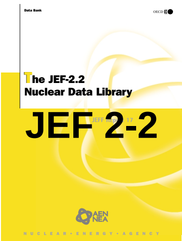

INTERCOMPARISON OF CALCULATIONS MADE FOR GODIVA AND JEZEBEL

An intercomparison study organised by the JEF Project, with contributions by Britain, France, The Netherlands and Switzerland.

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ABSTRACT

Several benchmark intercomparison studies have been carried out to investigate the accuracy of calculation methods, by adopting the same nuclear data library, JEF-2.2, in all codes. The objective has been to estimate the uncertainties arising from approximations in the methods of processing the data, and in the way data are represented in the codes, and to provide guidance on possible improvements by investigating the sources of differences. In the present report the comparisons made for the small Los Alamos fast spectrum critical spheres, GODIVA and JEZEBEL are summarised.

1. INTRODUCTION

The specifications adopted (see Appendix 1) for these intercomparison calculations are those given in the CSEWG Benchmark Book, BNL 19302, ENDF 202. JEZEBEL is fast reactor benchmark number F1 (Revised 11-81) and GODIVA is benchmark F5 (Revised 11-81). JEZEBEL is a bare sphere of plutonium metal and GODIVA a bare sphere of highly enriched uranium. In addition to the values of k_{eff}, a three-group neutron balance was requested, with intermediate energy boundaries at 2.2313 MeV and 0.49787 MeV (these being boundaries of the half-lethargy scale based on 10 MeV).

The calculations have been made using different code systems with nuclear data derived from the JEF-2.2 library. Both deterministic and Monte Carlo methods have been used. The deterministic codes used are MICROX-2/ONEDANT (PSI), which uses a modified P2 library in 93 energy groups, SCALE-4.2/XSDRNPM (IRI TU Delft) (using the ‘XMAS’ 172 energy group scheme in P3 approximation), SHIVA/ECCO/ERANOS and SHIVA/ERANOS (Cadarache) (which use the SHIVA P5 library in the ‘XMAS’ 172 group scheme). The continuous-energy (or hyperfine group) Monte Carlo codes used are MCNP-4A (Petten, Cadarache and Delft), MONK (Winfrith) and TRIPOLI-4 (Saclay and Cadarache). In addition, the multigroup Monte Carlo code KENO (Delft) (in the SCALE-4 system) has been used at Delft. A comparison has also been made at Delft between KENO and MCNP(groupwise mode) using the SCALE-4.2 group cross-section data, in addition to MCNP-4A (continuous energy). The MCNP(groupwise) and KENO results are essentially in agreement with the Sn results.

The first aim of the intercomparison study has been to get information about the ranges of the values calculated using different methods. This is of relevance to the evaluation of the performance of the JEF nuclear data library and to the adjustment of the data. The second aim has been to try to identify the sources of the differences between the different methods.

2. APPROXIMATIONS IN THE METHODS

There are some significant differences between the results obtained using different methods. Reaction rates have been edited in three energy groups so as to try to identify the sources of the differences.

There are approximations in the representation of some items of nuclear data in the continuous energy Monte Carlo codes. An approximation in the standard version of MCNP is the neglect of resonance shielding in unresolved resonance regions but the calculations made at Petten include a treatment of this. There are some approximations made in the hyperfine group representation of cross-sections in the MONK code. The representation is on a 1/128 lethargy group structure above 10 keV, together with a 2 element subgroup to treat within fine group structure in an approximate way. (Below this energy the group structure is much finer.) Both of these codes also use only the prompt fission spectrum. In TRIPOLI the total fission spectrum is used.

Some methods are still undergoing refinement and approximations in the nuclear data libraries are being identified and corrected. A particular problem identified has been the Pu-239 fission spectrum used in the different codes. The total fission spectrum (MT=18) in the JEF-2.2 file is the one which has been recommended for use but the standard procedure in NJOY is to combine the partial fission cross-section spectra (MT=19 to 38) when these are available in the file. These are not consistent with the total spectrum in the Pu-239 file. There are also differences in the Pu-239 unresolved resonance region data (1 to 30 keV) in a version of the file used in France, where corrected data have been used.

Calculations with different numbers of energy groups and different weighting spectra have shown the effect of number of groups and weighting spectrum to be very small in the group schemes used here, apart from the effect on the condensation of the fission spectrum matrix to a vector. The effect of approximations in the treatment of resonance shielding is also found to be negligible. Simplifications in the treatment of the isotope and incident neutron energy dependence of fission spectra could be a source of some of the differences between the results obtained using the multigroup methods. These use a single fission spectrum vector, rather than the incident neutron energy dependent fission spectrum matrix, and the method used to condense the matrix to obtain a fission spectrum vector can affect the results. Calculations have been made at P.S.I. (MICROX-2) and at Delft (SCALE-4.2) by condensing the fission matrix using a previously calculated reactor spectrum, as well as other spectrum approximations.

A problem which was found and corrected was the neglect of the anisotropic component of continuum inelastic scattering and (n,xn) neutrons in one of the calculation schemes. This had a significant effect on the GODIVA calculations, producing a value about

200 pcm higher. The continuum inelastic scattering and (n,xn) for Pu-239 in JEF-2.2 are isotropic and so there was no corresponding effect for JEZEBEL. However, one should consider whether the continuum inelastic scattering of Pu-239 should be similarly anisotropic because this could have a comparable effect in the case of JEZEBEL.

