SK00ST143

INFORMATION ABOUT THE NEW 8-GROUP DELAYED NEUTRON SET PREPARATION

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ABSTRAKT

Some comments to the present state concerning delayed neutron data preparation is given and preliminary analysis of the new 8-group delayed neutron data (relative abundances) is presented. Comparisons of the 8-group to 6-group set is given for rod drop experiment (Unit 1, Cycle 14, NPP Dukovany).

1. Introduction (some conclusions of the NEANSC/WPEC SG6)

The NEANSC/WPEC Subgroup 6 (SG6) on delayed neutron data is one of the first technical subgroups that was created in the framework of the WPEC activities. The task of the SG 6 was outlined as follows: „Current calculation - to experiment discrepancies (up to 10%) on integral measurements of β_{eff} result in undesirable conservatism in design and operation of reactor control systems. Delayed neutron data uncertainties, which are significant in β_{eff} calculations may be summarized as follows: absolute yields ± 4 to 5%; group parameters ± 3 to 15%; delayed spectra ± 10% to 20%." The main goal of the SG 6 activity is to upgrade β_{eff} of Pu239, U235 and U238 delayed neutron data.

The earlier approach to getting delayed data was to depend on direct counting of delayed neutrons emitted from fissining system samples. Keepin [1] derived approximate temporal group representation by fitting of measured delayed neutron emissions following fission pulse and saturation irradiation experiments in critical assemblies.

Tuttle (reference in [2]) revised Keepin fitted traditional six temporal groups became the basis of data file ENDF/B-V.

Brady and England [2] have evaluated the measured data, supplemented it with model spectra for completeness, and added model values for probable unmeasured precursors. These evaluations and calculations formed the basis of data file ENDF/B-VI. The method of Brady and England was called as „summation approach" and gives significant differences between total yields and those evaluated earlier from direct measurements based mainly on the work of Keepin and others.

We can define 3 kinds of delayed neutron data preparation:

1. Total delayed neutron yields
2. Time depending group parameters
3. Spectra

1.1. Total delayed neutron yields (DNY)

Measurements concerning the major actinides (U235, U238 and Pu239) are yet in progress with growing interest in the DNY incident neutron energy dependence. But the present requests for delayed neutron data are no more focused on major actinides, but on a quite large number of isotopes of interest for transmutation applications (Np237, Am and Cm isotopes) and for Th fuel cycle (Th232 and U233).

More particular:

1)some differences existing among the Np237 preliminary results obtained by the different teems.

2)The final uncertainties relevant to the main isotope DNY average values are yet close to the requirements:

U235	2%
U238	3%
Pu239	2%

1.2. Time depending group parameters

The comparison was made by considering the impact of the different data on either the total delayed neutron emission versus the time or the reactivity versus the reactor stable period (relevant to the inhour equation). The results were very close to each others with the only exception of those obtained by using time depending group parameters based on microscopic data summation. It is for that there is a problem of lack of coherence in group constants obtained by summation of microscopic data and renormalization of the group yields, which causes discrepancies in ENDF/B-VI, JEFF2.2 and JENDL-3.2 libraries.

The calibration of the same rod can give different results by using rod-drop or stable-period techniques. The significant source of uncertainties in comparing calculated and measured reactivates is probably related to the decay λ values of the first group relevant to the classical Keepin' 6 group representation. For instance, none of λ_1 $\lambda_2\lambda_3$ Keepin values satisfy the asymptotic die-away time constants associated with the three longest precursors of significant yield: Br87, I137 and Br88. It can be worthwhile to underline that we have also difficulty in modelling reactor transients that involve significant local changes of the neutron spectrum (the different fissionable isotopes weight itself can change during particular transient).

Moreover, the classical Keepin's 6 temporal group definition should be revised. A more suitable time dependence grouping , based on the half-lives of the ≈ 3 predominant long-lived precursors, ≈ 3 predominant short-lived precursors plus few other time constants to be optimized , should be sought for all major actinides.

1.3. Spectra

The agreement between the Lowell (the University of Massachusetts) measured spectra and the Brady and England delayed neutron spectra obtained at Los Alamos using summation technique is generally very good. Owing to this experience we can say that the nowadays knowledge of the main fissile isotopes (U235, U238 and Pu239) delayed neutron spectra can be considered satisfactory.

2. The new 8-group delayed neutron set preparation

Over 250 fission products have been identified as potential delayed neutron sources. The results of experiments showed that both decay constants and the relative abundances vary from isotope to isotope as well as a function of energy of the neutron inducing fission. There is not physical basis for the half-life defined in classical few group delayed neutron sets.

Delayed neutron parameters used in reactor dynamic calculations have traditionally been determined from a least-square fit (LSF) of an decay curve of delayed neutrons emitted from small sample of fissionable material irradiated by a strong neutron source. In this LSF both the abundances, α_i, and the decay constants, λ_i, are free parameters in the fit. Many studies have shown that at least 82% of delayed neutrons are produced approximately by dozen that are common to all fissioning isotopes. Therefore, it seems reasonable **to increase the number of delayed neutron groups and fix the decay constants to a subset that cover the known range of half-lives.** This method is called *constrained fit*. This project is provided by Spriggs and Campbell [3].

The basic idea of this project of constrained fit is to expand the experimentally measured 4-, 5-, or 6-group parameters into their equivalent 8-group values. This alternative delayed-neutron model comprises solution of the following tasks: (1) determine if there is a set of dominant precursors that are common to all fissionable isotopes, (2) expand the existing experimentally measured few-group models commonly used in the reactor industry into their 8-group equivalent using a consistent set of decay constants corresponding to these dominant precursors, (3) formulate new group spectra for equivalent 8-group model. The first representative decay constants from [3] are:

Group	Precursor	Decay constant
1	Br-87	0.01246
2	I-137	0.02829
3	Br-88	0.04252
4	Br-89	0.15933
5	Br-90	0.3628
6	Y-98	1.2648
7	Rb-95	1.8330
8	Rb-96	3.4142

3. Preliminary analysis of the new 8 group delayed neutron data set

The VVER-440 type reactors have specific control mechanism - control fuel assemblies with time of droping more then 10 seconds and negative reactivity more then 10%. Control fuel assemblies worth is measured by the reactimeter readings (calculated by standard Inverse Kinetics Method (IKM)) which uses kinetics parameters as a input. Analysis of this algorithm was given in paper [4]. Theoretical and practical problems of calculation kinetics parameters are broadly discussed in article [5]. Some sensitivity analysis of kinetics parameters calculation of VVER type reactors are provided in paper [6].

