Test of JEF2 Decay Data and Fission Yields by means of Decay Heat Calculations.

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Introduction.

New evaluations of both decay data and fission yields based on theoretical and experimental studies have been introduced in JEF2. These data have been used for a series of summation calculations and the results have been compared with experimental determinations of decay heat, and some new standards. The comparisons are limited to pulse thermal fission of U235 and Pu239. JEF2 calculations are obviously better then JEF1 at short cooling times, and seem to be in good agreement with JNDC-FP-V2 ones (Japanese library). Some discrepancies at longer cooling times were found using JEF2.2.1 and this has led to the development of JEF2.2.2 which gives better results and better consistency between decay data and fission yield libraries. Some comments on the way to get recommended decay heat values will be presented here.

1°) JEF2 Decay Data.

Here are the different releases of JEF decay data library:

Library	Release	Number of evaluated nuclides
JEF1	July 1987	1310
JEF2.1	May 1990	2310
JEF2.2.0	January 1992	2344
JEF2.2.1	July 1992	2344
JEF2.2.2	February 1993	2345

We should notice that JEF2 Draft Report 13 (ref.0) corresponds to JEF2.2.0 library. A trace-back about JEF2 evolution according to integral data testing is available in ref.1 and 2. The evaluation philosophy is presented in ref.3.
The JEF2 "Special Purpose File" Working Group has decided to clearly separate experimental evaluations from theoretical ones, and to avoid augmented spectra by calculated ones (table.1 and figure.1).

It is possible to distinguish four evaluation procedures of the decay data (as presented in ref.4 and 5):

a°) Decay schemes are constructed from spectroscopic investigations and recorded in an ENSDF type of library. In this case, average beta and gamma energies are derived from the level schemes, which may be incomplete, leading to "pandemonium effects" (over-estimation of mean beta energy, and under-estimation of gamma one, with balance on the total, ref.6 and 7).
In JEF2.2, 2110 nuclides belong to this class, and around 500 Fission Products among them.

b°) Average decay energies are directly evaluated. Rudstam et al.(ref.8) have measured continuous spectra of beta particles and gamma rays of short-lived Fission Products (FPs) from which average energies are obtained.
109 nuclides of this type are present in JEF2.2.

c°) Some nuclides have incomplete decay schemes. Their evaluation is thus partially based on the type a°) approach, completed by the b°) one, or a specific evaluation based on systematics.
In fact, 6 have their spectra modified by Rudstam's evaluation, and 18 have their half-lives obtained from Blachot'systematics (ref.8).
We should notice that ENDF.B/VI (ref.4) and the French CEA-1987 (ref.9) libraries have completed some a°) evaluations with theoretical calculations based on the gross theory of beta decay (ref.10), in the former library, and a simple statistical approach (ref.11) for the latter one (with one free global parameter defined by Mann(ref.12)).

d°) For nuclides without any experimental information, decay data have been calculated using a nuclear shell model based upon the proton-neutron Quasiparticle Random Phase Approximation (p-n QRPA) by Klapdor et al.(ref.13).
101 nuclides of this type are included in JEF2.2.
Three steps are necessary for such a semi-microscopic calculation:

- Single-particle energies and wave functions are calculated using a Nilsson modified oscillator model.
- Occupation amplitudes are determined in a BCS calculation (pairing effect).
- The residual interaction responsible for collective states is treated by the Random Phase Approximation.

It is important to underline the semi-microscopic way of description used here (independant particles), whereas a macroscopic one (dependant particles) is taken in the gross theory , which has been preferred in the ENDF.B/VI (ref.4) and in JNDC-FP-V2 (ref.14) libraries for the d°) class. A real microscopic model with independant particles would have been to use a self-consistant Hartree-Fock-Bogolyubov (HFB) calculation in order to get the nuclear Hamiltonien, which is difficult, very long and expensive for so much FPs to calculate.

Starting from a Fermi gas picture, the gross theory assumes that the beta strength function can be described by a Gaussian or modified Lorentzian shape, including in a semi-empirical fashion the Gamow-Teller Giant Resonance (GTGR). This model thus ignores any fine stucture in the low energy part of the beta strength function, which has been experimentally demonstrated by Kratz et al.(ref.15), such as Core Polarization States (CPS).
Nevertheless, comparing average energies available for 100 nuclides from four compilations (either experimental or theoretical evaluations as presented earlier), Dickens (ref.5) concluded that none of these predictions is superior in reproducing experimental data.
The main result of this study indicates that $<E_\beta>/Q$ varies from 0.11 to 0.46 and that the approximation $<E_\beta>/Q \simeq 1/3$ proposed by Tobias (ref.16) and Blachot et al. (ref.17) is not so bad (but tends to overestimate $<E_\beta>$ on the average).
On the other hand, Klapdor et al. (ref.18) propose a simple formula ($<E_\beta> = 0.5 * (Q_\beta - <E_\gamma>) - 0.5 *$(higher order terms)) in order to verify that $<E_\beta>$ and $<E_\gamma>$ are not inconsistent. It is however possible with this formula to deduce $<E_\beta>$ (resp.$<E_\gamma>$) when $<E_\gamma>$ (resp.$<E_\beta>$) has been only measured , or derived from decay schemes.
In the following we show the contribution of these four JEF2.2 FPs'classes to the total decay heat. In fact, as it will be seen later, we have added class a°) and c°) contribution because c°) class 's contribution is not very significant (24 nuclides only belong to this class).
We have developed a computer program (ref.19) called CYDRE (CYcle: Décroissances Radioactives et Energies) in order to read JEF2 decay data in ENDF-6 format, and thus make it available in a Data Base Management System (ref.21 and 22) which can be used to process decay chains and make decay heat calculation.

NB:

The JEF2.2 evaluated beta delayed neutron branches (Pn values) may be obtained either from Rudstam's experiments or Klapdor's calculations. These values are essential because they affect isobaric beta - decay. So they are necessary for prediction of both $<E_\gamma>$ and $<E_\beta>$, and also to calculate cumulative fission yields. The different evaluations of Pn values are one reason why the evaluations of Meek-Rider, JEF1, JEF2, and ENDF.B/VI may be so different.

2°) JEF2 Fission Yields:

The most recent review papers are those of ref.23 and ref.24, which are complementary. The UKFY2 library was retained for JEF2. Methods used for this evaluation are presented in ref.25.
39 fissile systems (instead of the 15 in JEF1) are available for 21 nuclides (7 in JEF1-table.2). The differences between the May 1990 version and the January 1992 one relate to some of the uncertainties/covariances. Discrepancies between JEF1 and JEF2 decay heat at long cooling times (ref.1), where very

few and well known FPs are contributing, has led to the JEF2.2.2 release:

Library	Release	Fissile Systems	Observations
JEF1	July 1987	15	No covariances No ternary fission
JEF2.1	May 1990	39	Covariances Ternary fission
JEF2.2.0	January 1992	39	Cov.modified.
JEF2.2.1	July 1992	39	Same library.
JEF2.2.2	February 1993	39	New JEF2 decay data used, A =90 and 137 chain yields corrected.

We have also to distinguish between the yields given in ref.25 and those given in the file. The former ones result from a direct evaluation of measurements to avoid discrepancies, whereas the second set results from adjustments made to satisfy four physical constraints (mass and charge conservation laws).

a°) Independent Yields

According to ref.25 :

$$y(Z,A,I) = Y(A) * f(Z,A) * r(Z,A,I)$$

Y(A) : Chain Yield or Total Independant Yield.
f(Z,A): Fractional Independant Yield.
r(Z,A,I): Isomeric Yield Ratio.

The main features of this evaluation (ref.25) are :
- new fissile systems are included.
- experimental yields renormalised to standards current in early 1988.
- ternary fission is taken into account.
- Y(A) interpolation is based upon the five Gaussian fit method of Musgrove et al. (ref.26), used more recently by Dickens (ref.27).
- f(Z,A) interpolation is made using the Wahl model (ref.28 and fig.2).
- r(Z,A,I) evaluation is according to the Madland and England model (ref.29).
- adjustment and covariance matrix production.

b°) Cumulative Fission Yields

According to ref.25 :

$$C(Z,A,I) = y(Z,A,I) + b'(Z',A',I' \rightarrow Z,A,I).C(Z,A,I)$$

and for the last nuclide of the chain (stable):

$$C(Zs,A) = Y(A) + \sum_{Z} Pn(Z,A+1,I).C(Z,A+1,I) - Pn(Z,A,I).C(Z,A,I)$$

The main points to note are:
- use of the last JEF2 decay data (branches and Pn values).
- alpha long-lived decay is neglected.
- adjustment and covariance matrix production.

Both independant and cumulative fission yields are read in ENDF-6 format by the CYTARE (ref.30) computer program (CYcle: Traitement Appliqué aux REndements).

c°) Fission Products recognized by JEF2 Decay Data or Incident Neutron Data.

FPs are denoted in the JEF2 fission yield evaluation by :

ZA = Z * 1000 + A.

They may result from interpolation and thus may not be present neither in the decay data library nor in the incident neutron data file.
For example, we have:

Independent Yields (JEF2.2.1)

	U235 T	Pu239T
Number of FPs read by ZA :	977	1071
(1) Yields sum :	2.001837	2.002483
Number of FPs evaluated : (known radioactive + stable FPs)	789	861
FPs radioactive :	666	730
FPs stable :	123	131
(2) Yields sum :	1.999162	1.999443
Number of FPs rejected : (as unknown)	188	210
(3) Yields sum :	$2.675232\ 10^{-3}$	$3.040399\ 10^{-3}$
(3) / (1) (%) :	0.134	0.152

Independent Yields (JEF2.2.2)

	U235 T	Pu239T
Number of FPs read by ZA :	793	872
(1) Yields sum :	2.001615	2.002312
Number of FPs evaluated : (known radioactive + stable FPs)	778	848
FPs radioactive :	660	721
FPs stable :	118	127
(2) Yields sum :	2.001612	2.002312
Number of FPs rejected : (as unknown)	15	24
(3) Yields sum :	$2.3818\ 10^{-6}$	$2.6654\ 10^{-8}$
(3) / (1) (%) :	$1.1898.10^{-4}$	$1.331.10^{-6}$

We have now reached better consistency between decay data and fission yield libraries because the number of FPs rejected in the latter one, as unknown, has extensively dropped down from JEF2.2.1 to JEF2.2.2 (from 188 to 15 for U235 as example).