3. RESULTS OF THE CALCULATIONS

The calculated values of the effective multiplication, k_{eff} , are presented in Table 1 and neutron balances in Tables 2 to 5. Spectral indices are presented in Table 6. In the case of JEZEBEL results are given for both the MT=19 etc. fission spectrum and the MT=18 fission spectrum. The results have been grouped in the following way:

(a) Continuous energy and fine group Monte Carlo. TRIPOLI, MCNP and MONK.
The three group neutron balances calculated using MCNP and MONK have been modified to include an approximate correction for the delayed neutron component of the fission spectrum. Refinements have been made in the representation and interpolation in the MONK fission spectra and continuum inelastic scattering secondary energy distributions (the standard representation being 32 equiprobable bin data) and this has resulted in a significantly improved agreement with MCNP.

(b) Multigroup methods using fission spectrum vectors obtained using an appropriate reactor weighting spectrum. MICROX-2/ONEDANT and SCALE-4.2/(XSDRNPM and KENO). The data in these calculations were derived using NJOY-97.62.

(c) Multigroup methods using fission spectrum vectors obtained using other weighting spectra. These include the SHIVA/ECCO/ERANOS and SHIVA/ERANOS results.

It is the differences between the results of the codes in groups (a) and (b) which are of special interest as a test of the accuracy of the processing and representation of the data in continuous-energy or multigroup form.

Treatment of the fission spectrum and inelastic secondary energy and angular distributions.

Concerning the results in group (c), calculations made at Cadarache show that the value of k_{eff} increases by about 100 pcm when the incident neutron energy for which the fission spectrum is calculated increases from thermal to 1 MeV, the increase being approximately linear in incident neutron energy (the values being 94 pcm for GODIVA and 91 pcm for JEZEBEL, using the partial MT=19 etc. Pu-239 fission spectrum). In some methods only the fission spectrum of the dominant fissile isotope is used (an acceptable approximation in these cases). In one of the first calculations which was performed the weighting spectrum used for deriving the single fission spectrum from the group dependent fission spectrum matrix was not well chosen, being the VITAMIN-J weighting spectrum, with its fusion peak. This had a significant effect on the derived fission spectra, reaction rate ratios and k_{eff} values (about 200 pcm).

Investigations have been made of aspects of the data representation in the MONK code, in particular the representation of the fission spectrum and the secondary energy and angular distributions of inelastic scattering to the continuum, (n,2n) etc. There are two approximations made in the case of U-235: the coupled energy-angular distribution is replaced by separate energy and angular distributions calculated using the SIXPAK code. Secondly, in the standard treatment secondary energy and angular distributions are represented by 32 equiprobable bin data, the primary energy grid on which these are stored being the energies at which the data are stored in the JEF-2.2 files plus a ¼ lethargy grid.

The effect of the separation of the continuum inelastic scattering secondary energy and angular distributions in the case of GODIVA has been investigated by Pelloni at P.S.I. and the effect on k_{eff} is found to be very small, about 13 pcm.

An investigation of the effect of using 32 bins to represent the fission spectrum and continuum inelastic scattering secondary energy and angular distributions has been made at Winfrith, both by using a 950 equiprobable bin representation and by using an improved method of interpolation in both the primary energy representation and the secondary 32 bin data and the 950 bin data. The effects on the k_{eff} value of GODIVA and on the three group spectra are found to be significant.

The GODIVA results are taken from calculations using the special MONK DICE library with 950 bins for the secondary energy/angle distributions for U235. It was found that there was a difference between results obtained with the 950 bin data and results obtained using 32 bins with the improved interpolation. The JEZEBEL results are taken from calculations using Pu239 data with the fine incident energy grid. Interpolation was used on top of this. The calculations used 32 bins, with the SQRT(E) interpolation method in the lowest energy bin for the fission spectrum.

In the standard MONK treatment of secondary energy distributions there is a test of the consistency of the energy of a scattered neutron with the Q value. In the case of the U-235 continuum inelastic scattering distributions there is an inconsistency which is significant near the threshold. P. G. Young has explained this as a consequence of the energy bins used in the nuclear reaction theory code, GNASH. He plans to correct this inconsistency in the next version of the U-235 evaluation. MONK calculations have been made both with and without this Q value test. In the case of GODIVA the difference is significant and the two sets of results are presented in the tables, MONKQ denoting the results including the Q test. The TRIPOLI and MCNP results for GODIVA are somewhat more consistent with the results obtained without the Q test.

In the representation of the anisotropy for elastic scattering TRIPOLI-4 uses as many equiprobable cosine bins as necessary to achieve an internal criterion of precision in the approximation of the Legendre polynomial expansion of angular distributions. Moreover there is linear interpolation of density within each bin. At the energies of interest in the present benchmarks there are only 32 cosine bins but there is still the interpolation in each bin which is perhaps a source of difference with MCNP in the leakage treatment.

GODIVA

Range of k_{eff} values.

There is a difference of 114 (±14) pcm between the TRIPOLI continuous energy and the KENO multigroup k_{eff} values, these being the lowest and highest values. The Petten and Cadarache MCNP results are consistent with the TRIPOLI result whereas the MONK result including the Q test is closer to the MICROX and SCALE results. The difference between the TRIPOLI and MCNP Monte Carlo results and the multigroup methods appears to be significant.

Neutron balances.