In [4] have been shown that in the rod drop experiments IKM analysis the first derivative of neutron density of time can be omitted and reactivity $\rho(t_n)$ can be calculated by formula

$$\rho(t_n) \doteq \left[1-\sum_{i=1}^{6}\frac{\beta_i}{\beta_{eff}}W_i(t_n)\right]\beta_{eff} \qquad (1)$$

where $\rho(t_n)$ in reactivity at time t_n

$\frac{\beta_i}{\beta_{eff}}$ are relative abundances of delayed neutrons of group i (e.g. i=1 to 6)

$W_i(t_n)$ is so called weight function derived during IKM application and (this weight function is dependent only on neutron density at time t_n and decay constant λ_i of delayed neutrons of group i)

It is clear that neutron density depends on real kinetics parameters. The weight function $W_i(t_n)$ is very good representation of given experimental process (defined by neutron density) when we have fixed λ_i . In such case this weight function can be used for sensitivity analysis and calculation of impacts of relative abundances of delayed neutron on IKM reactivity calculation.

The real NPP measurements (IKM analysis) are provided just after the rod drop (from 20 to 180 sec) and when the process is stable.

In the beginning, for the better understanding the quality of your new 8-group library, was analyzed simulated rod drop experiment (rod drop of all control fuel assemblies) on the basis of data γ) from Table 1 (inserted reactivity was - 0.147 within 10.5 sec with a real reactivity „insertion" rate modeled by 9th order polynomial in time scale). On the basis of point kinetics equation was calculated development of neutron density and for data from Table 1 were calculated weight functions W_i which are presented in Table 2:

α) Keepin et al. (1957)[1] data for U235
β) G.Spriggs [3] data for U235
γ) VVER-440 core [4,10]

From Table 2 is seen strong dependence of the weight function on time: in the beginning are important the first 3-4 delayed neutron groups but after 300 sec only first one. For this reason was possible to restrict weight function calculation on 6 group also for your 8-group representation β). Weight function for group 7 and 8 is for our time points close to 1.

The summation on the right side of equation (1) can be called „weighted effective beta" (WEB)

$$\text{WEB} = \sum_{i=1}^{6} \frac{\beta_i}{\beta_{eff}} W_i \qquad (2)$$

In Table 3 in the first column is given evidence that in IKM for relatively slow reactivity change, like VVER-440 rod drop is, are important only the first 4 delayed neutron groups and when we have precise predicted kinetics parameters (see case γ)) it does not matter at what time the IKM analysis will be provided. Very objective information of this phenomena is seen from Figure 1. If we are sure that measurement is correct (no reactor technological parameters feedbacks, no errors from background), the WEB is good measure of relative abundance qualities (for excellent relative abundance is WEB constant).

It is also seen from case β) that new 8-group representation has different weight functions and relative abundances in first 3 groups, which may cause great differences in prediction of reactivity change by IKM.

The group parameters for 238 sets of experimentaly-measured delayed neutron group constants for 20 fissionable isotopes was expanded into 8-group representation in reference [9]. The list of this sets is given in Table 4. Substituting these relative abundances into eq (2) with weight functions W_i from Table 2 we can get good information about contribution of such set into reactivity calculation. In Fig.2-6 are given values of the weighted effective beta (WEB) of some important isotopes and in Fig.7 summary of WEB values of all isotopes from Table 4. From Fig. 1 is seen that greater impact on reactivity calculation will have 8-group U235 set just after rod drop. After more than 300 sec. the difference is induced (see values of W_i in Table 2) mainly by the first β_1 which will become dominant. Results presented in Fig.2 and 3 for U235 are in good agreement with Fig.1. In Fig.2 are used for time 12 sec two types of weight functions: (β) calculated for 8-group decay neutron set and γ) calculated for 6-group decay neutron set of real VVER-440 core - see [4]). From this Fig.2 is seen that sensitivity of WEB to weight function is smaller then sensitivity to differences in relative abundances of 6 and 8 group delayed neutron sets. From Fig.4 is seen that the 8-group set of U238 at 320 sec decreases WEB values and from Fig.5 and 6 is evident that impact of 8-group structure in time scale is not for Pu isotopes so unambiguous as for U235.

The first analysis of impact of the new 8-group abundances on rod drop experiment interpretation was provided for Unit 1 and Cycle 14 NPP Dukovany. In reactivity algorithm were used following delayed neutron sets.

beta 6 gr. (MD b/)	6 group data produced by MOBY-DICK with relative abundances of BRADY and ENGLAND [2] and delayed neutron yields ENDF/B-V (see [2], Table I,II).
beta 8 gr. (Var.A)	8 group data produced from sets number 77, 93, 197, 202, 221, 223, 225 and 242 of Table 4. Delayed neutron yield the same as in beta 6 gr. (MD b/).
beta 6 gr. (Keepin)	6 group data produced by sets number 68, 81, 118, 194 provided by Keepin and other Pu sets same as in beta 8 gr. (Var.A).
beta 8 gr. (Keepin)	8-group data produced for the same sets as in beta 6 gr. (Keepin).

The resulted delayed neutron yields are depicted in histogram of Fig.8. It is seen that the first delayed neutron group is nearly same in all variants, the others values of 8-group sets are shifted to the higher groups. DNY was for all variants same, and β_{eff} had value 0.00634, that means differences in calculated reactivity in Fig.9 are given by the differences of relative abundance and decay constants. The extension of 6-group to 8-group abundances gives for our tests changes in calculation of reactivity during rod drop ±10 %.

CONCLUSIONS

It was found that in general qualities of basic delayed neutron characteristics (DNY, decay constants, relative abundances and spectra) are on good level. But the application in reactivity readings during rod drop experiments has specific features. The changing of relative abundances (from 6-group to 8-group) may cause 10 % deviations in calculation of control FA reactivity worth. Further analysis of the new 8-group delayed neutron data needs continuation and is desirable.

