STUDY OF MULTIPLICATION FACTOR SENSITIVITY TO THE SPREAD OF WWER SPENT FUEL ISOTOPICS CALCULATED BY DIFFERENT CODES

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Abstract

As a sensitivity study the impact on the system reactivity was studied in the case that different calculational methodologies of spent fuel isotopic concentrations were used for WWER spent fuel inventory computations. The sets of isotopic concentrations obtained by calculations with different codes and libraries as a result of the CB2 international benchmark focused on WWER-440 burnup credit were used to show the spread of the calculated spent fuel system reactivity. Using the MCNP 4B code and changing the isotopics input data, the multiplication factor of an infinite array of the WWER-440 fuel pin cells was calculated. The evaluation of the results shows the sensitivity of the calculated reactivity to different calculational methodologies used for the spent fuel inventory computation. In the studied cases of the CB2 benchmark, the spread of the reference k-results relative to the mean was found less or about ±1% in spite of the fact that the data of isotopic concentrations were spread much more.

1. INTRODUCTION

According to the burnup credit methodology, two calculational steps must be performed because of the criticality safety analysis of spent fuel systems.

Spent fuel consists of many nuclides resulting from reactions in progress during the fuel irradiation in nuclear reactors. Therefore, the first phase of any spent fuel system analysis should be finding the spent fuel inventory relating to the irradiation history of the specified fuel. In spite of the fact that the spent fuel contains more than 200 isotopes, analysts have agreed on a relatively small number of isotopes which are the most valuable contributors to the reactivity of spent fuel systems. The chosen set of the recommended isotopes (actinides and fission products) was proved to be a conservative one. The description of the spent fuel using concentrations only of the selected isotopes makes the criticality analysis of the spent fuel systems less time consuming.

Due to spent fuel system licensing, the maximum k_{eff} must be evaluated taking into account all uncertainties and the methodology bias and compared with the k regulatory safety limit. Connected with this, an impact on the system reactivity was studied in the case that different calculational methodologies of spent fuel isotopic concentrations were used for the spent fuel inventory computation. Following the sensitivity study which has recently been performed for PWRs by members of OECD/NEA/NSC Burnup Credit Criticality Benchmark Working Group [1], a similar study has just been made also for WWERs. Up to twelve sets of isotopic concentrations obtained by calculations with different codes and libraries as a result of an international benchmark focused on WWER-440 burnup credit [2] were used to show the spread of the calculated spent fuel system reactivity. Using the MCNP 4B code and changing the isotopics input data, the multiplication factors of an infinite array of the WWER-440 fuel pin cells were calculated. The evaluation of the results shows the sensitivity of the calculated reactivity to different calculational methodologies used for the spent fuel inventory computation.

2. SENSITIVITY STUDY

The four-piece international benchmark focused on burnup credit issues was specified for WWER spent fuel in 1996 [2] in collaboration with OECD/NEA/NSC Burnup Credit Criticality Benchmark Working Group. The benchmark was designed and proposed to be calculated by analyst in Eastern and Central European countries and possibly members of the Burnup Credit Criticality Benchmark Working Group interested in the WWER applications. The second portion of the benchmark, CB2 [3], consisted of the nuclide concentration computation for depletion in a simple WWER-440 pin cell. Fresh fuel of 3.6 wt % ^{235}U enrichment was supposed to be burnt to 30 and 40 GWd/t_U and cooled 0, 1 and 5 years after discharge. Since no supporting data obtained from sample measurements were available, the benchmark evaluation resulted in the methodology intercomparison only.

As the CB2 results, 12, 10, 11 and 10 sets of 26 nuclide concentrations [4] were obtained from the benchmark participants for the cases of 30 GWd/t_U and 1 year of cooling time, 30 GWd/t_U and 5 years of cooling time, 40 GWd/t_U and 1 year of cooling time, 40 GWd/t_U and 5 years of cooling time, respectively. Each set of the nuclide concentrations resulted from a calculation using a calculational methodology specific to the given participant. The selected nuclides consist of 11 actinides and 15 major fission products, main contributors to the spent fuel reactivity [3] recommended for the burnup credit calculations: U-235, 236, 238, Pu-238, 239, 240, 241, 242, Am-241, 243, Np-237, Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Cs-133, Nd-143, Nd-145, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Eu-153, Gd-155.