The neutron balances have been normalised to the fission neutron production, the sum of the absorption and leakage then being equal to 1/ k_{eff}. The three group neutron balances are within about 100 pcm of each other. The ratios of leakage to absorption (see Table 3.3) are also about the same for all the codes.

The accuracy of the TRIPOLI, MONK and MCNP calculations is high (~10 to 15 pcm) but the correction applied to the MCNP and MONK results for the effect of the delayed neutron spectrum is only approximate. A higher accuracy is needed to give a clear indication of the sources of the differences. The ν value in TRIPOLI appears to be about 0.1% low and the leakage fractions in MONKQ, MICROX-2 and SCALE-4.2 appear to be about 0.1% lower than in TRIPOLI, MCNP and MONK (no Qcheck).

Spectral indices.

The spectral index calculations (Table 6) made using the deterministic codes agree to within 0.02% for the fission ratios, Pu-239/U-235 and U-233/U-235. For the threshold fission rate ratios, U-238/U-235 and Np-237/U-235, the differences are larger, 0.16% and 0.14%, and for the Au-197 capture there is a similar difference. The MCNP and TRIPOLI results are consistent with the P.S.I. MICROX and Delft SCALE-4 Sn results, taking into account the statistical uncertainties. The MONK results for the threshold fission reaction U-238/U-235 is about 1% higher than the values given by the other methods.

JEZEBEL

Effect of the choice of fission spectrum, MT=18 or MT=19,etc.

The calculations for JEZEBEL have been made using the two different fission spectra for Pu-239 as well as different methods for treating the incident neutron energy dependence, and different options in NJOY. The standard NJOY processing uses the spectra for the partial fission cross-sections (first chance, second chance etc. MT=19, etc.) to produce the fission spectrum matrix whereas the recommended fission spectrum is the one tabulated for the total fission cross-section, MT=18. At P.S.I. calculations have been made using both spectra. Using the spectrum associated with the total fission cross-section gives a value of k_{eff} which is 183 pcm higher than the value calculated using the sum of the partial fission cross-section spectra. The U-238 fission rate at the core centre (relative to the U-235 fission rate) is calculated to be 3.3% higher in the P.S.I. calculation using the total fission spectrum, in much better agreement with the measured value. There are similar changes for the Np-237 fission rate (+2%) and the gold capture (-2.7%). Different fission spectra are compared in Table 7. Calculations have also been made at Cadarache of the effect of choice of fission spectrum on the value of k_{eff}.

Ranges of k_{eff} values.

For the MT=19,etc fission spectrum there is the Petten MCNP continuous energy Monte Carlo result, and the MICROX-2 result (using the appropriately averaged fission spectrum). The difference between the two k_{eff} values is 62 (±10) pcm. The fission spectrum in the SHIVA/ECCO/ERANOS calculation is closely similar to that in the MICROX-2 calculation and the k_{eff} value is close to the MCNP result. However, the SHIVA/ERANOS value is much lower.

The k_{eff} values obtained using the MT=18 fission spectrum are higher than for the MT=19 + spectrum. The MCNP value is 75 (±11) pcm higher than the TRIPOLI value, with the MICROX-2 value being close to TRIPOLI and the SCALE-4.2 multigroup value intermediate between the two. The MONK results are intermediate between the TRIPOLI and MCNP values.

Neutron balances.

The neutron balances show a tendency for the MICROX-2 results to have a smaller group 1 leakage fraction and a larger group 2 fraction, but the differences for the some of the other codes are of the same order. The components of the neutron balances calculated using TRIPOLI, MCNP, MONK, MICROX-2, SCALE-4.2 and SHIVA/ECCO/ERANOS agree to better than 100 pcm.

Spectral indices.

There is similar good agreement for the deterministic Sn codes to that found for GODIVA. They agree to within 0.02% for the fission ratios, Pu-239/U-235 and U-233/U-235 and to better than 0.2% for the other ratios (excluding the SHIVA results for Au-197 capture/U-235 fission). The TRIPOLI and MCNP results are consistent with these to within the estimated uncertainties. Again the MONK values for the threshold fission ratio, U-238/U-235 is higher than for the other codes, although the difference is smaller than for GODIVA.

The use of the MT=18 fission spectrum improves the C/E values for the U-238/U-235 and Np-237/U-235 fission ratios. When this spectrum is used there is a similar pattern of C/E values for JEZEBEL to those obtained for GODIVA.

4. CONCLUSIONS

We take as the primary solutions (a) the continuous energy, or fine group, Monte Carlo results obtained using TRIPOLI, MONK and MCNP, and (b) the Multigroup Sn solutions calculated using fission spectrum vectors derived by means of appropriate reactor weighting spectra (P.S.I. MICROX-2 and Delft SCALE-4.2). It has been found that the multigroup solutions are very sensitive to the way in which the fission spectrum vector is derived. Those multigroup codes using other fission spectra have been separated in the comparisons. The

MCNP and MONK neutron balances have been modified to make an approximate allowance for the delayed neutron component of the fission spectra (which hasn't been treated in the versions of MCNP and MONK used in the calculations described here).

There are some significant differences between the different solutions. The TRIPOLI and MCNP k_{eff} results for JEZEBEL (MT=18) appear to be significantly different (75 ±11 pcm), with the MONK and the multigroup results being intermediate between the two (Note: the Pu-239 evaluation used in the TRIPOLI and SHIVA libraries differs from the standard JEF-2.2 file in the unresolved resonance range - 1 to 30 keV). The multigroup k_{eff} results for GODIVA appear to be significantly higher (about 70 pcm) than the TRIPOLI and MCNP Monte Carlo results. There are some significant differences between the MICROX-2 and SCALE-4.2 three-group neutron balance components, suggesting some small spectrum calculation approximations.

