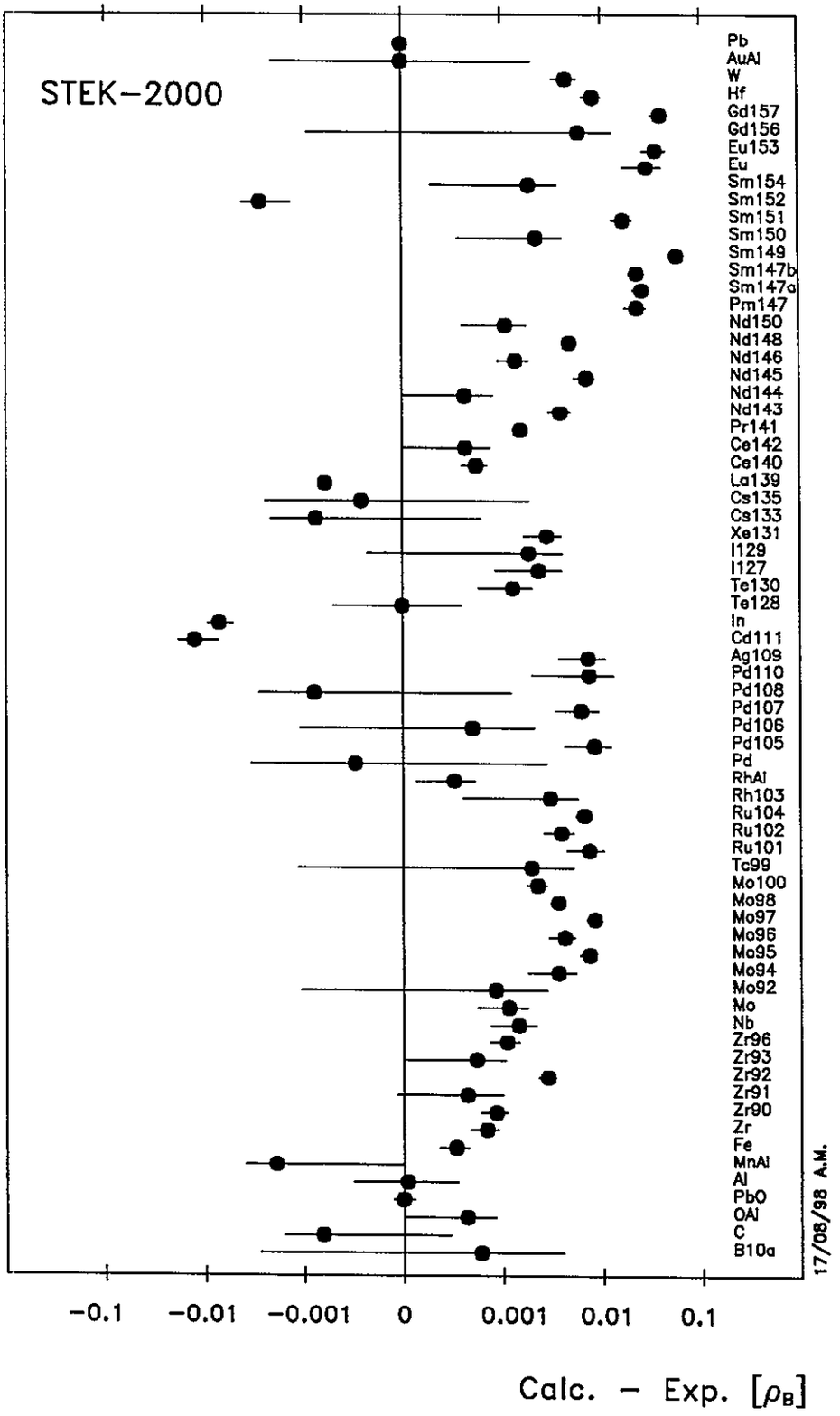


Figure 7:
Differences between the calculated and experimental reactivity worths measured in STEK-2000. 1g of Boron has a reactivity worth of about 6.5 pcm.