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Table 1 Three types decay const. and relative abundances

	α) U 235 Keepin et.al. (1957)[1]		β) U 235 G.Spriggs [7]		γ) VVER-440 reactor core [4]	
Delayed n. group	Decay con. λ_i	Rel.Abun. β_i/β_{eff}	Decay con. λ_i	Rel.Abun. β_i/β_{eff}	Decay con. λ_i	Rel.Abun. β_i/β_{eff}
1	0.0124	0.033	0.0124	0.033	0.013	0.037
2	0.0305	0.219	0.0283	0.154	0.032	0.182
3	0.1114	0.196	0.0425	0.091	0.122	0.211
4	0.3013	0.395	0.1593	0.197	0.310	0.382
5	1.1362	0.115	0.3628	0.331	0.9907	0.139
6	3.0134	0.042	1.2648	0.090	2.951	0.0361
7			1.8333	0.081		
8			3.4142	0.023		

Table 2 Weight functions W_i for rod drop experiment of VVER core

sec.after starting rod drop	Weight function W_i of delayed neutron group i					
	1	2	3	4	5	6
α)	**for λ_i of U 235 from Tab.1, Keepin (1957)**					
12 sec	73.323	59.527	27.00	5.246	1.083	1.024
20 sec	99.51	72.02	17.72	1.755	1.041	1.014
60 sec	200.89	71.34	1.94	1.083	1.022	1.01
320 sec	542.44	3.518	1.13	1.044	1.011	1.004
β)	**for λ_i of U 235 from Tab.1, G.Spriggs [3]**					
12 sec	47.40	40.58	34.31	11.92	2.74	1.06
20 sec	64.60	48.87	36.18	5.84	1.28	1.04
60 sec	143.60	58.5	22.64	1.25	1.08	1.02
320 sec	530.39	5.48	1.43	1.09	1.04	1.01
γ)	**for λ_i of VVER 440 core [5]**					
12 sec	75.44	61.99	25.02	4.79	1.10	1.02
20 sec	103.60	73.77	15.60	1.70	1.05	1.01
60 sec	208.23	70.20	1.64	1.09	1.02	1.01
320 sec	544.71	3.06	1.12	1.04	1.01	1.00

Table 3 The Weighted Effective Beta (WEB) dependence on time

sec.after starting rod drop	$\sum_{i=1}^{4}\frac{\beta_i}{\beta_{eff}}W_i$	$\sum_{i=1}^{6}\frac{\beta_i}{\beta_{eff}}W_i$
α) Rel.abund. β_i/β_{eff} of U235 from 6-groups, Keepin et al. (1957) from Tab.1, W_i from Tab.2 α)		
12 sec	22.755	22.923
20 sec	23.222	23.385
60 sec	23.063	23.223
320 sec	19.305	19.463
β) Rel.abund. β_i/β_{eff} of U235 from 8-groups set from Tab.1, W_i from Tab.2 β)		
12 sec	13.28	14.41
20 sec	14.10	14.74
60 sec	16.05	16.62
320 sec	18.69	19.25
γ) Rel.abund. β_i/β_{eff} from VVER 440 reactor from Tab.1, W_i from Tab.2 γ)		
12 sec	21.13	21.31
20 sec	21.13	21.31
60 sec	21.14	21.31
320 sec	21.14	21.31

Table 4 A list of the experimentally - measured delayed neutron group constants processed by Spriggs and Campbell [9] into an 8-group delayed neutron sets based on a consistent set of half-lives

1: Th-229_ther: Thermal Spectrum, 5-groups, Gudkov et al. (1989)
2: Th-232_fast: Fast Neutrons, 4-groups, Brolley et al. (1943)
3: Th-232_fast: Fast Neutrons, 5-groups, Crevelling et al. (1949)
4: Th-232_fast: Fast Neutrons, 5-groups, Rose and Smith (1957)
5: Th-232_fast: Fast Spectrum, 6-groups, Keepin et al. (1957)
6: Th-232_fast: Fast Spectrum, 5-groups, Waldo et al. (1981)
7: Th-232_fast: 1.6 Mev, 5-groups, Maksyutenko (1965)
8: Th-232_fast: 1.9 Mev, 5-groups, Maksyutenko (1965)
9: Th-232_fast: 2.2 Mev, 5-groups, Maksyutenko (1965)
10: Th-232_fast: 2.4 Mev, 5-groups, Maksyutenko et al. (1958)
11: Th-232_fast: 2.6 Mev, 5-groups, Maksyutenko (1965)
12: Th-232_inte: 3.3 Mev, 5-groups, Maksyutenko et al. (1958)
13: Th-232_inte: 5 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
14: Th-232_inte: 6 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
15: Th-232_inte: 6.2 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
16: Th-232_inte: 6.4 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
17: Th-232_inte: 6.6 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
18: Th-232_inte: 6.8 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
19: Th-232_inte: 7.25 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
20: Th-232_inte: 7.5 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
21: Th-232_inte: 7.75 Mev, 5-groups, Maksyutenko, Pyshin, Tarasko (1967)
22: Th-232_high: 14 Mev max, 5-groups, Sun et al. (1950)
23: Th-232_high: 14 Mev max, 4-groups, Hermann et al. (1965)
24: Th-232_high: 14 Mev max, 6-groups, Hermann (1967)
25: Th-232_high: 14 Mev max, 5-groups, Notea (1969)
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33: Pa-231_high: 14.8 Mev max, 4-groups, Brown et al. (1971)
34: U-232_fast: Fast Spectrum, 5-groups, Waldo et al. (1981)
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51: U-233_high: 14.7 MeV, 6-groups, East et al. (1970)
52: U-233_high: 15 MeV, 5-groups, Maksyutenko (1963)
53: U-233_high: 18 MeV, 11-groups, Maksyutenko (1971)
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118: U-238_fast: Fission Spectrum, 6-groups, Keepin et al. (1957)
119: U-238_fast: 1.5 MeV, 5-groups, Maksyutenko et al. (1965)
120: U-238_fast: 1.75 MeV max, 5-groups, Maksyutenko (1965)
121: U-238_fast: 2.3 MeV, 6-groups, Maksyutenko et al. (1965)
122: U-238_fast: 2.4 MeV, 5-groups, Maksyutenko et al. (1958)
123: U-238_fast: 3.3 MeV, 5-groups, Maksyutenko et al. (1958)
124: U-238_fast: 3.8 MeV, 6-groups, Maksyutenko et al. (1965)
125: U-238_fast: 3.9 Mev, 4-groups, Maksyutenko (1974)
126: U-238_inte: 4.2 Mev, 4-groups, Maksyutenko (1974)
127: U-238_inte: 4.5 Mev, 4-groups, Maksyutenko (1974)
128: U-238_inte: 4.8 Mev, 4-groups, Maksyutenko (1974)
129: U-238_inte: 5 Mev, 5-groups, Maksyutenko (1967)
130: U-238_inte: 5.1 Mev, 4-groups, Maksyutenko (1974)
131: U-238_inte: 5.75 MeV, 5-groups, Maksyutenko et al. (1965)
132: U-238_inte: 6 Mev, 5-groups, Maksyutenko (1967)
133: U-238_inte: 6.4 Mev, 5-groups, Maksyutenko (1967)
134: U-238_inte: 6.6 MeV, 5-groups, Maksyutenko et al. (1965)
135: U-238_inte: 6.8 Mev, 5-groups, Maksyutenko (1967)
136: U-238_inte: 6.9 Mev, 5-groups, Maksyutenko (1967)
137: U-238_inte: 7.1 Mev, 5-groups, Maksyutenko (1967)
138: U-238_inte: 7.25 Mev, 5-groups, Maksyutenko (1967)
139: U-238_inte: 7.5 Mev, 5-groups, Maksyutenko (1967)
140: U-238_inte: 7.76 Mev, 5-groups, Maksyutenko (1967)
141: U-238_high: 14 Mev max, 5-groups, Sun et al. (1950)
142: U-238_high: 14 Mev max, 4-groups, Hermann et al. (1965)
143: U-238_high: 14 Mev max, 6-groups, Hermann (1967)
144: U-238_high: 14 Mev, 5-groups, Notea (1969)
145: U-238_high: 14.7 MeV, 5-groups, Bucko (1966)
146: U-238_high: 14.7 MeV, 6-groups, East et al. (1970)
147: U-238_high: 14.8 Mev max, 4-groups, Brown et al. (1971)
148: U-238_high: 14.8 Mev max, 6-groups, Benedict et al. (1972)
149: U-238_high: 14.9 MeV, 6-groups, Auguston et al. (1969)
150: U-238_high: 15 MeV, 5-groups, Maksyutenko et al. (1958)
151: U-238_high: 15 MeV, 6-groups, Maksyutenko et al. (1965)
152: U-238_high: 18.0 MeV, 5-groups, Maksyutenko et al. (1967)
153: U-238_high: 18.2 MeV, 5-groups, Maksyutenko et al. (1968)
154: U-238_high: 18.5 MeV, 5-groups, Maksyutenko et al. (1968)
155: U-238_high: 18.8 MeV, 5-groups, Maksyutenko et al. (1968)
156: U-238_high: 19.0 MeV, 5-groups, Maksyutenko et al. (1967)
157: U-238_high: 19.3 MeV, 5-groups, Maksyutenko et al. (1968)
158: U-238_high: 19.5 MeV, 5-groups, Maksyutenko et al. (1967)
159: U-238_high: 19.7 MeV, 5-groups, Maksyutenko et al. (1968)
160: U-238_high: 20.0 MeV, 5-groups, Maksyutenko et al. (1967)
161: U-238_high: 20.5 MeV, 5-groups, Maksyutenko et al. (1968)
162: U-238_high: 21.0 MeV, 5-groups, Maksyutenko et al. (1968)
163: U-238_high: 29 Mev max, 2-groups, Sun et al. (1950)
164: Np-237_fast: Fast Spectrum, 6-groups, Waldo et al. (1981)
165: Np-237_fast: Fast Spectrum, 5-groups, Benedetti et al. (1982)
166: Np-237_fast: ~Fission Spectrum, 6-groups, Gudkov et al. (1989)
167: Np-237_fast: TRIGA Reactor Spectrum, 5-groups, Saleh et al. (1997)
168: Np-237_fast: 0.4 MeV, 4-groups, Maksyutenko et al. (1974)
169: Np-237_fast: 0.5 MeV, 4-groups, Maksyutenko et al. (1974)
170: Np-237_fast: 0.586 MeV, 6-groups, Piksaikin et al. (1997)
171: Np-237_fast: 0.586 MeV, 8-groups, Piksaikin et al. (1997)