The results relating to the effect of the difference between the use of the total fission spectrum (MT=18) for Pu-239, rather than the partial fission spectra (MT=19 etc.), and for the incident neutron energy dependence of both the U-235 and Pu-239 fission spectra, show how important the choice is.

The JEF-2.2 data give values of k_{eff} which are about 420 - 520 pcm low for GODIVA and about 350 pcm low for JEZEBEL(MT=18 fission spectrum). The C/E values for the spectral indices are consistent between GODIVA and JEZEBEL when the Pu-239 MT=18 fission spectrum is used. The Pu-239/U-235 fission ratio is about 1% low, the U-233/U-235, U-238/U-235 and the Np-237/U-235 fission ratios are about 3% low, and the Au-197capture/U-235 fission ratio is about 5% low.

Further calculations would be helpful in refining the comparisons.

(i) The fission spectra used in MCNP and MONK should be modified to include the delayed neutron component or calculations should be made using a deterministic code to determine the corrections to be applied to the three group neutron balances.

(ii) It is only in the Delft SCALE-4.2 calculations that the reactor spectra have been used to obtain both the group averaged cross-sections and the fission spectrum vector (the P.S.I. calculations treat just the fission spectrum effect). It would be helpful to have a second calculation to determine the magnitude of the effect for the group cross-sections.

(iii) Calculations made using multigroup cross-sections derived from the cross-section data as it is used in TRIPOLI, MCNP and MONK would be interesting in helping to see if there are differences between the data processing and representation.

J L Rowlands, NEA Data Bank, 9 April 1999.

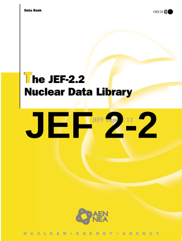


TABLE 1
k_{eff} Results for GODIVA and JEZEBEL

Laboratory and Method.	**GODIVA**	**JEZEBEL**	
		MT=19+	* MT=18

Continuous Energy and Hyperfine Group Monte Carlo methods.

Cadarache TRIPOLI-4 (Continuous energy)	0.99476 **L**		0.99636**L**
	±0.00010		±0.00010
ECN Petten MCNP 4A (Continuous energy)	0.9951	0.9952 **H**	
(dn fission spectrum component not treated)	±0.00010	±0.0001	
Cadarache MCNP 4A (Continuous energy)	0.99487		0.99711**H**
(dn fission spectrum component not treated)	±0.00030		±0.00005
Winfrith. MONK (including Qcheck)	0.9958		0.9968
(dn fission spectrum component not treated)	±0.00015		±0.00015
Winfrith. MONK (no Qcheck)	0.9953		0.9966
(dn fission spectrum component not treated)	±0.00015		±0.00015

Multigroup methods using fission spectrum vectors derived for the particular system.

P.S.I.MICROX-2; (P_2 mod. S_{32} extrap. S_∞)	0.99565	0.99458**L**	0.99641
Delft. SCALE 4.2 XSD; (P_3 S_{32} extrap. S_{128})	0.99573		0.99671
Delft. KENO (Multigroup)	0.9959 **H**		0.9966
	±0.00010		±0.00010

* *Calculated using the total Pu-239 fission spectrum (MT=18).*

H and **L** denote the highest and lowest values

Range (in pcm)	114 (±14)	62 (±10)	75 (±11)

Multigroup methods using fission spectrum vectors derived using other weighting methods.

Delft. SCALE 4.2 XSD; (IWT=4 standard thermal)	0.99431		0.99491
Delft. KENO(Multigroup) (IWT=4 standard therm.)	0.9941		0.9949
	±0.00010		±0.00010
Delft. SCALE 4.2 XSD; (IWT=4 fission spec> 1 keV)	0.99599		0.99671
Delft. KENO(Multigroup) (IWT=4 fission spec> 1 keV.)	0.9958		0.9967
	±0.00010		±0.00010
Cadarache SHIVA/ECCO/ERANOS. (P5; S_{16} extrap. S_∞)	0.99618	0.99520	
Cadarache SHIVA/ERANOS (P5; S_{32} extrap. S_∞)	0.99483	0.99321	

Sn order extrapolation.

Increasing the Sn order increases the leakage fraction and thus decreases the value of k_{eff} . The differences will depend on the particular angular quadrature set used but, in fact, they are approximately the same for all the deterministic calculations.

Cadarache studies of dependence on Sn order.

In the Cadarache SHIVA/ERANOS study the extrapolation to infinite Sn order was made using the formula of Kato in terms of reactivity, ρ:

$$\rho(inf)=2*\rho(2n)-\rho(n)$$

The calculations were performed up to order 32 . Identical results were obtained with the orders 16 and 8 showing that there is linearity.
Special attention was given to the spatial mesh so that the results of direct and adjoint calculation were identical (within 0.6 pcm max). The spatial mesh was 0.1 mm.

In the SHIVA/ECCO/ERANOS study the S_{16} values for GODIVA and JEZEBEL were extrapolated using the Kato formula in terms of keff:

$$k(inf)=[4*k(2n)-k(n)]/3 ,$$

resulting in a reduction of the S16 values by 67 pcm and 100 pcm, respectively, to extrapolate to S_∞.