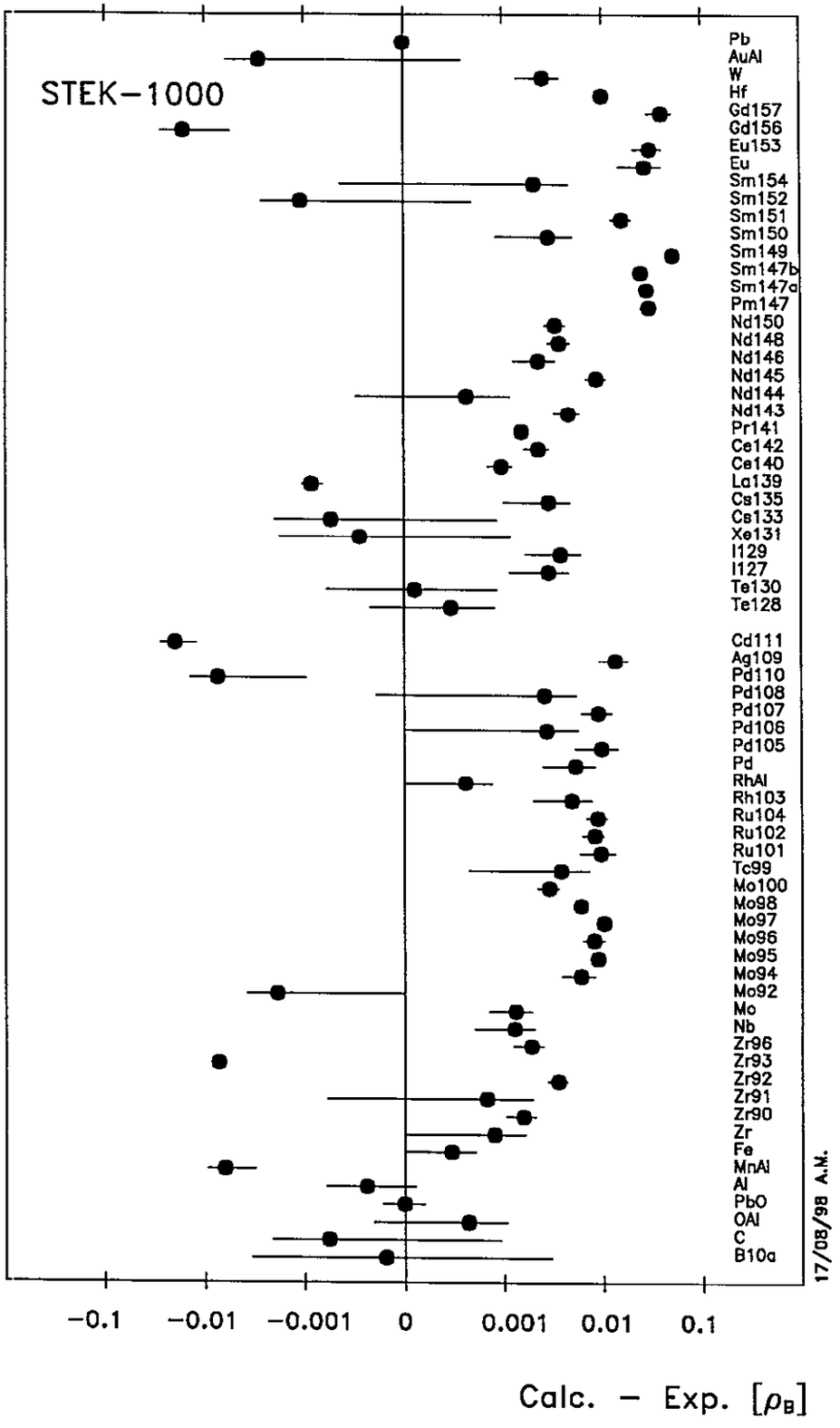


Figure 8:
Differences between the calculated and experimental reactivity worths measured in STEK-1000. 1g of Boron has a reactivity worth of about 4.6 pcm.

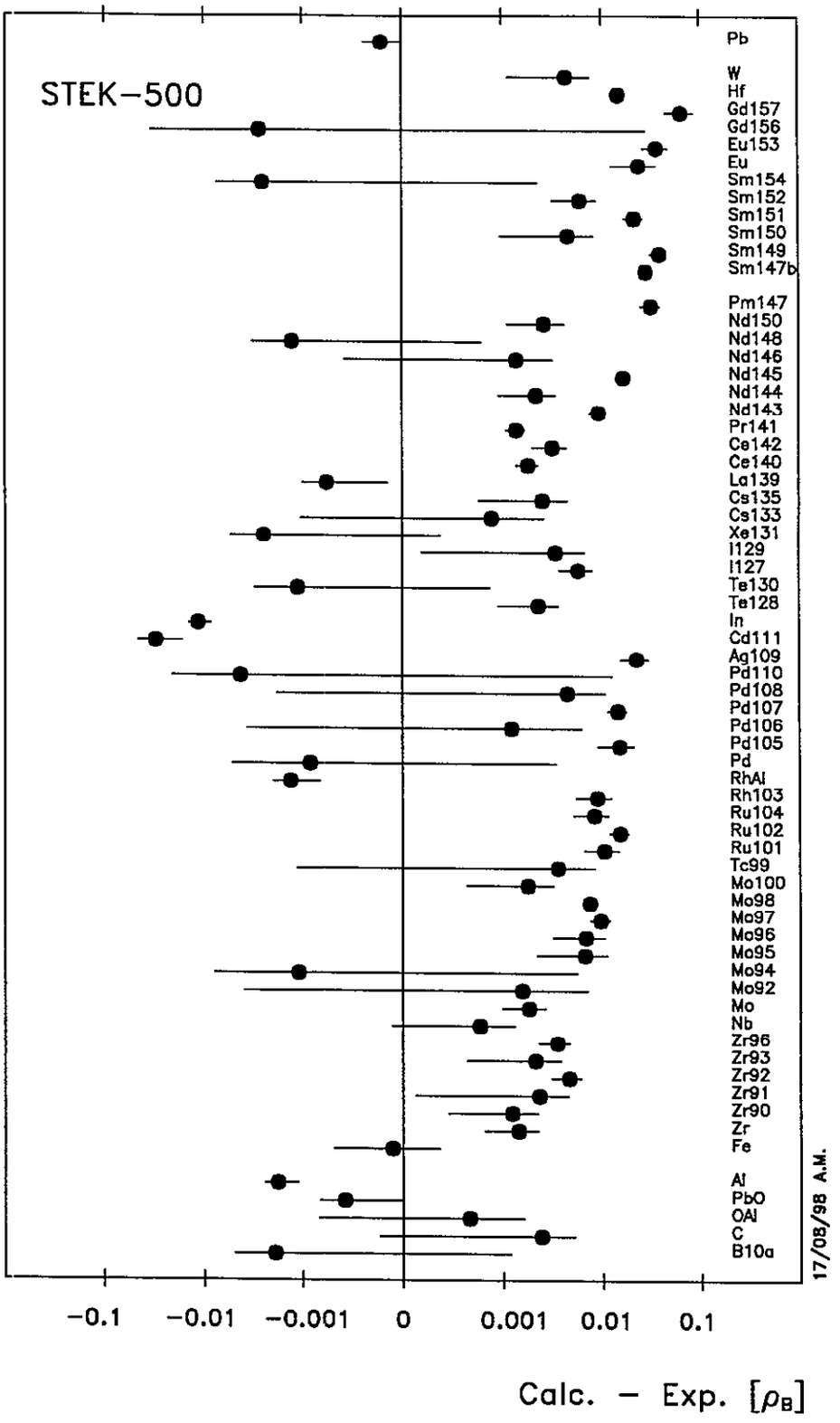


Figure 9:
Differences between the calculated and experimental reactivity worths measured in STEK-500. 1g of Boron has a reactivity worth of about 2.4 pcm.