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172: Np-237_fast: 0.6 MeV, 4-groups, Maksyutenko et al. (1974)
173: Np-237_fast: 0.7 MeV, 4-groups, Maksyutenko et al. (1974)
174: Np-237_fast: 0.8 MeV, 4-groups, Maksyutenko et al. (1974)
175: Np-237_fast: 0.9 MeV, 4-groups, Maksyutenko et al. (1974)
176: Np-237_fast: 1.0 MeV, 4-groups, Maksyutenko et al. (1974)
177: Np-237_fast: 1.008 MeV, 6-groups, Piksaikin et al. (1997)
178: Np-237_fast: 1.008 MeV, 8-groups, Piksaikin et al. (1997)
179: Np-237_fast: 1.1 MeV, 4-groups, Maksyutenko et al. (1974)
180: Np-237_fast: 1.2 MeV, 4-groups, Maksyutenko et al. (1974)
181: Np-237_fast: 1.2 MeV, 6-groups, Piksaikin et al. (1997)
182: Np-237_fast: 1.2 MeV, 8-groups, Piksaikin et al. (1997)
183: Np-237_inte: 3.23 MeV, 6-groups, Piksaikin et al. (1997)
184: Np-237_inte: 3.745 MeV, 6-groups, Piksaikin et al. (1997)
185: Np-237_inte: 3.745 MeV, 8-groups, Piksaikin et al. (1997)
186: Np-237_inte: 4.196 MeV, 6-groups, Piksaikin et al. (1997)
187: Np-237_inte: 4.196 MeV, 8-groups, Piksaikin et al. (1997)
188: Np-237_inte: 4.719 MeV, 6-groups, Piksaikin et al. (1997)
189: Np-237_inte: 4.719 MeV, 8-groups, Piksaikin et al. (1997)
190: Pu-238_ther: Thermal Spectrum, 6-groups, Waldo et al. (1981)
191: Pu-238_fast: Fast Spectrum, 5-groups, Benedetti et al. (1982)
192: Pu-239_ther: Thermal Spectrum, 4-groups, Redman & Saxon (1944, 1947)
193: Pu-239_ther: Thermal Spectrum, 4-groups, Feld & de Hoffman (1945)
194: Pu-239_ther: Thermal Spectrum, 6-groups, Keepin et al. (1957)
195: Pu-239_ther: Thermal Spectrum, 5-groups, Huizinga (1968)
196: Pu-239_ther: Thermal Spectrum, 5-groups, Onega et al. (1969)
197: Pu-239_ther: Thermal Spectrum, 6-groups, Waldo et al. (1981)
198: Pu-239_fast: Fast Spectrum, 5-groups, Perry et al (1946)
199: Pu-239_fast: Fast Spectrum, 6-groups, Keepin et al. (1956)
200: Pu-239_fast: Fast Neutrons, 5-groups, Rose and Smith (1957)
201: Pu-239_fast: Fast Spectrum, 6-groups, Besant et al. (1977)
202: Pu-239_fast: Fission Spectrum, 6-groups, Keepin et al. (1957)
203: Pu-239_inte: 3.8 MeV, 5-groups, Maksyutenko (1963a)
204: Pu-239_inte: 5.5 Mev, 5-groups, Maksyutenko (1967)
205: Pu-239_inte: 6.5 Mev, 5-groups, Maksyutenko (1967)
206: Pu-239_inte: 7.0 Mev, 5-groups, Maksyutenko (1967)
207: Pu-239_inte: 7.5 Mev, 5-groups, Maksyutenko (1967)
208: Pu-239_inte: 7.8 Mev, 5-groups, Maksyutenko (1967)
209: Pu-239_high: 15 MeV, 6-groups, Maksyutenko (1963a)
210: Pu-239_high: 18 MeV, 11-groups, Maksyutenko (1971)
211: Pu-239_high: 18.2 MeV, 11-groups, Maksyutenko (1971)
212: Pu-239_high: 18.5 MeV, 11-groups, Maksyutenko (1971)
213: Pu-239_high: 18.8 MeV, 11-groups, Maksyutenko (1971)
214: Pu-239_high: 19.0 MeV, 11-groups, Maksyutenko (1971)
215: Pu-239_high: 19.5 MeV, 11-groups, Maksyutenko (1971)
216: Pu-239_high: 20.0 MeV, 11-groups, Maksyutenko (1971)
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217: Pu-239_high: 20.5 MeV, 11-groups, Maksyutenko (1971)
218: Pu-239_high: 21.0 MeV, 11-groups, Maksyutenko (1971)
219: Pu-240_fast: Fast Spectrum, 6-groups, Keepin et al. (1957)
220: Pu-240_fast: Fast Spectrum, 5-groups, Benedetti et al. (1982)
221: Pu-240_fast: ~Fission Spectrum, 6-groups, Gudkov et al. (1989)
222: Pu-241_ther: Thermal Spectrum, 5-groups, Cox (1961)
223: Pu-241_ther: Thermal Spectrum, 6-groups, Waldo et al. (1981)
224: Pu-241_fast: Fast Spectrum, 5-groups, Benedetti et al. (1982)
225: Pu-241_fast: ~Fission Spectrum, 6-groups, Gudkov et al. (1989)
226: Pu-242_fast: Fast Spectrum, 6-groups, Waldo et al. (1981)
227: Pu-242_high: 14.7 MeV, 6-groups, Auguston et al. (1969)
228: Pu-242_high: 14.7 MeV, 6-groups, East et al. (1970)
229: Am-241_ther: Thermal Spectrum, 5-groups, Waldo et al. (1981)
230: Am-241_fast: Fast Spectrum, 5-groups, Benedetti et al. (1982)
231: Am-241_fast: ~Fission Spectrum, 6-groups, Gudkov et al. (1989)
232: Am-241_fast: TRIGA Reactor Spectrum, 5-groups, Saleh et al. (1995)
233: Am-42m_ther: Thermal Spectrum, 6-groups, Waldo et al. (1981)
234: Am-243_fast: TRIGA Reactor Spectrum, 5-groups, Saleh et al. (1995)
235: Cm-245_ther: Thermal Spectrum, 6-groups, Waldo et al. (1981)
236: Cf-249_ther: Thermal Spectrum, 4-groups, Waldo et al. (1981)
237: Cf-252_s:    Spontaneous Fission, 3-groups, Smith et al. (1958)
238: Cf-252_s:    Spontaneous Fission, 4-groups, Chulick et al. (1969)
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Fig.1 Weighted Effective Beta (WEB) dependence on time (according the Table 3)