3°) JEF2 Fission Product Decay Heat Calculation for U235 and Pu239 following an Instantaneous Fission Burst.

a°) Principle.

As is explained by Tobias (ref.31), an irradiation may be regarded as a series of fission bursts (neglecting the capture effect). Such curves are easily obtained by summation calculations and are directly comparable to unfolded decay heat measurements on each important fissile nuclide sample for both Thermal and Fast reactor spectra (U235(T,F),U238(F), Pu239(T,F),Pu240(F), and Pu241(T,F) are the major fissile systems). These decreasing exponential curves are called Elementary Fission Curves (ECF) or decay heat burst functions. They only give the FP decay heat contribution. C/E values depend on the number (and quality) of FPs evaluated in the data file (ref.32).
To solve the generalised Bateman equations, we have used a numerical method (the Sidell method (ref.33), as used in the FISPIN inventory code (ref.34)), programmed by Gillet (ref.35) in the FBR inventory code called MECCYCO (ref.36), and adopted in DARWIN (ref.22), following the succesful 1989 benchmark method intercomparison(ref.37).

Here, we are just intending to produce preliminary results with JEF2 and make a comparison of:

- available standards .

- both JEF2 and JEF1 results to experimental ones.

- contribution of the different FP classes to the total decay heat according to 1°).

b°) Decay Chains per Fissile System.

Starting from the FPs retained as previously explained and JEF2 decay chains (CYDRE and CYTARE tools are coupled-figure.3), we are able to define the number of FPs plus Desintegration Products (DPs) useful for each fissioning system and thus, according to decay branches, the number of non-zero matrix elements.
In order to show the contribution of each new type of decay data evaluation at short cooling times, three cases were considered for both U235 T and Pu239 T (with JEF2.2.1 data):

	Number of nuclides	Number of non zero matrix elements
(1) All evaluated FPs+DPs in JEF2 Decay Data		
* U235 T	668	1380
* Pu239 T	730	1468
(2) = (1) - (FPs+DPs) evaluated by Rudstam		
* U235 T	559	1020
* Pu239 T	662	1108
(3) = (1) - (FPs+DPs) evaluated by Klapdor		
* U235 T	567	1088
* Pu239 T	630	1176

We have only recalculated case (1) with JEF2.2.2 because we knwow that differences between JEF2.2.1 and JEF2.2.2 occur at long cooling times.

c°) Results and Discussion .

c°1) Standards Comparison.

Three main standards are available :

- the American National Standard (ref.38) for Light Water Reactors. As indicated in table 3, three fissile nuclides are concerned: U235 T, Pu239 T, and U238 F. Both U235 T and Pu239 T standards are based upon least squares fits to measured and calculated results for cooling time < 10^5 s. Beyond 10^5 s, they rely solely on summation calculations, whereas the U238 F standard is completely dependent on calculation.

- the 1989 Tobias' least squares fit (according to Schmittroth and Schenter method used in ANS standard) to all recent U235 and Pu239 decay heat measurements (ref.39 and table 3) currently used as the European experimental standard. Measurements of fast fission have been included "because of the view that average neutron energies for current designs of fast reactors are much lower than those in the bulk of fast fission yield measurements", according to Tobias. This is not really the case (table 4). In my opinion, U235 T and U235 F (resp.Pu239 T and Pu239 F) decay heat calculations (and measurements) are not so different because thermal and fast yields are not so different.

- the Japanese standard (ref.40 and table 3), denoted as JAERI-M-094 on viewgraph (U235 as example on fig.4), for U235 T, Pu239T, U238 F, Pu240 F, Pu241 T, is completely based on summation calculations and is applicable for both LWRs and FBRs.
It is obvious that on the three standards, the JAERI one underestimates the total decay heat at short cooling times due to a lack of known short-lived FPs in the summation calculation, even if there is a great progress in JNDC-FP-V2 decay data library with regard to the past. The given uncertainties are thus augmented at short cooling times in order to balance this drawback.
An outstanding point is the fact that, around 10000 seconds, Tobias'experimental fit is below ANS standard (with partial caculational basis) and JAERI one (calculational basis only), and with a very small uncertainty given by the fit. This is probably due to a statistical effect in the fitting method. That is why it is probably useful to take into account the calculation tendency in the fit, as it is done in the ANS standard.
Above 10^5 seconds, there is no choice because we have no experimental results and thus only calculational basis.

Tobias'standard for cooling times below 10^5 seconds is therefore the only one entirely based upon decay heat measurements for U235 and Pu239, that is why it will be retained in our calculation to experiment comparison.

c°2) JEF2 and JEF1 Calculation Comparison to Tobias'Standard.

Tables 5 and 6 are giving JEF2 results for U235 T and PU239 T. As it is shown on figure 5 for U235 T, JEF2 decay heat calculations are obviously better than JEF1 ones at short cooling times because of the new decay data evaluations (Rudstam and Klapdor ones) involved in the decay chains:

- better JEF2 evaluation quality for JEF1 already known FPs.
- almost 200 more FPs taken into account in JEF2 calculation (see table.1).

According to ref.4: " spectroscopists rarely measure complete beta spectra. Instead, beta spectra are evaluated from level schemes deduced from gamma measurements. But the level scheme may be incorrect because of erroneous placements of gamma transitions, or gamma rays not put into the decay scheme. This leads to an error of the beta energy. It may also be wrong because some gamma are missing, usually high-energy ones leading to overlooking highly excited levels. this means that low-energy beta branches to these levels will be omitted. The average beta energy will then become too high and the average gamma energy (per decay) too low." This is the so-called "Pandemonium effect".
This effect still exists. But it seems clearly to be better treated (fig.6). We have nevertheless no augmented spectra by calculated ones in JEF2. This progress is therefore probable reliant on Rudstam's evaluations, mainly contributing at short cooling times (as it will be demonstrated in next chapter),and with better experimental resolution at higher excitation energy (complete beta spectra are measured).

c°3) Contribution of the Klapdor and Rudstam Evaluations to the Total Decay Heat of U235 T and Pu239 T.

Fig.7 gives the contributions of the ENSDF, Klapdor and Rudstam types of evaluation, according to the classes presented in 1°), as a function of cooling time for U235 T.
The main decay data component of decay heat is coming from evaluations with average gamma and beta energies obtained by Rudstam's measurements for both U235 T and Pu 239 T, belonging to class b°) in 1°). Meanwhile, this kind of evaluation is also represented in ENDF-B-VI library. We do not know if this is the case in JNDC-FP-V2 (to our knowledge, Rudstam's evaluations are not included in the Japanese library). The decay heat calculations made using the JEF2 and ENDF-B-VI libraries are now expected to be in close agreement. Figure.8a and 8b show that JEF2 results and JNDC-FP-V2 ones are also not so different. This is certainly due to Rudstam's evaluations in the former library and to the augmentation of measured spectra by calculated ones in the latter one. Anyway, it is complicated to add a theoretical component to the experimental spectra as is done in both American and Japanese libraries for

some FPs belonging to c°) evaluation type (chapter 1), even if this contribution is less significant in ENDF-B-VI.
Klapdor'evaluations contribute mainly around 10 seconds, whereas pure ENSDF type evaluations contribute above 8 10^3 s.
As it was pointed out in ref.4 for ENDF-B-VI and as it is visible on figure 7a for JEF2, the experimental data basis for the decay heat calculation (ENSDF plus Rudstam's evaluations) represents almost 90 % of the total effect.

CONCLUSION:

A major work has been accomplished to produce entirely new decay data and fission yield libraries. We have calculated JEF2 decay heat for U235 T and Pu239 T, and compared the results with new standards based on all recent experiments. The new integral decay data evaluations by Rudstam and theoretical ones by Klapdor improve decay heat calculations at short cooling times between JEF1 and JEF2. Pandemonium effect on beta and gamma decay heat still exists but is better treated, although we have no augmented spectra by calculated ones in JEF2. This fact is certainly due to the high resolution of Rudstam's decay energy measurements. Meanwhile, consistency between ENDF-B-VI and JEF2 is to be expected because this evaluation method is adopted in the two libraries, for which the experimental data basis represents almost 90 % of the total effect. Even if Rudstam's measurements are not included in JNDC-FP-V2, decay heat results are similar to JEF2 ones. Differences appear in the way to get decay heat standards according to the basis of the recommended values, either on calculational, calculational plus experimental, or only experimental basis.