P.S.I. Studies of Dependence on Sn Order.

GODIVA

32	0.99582	0.1437	0.2880	0.1442	0.5760
96	0.99566	0.1438	0.2881	0.1442	0.5762

k-eff(extr.) = 0.99565

The k-eff decrease between the S32 and S96 value is 16 pcm, the suggested decrease from the S32 to the Sinf value of 17 pcm being appropriate.

Results from an earlier study (keff too high)

SN Order	4	8	16	32	infinite (extrap)
keff	1.00889	1.00251	1.00075	1.00025	1.00008
F49/F25	0.99302	0.99317	0.99320	0.99321	0.99321
F28/F25	0.97250	0.97476	0.97529	0.97542	0.97546
F37/F25	0.96727	0.96832	0.96855	0.96862	0.96864
F23/F25	0.96677	0.96666	0.96663	0.96662	0.96662
C197/F25	0.93993	0.93909	0.93891	0.93886	0.93884

In the earlier study the difference between the S16 and S32 values was found to be 50 pcm. These values are consistent with the Cadarache extrapolations.

JEZEBEL (MT=19,...)

SN order	keff	Lkg (gr. 1)	Lkg (gr. 2)	Lkg (gr. 3)	Lkg (tot)
16	0.99558	0.2083	0.3281	0.1340	0.6705
32	0.99484	0.2086	0.3285	0.1341	0.6712
96	0.99461	0.2087	0.3286	0.1341	0.6715

k-eff(extr.) = 0.99458

The k-eff decrease between the S16 and S32 value is 74 pcm and between the S16 and S96 value is 97 pcm. The extrapolated value is 100 pcm lower than the S16 value, as in the Cadarache SHIVA/ECCO/ERANOS study.

JEZEBEL (MT=18)

SN order	keff	Lkg (gr. 1)	Lkg (gr. 2)	Lkg (gr. 3)	Lkg (tot)
16	0.99741	0.2154	0.3275	0.1265	0.6694
32	0.99676	0.2156	0.3279	0.1266	0.6701
96	0.99644	0.2157	0.3280	0.1266	0.6703

k-eff(extr.) = 0.99641

The k-eff decrease between the S16 and S32 value is 65 pcm and between the S16 and S92 value is 97 pcm. The extrapolated value is again taken to be 100 pcm lower than the S16 value. It is 35 pcm lower than the S32 value.

Delft Studies of the effect of varying the Sn order.

(Weight used IWT=1, a previously calculated reactor spectrum)

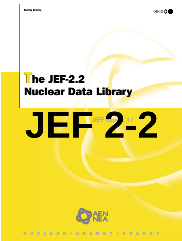
Sn	32	128	256	Diff. between S32 and S256
GODIVA	0.99591	0.99574	0.99573	-18 pcm
JEZEBEL	0.99698	0.99673	0.99671	-27 pcm

Studies of the effect of varying the order of the Pn treatment.

The Cadarache SHIVA studies have used P5, the Delft SCALE-4.2 studies used P3 and the P.S.I. MICROX-2 studies used a modified P2.
P.S.I.studies showed that increasing the order from P2 modified to P4 modified had very little effect.

Multigroup Weighting Spectra.

The P.S.I. and Delft calculations have used NJOY 97-62.
In the P.S.I. calculations the cross-sections were derived using the weighting spectrum IWT=4 with the fission spectrum boundary at 820.3 keV. For the group (b) results the fission spectrum vectors were derived using the weighting spectrum IWT=1 and precalculated reactor spectra.
In the Delft calculations the cross-sections and the fission spectrum vector were derived using the same weighting spectrum, IWT=1 and precalculated reactor spectra for the results given in



group (b). Results have also been obtained using IWT=4 and fission spectrum boundaries at 830.3 keV, 1 keV and 1 eV.

TRIPOLI and MCNP results.

Results have been provided by different contributors and to different accuracies and it is only the results with the smallest standard deviations which have been included in the Tables. There are different results for the different components of the TRIPOLI calculations - One group neutron balance, Three group neutron balance and spectral index calculations. However, it is understood that the results are not independent but that the same random number sequences are used in each calculation. It is the values which were obtained in the Three group neutron balances at Cadarache which have been included in Table 1.

TABLE 2
NEUTRON BALANCES FOR GODIVA

BALANCES NORMALISED TO 1 FISSION NEUTRON PRODUCTION

The absorption + leakage values have been normalised to the quoted values of $1/k_{eff}$

	Fission	Capture	(n,2n)	Leakage	Total	Derived k_{eff}	Quoted k_{eff}
TRIPOLI	0.3859	0.0453	-0.0027	0.5768	1.0053		0.9947
Petten MCNP	0.3854	0.0450	-0.0027	0.5773	1.0050	0.9950	0.9951
MCNP(dn mod.)	0.3854	0.0454	-0.0027	0.5769	1.0050		
MONKQ	0.3854	0.0451	-0.0027	0.5763	1.0041	0.9959	0.9958
MONKQ(dnmd)	0.3854	0.0455	-0.0027	0.5759	1.0041		
MONK	0.3854	0.0449	-0.0027	0.5770	1.0046	0.9954	0.9953
MONK(dn mod.)	0.3854	0.0453	-0.0027	0.5766	1.0046		
MICROX (PSI)	0.3856	0.0453	-0.0027	0.5762	1.0044		0.9957
Delft (IWT=1)	0.3855	0.0452	-0.0027	0.5764*	1.0044		0.9957*
Delft (Thermal)	0.3861	0.0458	-0.0024				0.9946
Delft (X>1keV)	0.3853	0.0451	-0.0027		1.0040		
SHIVA /ECCO	0.3854	0.0451	-0.0027	0.5760**	1.0038		0.9962**