The CB2 evaluation [4] showed the spread of nuclide concentrations calculated by the participants. If the estimated standard deviation of 10% was chosen as a point of a change between 'good' and 'poor' agreement in the calculations of the nuclide concentration for a given isotope by the participants, there were several more spread isotopes : Am-241 (11%), Am-243 (12%), Ag-109 (13%), Sm-149 (12%), Sm-151 (15%) and even Gd-155 (52%). It should be noted that a similar spread resulted from the evaluated results of the similar OECD benchmark (Pu-238 (14.78%), Am-243 (10.71%), Ag-109 (10.62%), Sm-149 (14.92%), Sm-151 (22.15%) and Gd-155 (33.23%)) [1].

Each set of the CB2 results were used as input data for a reference criticality calculation by MCNP 4B + DLC189. Thus, in total, 12, 10, 11 and 10 sets of multiplication factors of the infinite array of the WWER-440 fuel pin cells were computed. It was believed that the k-results should be normally distributed for each separate case of a given burnup and cooling time if the calculational methodology was good and used in a right manner. To confirm or reject this hypothesis, all the sets were statistically explored and tested (α=0.05). The statistical evaluations found two outliers (see Fig. 1, 3, 5, 7 below). One marked calculational methodology (the Cuban participant) was the ORIGEN II code with PWRU libraries [5], which is an obsolete approach not using any flux and library recalculation, the other one (the Finnish participant) used the SCALE 4.3 code [6], but, unfortunately, some specific features of the calculational sequence SAS2 were not fully utilized so the correct result could not be obtained. It can be seen in the pictures, that SCALE 4.3 was used by three other participant successfully.

After removing outliers the sets of k-results were explored once again and found normally distributed. As figures 2, 4, 6 and 8 show, the spread of the k-results relative to the mean is a little more than ± 0.5 % for both cases with the burnup of 30 GWd/t_U (30_1 and 30_5 cases) and about ± 1 % for 40 GWd/t_U and 5 years of cooling time (40_5 case). In the case of 40

GWd/t_U and 1 year of cooling time (40_1 case), an outlier was not found at the chosen confidence level. The spread of the relative deviations in this case - except of the 'potential' outlier (which was found in all the other cases) - is less than ± 1 %.

3. CONCLUSIONS

In the field of WWER spent fuel applications, there is a total lack of open experimental data which could help to find out the methodology bias for the isotopic concentration calculations. The bias should correct nuclide concentration data prior to the criticality calculation of a given spent fuel facility. The only publicly mentioned experimental data coming from Russian assays in seventies ([7], [8]) involve only actinides (except ^{237}Np) and do not yield any results for fission products which would be important for the validation of the burnup credit calculational methodologies. The detailed data for operational codes were published only in 1998 [9] to offer the measured isotopics eventually for an open recalculation and comparison. The proposed calculational case was entitled as a benchmark but rather it is a large calculational exercise relating to the whole reactor core and needs several codes to be involved to deal with the detailed operational history.

For benchmarking methodologies used for the isotopic concentration calculations due to the spent fuel applications, it would be more useful to take a benchmark preparation after [1]. The calculational benchmark [1] was specified in context with existing chemical assay measurements, however, in contrast to the reality of the sample depletion, the problem specification was simplified somewhat to provide an approximate representation of the fuel configuration during the depletion. The simplification would allow a more straightforward and consistent comparison between the codes used by various benchmark participants.

An urgent need of benchmarks for WWER spent fuel isotopic concentration supported by 'well documented' samples persists. Measured data only would serve as a quantitative measure of a code ability to predict the spent fuel composition.

For the time being, only-calculational benchmarks can only show spread of results which - projected into a spread of the multiplication factor - yields a certain relative piece of information about a selected methodology. In the studied cases of the CB2 benchmark it resulted in finding two outlying methodologies (and, of course, reasons for it) and the spread of the reference k-results relative to the mean less or about ±1% beside the estimated standard deviations less or about 1%. At the same time, the spread of the nuclide concentrations data described by the estimated standard deviation was of the order of one and ten % (see above).