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Fig. 1: Status of the experimental knowledge of β-decay data in the region of fission products. Black squares denote stable isotopes. Isotopes for which only half-lives were experimentally determined are shown as grey-shaded area. The white area between these two cases represents nuclei for which at least experimental mean β- or mean γ-energies are known. (from ref. 18)

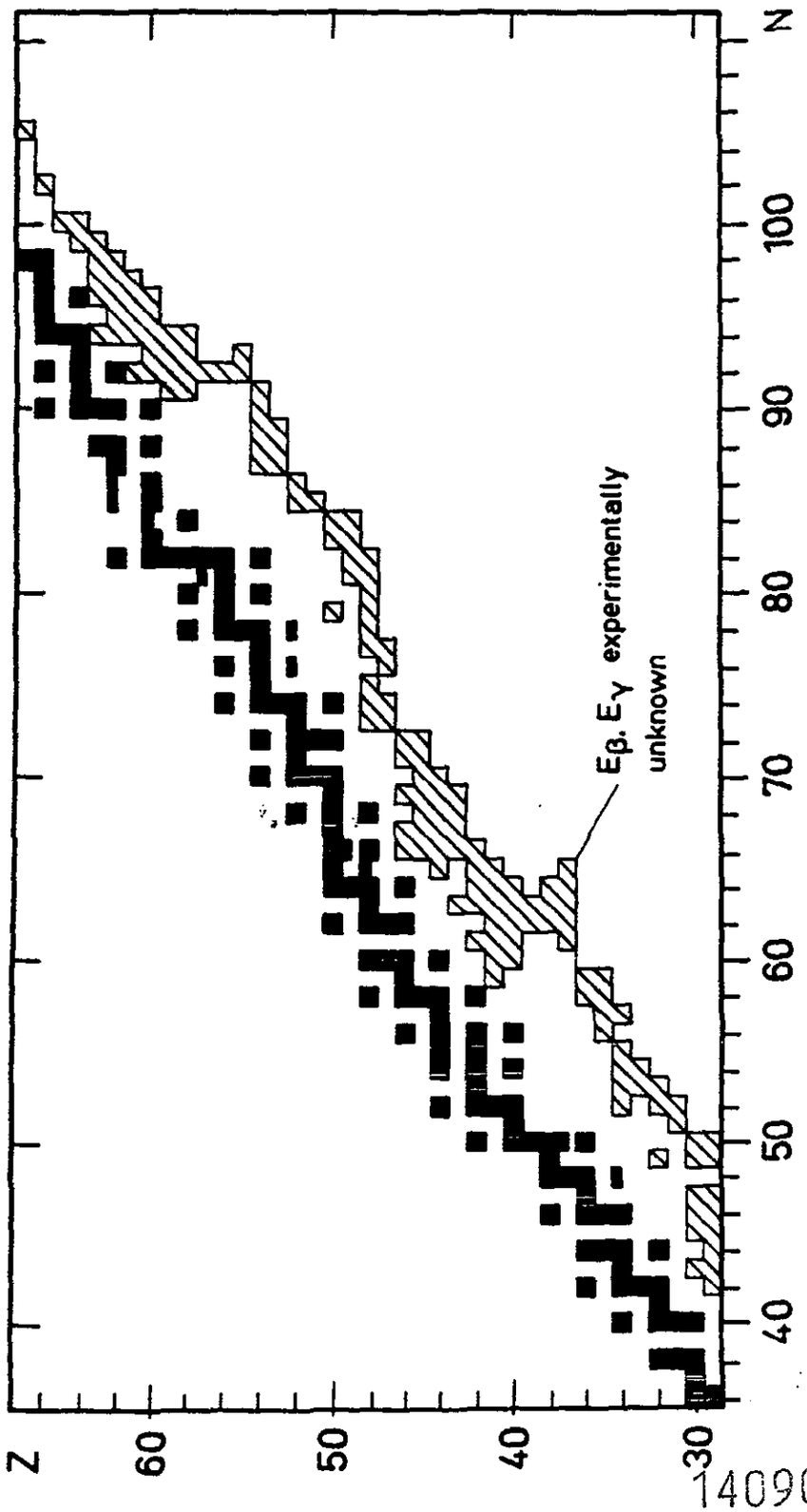

Fig. 2: Fission yields according to the Z_p model of A.C. Wahl .
a) Thermal fission of ^{235}U. b) Thermal fission of ^{239}Pu. As usual in reactor physics fission yields are normalized to 200%, corresponding to 100% per peak. (from ref. 18)

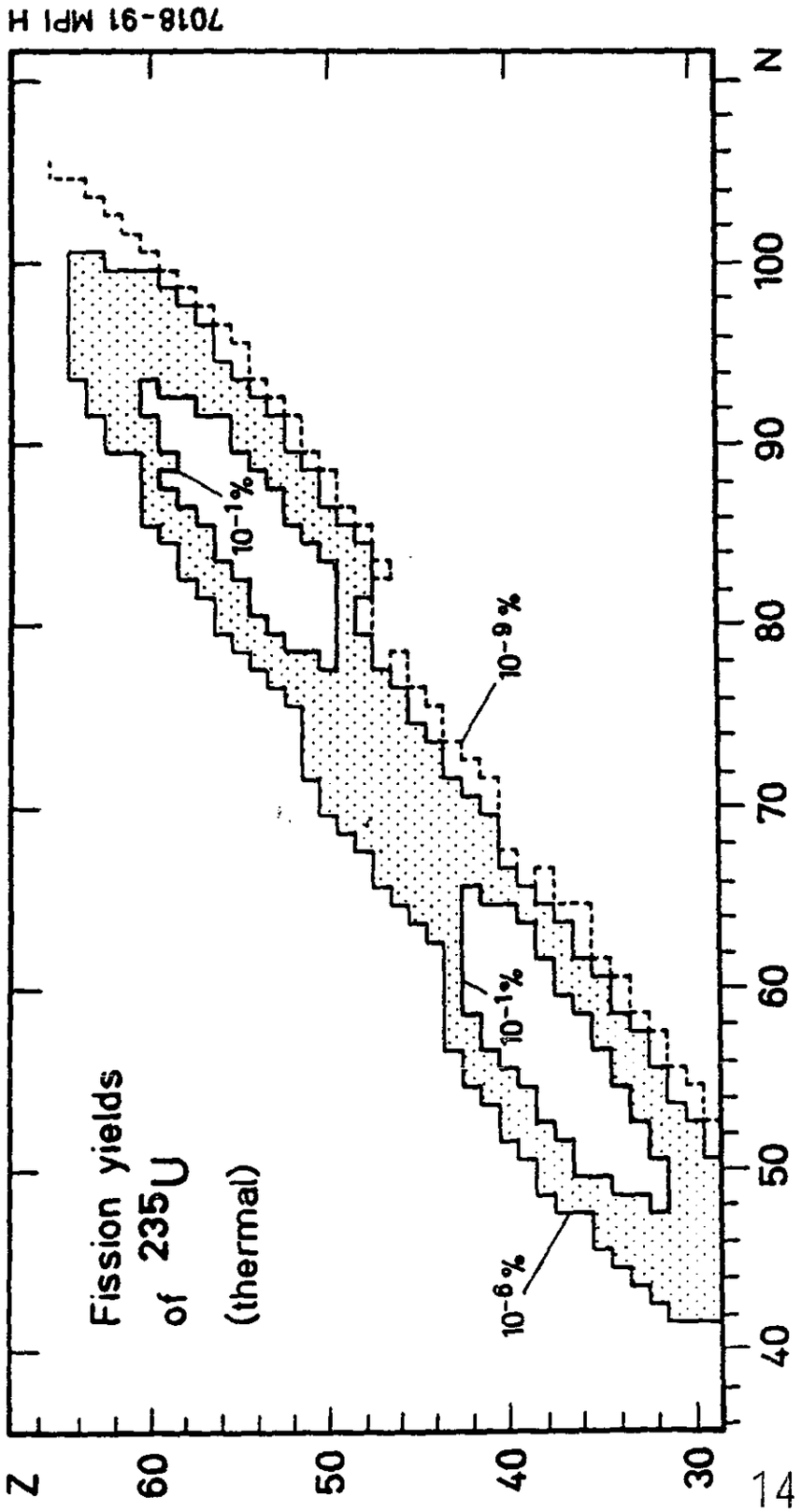

Fig. 2: Fission yields according to the Z_p model of A.C. Wahl
a) Thermal fission of ^{235}U. b) Thermal fission of ^{239}Pu. As usual in reactor physics fission yields are normalized to 200%. corresponding to 100% per peak. (from ref. 18)

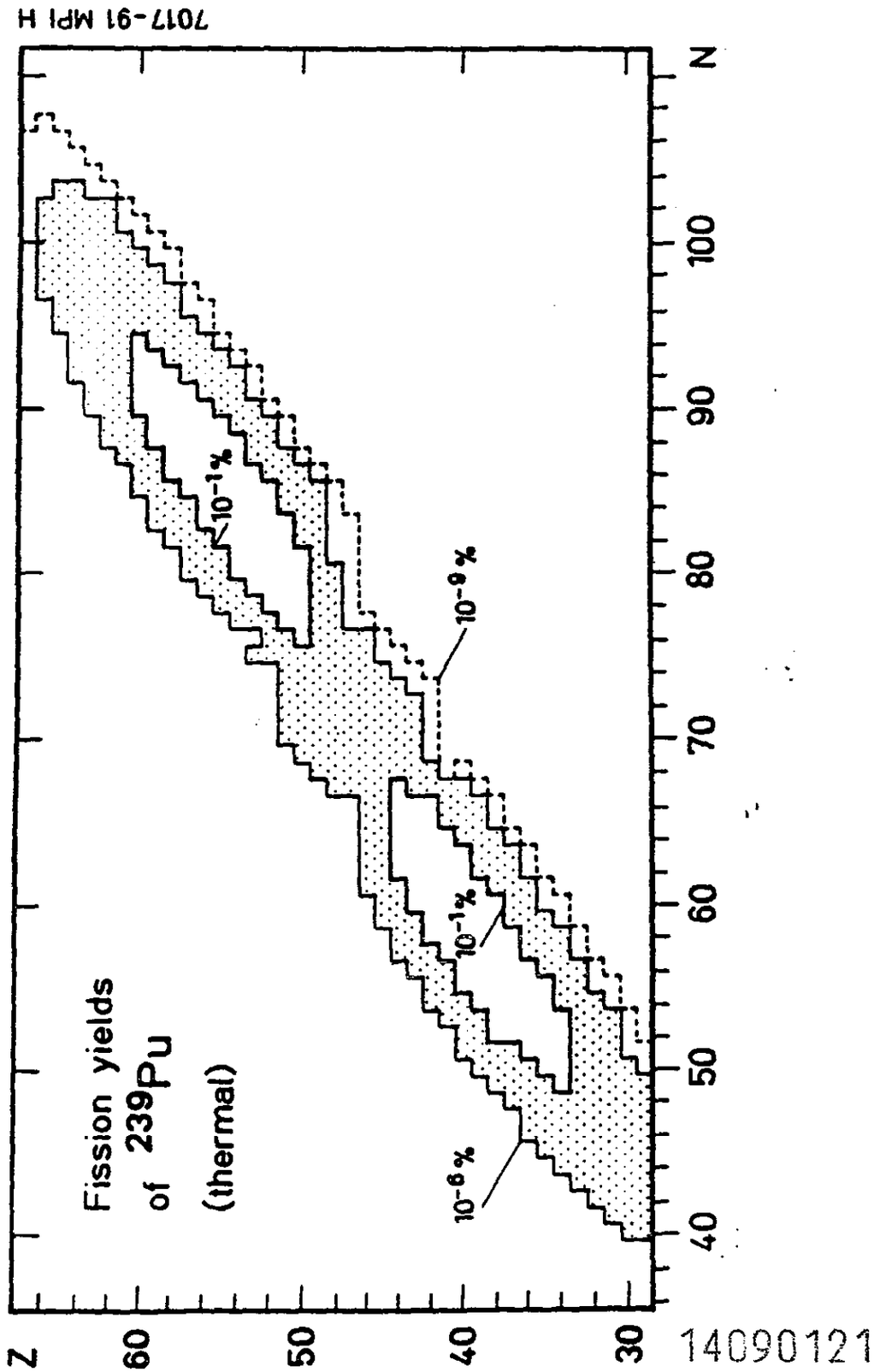

Figure 3:

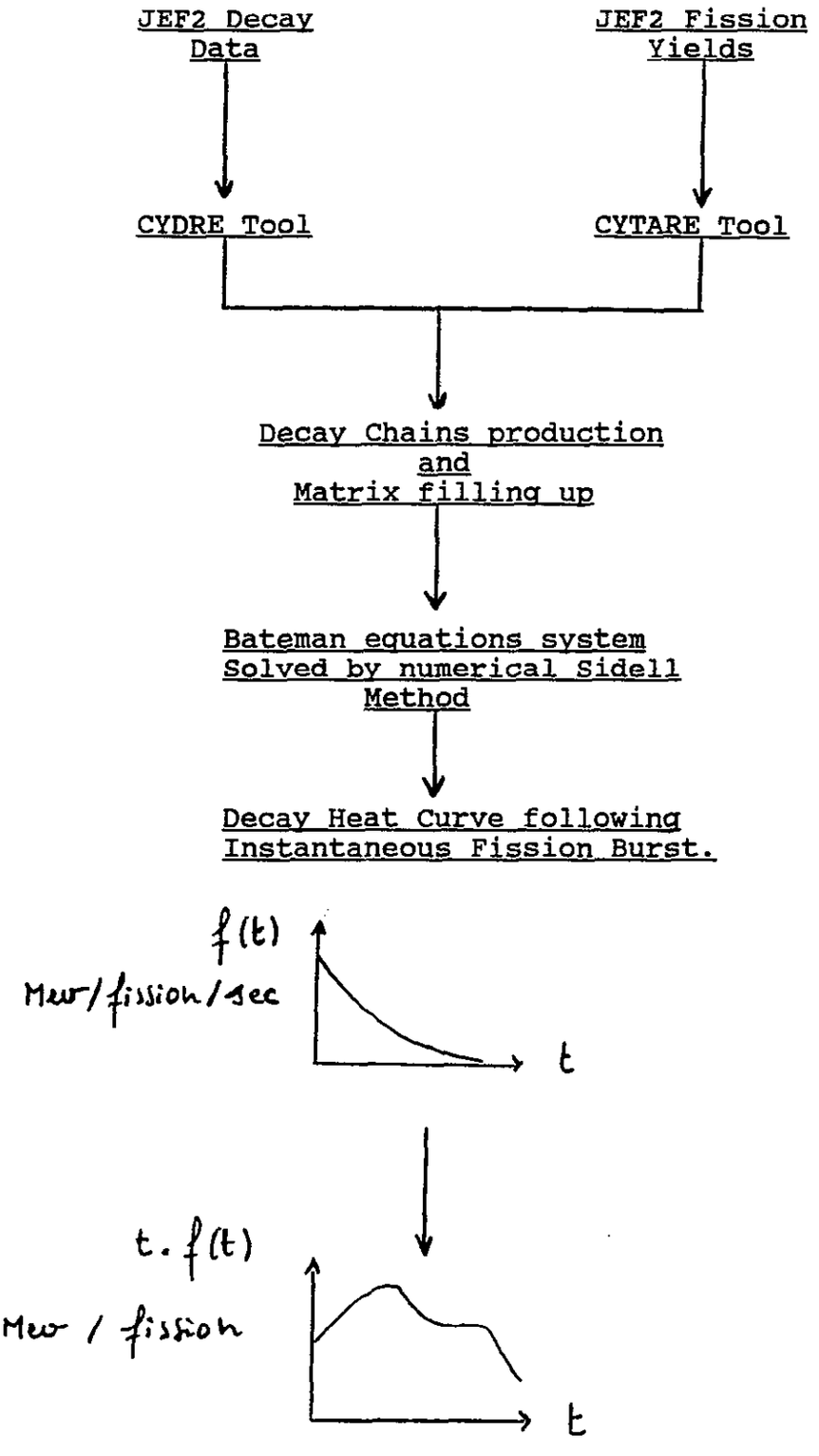
JEF2 Decay Data
JEF2 Fission Yields
CYDRE Tool
CYTARE Tool
Decay Chains production and Matrix filling up
Bateman equations system Solved by numerical Sidell Method
Decay Heat Curve following Instantaneous Fission Burst.
f(t)
Mew/fission/sec
t
t.f(t)
Mew / fission
t

Figure 4a:

Comparison of Decay Heat Standards for U235 Fission Burst.

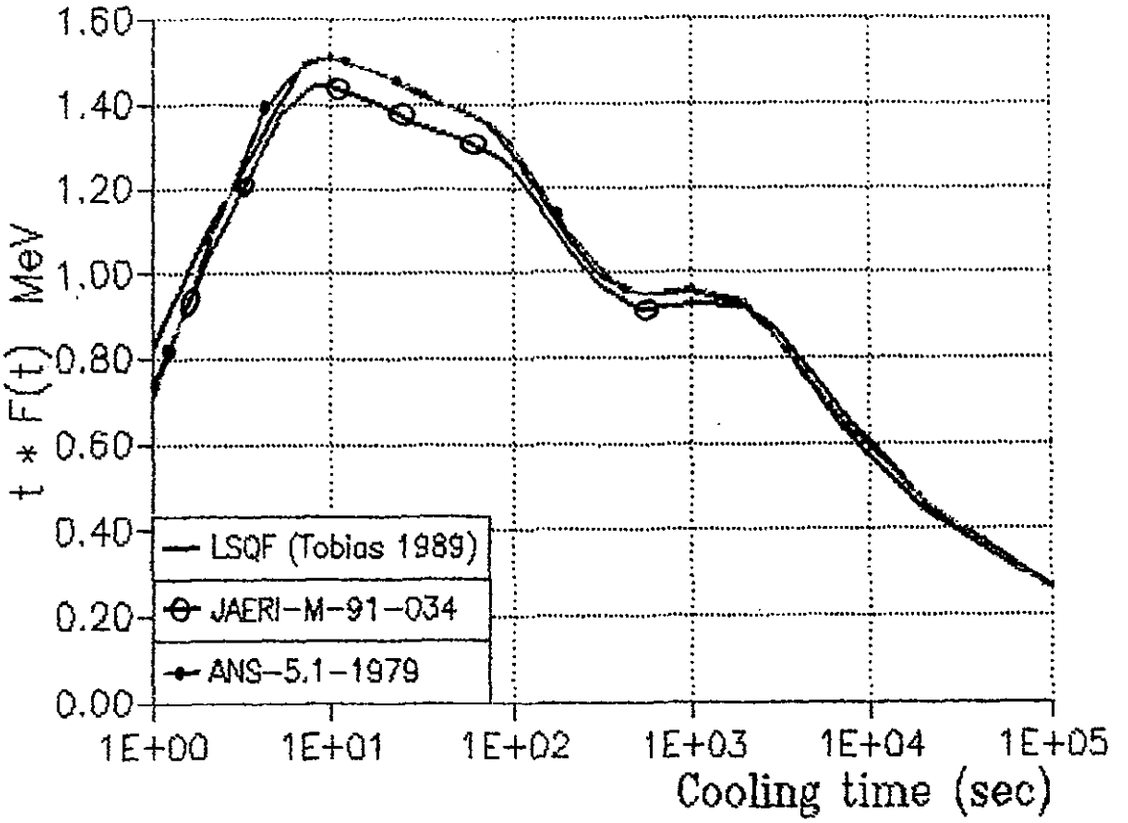

Figure 4b:

Comparison of Decay Heat Standards for U235 Fission Burst. (Thermal Reactor Spectrum).