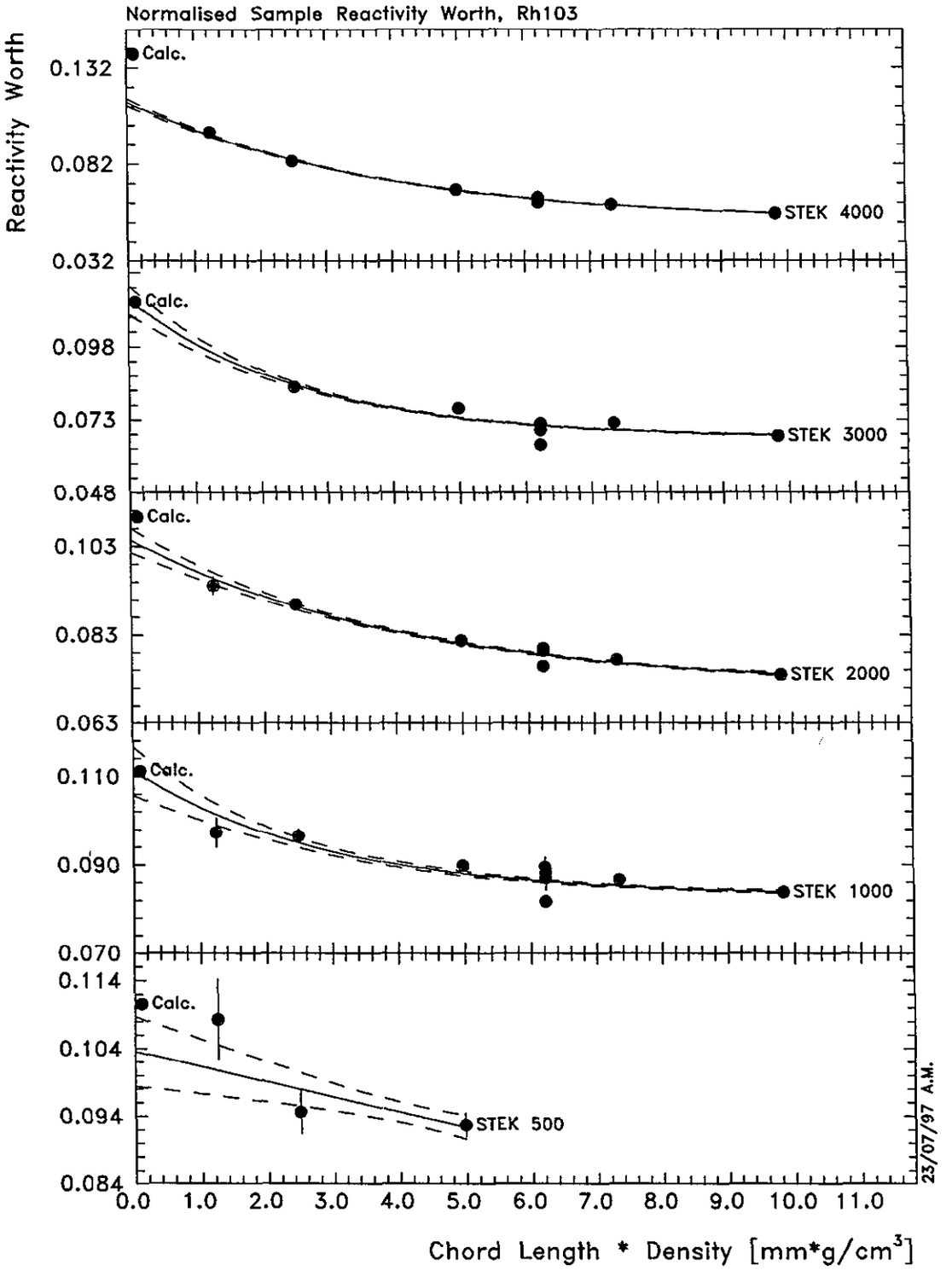


Figure 10:
Reactivity worths of 1g ^{103}Rh with different chord lengths in the STEK cores. The experimental data is given with statistical errors and it is extrapolated to infinite dilution (zero density), the dashed curves include the region of the standard deviation of extrapolation.