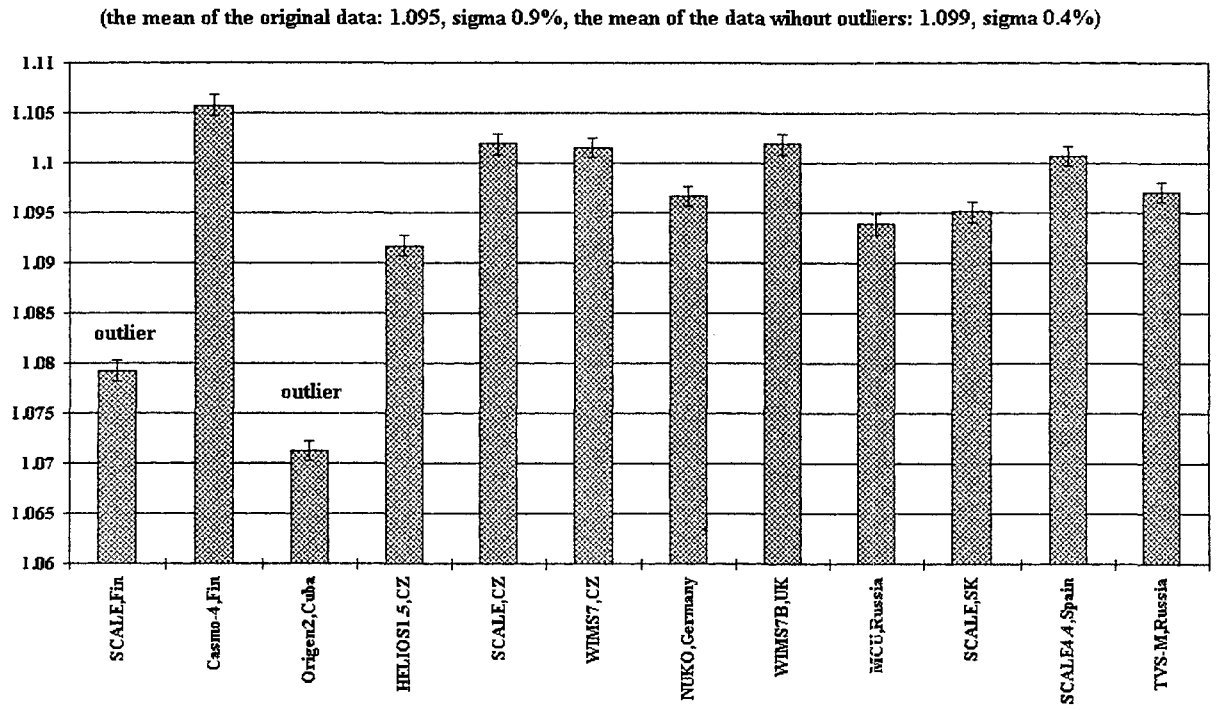

FIG.1. Multiplication factors resulted from the MCNP calculation for WWER fuel of 3.6% enrichment, 30MWd/kg burnup, 1y cooling tome