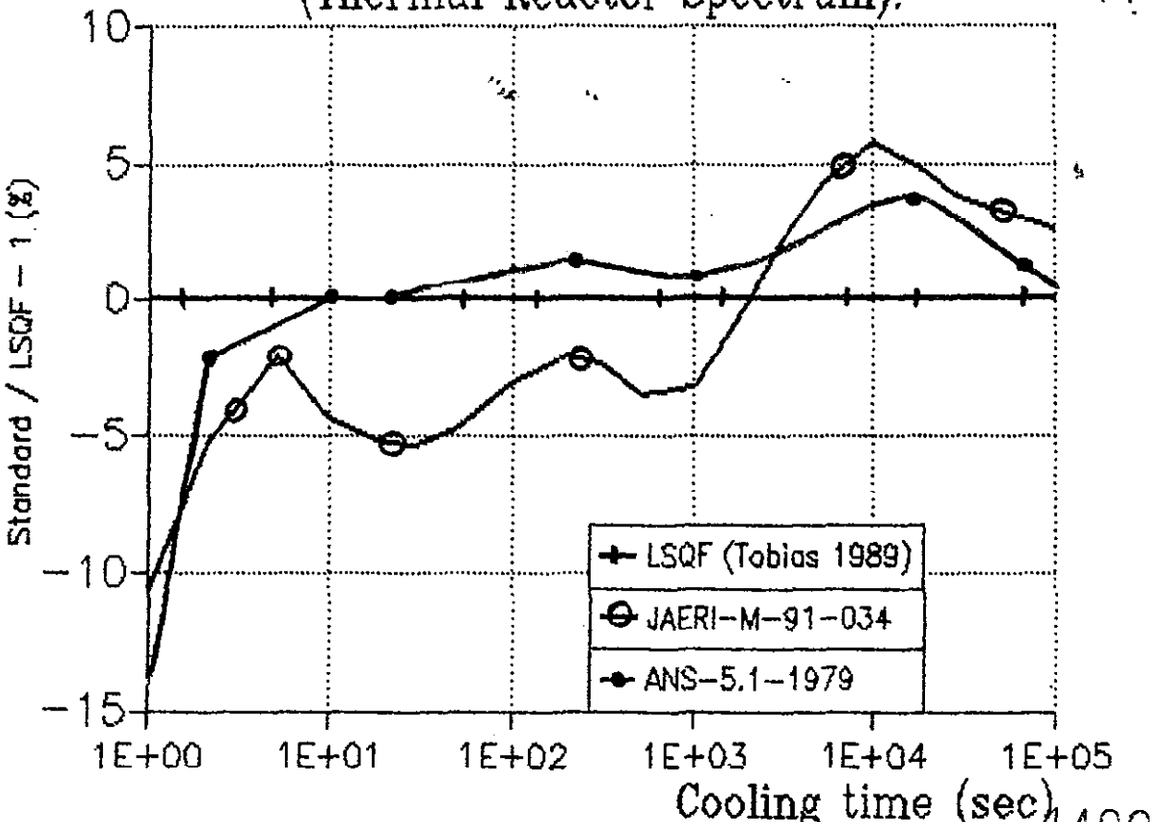

Figure 5a:

Comparison of Decay Heat Calculations with a best fit to Measurements for U235 Fission Burst (Thermal Reactor Spectrum)

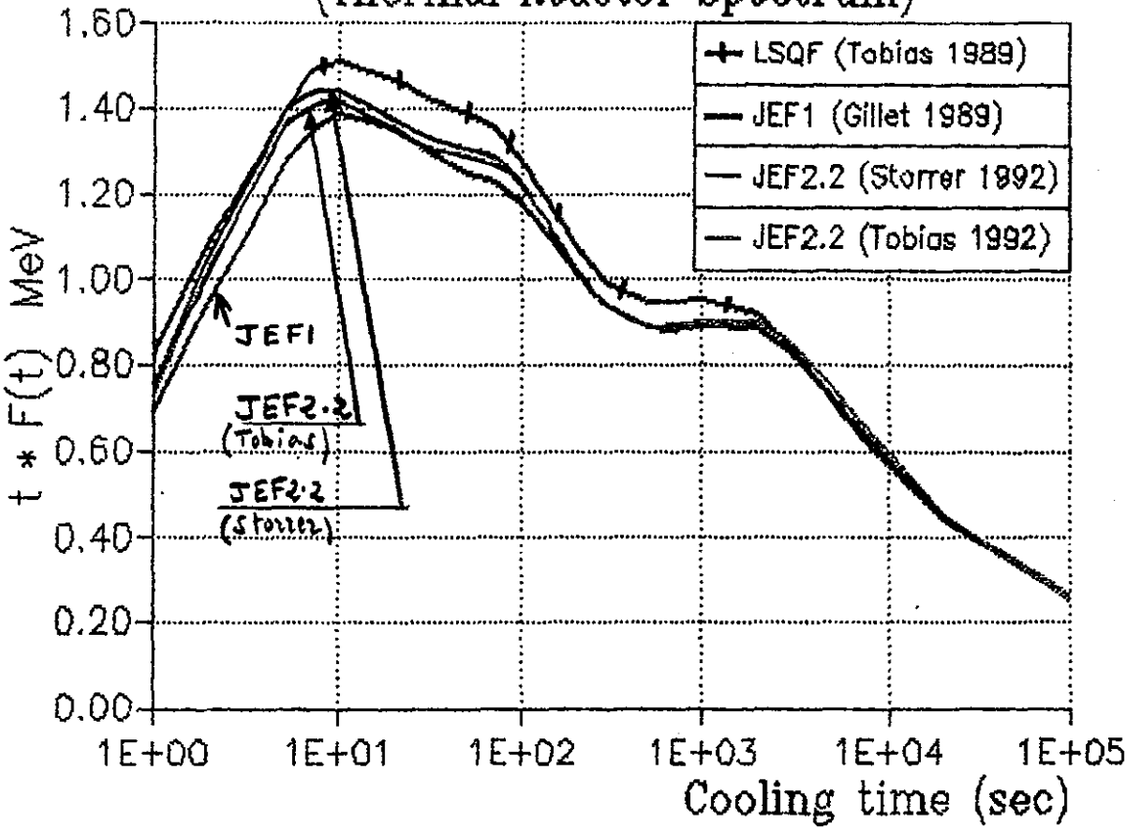

Figure 5b:

Comparison of Decay Heat Calculations with a best fit to Measurements for U235 Fission Burst. (Thermal Reactor Spectrum)

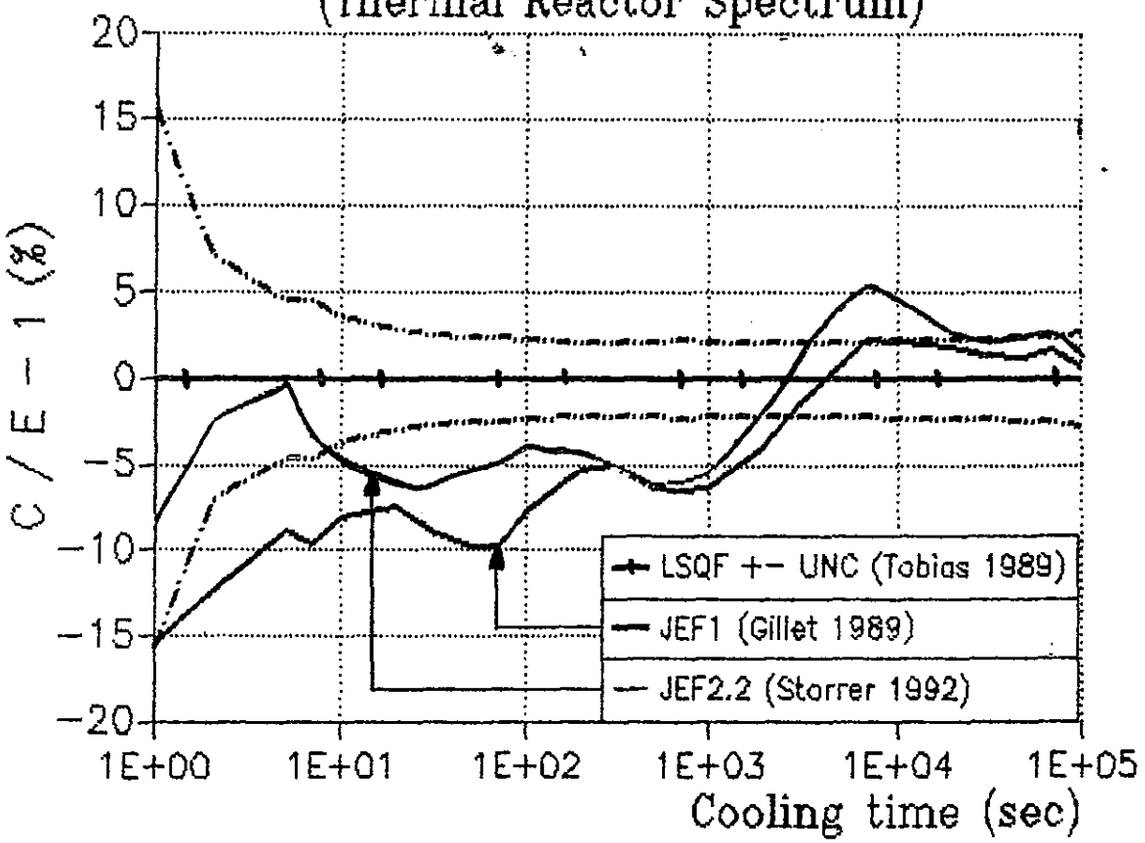

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Figure 6a :

Gamma contribution to total U235(Thermal) Decay Heat (pulse fission).