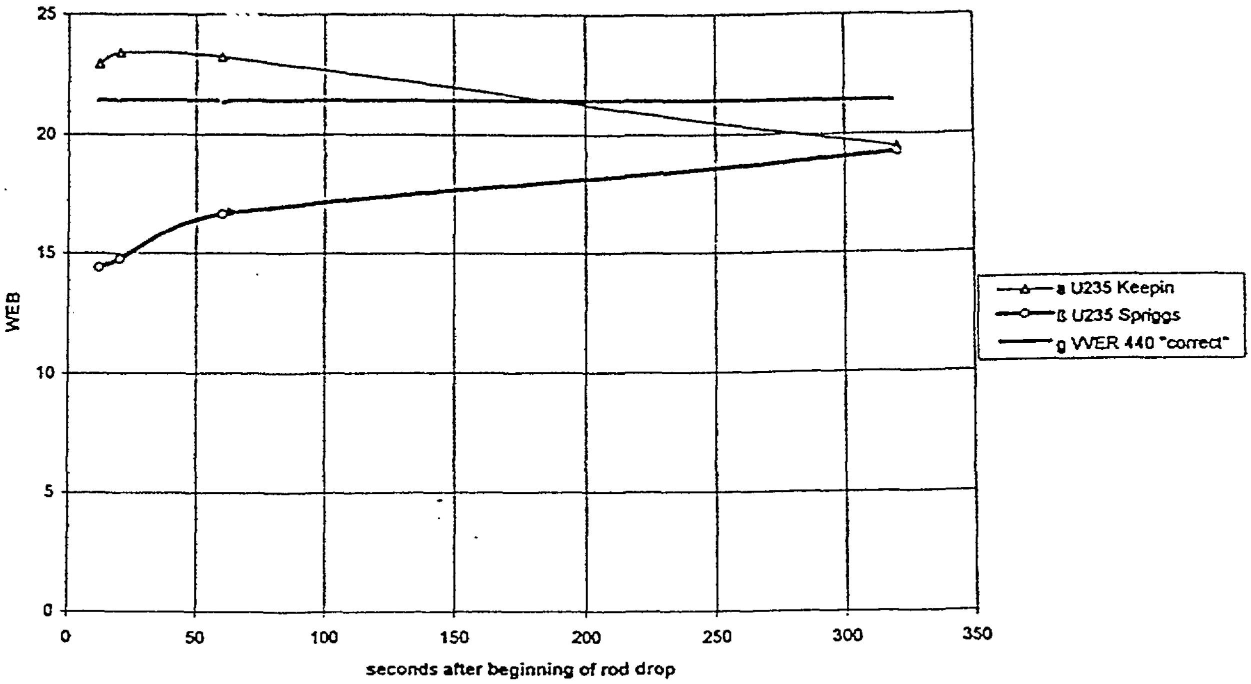

Fig. 2 WEB calculated for thermal spectrum U235 8-group relative abundances and two Wieght functions (Wi beta and gama from Table 2)