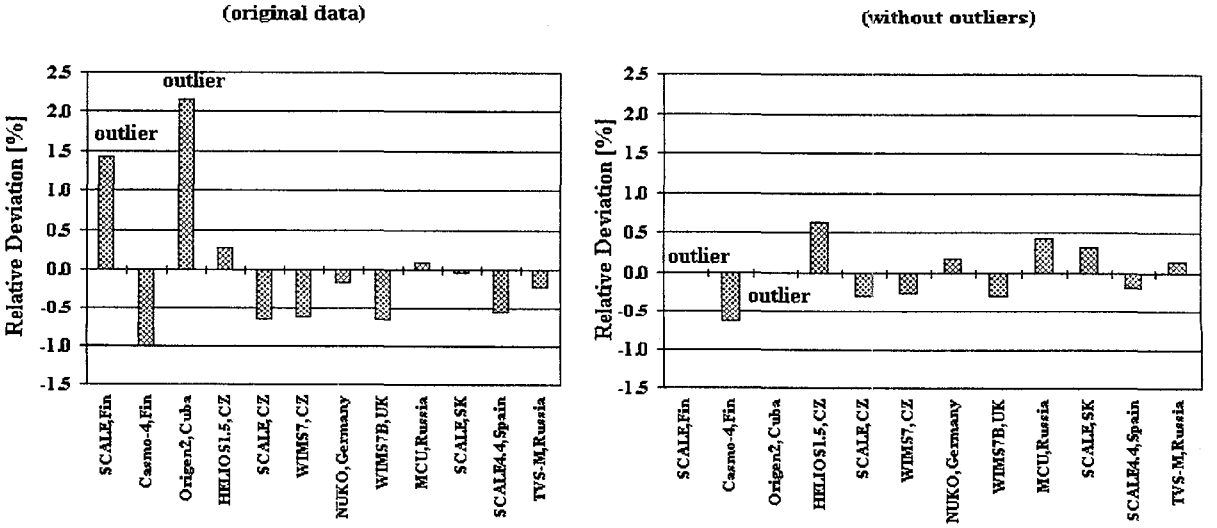

FIG.2. 30-1 k Results Relative to the Mean

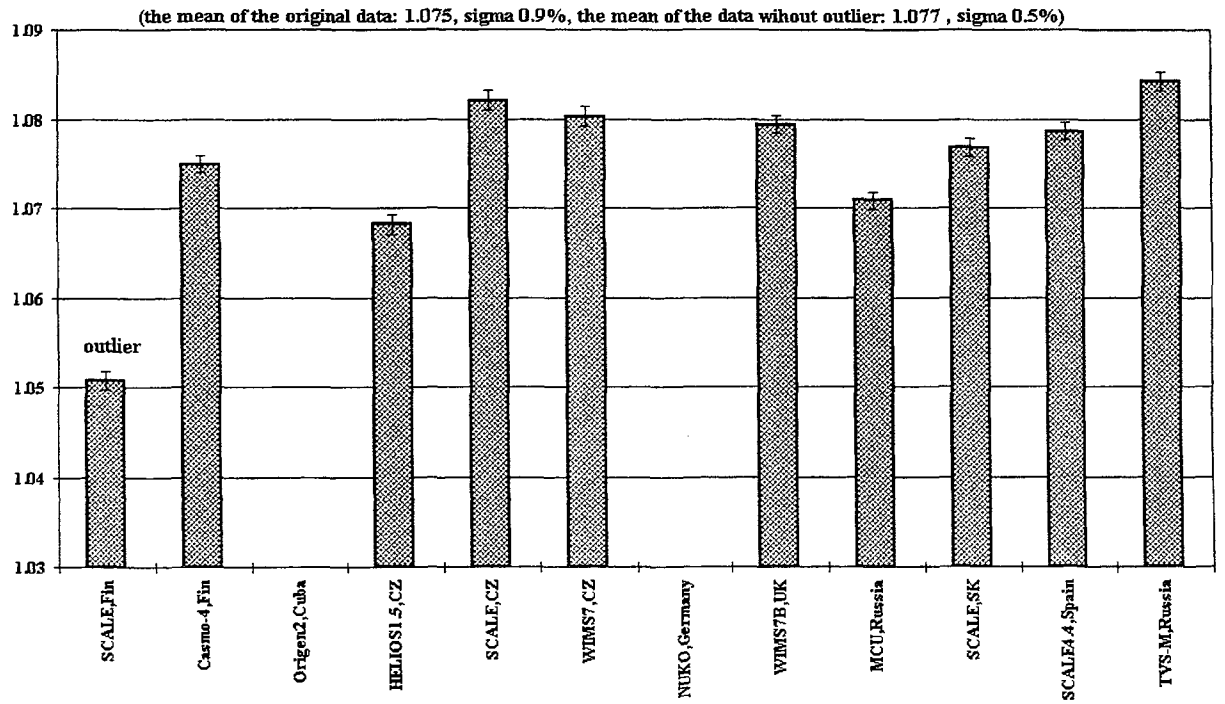

FIG.3. Multiplication factors resulted from the MCNP calculation for WWER fuel of 3.6% enrichment, 30MWd/kg burnup, 5y cooling time