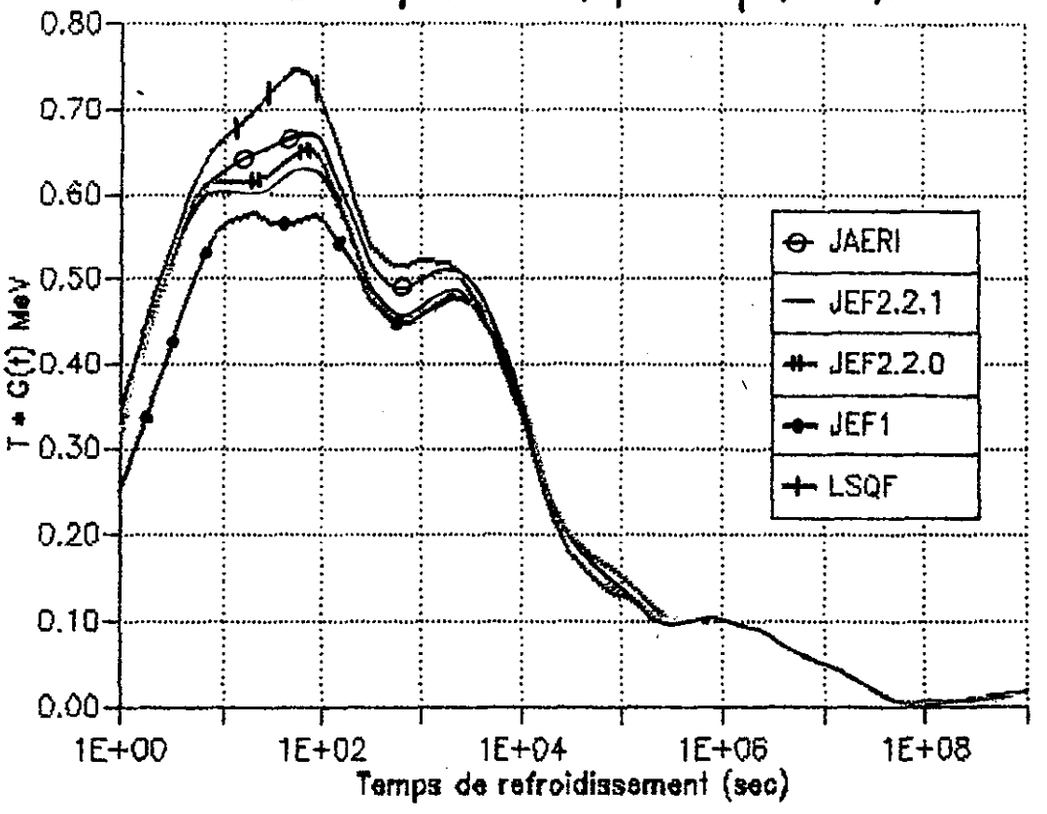

Figure 6b :

Beta contribution to total U235(Thermal) Decay Heat (pulse fission).

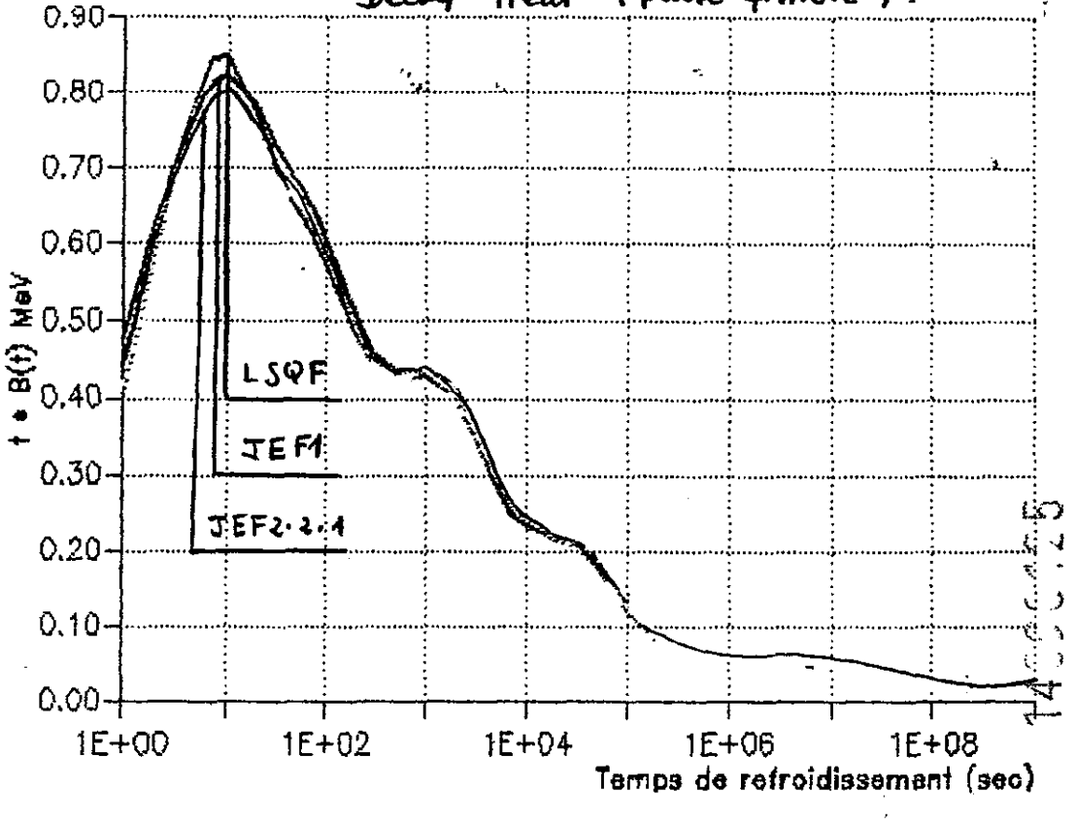

Figure 7a

JEF2.2.1 Total Decay Heat after U235T Fission Pulse showing
Rudstam and Klapdor evaluations contribution.

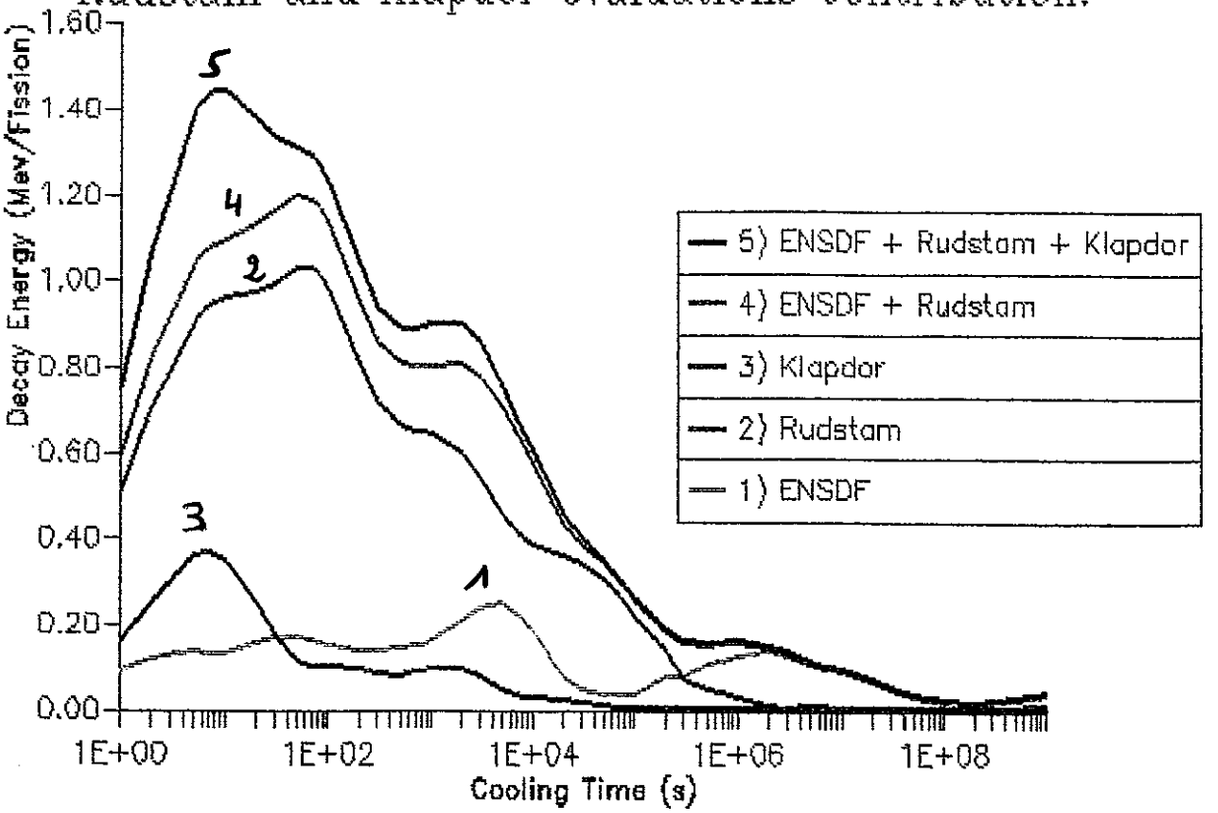

Figure 7b

JEF2.2.1 Total Decay Heat after U235T Fission Pulse showing
Rudstam and Klapdor evaluations contribution.

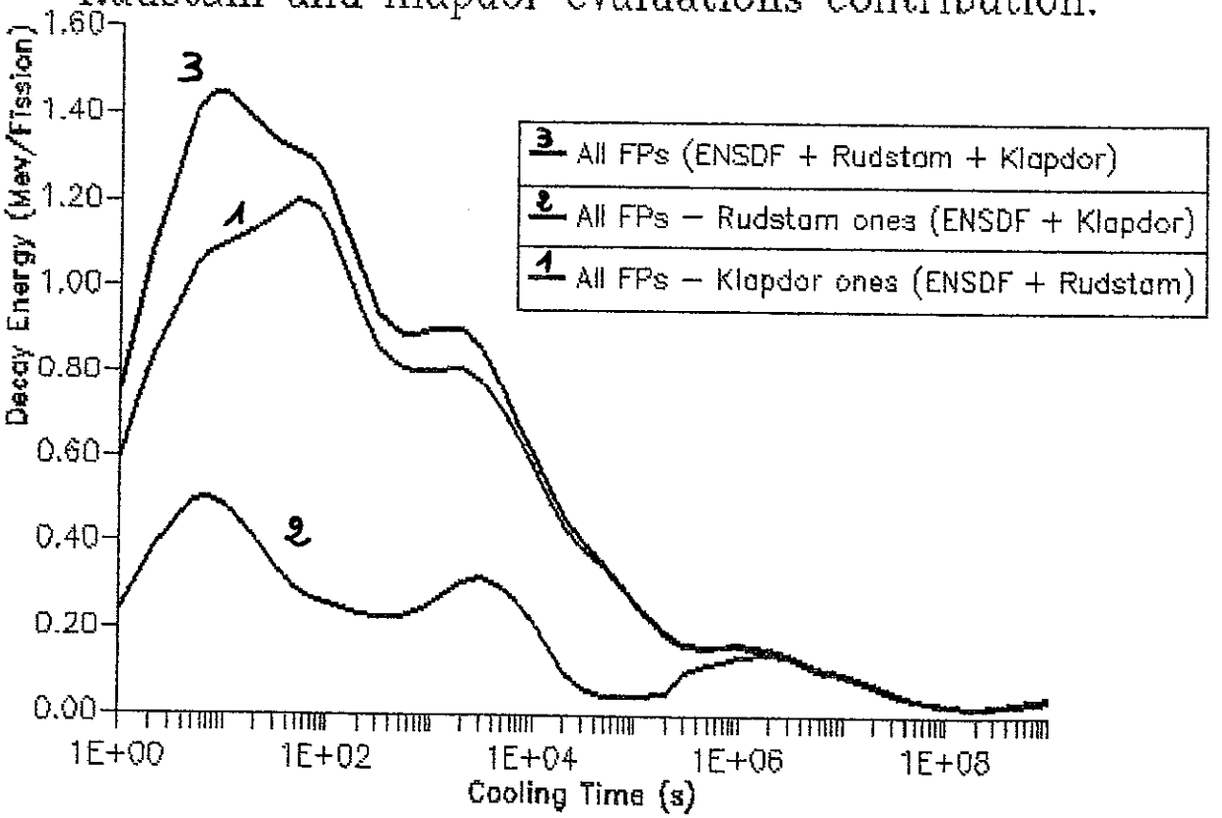

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Figure 8a

Comparison of JEF2.2.2 and JNDC-FP-V2 Decay Heat Calculations with Tobias' best fit to Measurements for U235 Thermal Fission Burst.