(dn mod.) indicates that corrections have been estimated and applied for the effect of including the delayed neutron component of the fission spectrum.
*Delft result for S32 extrapolated using the data of Pelloni.
**Cadarache result for SHIVA/ECCO S16 extrapolated

Table 2.1. Differences relative to TRIPOLI ($x10^{-4}$)

	Fission	Capture	(n,2n)	Leakage	Total
MCNP(dn mod.)	-5	1	-	1	-3
MONKQ(dn mod)	-5	2	-	-9	-12
MONK(dn mod)	-5	-	-	-2	-7
MICROX	-3	-	-	-6	-9
Delft XSD (IWT=1)	-4	-1	-	-4	-9
SHIVA/ECCO	-5	-2	-	-8	-15

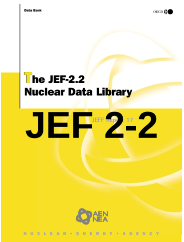


TABLE 3. THREE GROUP NEUTRON BALANCES FOR GODIVA

		Absorp.			Leakage	
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
	>2.2313	> 0.49787				
TRIPOLI	0.0881	0.1933	0.1499	0.1441	0.2882	0.1444
MCNP	0.0886	0.1939	0.1480	0.1449	0.2893	0.1431
MCNP(dn mod)	0.0880	0.1930	0.1499	0.1439	0.2880	0.1450
MONKQ	0.0885	0.1936	0.1487	0.1446	0.2884	0.1433
MONKQdnmod	0.0879	0.1927	0.1506	0.1436	0.2871	0.1452
MONK	0.0886	0.1937	0.1482	0.1449	0.2890	0.1432
MONK dn mod	0.0880	0.1928	0.1501	0.1439	0.2877	0.1451
MICROX	0.0880	0.1931	0.1498	0.1438	0.2881	0.1442
Delft XSD	0.0882	0.1930	0.1495	0.1442*	0.2879*	0.1443*
Delft (X>1keV)	0.0887	0.1927	0.1490			
SHIVA/EC	0.0885	0.1930	0.1490	0.1444**	0.2877**	0.1439**

*Delft result for S32 extrapolated to S96

**Cadarache result for SHIVA/ECCO S16 with an approximate extrapolation

Table 3.1. Differences relative to TRIPOLI (x10^{-4})

		Absorp.			Leakage	
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
MCNP dn mod.	-1	-3	0	-2	-2	6
MONKQdnmod	-2	-6	7	-5	-11	8
MONK dn mod.	-1	-5	2	-2	-5	7
MICROX	-1	-2	-1	-3	-1	-2
Delft XSD	1	-3	-4	1*	-3*	-1*
Delft (X>1keV)	6	-6	-9			
SHIVA/ECCO	4	-3	-9	3**	-5**	-5**

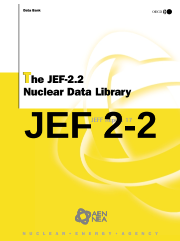


Table 3.2. Ratio of leakage to absorption

	Group 1	Group 2	Group 3
MCNP	1.635	1.492	0.967
TRIPOLI	1.636	1.491	0.963
MONKQ	1.635	1.490	0.964
MONK	1.635	1.492	0.966
MICROX	1.634	1.492	0.963
Delft XSD	1.635	1.492	0.965
SHIVA/ECCO	1.632**	1.491**	0.966**

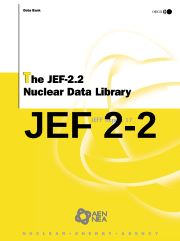


TABLE 4. NEUTRON BALANCES FOR JEZEBEL

	Fission	Capture	(n,2n)	Leakage	Total	Derived k_{eff}	Quoted k_{eff}
MT=19 etc							
Petten MCNP	0.3186	0.0159	-0.0007	0.6711	1.0049	0.9951	0.9952
MCNP dn mod.	0.3186	0.0159	-0.0007	0.6711	1.0049		
PSI MICROX	0.3188	0.0160	-0.0007	0.6715	1.0056		0.99461
SHIVA/ECCO	0.3187	0.0159	-0.0008	0.6709*	1.0047		0.99520
MT=18							
Cad. TRIPOLI	0.3185	0.0153	-0.0006	0.6705	1.0037		0.9963
Cadarache MCNP	0.3184	0.0153	-0.0006	0.6698	1.0029		0.9971
MCNP dn mod.	0.3184	0.0153	-0.0006	0.6698	1.0029		
Winfrith MONKQ	0.3182	0.0153	-0.0006	0.6700	1.0031		0.9968
MONKQ dn mod.	0.3182	0.0153	-0.0006	0.6700	1.0031		
PSI MICROX	0.3185	0.0154	-0.0006	0.6703	1.0036		0.99644
Delft XSD	0.3184	0.0153	-0.0006	0.6701*	1.0032		0.9967
Delft (Standard thermal spec)	0.3190	0.0156	-0.0006				0.9952

* Cadarache SHIVA/ECCO extrapolated from S16 to S96 using the data of Pelloni.