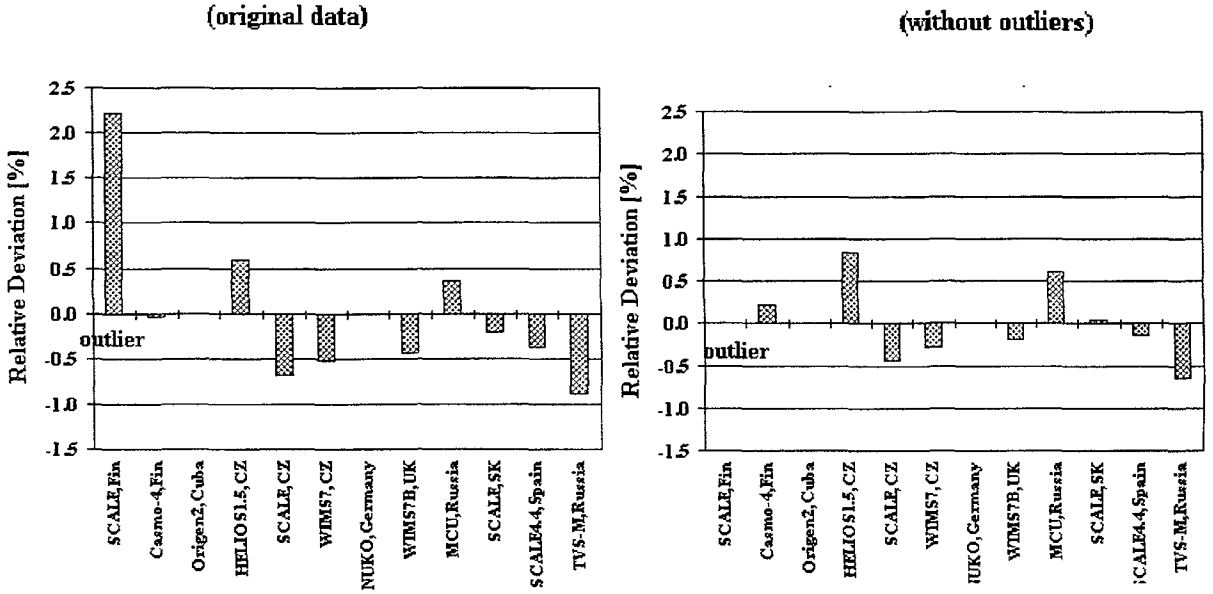

FIG.4. 30-5 k Results Relative to the Mean

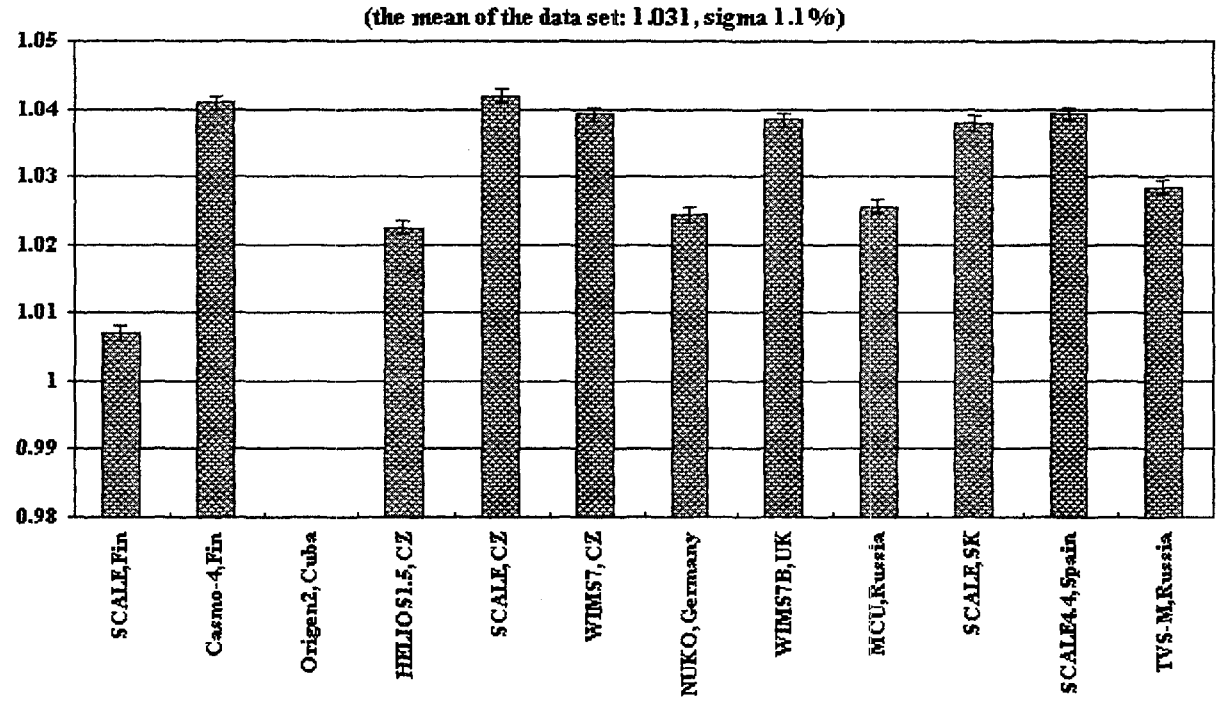

FIG.5. Multiplication factors resulted from the MCNP calculation for WWER fuel of 3.6% enrichment, 40MWd/kg burnup, 1y cooling time