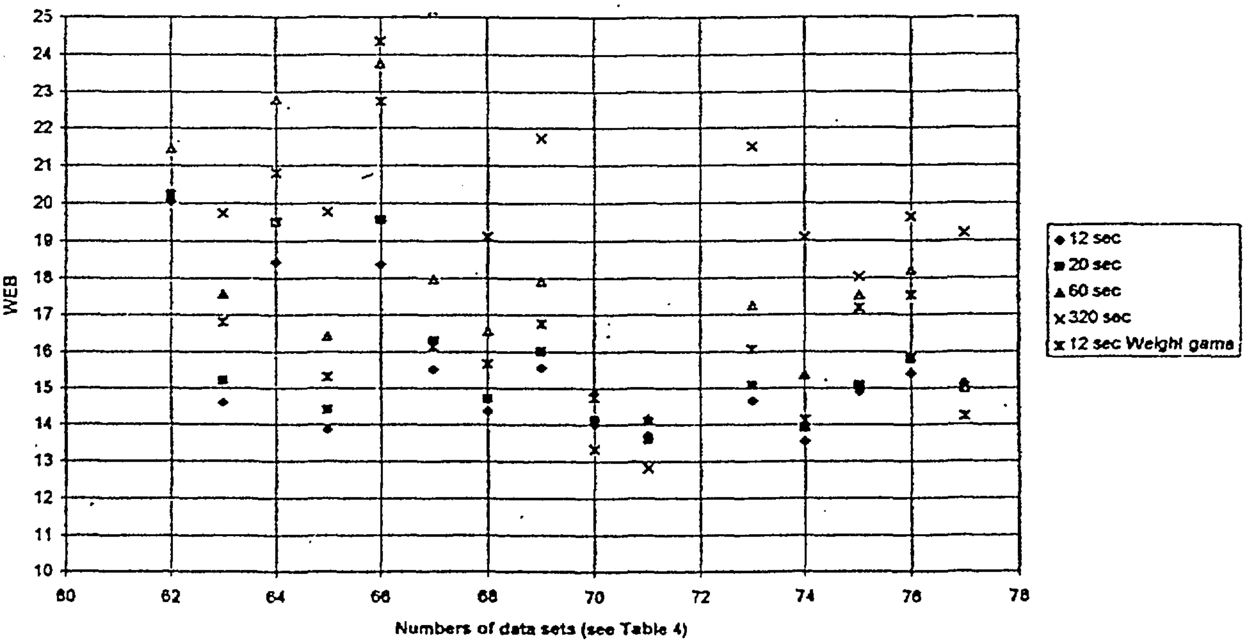

Fig. 3 WEB calculated for fast spectrum U235 8-group relative abundances (Weight function Wi beta from Table 2)

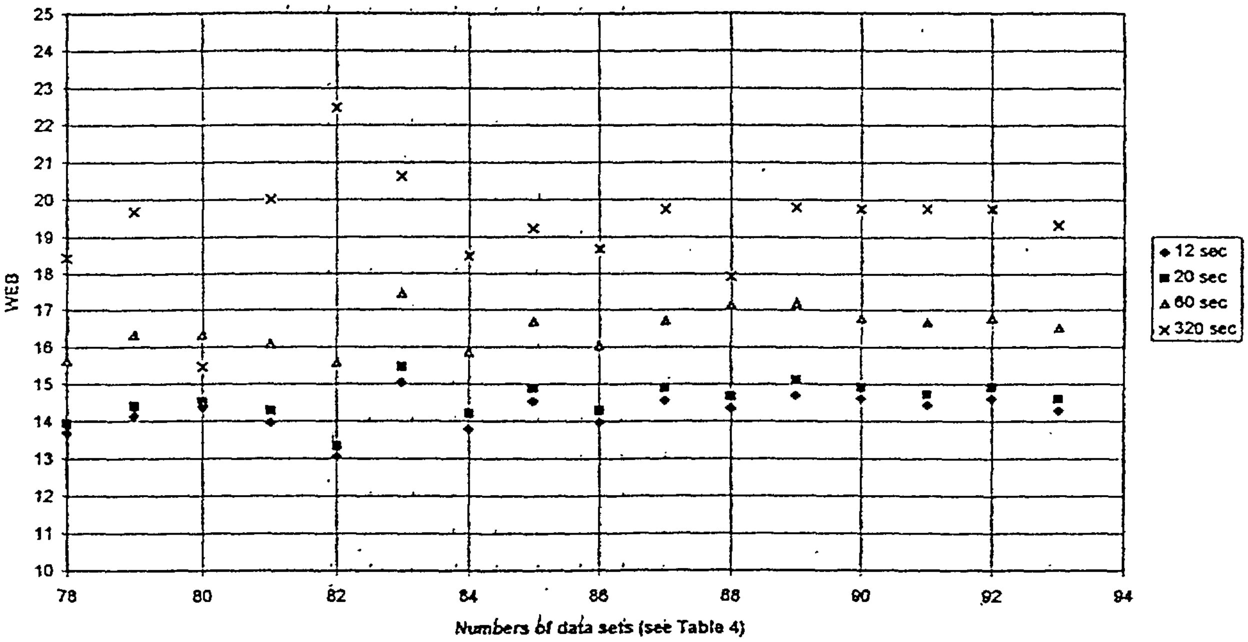

Fig. 4 WEB calculated for fast spectrum U238 8-group relative abundances (Wieght function Wi beta from Table 2)