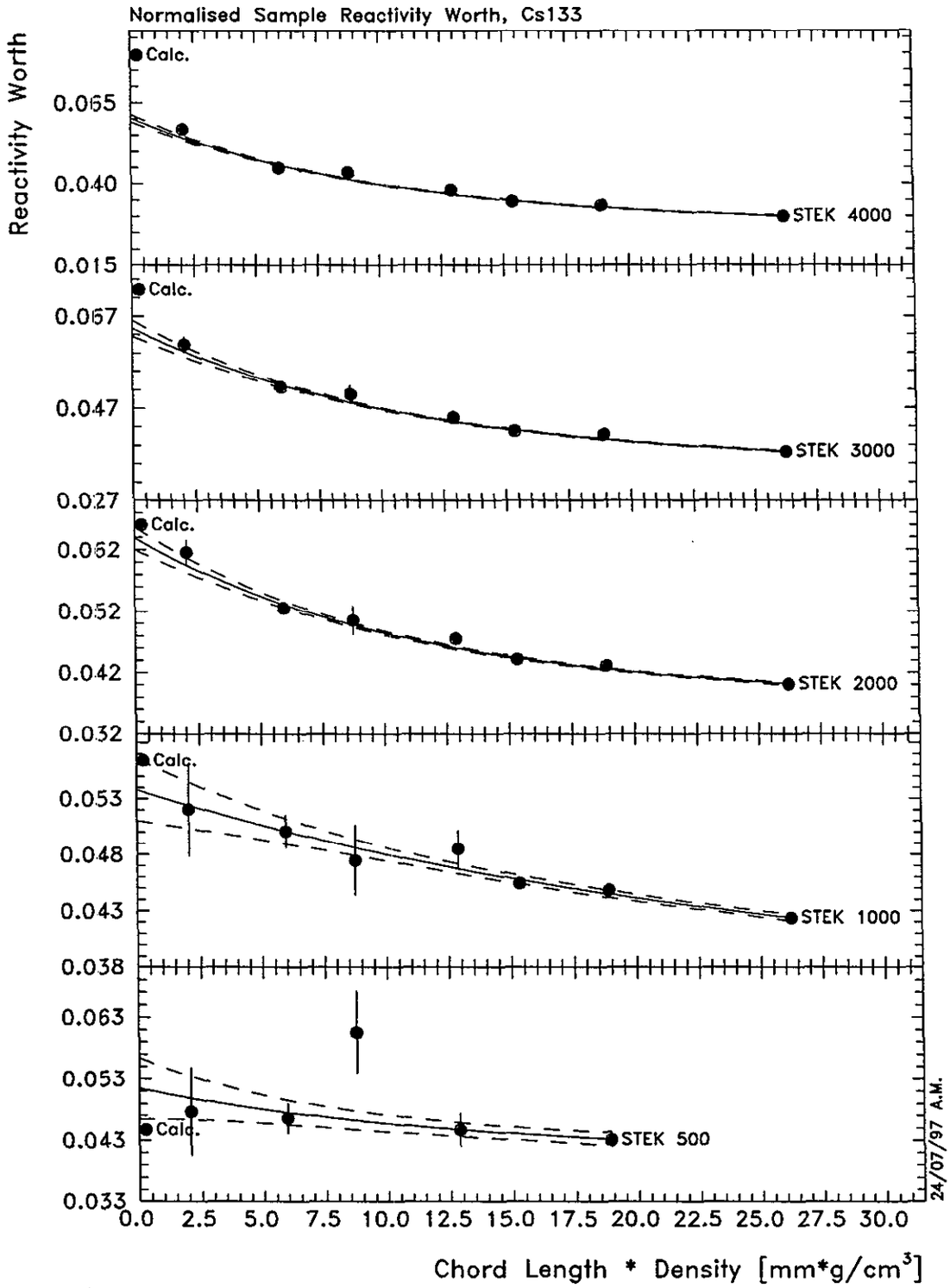
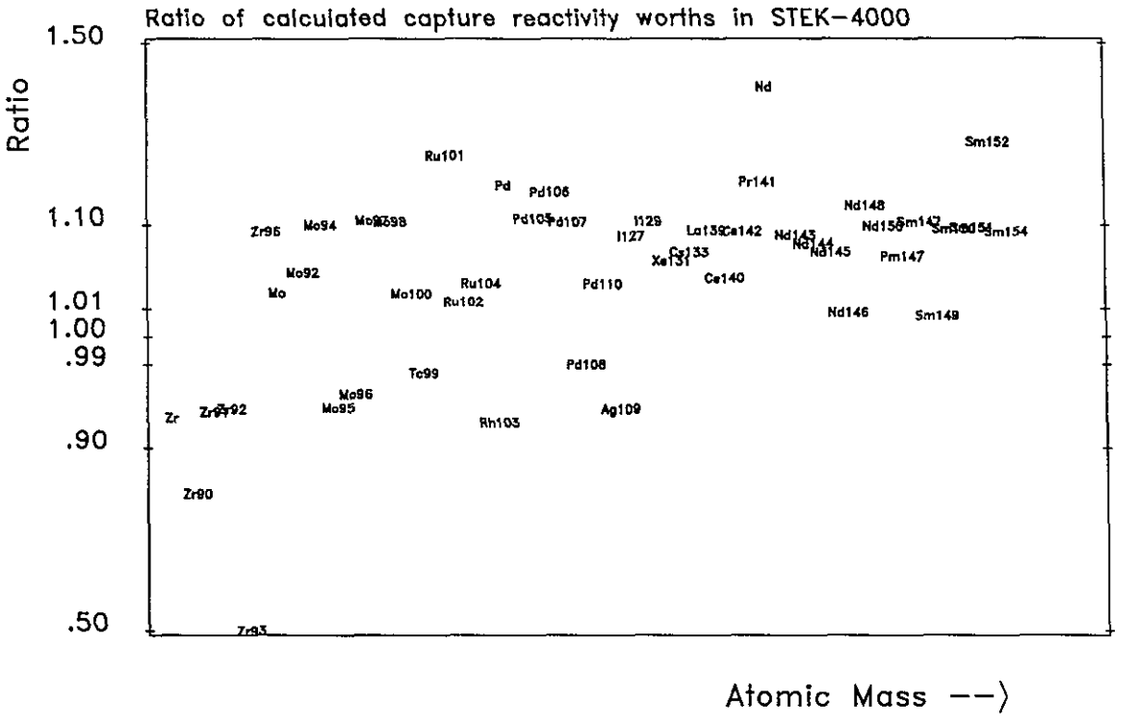


Figure 11:
Reactivity worths of 1g CsCl enriched in ^{133}Cs and measured with samples of different chord lengths in the STEK cores. The experimental data is given with statistical errors and it is extrapolated to infinite dilution (zero density), the dashed curves include the region of the standard deviation of extrapolation.