* Delft XSD extrapolated from S32 to S96 using the data of Pelloni.

Table 4.1 Differences relative to MCNP(dn mod.) = MCNP for cases using MT=19 etc. fission spectra (x10^{-4})

	Fission	Capture	(n,2n)	Leakage	Total
MICROX	2	1	-	4	7
SHIVA/ECCO	1	-	-1	-2	-2

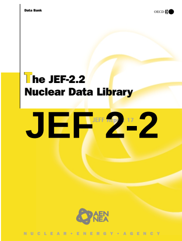


Table 4.2. Differences relative to TRIPOLI for MT=18 fission spectrum cases

	Fission	Capture	(n,2n)	Leakage	Total
MCNP	-1	0	0	-7	-8
MONKQ	-3	0	0	-5	-7
MICROX	0	1	0	-2	-1
Delft XSD	-1	0	0	-4	-5

Table 4.3 Differences for MCNP between MT=19 etc. and MT=18 fission spectra ($x10^{-4}$)

MCNP	2	6	-1	13	20

TABLE 5. THREE GROUP NEUTRON BALANCES FOR JEZEBEL

		Absorp.			Leakage	
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
	>2.2313 MeV	> 0.49787 MeV				
MT=19 etc						
Petten MCNP	0.0991	0.1654	0.0701	0.2095	0.3285	0.1331
MCNP dn mod.	0.0989	0.1651	0.0706	0.2091	0.3279	0.1341
PSI MICROX	0.0988	0.1653	0.0706	0.2087	0.3286	0.1341
Cadarache SHIVA	0.0990	0.1652	0.0704	0.2090*	0.3279*	0.1338*
MT=18						
Cad. TRIPOLI	0.1022	0.1651	0.0665	0.2163	0.3274	0.1267
Cadarache MCNP	0.1023	0.1654	0.0660	0.2164	0.3278	0.1256
MCNP dn mod.	0.1021	0.1651	0.0665	0.2160	0.3272	0.1266
Winfrith MONKQ	0.1026	0.1650	0.0657	0.2170	0.3274	0.1256
MONKQ dn mod.	0.1024	0.1647	0.0662	0.2166	0.3268	0.1266
PSI MICROX	0.1021	0.1652	0.0665	0.2157	0.3280	0.1266
Delft XSD	0.1023	0.1650	0.0664	0.2164**	0.3273**	0.1264**

* Cadarache SHIVA/ECCO extrapolated from S16 to S96 using the data of Pelloni.
** Delft XSD extrapolated from S32 to S96 using the data of Pelloni.

Table 5.1 Differences relative to Petten MCNP (dn mod) for cases using MT=19 etc. fission spectra

		Absorp.			Leakage	
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
MICROX	-1	2	-	-4	7	-
SHIVA/ECCO	1	1	-2	-1	0	-3

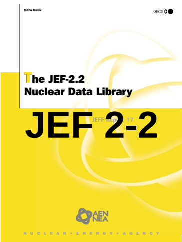


Table 5.2. Differences relative to TRIPOLI for MT=18 fission spectrum cases

		Absorp.			Leakage	
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
MCNP dn mod.	-1	-	-	-3	-2	-1
MONKQ dn mod	2	-4	-3	3	-6	-1
PSI MICROX	-1	1	-	-6	6	-1
Delft XSD	1	-1	-1	1	-1	-3

Table 5.3. Ratio of leakage to absorption

	Group 1	Group 2	Group 3
MT=19 etc			
MCNP	2.114	1.986	1.899
PSI MICROX	2.112	1.988	1.899
SHIVA/ECCO	2.111	1.985	1.901
MT=18			
TRIPOLI	2.117	1.983	1.905
MCNP	2.115	1.982	1.903
MONKQ	2.114	1.984	1.911
PSI MICROX	2.113	1.985	1.904
Delft XSD	2.115	1.984	1.904

Table 5.4 Differences for MCNP of using MT=19 etc. instead of MT=18 fission spectra ($x10^{-4}$)

MCNP	-32	0	41	-69	7	75

Table 5.5. Percent differences between MCNP MT=19 etc. and MT=18 fission spectrum cases.

MCNP	-3.1%	-	6.2%	-3.2%	0.2%	6.0%

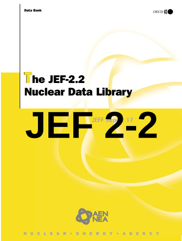


TABLE 6
Values of (C/E - 1)% for the Central Reaction Rate Ratios

GODIVA

	F49/F25	F28/F25	F37/F25	F23/F25	C197/F25
TRIPOLI (Cadarache)	-0.80(±0.13)	-3.00(±0.8)	-3.41(±0.16)	-3.31(±0.13)	-5.6(±1.3)
MCNP (Petten)	-0.66(±1.0)	-3.18(±1.0)	-3.26(±1.0)	-3.28(±1.0)	-6.42(±1.0)
MONKQ (Winfrith)	-0.67	-2.08	-3.13	-3.35	-6.01
MONK (Winfrith)	-0.64	-2.10	-3.02	-3.34	-6.10
MICROX (Sn)	-0.76	-2.94	-3.50	-3.33	-5.52
Delft XSD (Sn)	-0.74	-2.78	-3.38	-3.33	-5.69
Range excluding the Monte Carlo results	0.02	0.16	0.12	0	0.17
SHIVA/ERANOS(Sn)	-0.74	-2.49	-3.14	-3.33	-6.03