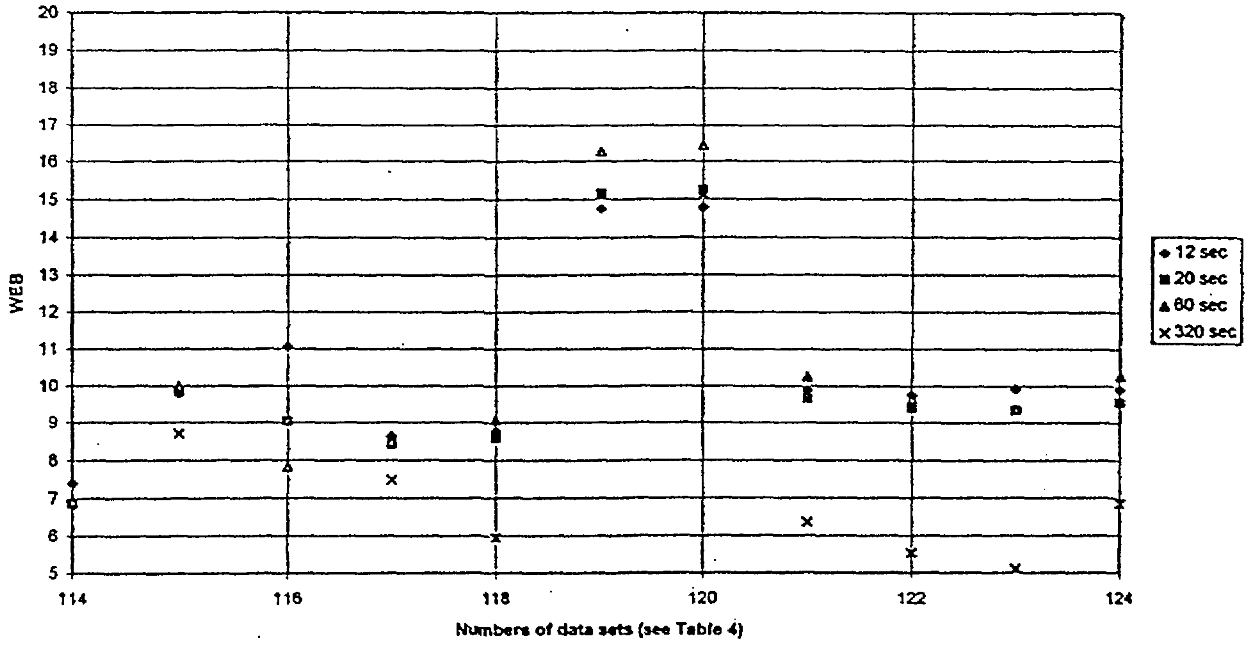

Fig. 5 WEB calculated for thermal (192-197) and fast (198-202) spectrum Pu239 8-group relative abundances (Wieght function Wi beta from Table 2)

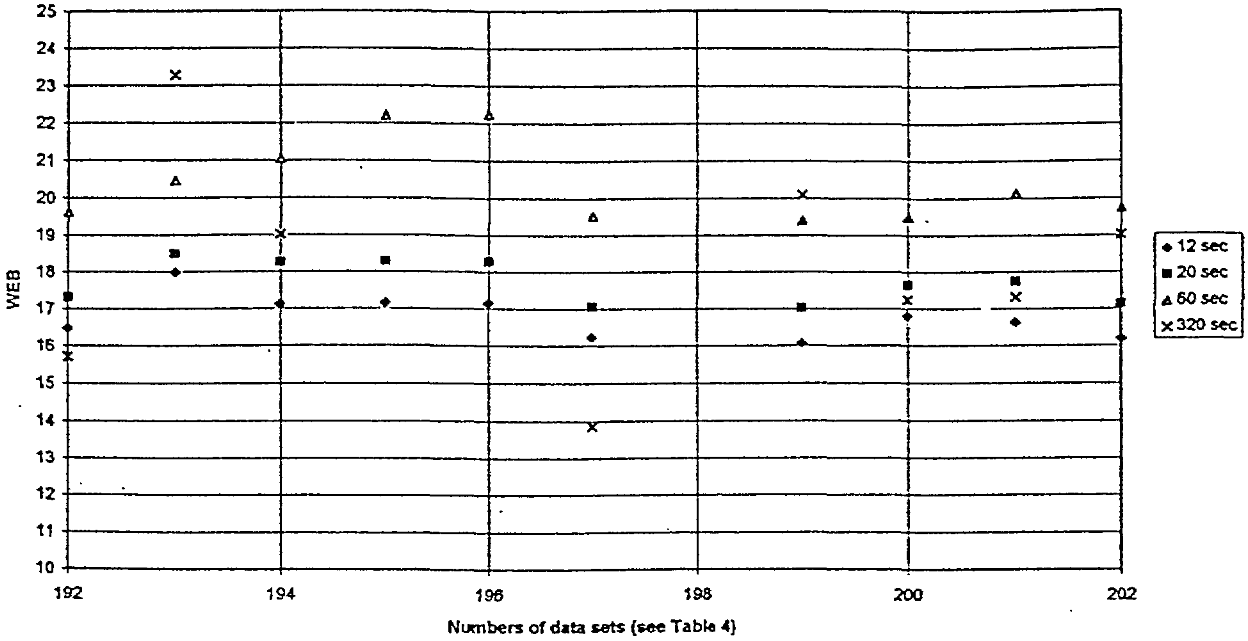

Fig. 6 WEB calculated for fast Pu240 (219-221) thermal PU241 (222, 223) fast Pu241 (224, 225) and fast PU242 (226) spectrum 8-group relative abundances (Weight function Wi beta from Table 2)

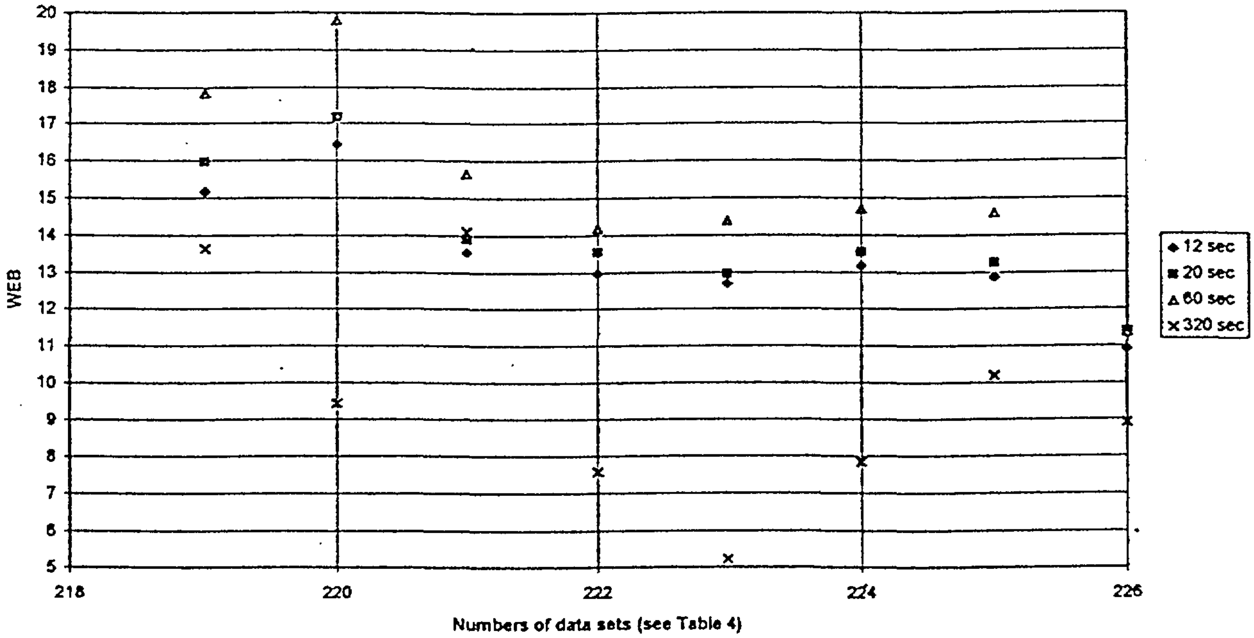

Fig. 7 WEB calculated for 8-group relative abundances and two Weight functions (see Table 2 (beta and gama))