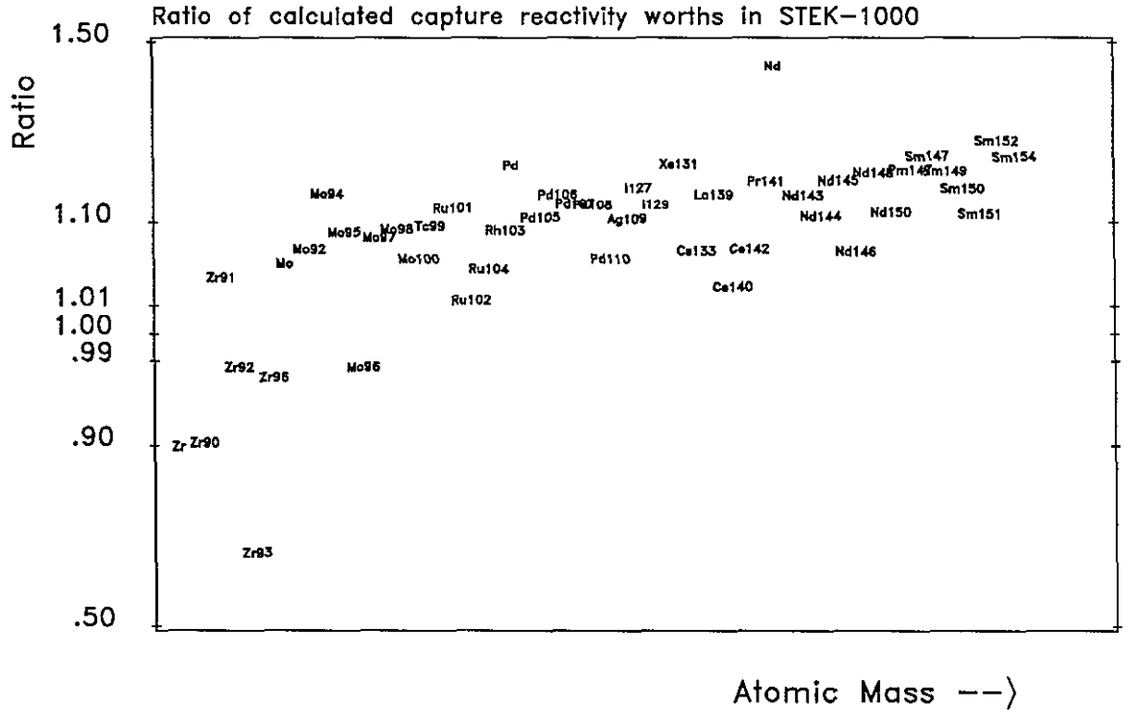


Figure 12:
Ratio of the capture reactivity worths of the indicated samples in STEK-4000 and STEK-1000 calculated for infinite diluted samples:
- 1st with the ECCO / ERANOS codes and JEF-2.2
- 2nd from JEF-1 cross sections and adjusted neutron spectra in Reference [7].

Table 1:
Ratio C/E of calculated and experimental sample reactivity worths measured in the STEK facility. The analysis of the measurements has been performed with the codes ECCO and ERANOS for the neutronic calculation of the STEK-reactors with the JEF-2.2 neutron cross section library and accounting for sample size effects
(1) - by geometry calculations
(2) - in the capture contribution with data from Reference [7]
(3) - by extrapolation of the data to zero sample mass.

Sample	Cor.	STEK-4000	STEK-3000	STEK-2000	STEK-1000	STEK-500	Remark
H	(3)	1.04±4.%	1.06±4.%	1.06±3.%	1.05±3.%	1.01±4.%	
B10	(1)	1.02±2.4%	1.00±1.6%	1.01±1.0%	1.00±0.7%	.98±0.7%	Used for the
B10	(3)	1.03±2.5%	1.02±2.1%	1.00±1.9%	1.00±1.6%	1.04±3.6%	Normalisation
C	(1)	1.06± 4%	1.02± 4%	1.02± 3%	1.01± 3%	.97± 3%	Agreement
C	(3)	.99±18%	.98± 5%	1.01± 4%	.95± 8%	.99± 3%	better than 5%
OAl	(1)	1.01± 4%	.98± 4%	.96± 3%	.98± 3%	.99± 4%	Agreement
OAl	(3)	1.13±11%	1.03± 7%	.92± 6%	1.02± 7%	.99± 4%	better than 5%
PbO	(1)	1.06± 5%	.98± 5%	.98± 4%	1.01± 4%	1.07± 5%	Agreement
PbO	(3)	1.03± 5%	.96± 5%	.96± 4%	.99± 4%	1.06± 5%	better than 10%
O	(3)	1.04± 5%	.98± 4%	.95± 4%	.95± 3%	.96± 4%	Agreement
(metal subtracted)							better than 5%
Al	(1)	1.00± 4%	.98± 4%	.98± 3%	1.02± 3%	1.10± 4%	Agreement
Al	(3)	.90±11%	.92±10%	1.03±16%	.98± 9%	1.08± 4%	better than 5% except STEK-500
MnAl	(1)	.48±55%		1.64±65%	2.96±97%		Agreement within
MnAl	(3)	.47±55%		1.63±65%	2.95±97%		Error Limit
Fe	(1)	.78± 6%	.83± 4%	.89± 4%	.94± 4%	1.01± 4%	
Fe	(3)	.28±67%	.79±39%	.67±16%	.88± 9%	.98± 4%	
Zr	(1)	1.35±16%	4.35±86%	-1.96±89%	.48±53%	.76±13%	
Zr	(2)	1.37±16%	4.49±87%	-1.85±90%	.46±53%	.77±13%	
Zr90	(1)	.79± 7%	.83± 6%	.84± 5%	.83± 5%	.92± 6%	Discrepancy ≥20%
Zr90	(2)	.86± 7%	.89± 6%	.90± 5%	.87± 5%	.94± 6%	
Zr90	(3)	.77± 7%	.81± 6%	.83± 5%	.82± 5%	.90± 6%	
Zr91	(1)	1.11±16%	.86±17%	1.23±34%	.65±78%	.79±20%	Agreement within
Zr91	(2)	1.09±16%	.81±17%	1.08±34%	.88±78%	.80±20%	Exp. Error
Zr92	(1)	.57±15%	.59± 7%	.59± 7%	.68± 6%	.76± 8%	Discrepancy ≥20%
Zr92	(2)	.59±15%	.62± 7%	.63± 7%	.69± 6%	.78± 8%	
Zr93	(1)	.58±10%	.66±22%	-1.08±194%	3.04±23%	.85±12%	Discrepancy
Zr93	(2)	.39± 9%	.22±20%	4.29±216%	1.27±21%	.86±11%	Important FP
Zr96	(1)	-.70±115%	.73±17%	.72± 9%	.78± 7%	.80± 7%	Discrepancy ≥20%
Zr96	(2)	13.54±738%	.56±17%	.66± 9%	.76± 7%	.80± 7%	
Nb	(1)	1.11± 4%	1.07± 4%	1.07± 3%	1.05± 3%	1.03± 3%	Agreement
Nb	(3)				1.12± 9%	1.12±32%	better than 10%
Mo	(1)	1.08± 4%	1.04± 4%	1.07± 3%	1.08± 4%	1.15± 7%	Agreement
Mo	(2)	1.05± 4%	1.05± 4%	1.07± 4%	1.03± 5%	1.15± 7%	within about 10%
Mo	(3)				1.05± 9%	.89±23%	
Mo92	(1)	1.22±40%	1.15±45%	1.26±61%	.69±31%	1.82±286%	Agreement within
Mo92	(2)	1.12±40%	1.05±45%	1.13±60%	.60±31%	1.56±286%	Exp. Error
Mo92	(3)	1.36±40%	1.30±45%	1.45±61%	.80±31%	2.21±286%	
Mo94	(1)	3.09±60%	1.33±29%	1.66±33%	2.45±51%	.91±56%	
Mo94	(2)	2.68±60%	1.14±29%	1.40±33%	2.06±51%	.77±56%	
Mo94	(3)				2.63±51%	.96±56%	