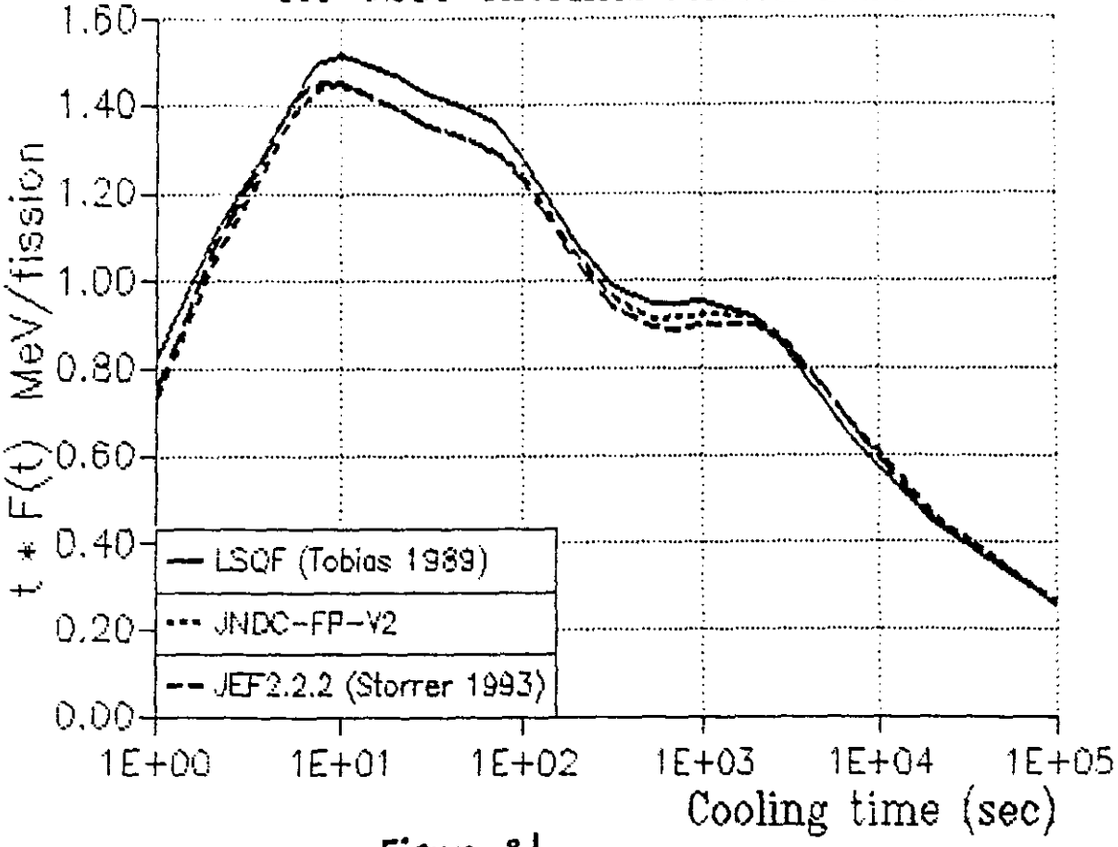

Figure 8b

Comparison of JEF2.2.2 and JNDC-FP-V2 Decay Heat Calculations with Tobias' best fit to Measurements for U235 Thermal Fission Burst.

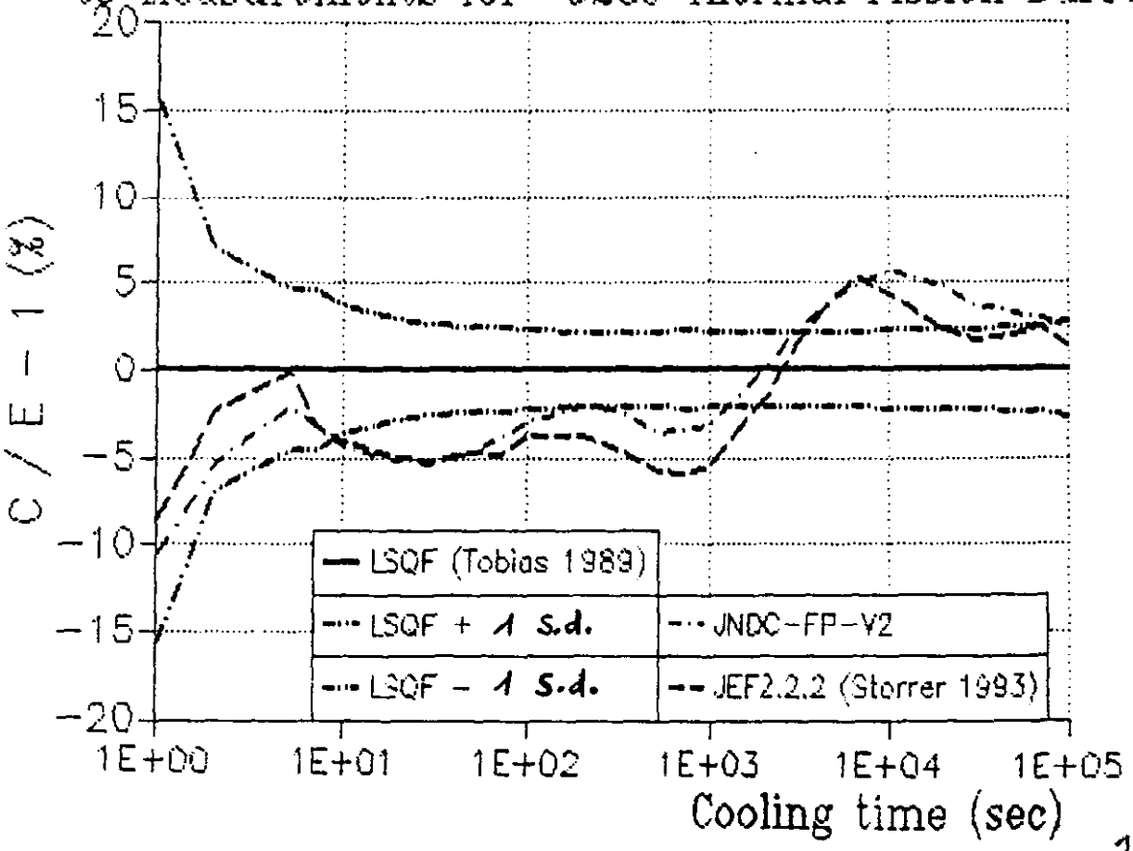

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Table 1.

	JEF1	JEF2	JNDC-FP-V2	ENDF-B-VI
Evaluated FPs	700	860	1227	891
Radioactive FPs	540	730	1078	764
Stable FPs	120	130	149	127
FPs with known decay energies. (types a and b)	540	611	536	471
FPs with estimated decay energies. (types c and d)	0	119	542	420

TABLE 2 : YIELD SETS INCLUDED IN EVALUATIONS

fissioning nucleus	ENDF/B-VI				UKFY2 (JEF-2)				Chinese		
	S	T	F	H	S	T	F	H	T	F	H
Th227		X									
Th229		X									
Th232			X	X			X	X		X	
Pa231			X								
U232		X									
U233		X	X	X		X	X	X	X		
U234			X	X			X				
U235		X	X	X		X	X	X	X	X	X
U236			X	X			X				
U237			X								
U238			X	X			X	X		X	X
Np237	X	X	X	X		X	X				
Np238			X			X	X				
Pu238			X			X	X				
Pu239		X	X	X		X	X		X	X	
Pu240		X	X	X			X				
Pu241		X	X			X	X		X		
Pu242		X	X	X			X				
Am241		X	X	X		X	X				
Am242m		X				X	X				
Am243			X			X	X				
Cm242			X		X						
Cm243		X	X			X	X				
Cm244	X		X		X	X	X				
Cm245		X				X	X				
Cm246	X		X								
Cm248	X		X								
Cf249		X									
Cf250	X										
Cf251		X									
Cf252	X				X						
Es253	X										
Es254		X									
Fm254	X										
Fm255		X									
Fm256	X										

T = thermal, F = fast, H = high (14 MeV), S = spontaneous

Table 3 : The three main standards characteristics (Ref. 38, 39 and 40)

	ANSI/ANS-5.1-1979 revised [38]	Tobias' LSQF 1989 [39]	JAERI Standard 1991 [40].
Reactor Type	LWR	both U5 and Pu9 contribution for LWR and FBR.	LWR and FBR
Fissioning Nuclides	U5T, Pu9T, U8F	U5(T+F), Pu9(T+F)	U5T, Pu9T, U8F Pu0F, Pu1T.
Irradiation Time	pulse + infinite(10^{13} s)	pulse + 20, 100, 500, 2000, 10000, 50000, 100 000 seconds.	pulse, one year, infinite (10^{13} s)
Cooling Time	1 s to 10^{13} s	1 s to 10^{5} s	0 s to 10^{13} s
Experimental Source Solely	none	U5T, U5F, Pu9T, Pu9F	none
Both Experimental and Calculation Source (fit)	U5T and Pu9T for $t_c < 10^5$ s	none	none
Summation Calculation Source	U5T and Pu9T for $t_c > 10^5$ s, U8F all t_c.	none	All nuclides.
Fast and thermal Experiments Included	no	yes	no
Spectrometric and Calorimetric Experiments mixed	yes	. no for U5 . yes for Pu9	no measurement
Database used for Calculation	ENDF-BIV	none	JNDC-FP-V2
Np9 and U9 contribution is given	yes	no	yes
Capture effect given	yes	no	yes.
Exponential Fit to burst functions	yes	not but enough irradiation times are given	yes.
Uncertainties given	yes	yes	yes

Table 4 : Phenix average energy causing fission for the main fissioning nuclides (G. GILLET private communication).