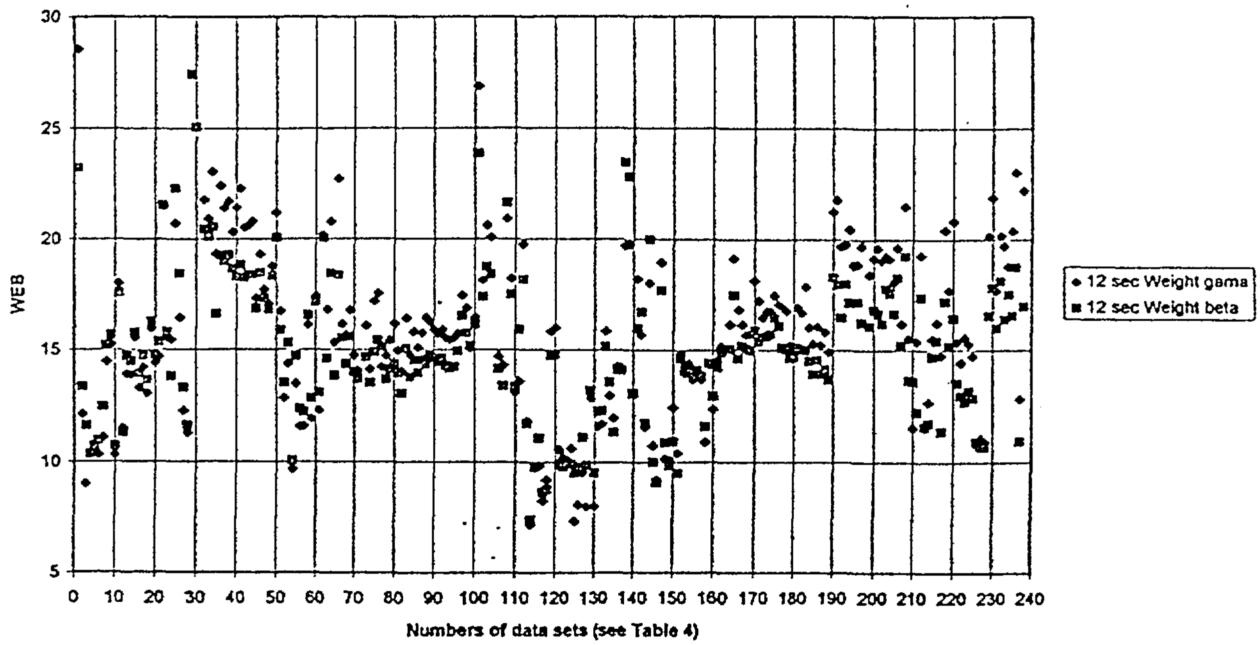

Fig. 8 Delayed neutron group yields (DNY) for 6 and 8 group representatin of core

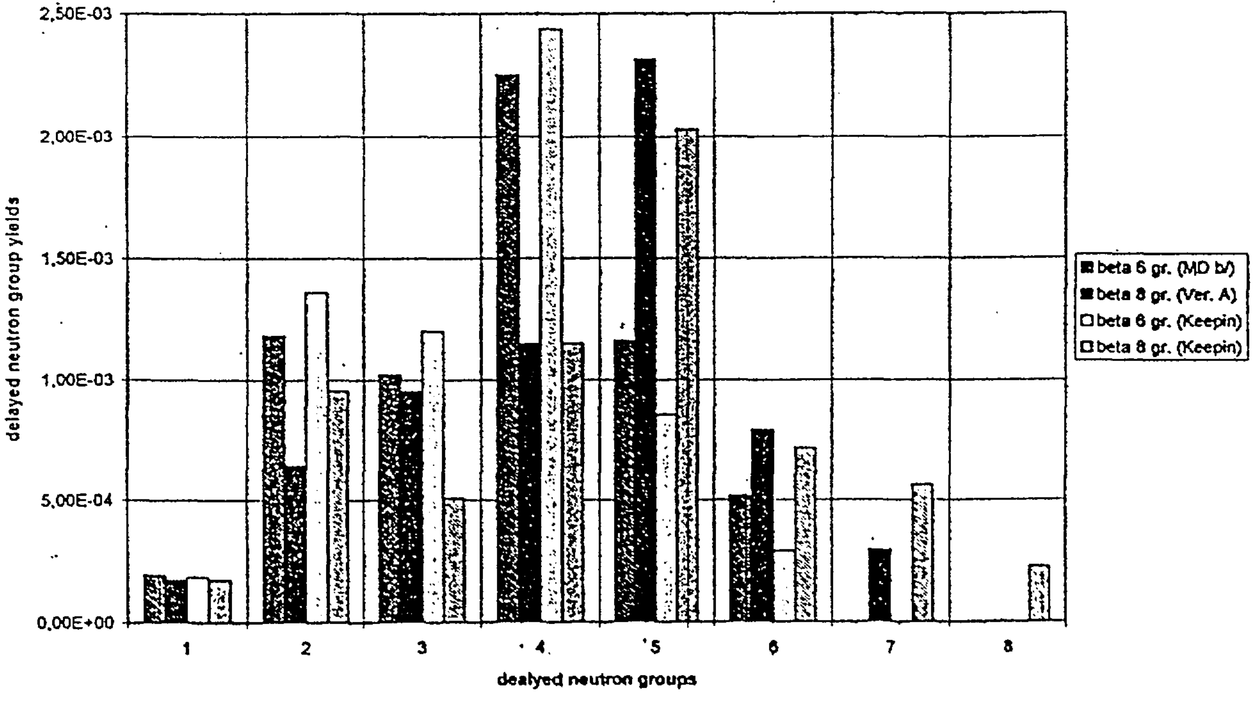

Fig. 9 Reactivity calculation from rod drop (HOI) experiment for different input daelyed neutron data (NPP Dukovany, Unit 1, Cycle 14)