continued
FP=Fission Product

Table 1 continued:

Sample	Cor.	STEK-4000	STEK-3000	STEK-2000	STEK-1000	STEK-500	Remark
Mo95	(1)	1.14± 4%	1.15± 4%	1.22± 4%	1.25± 4%	1.17±12%	Discrepancy
Mo95	(2)	1.05± 4%	1.10± 4%	1.16± 4%	1.20± 4%	1.13±12%	Important FP
Mo95	(3)				1.32±20%	1.54±123%	
Mo96	(1)	1.60±15%	2.47± 35%	1.70±20%	4.95±94%	2.95±104%	Discrepancy
Mo96	(2)	1.37±15%	1.94±35%	1.28±20%	3.57±94%	2.27±104%	Important FP
Mo97	(1)	1.24± 4%	1.22± 4%	1.23± 4%	1.27± 4%	1.26± 5%	Discrepancy
Mo97	(2)	1.19± 4%	1.17± 4%	1.17± 4%	1.20± 4%	1.20± 5%	Important FP
Mo97	(3)	.91±59%	1.22±33%	.94±24%	1.11±20%	1.66±34%	
Mo98	(1)	1.50± 6%	1.66± 7%	1.99±10%	11.00±65%	-.69±24%	Discrepancy
Mo98	(2)	1.41± 6%	1.50± 7%	1.72±10%	8.55±65%	-.27±24%	Important FP
Mo100	(1)	1.46± 9%	1.62±12%	1.61±13%	2.93±44%	.45±42%	Discrepancy ≥20%
Mo100	(2)	1.13± 9%	1.18±12%	1.10±13%	1.65±45%	1.03±42%	
Tc99	(1)	1.09± 4%	1.03± 4%	1.02± 4%	1.04± 4%	1.04± 5%	Agreement
Tc99	(2)	.98± 4%	.97± 4%	.98± 3%	1.02± 4%	1.02± 5%	better than 10%
Tc99	(3)			1.03± 7%	1.08±10%	1.09±27%	
Ru101	(1)	1.11± 4%	1.07± 4%	1.09± 4%	1.11± 4%	1.11± 4%	Agreement
Ru101	(2)	1.14± 4%	1.13± 4%	1.14± 4%	1.14± 4%	1.11± 4%	within about 10%
Ru102	(1)	1.15±11%	1.40±13%	1.32±10%	1.73±17%	2.96±40%	
Ru102	(2)	1.07±11%	1.29±13%	1.21±10%	1.59±17%	2.73±40%	
Ru102	(3)	.95±50%		1.08±70%	1.30±125%		
Ru104	(1)	1.45±11%	1.61±15%	1.79±13%	2.08±24%	1.88±34%	
Ru104	(2)	1.16±11%	1.32±15%	1.46±13%	1.71±24%	1.59±34%	
Ru104	(3)	1.38±51%	1.68±46%				
Rh103	(1)	.98± 4%	1.01± 4%	1.04± 3%	1.06± 3%	1.09± 4%	Agreement
Rh103	(2)	.92± 4%	.96± 4%	1.02± 3%	1.06± 3%	1.10± 4%	better than 10%
Rh103	(3)		.99± 6%	1.05± 4%	1.00± 6%	1.07± 6%	
RhAl	(1)	.85± 5%		.88± 7%	.94± 5%	1.10± 5%	
RhAl	(3)	.98±10%		.97±40%	1.58±35%	1.06±19%	
Pd	(1)	1.04± 7%	0.99± 7%	0.99± 7%	1.12± 7%	0.98± 7%	Agreement
Pd	(2)	1.08± 4%	1.03± 4%	1.02± 4%	1.15± 4%	1.01± 6%	better than 10%
Pd	(3)					1.04± 6%	
Pd105	(1)	1.09± 4%	1.05± 4%	1.07± 4%	1.07± 4%	1.12± 5%	Agreement
Pd105	(2)	1.09± 4%	1.03± 4%	1.06± 3%	1.07± 3%	1.11± 5%	within about 10%
Pd105	(3)	1.06±11%	.82±16%	.99±11%	1.03±13%	1.09± 4%	
Pd106	(1)	1.12± 9%	1.08± 9%	1.02± 8%	1.13±13%	1.05±20%	Agreement within
Pd106	(3)	1.02± 9%	.98± 9%	.92± 8%	1.01±13%	.96±20%	10% or Exp. Error
Pd107	(1)	1.08± 4%	1.06± 4%	1.07± 3%	1.10± 3%	1.16± 3%	Agreement
Pd107	(2)	1.06± 4%	1.04± 4%	1.06± 3%	1.09± 3%	1.15± 3%	within about 10%
Pd107	(3)	1.03± 5%	.93± 5%	.92± 6%	.69±41%	1.20± 9%	
Pd108	(1)	1.02± 8%	.93± 9%	.96± 9%	1.16±17%	1.36±50%	Agreement better
Pd108	(2)	.92± 8%	.84± 9%	.85± 9%	1.06±17%	1.28±50%	than 10% or
Pd108	(3)					1.66±50%	in Error Limit
Pd110	(1)	1.22±59%	-3.96±269%	10.90±722%	.50±44%	.48±204%	Large Experim.
Pd110	(2)	1.17±59%	-3.74±269%	10.27±726%	.46±44%	.41±204%	Uncertainty
Pd110	(3)	1.34±59%	-4.23±269%	11.38±720%	.51±44%	.49±204%	
Ag109	(1)	1.06± 4%	1.05± 4%	1.08± 4%	1.15± 5%	1.24± 8%	Agreement within
Ag109	(2)	.96± 4%	.95± 4%	.99± 4%	1.11± 5%	1.22± 8%	10%, except
Ag109	(3)		.98± 7%		1.01± 8%	.67±34%	STEK-2000 to 500
Cd111	(1)	1.05± 9%	.97± 9%	.79± 9%	.71±11%	.59±19%	Agreement within
Cd111	(3)	.97±37%	.73±34%	.62±40%	.50±38%	.62±19%	10%, except
							STEK-2000 to 500