JEZEBEL

	F49/F25	F28/F25	F37/F25	F23/F25	C197/F25
MT=19 etc fission spec. results					
MCNP (Petten)	-1.45(±1.0)	-6.28(±1.0)	-4.84(±1.0)	-3.44(±1.0)	-2.60(±1.0)
MICROX (Sn)	-1.58	-6.51	-5.39	-3.41	-1.76
SHIVA/ERANOS(Sn)	-1.60	-6.41	-5.27	-3.42	-1.99
SHIVA/ECCO/ERAN	-1.59	-6.41	-5.30	-3.42	-2.41
Range excluding the MCNP results	0.02	0.10	0.12	0.01	0.65
MT=18 fission spec. results					
TRIPOLI (Cadarache)	-1.07(±0.11)	-3.04(±0.5)	-3.31(±0.12)	-3.50(±0.11)	-4.7(±1.2)
MONKQ (Winfrith)	-1.04	-2.70	-3.19	-3.53	-4.25
MICROX (Sn)	-1.05	-3.19	-3.38	-3.50	-4.45
Delft XSD (Sn)	-1.04	-3.08	-3.32	-3.52	-4.60
Range excluding the Monte Carlo results	0.01	0.11	0.06	0.02	0.15

There is an improvement in the threshold fission rates, F28/F25 and F37/F25, resulting from the use of the recommended fission spectrum (total fis. spec, MT=18).

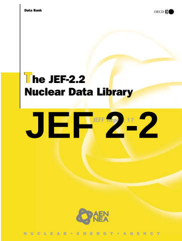
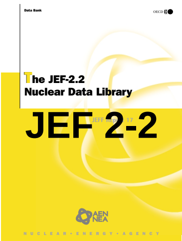


TABLE 7.
Comparison of JEZEBEL fission spectra.

Energy group (MeV)	Thermal (MT=18) Prompt	1 MeV (MT=18) Prompt	MICROX (MT=18) (P.S.I)	SCALE-4.2 (MT=18) (Delft)	MICROX (MT=19) (P.S.I)	Pu-239 (MT=19) (SHIVA) Fast
20 - 10	148	163	193	198	277	286
10 - 6.0653	2671	2820	3016	3053	3296	3314
6.0653 - 3.6788	11996	12277	12596	12653	12224	12258
3.6788 - 2.2313	22147	22258	22372	22378	21042	21060
2.2313 - 1.3534	23174	23057	22967	22929	22159	22150
1.3534 - 0.82085	17171	17007	16859	16824	17155	17134
0.82085 - 0.49787	10562	10438	10321	10304	10975	10956
0.49787 - 0.30197	5891	5817	5726	5719	6252	6239
0.30197 - 0	6241	6161	5950	5942	6621	6604
Fraction above 1.3534 MeV	60135	60577	61144	61211	58998	59068

At P.S.I. and Delft the fission spectra have been incident neutron energy averaged using a precalculated JEZEBEL flux to condense from the fission spectrum matrix to a single fission spectrum. At CEA Cadarache the SHIVA (MT=19 +) spectrum is a fast reactor averaged fission spectrum. However, it is similar to the P.S.I. spectrum.



APPENDIX 1

MODEL DESCRIPTIONS FOR GODIVA AND JEZEBEL

(CSEWG Benchmark Book, BNL 19302, ENDF 202, Revised 11-81)

Fast Reactor Benchmark No. 5: GODIVA,

a homogeneous bare sphere of enriched uranium, measured eigenvalue = 1.000 ± 0.001.

Radius: 8.741 cm.

Composition:

Isotope	Density (nuclei / b-cm)
U-235	0.04500
U-238	0.002498
U-234	0.000492

Spectral indices.

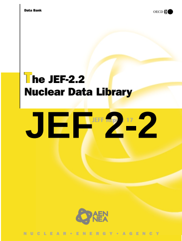
Central fission ratios (relative to U-235 fission)

F(U-238) / F(U-235)	0.1647 ± 0.0018
F(U-233) / F(U-235)	1.59 ± 0.03
F(Np-237) / F(U-235)	0.837 ± 0.013
F(Pu-239) / F(U-235)	1.402 ± 0.025

Ratio of capture in Au-197 to U-235 fission

C(Au-197) / F(U-235)	0.100 ± 0.002

(relative to thermal Au-197 (n,g) of 98.8 ± 0.3)



Fast Reactor Benchmark No. 1: JEZEBEL,

A homogeneous bare sphere of plutonium metal, measured eigenvalue = 1.000 ± 0.002.

Radius: 6.385 cm.

Composition:

Isotope	Density (nuclei / b-cm)
Pu-239	0.03705
Pu-240	0.001751
Pu-241	0.000117
Ga	0.001375

Spectral indices

Central fission ratios (relative to U-235 fission)

F(U-238) / F(U-235)	0.2137 ± 0.0023
F(U-233) / F(U-235)	1.578 ± 0.027
F(Np-237) / F(U-235)	0.962 ± 0.016
F(Pu-239) / F(U-235)	1.448 ± 0.029

Ratio of capture in Au-197 to U-235 fission

C(Au-197) / F(U-235)	0.083 ± 0.002

(relative to thermal Au-197 (n,g) of 98.8 ± 0.3)