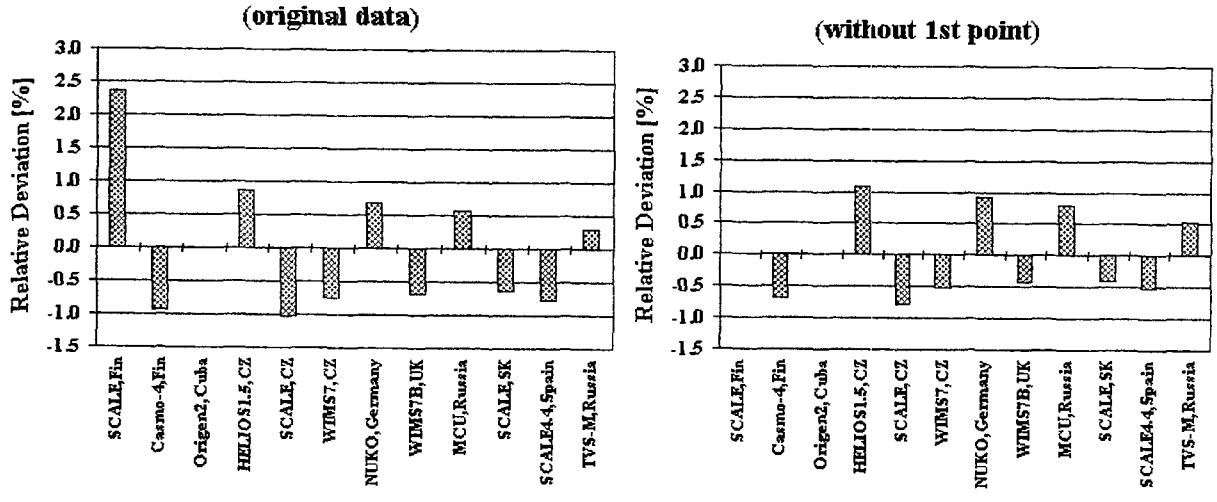

FIG.6. 40-1 k Results Relative to the Mean

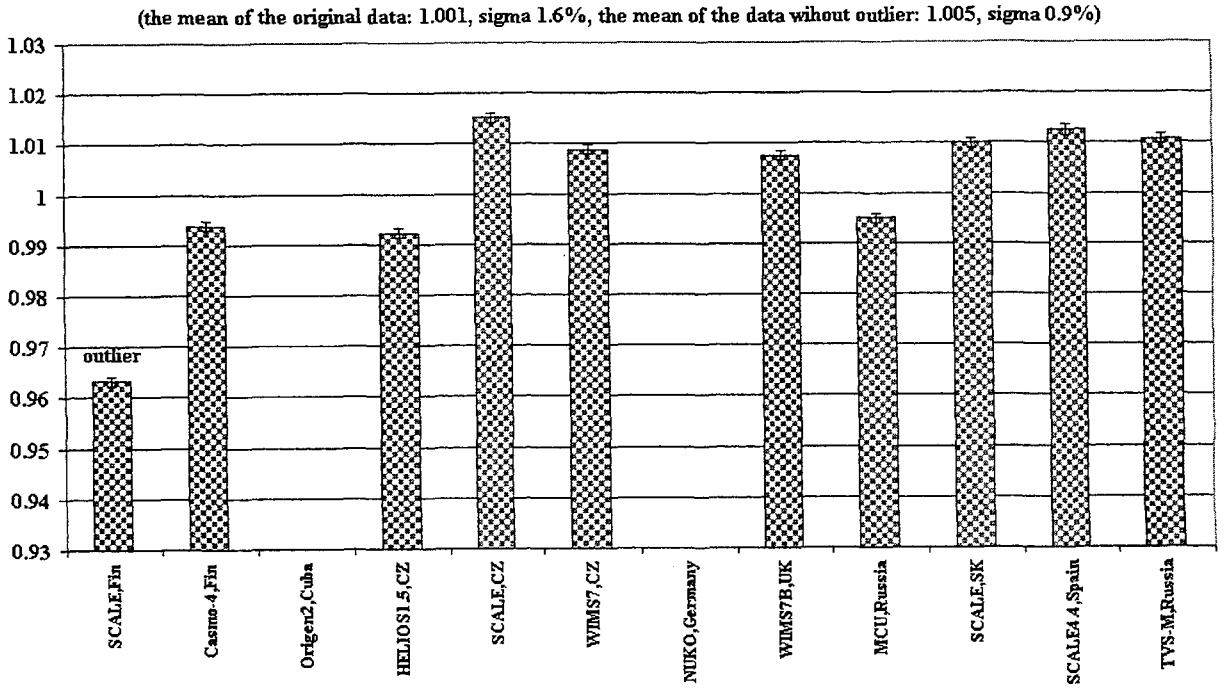

FIG.7. Multiplication factors resulted from the MCNP calculation for WWER