continued

Table 1 continued:

Sample	Cor.	STEK-4000	STEK-3000	STEK-2000	STEK-1000	STEK-500	Remark
In	(1)	.90± 4%		.88± 3%		.86± 3%	Agreement within 10% to 15%
Te128	(1)	1.49±46%	3.06±125%	.93±63%	.64±63%	.60±24% Exp.	Agreement within Error
Te130	(1)	.64±172%	.68±76%	.41±33%	.93±38%	1.42±70%	Agreement within Exp. Error, except STEK-2000
Te130	(3)			.37±33%	.87±38%	1.37±70%	
I127	(1)	1.03± 4%	1.03± 4%	1.06± 4%	1.07± 4%	1.16± 6%	Agreement within 5%, except STEK-1000 to 500
I127	(2)	1.03± 4%	1.04± 4%	1.08± 4%	1.09± 4%	1.17± 6%	
I127	(3)				.98±17%	.75±28%	
I129	(1)	1.22± 6%	1.14± 6%	1.08± 9%	1.17±10%	1.16±15%	
I129	(2)	1.20± 6%	1.12± 6%	1.06± 9%	1.16±10%	1.16±15%	
I129	(3)	1.53±34%	1.48±41%	1.14±40%	.96±49%		
Xe131	(1)	1.06± 5%	1.11± 4%	1.13± 5%	.98± 8%	.82±20%	Agreement within about 10% or Exp. Error
Xe131	(2)	1.07± 5%	1.13± 4%	1.13± 5%	.99± 8%	.84±20%	
Xe131	(3)					.89±20%	
Cs133	(1)	1.01± 4%	.98± 4%	.98± 3%	.99± 3%	1.02± 4%	Agreement better than 5%
Cs133	(2)	.95±10%	.90±10%	.88± 9%	.87± 9%	.85±10%	
Cs133	(3)			1.03±10%	1.05±12%	.87±15%	
Cs135	(1)	1.02± 9%	1.01± 9%	.99± 9%	1.17±10%	1.15±12%	Agreement within about 10%
Cs135	(3)	1.25±15%	1.17±15%	.96±15%	.70±20%	.89±20%	
La139	(1)	.51± 6%	-5.74±63%	1.45± 6%	1.22± 5%	1.06± 4%	
La139	(2)	.63± 6%	-4.04±64%	1.27± 6%	1.17± 5%	1.05± 4%	
La139	(3)				1.61±57%	.98± 4%	
Ce140	(1)	1.04± 6%	.94± 4%	.87± 4%	.86± 4%	.85± 4%	
Ce140	(2)	1.05± 6%	.94± 4%	.87± 4%	.86± 4%	.85± 4%	
Ce140	(3)	1.00± 6%	.91± 4%	.84± 4%	.84± 4%	.83± 4%	
Ce142	(1)	1.03±16%	.86± 9%	.89± 8%	.73± 7%	.79± 8%	
Ce142	(2)	1.20±16%	.97± 9%	.99± 8%	.79± 7%	.82± 8%	
Ce142	(3)	.95±16%	.83± 9%	.87± 8%	.73± 7%	.79± 8%	
Pr141	(1)	1.20± 4%	1.20± 4%	1.36± 4%	1.82± 9%	.68± 6%	
Pr141	(2)	1.33± 4%	1.32± 4%	1.49± 4%	1.98± 9%	.62± 6%	
Nd143	(1)	1.11± 4%	1.15± 4%	1.18± 4%	1.23± 6%	1.99±17%	Discrepancy Important FP
Nd143	(2)	1.12± 4%	1.12± 4%	1.12± 4%	1.16± 6%	1.90±17%	
Nd143	(3)	1.16±35%	.96±38%	1.17±41%			
Nd144	(1)	.90± 8%	1.03±11%	1.24±23%	.53±94%	.72±16%	Agreement within Error Limit
Nd144	(2)	.91± 8%	1.01±11%	1.14±23%	.97±91%	.78±16%	
Nd144	(3)	.38±53%				.62±16%	
Nd145	(1)	1.10± 4%	1.11± 4%	1.17± 4%	1.24± 5%	1.74±11%	Discrepancy Important FP
Nd145	(2)	1.02± 4%	1.05± 4%	1.10± 4%	1.15± 5%	1.62±11%	
Nd145	(3)	.89±28%	1.14±31%	.91±33%	.86±49%	.43±55%	
Nd146	(1)	1.12±13%	1.26±19%	2.26±44%	-.20±50%	.77±30%	Agreement within Error Limit
Nd146	(2)	.94±13%	.96±19%	1.56±44%	.27±59%	.91±30%	
Nd146	(3)	1.16±70%	.86±73%			.67±30%	
Nd148	(1)	1.54± 7%	1.53± 8%	1.98±12%	2.82±43%	1.59±88%	
Nd148	(2)	1.53± 7%	1.50± 8%	1.91±12%	2.65±43%	.85±88%	
Nd148	(3)	2.06±26%	3.15±46%	1.61±87%		-.70±88%	
Nd150	(1)	1.13± 7%	1.22± 8%	1.17±11%	2.99±42%	.11±42%	
Nd150	(2)	1.01± 7%	1.06± 8%	.97±11%	2.10±42%	.57±50%	
Pm147	(1)	1.13± 4%	1.13± 4%	1.15± 3%	1.22± 3%	1.29± 6%	Discrepancy Important FP
Pm147	(2)	1.06± 4%	1.07± 4%	1.10± 3%	1.19± 3%	1.28± 6%	
Pm147	(3)			1.27±10%	1.32±17%	1.80±62%	

continued

Table 1 continued:

Sample	Cor.	STEK-4000	STEK-3000	STEK-2000	STEK-1000	STEK-500	Remark
Sm147a	(1)	1.18± 4%	1.17± 4%	1.19± 4%	1.23± 4%		Discrepancy
Sm147a	(2)	1.12± 4%	1.14± 4%	1.17± 4%	1.22± 4%		Important FP
Sm147a	(3)				1.30± 6%		
Sm147b	(1)	1.19± 4%	1.16± 4%	1.20± 3%	1.22± 3%	1.29± 4%	
Sm147b	(3)				1.10±20%	1.46±23%	
Sm149	(1)	1.25± 4%	1.24± 4%	1.24± 3%	1.23± 3%	1.19± 3%	Discrepancy
Sm149	(2)	1.05± 4%	1.08± 4%	1.11± 3%	1.14± 3%	1.17± 3%	Important FP
Sm149	(3)				.96±28%	1.25±11%	
Sm150	(1)	1.14± 4%	1.08± 4%	1.06± 5%	1.08± 6%	1.15±12%	Agreement within
Sm150	(2)	1.08± 4%	1.05± 4%	1.01± 5%	1.00± 6%	1.08±12%	about 10% or
	(3)						Exp. Error
Sm151	(1)	1.16± 4%	1.13± 4%	1.16± 3%	1.17± 4%	1.29± 6%	Discrepancy
Sm151	(2)	1.21± 4%	1.16± 4%	1.16± 3%	1.20± 3%	1.28± 6%	Important FP
Sm151	(3)				1.10±10%	1.50±35%	
Sm152	(1)	.97± 4%	.95± 4%	.92± 4%	.96± 5%	1.31±14%	
Sm152	(2)	1.25± 4%	1.24± 4%	1.14± 4%	1.14± 5%	1.59±14%	
Sm152	(3)				1.55±26%	1.74±84%	
Sm154	(1)	1.02± 7%	1.00±10%	1.16±14%	1.48±18%	.80±37%	
Sm154	(2)	1.08± 9%	1.14±10%	1.31±14%	1.34±22%	.87±37%	
Sm154	(3)	1.43±42%			.87±72%		
Eu	(1)	1.08± 4%	1.06± 4%	1.08± 3%	1.07± 3%	1.07± 3%	Agreement
Eu	(3)					1.07± 5%	better than 10%
Eu153	(1)	1.14± 4%	1.13± 4%	1.13± 3%	1.11± 3%	1.15± 4%	Important FP
Eu153	(3)				1.03± 9%	.95±14%	
Gd156	(1)	1.29±17%	1.07±12%	1.14±17%	.75±17%	.94±66%	Agreement within
Gd156	(3)				.98±17%	1.07±66%	Exp. Error
Gd157	(1)	1.10± 5%	1.21± 5%	1.26± 5%	1.26± 7%	1.65±19%	
Hf	(1)	1.10± 4%	1.12± 4%	1.17± 3%	1.23± 3%	1.45± 4%	
Hf	(3)					1.17±30%	
W	(1)	1.10± 4%		1.15± 4%	1.10± 4%	1.27±20%	Agreement within about 10% or Error Limit
AuAl	(1)	.92±31%		1.02±110%	1.74±84%		Agreement within
AuAl	(3)	1.09±31%		.94±110%	1.72±84%		Error Limit
Pb	(1)	1.11± 4%	1.06± 4%	1.05± 4%	1.01± 4%	1.07± 3%	Agreement
Pb	(3)	1.14± 9%	.99± 8%	1.05± 7%	1.02± 4%	1.11± 3%	better than 10%
U235	(3)		1.06± 5%	1.01± 4%	1.00± 5%	1.07± 4%	
U235Al	(3)	.99± 8%	.98± 8%	1.00± 7%	1.01± 6%	.94±18%	
Pu239	(3)	1.01± 5%	.87± 5%	.98± 4%	.97± 4%	.95± 5%	Exp. Data Problem with STEK-3000

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