fuel of 3.6% enrichment, 40 MW d/kg U burnup, 5 yr. Cooling time.

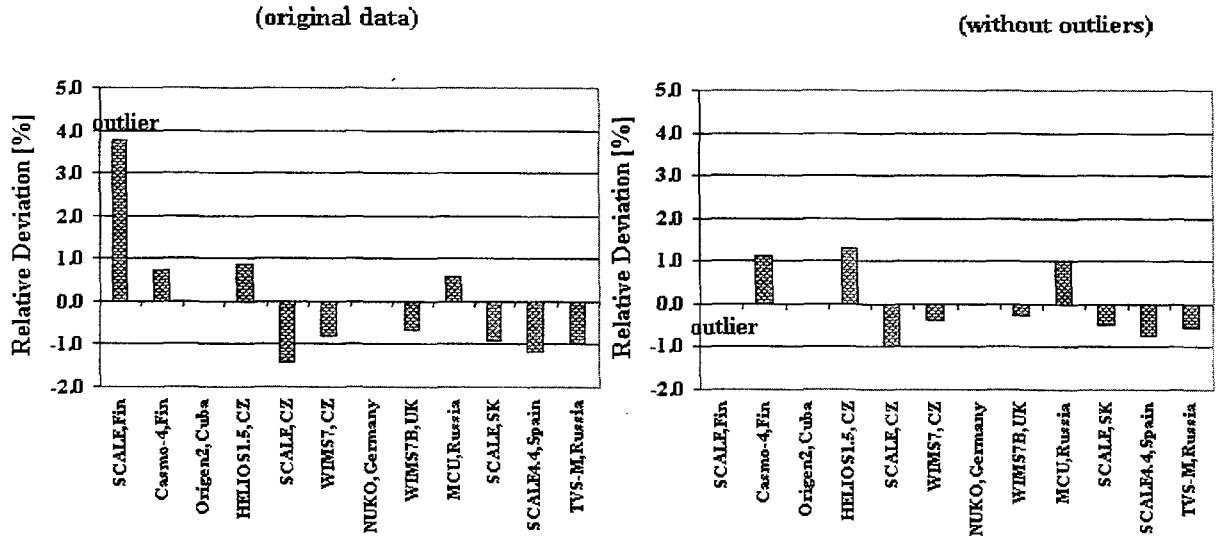

FIG.8. 40-5 k results relative to the mean.

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