$\overline{E}_n$ fission (kev)	U 5	U 8	Pu 8	Pu 9	Pu 40	Pu 41	Pu 42
CAI 1 (Inferior Axial Blanket 1)	149	2969	407	229	1067	148	1419
Core 1	390	3217	861	568	1573	386	1795
CAI 2	150	2989	25	230	1054	150	150
Core 2	428	3262	32	618	1632	425	427

Average neutron energy in JEF2 Fission yield Library for fast breeder reactor spectrum is 400 kev.

Table 5

Total Decay Heat after U235 Thermal Pulse Fission

t (sec)	JEF2.2.2.0 (Mev/fission/sec)	JEF2.2.1 (Mev/fission/sec)	JEF2.2.2 (Mev/fission/sec)
0.000E+00	1.297369E+00	1.337656E+00	1.330515E+00
1.000E+00	7.313724E-01	7.582243E-01	7.571121E-01
2.000E+00	5.230653E-01	5.388692E-01	5.386980E-01
5.000E+00	2.754298E-01	2.791948E-01	2.794204E-01
7.000E+00	2.034108E-01	2.055668E-01	2.060890E-01
8.000E+00	1.787799E-01	1.805454E-01	1.812077E-01
1.000E+01	1.428497E-01	1.441139E-01	1.449971E-01
2.000E+01	6.850876E-02	6.876036E-02	6.974811E-02
3.000E+01	4.446360E-02	4.443675E-02	4.506272E-02
5.000E+01	2.633696E-02	2.619674E-02	2.637430E-02
7.000E+01	1.855959E-02	1.841489E-02	1.846029E-02
8.000E+01	1.603812E-02	1.590064E-02	1.592602E-02
1.000E+02	1.241527E-02	1.229781E-02	1.231328E-02
2.000E+02	5.209161E-03	5.165256E-03	5.190141E-03
3.000E+02	3.143190E-03	3.121490E-03	3.140474E-03
5.000E+02	1.781727E-03	1.771986E-03	1.779181E-03
7.000E+02	1.271819E-03	1.266530E-03	1.269299E-03
8.000E+02	1.116840E-03	1.112886E-03	1.114703E-03
1.000E+03	9.005412E-04	8.982829E-04	8.991764E-04
2.000E+03	4.507109E-04	4.503451E-04	4.504417E-04
3.000E+03	2.849180E-04	2.846164E-04	2.845634E-04
5.000E+03	1.503946E-04	1.500711E-04	1.499496E-04
7.000E+03	9.670030E-05	9.635199E-05	9.621999E-05
8.000E+03	8.095612E-05	8.059570E-05	8.046334E-05
1.000E+04	5.996561E-05	5.958496E-05	5.945531E-05
2.000E+04	2.318732E-05	2.279133E-05	2.269465E-05
3.000E+04	1.373340E-05	1.337549E-05	1.331434E-05
5.000E+04	7.237802E-06	6.957073E-06	6.931805E-06
7.000E+04	4.596503E-06	4.375247E-06	4.362355E-06
8.000E+04	3.810332E-06	3.613486E-06	3.603538E-06
1.000E+05	2.768412E-06	2.612213E-06	2.605578E-06
2.000E+05	9.939551E-07	9.441707E-07	9.425759E-07
3.000E+05	5.639059E-07	5.481326E-07	5.479134E-07
5.000E+05	3.167134E-07	3.153278E-07	3.155459E-07
7.000E+05	2.283640E-07	2.284386E-07	2.286076E-07
8.000E+05	2.004783E-07	2.006591E-07	2.007988E-07
1.000E+06	1.601375E-07	1.603511E-07	1.604488E-07
2.000E+06	7.533758E-08	7.549368E-08	7.555085E-08
3.000E+06	4.608661E-08	4.619918E-08	4.626408E-08
5.000E+06	2.311734E-08	2.317674E-08	2.324460E-08
7.000E+06	1.489196E-08	1.492237E-08	1.498232E-08
8.000E+06	1.266151E-08	1.268254E-08	1.273741E-08
1.000E+07	9.716196E-09	9.724588E-09	9.769443E-09
2.000E+07	3.583385E-09	3.575294E-09	3.589139E-09
3.000E+07	1.688461E-09	1.679808E-09	1.684075E-09
5.000E+07	7.052196E-10	6.971274E-10	6.984073E-10
7.000E+07	4.220556E-10	4.142481E-10	4.156195E-10
8.000E+07	3.408018E-10	3.331021E-10	3.345725E-10
1.000E+08	2.343319E-10	2.268157E-10	2.284256E-10
2.000E+08	9.295417E-11	8.608703E-11	8.778282E-11
5.000E+08	6.481866E-11	5.935138E-11	6.070932E-11
7.000E+08	5.559174E-11	5.089016E-11	5.205487E-11
8.000E+08	5.153922E-11	4.717944E-11	4.825847E-11
1.000E+09	4.433386E-11	4.058484E-11	4.151177E-11

Table 6

Total Decay Heat after Pu239 Thermal Pulse Fission

t (sec)	JEF2.2.2.0 (Mev/fission/sec)	JEF2.2.1 (Mev/fission/sec)	JEF2.2.2 (Mev/fission/sec)
0.000E+00	8.243262E-01	8.422455E-01	8.674298E-01
1.000E+00	5.177025E-01	5.288170E-01	5.384248E-01
2.000E+00	3.795165E-01	3.858273E-01	3.883217E-01
5.000E+00	2.020171E-01	2.032717E-01	2.014595E-01
7.000E+00	1.501708E-01	1.507238E-01	1.493679E-01
8.000E+00	1.325108E-01	1.328940E-01	1.318765E-01
1.000E+01	1.067663E-01	1.069416E-01	1.065445E-01
2.000E+01	5.285060E-02	5.267740E-02	5.343928E-02
3.000E+01	3.488223E-02	3.465072E-02	3.528282E-02
5.000E+01	2.100894E-02	2.080472E-02	2.102000E-02
7.000E+01	1.493470E-02	1.477494E-02	1.483453E-02
8.000E+01	1.294537E-02	1.280527E-02	1.283526E-02
1.000E+02	1.006934E-02	9.961938E-03	9.967704E-03
2.000E+02	4.328282E-03	4.293229E-03	4.290594E-03
3.000E+02	2.706812E-03	2.687846E-03	2.687140E-03
5.000E+02	1.638377E-03	1.628766E-03	1.629294E-03
7.000E+02	1.221032E-03	1.215608E-03	1.216352E-03
8.000E+02	1.087141E-03	1.083022E-03	1.083822E-03
1.000E+03	8.904395E-04	8.880104E-04	8.889075E-04
2.000E+03	4.387800E-04	4.383286E-04	4.395071E-04
3.000E+03	2.680138E-04	2.676627E-04	2.687849E-04
5.000E+03	1.337556E-04	1.333938E-04	1.341265E-04
7.000E+03	8.235210E-05	8.197164E-05	8.239061E-05
8.000E+03	6.781331E-05	6.742506E-05	6.773409E-05
1.000E+04	4.902587E-05	4.862676E-05	4.878331E-05
2.000E+04	1.834913E-05	1.796512E-05	1.790367E-05
3.000E+04	1.106082E-05	1.072636E-05	1.065855E-05
5.000E+04	6.140495E-06	5.889520E-06	5.845720E-06
7.000E+04	4.068282E-06	3.875100E-06	3.845764E-06
8.000E+04	3.430183E-06	3.259567E-06	3.234769E-06
1.000E+05	2.563293E-06	2.429130E-06	2.410486E-06
2.000E+05	1.009413E-06	9.673589E-07	9.603550E-07
3.000E+05	5.946885E-07	5.818871E-07	5.787231E-07
5.000E+05	3.301663E-07	3.297302E-07	3.289902E-07
7.000E+05	2.301258E-07	2.308821E-07	2.306925E-07
8.000E+05	1.988184E-07	1.996324E-07	1.995339E-07
1.000E+06	1.544159E-07	1.551937E-07	1.551636E-07
2.000E+06	6.726782E-08	6.776145E-08	6.776460E-08
3.000E+06	4.020225E-08	4.052291E-08	4.053580E-08
5.000E+06	1.987143E-08	2.001769E-08	2.003556E-08
7.000E+06	1.274123E-08	1.281264E-08	1.282986E-08
8.000E+06	1.083656E-08	1.088681E-08	1.090318E-08
1.000E+07	8.364286E-09	8.388240E-09	8.402510E-09
2.000E+07	3.437804E-09	3.429969E-09	3.435525E-09
3.000E+07	1.903116E-09	1.894317E-09	1.896464E-09
5.000E+07	9.577935E-10	9.511476E-10	9.519970E-10
7.000E+07	5.949134E-10	5.897446E-10	5.905171E-10
8.000E+07	4.789695E-10	4.743304E-10	4.751052E-10
1.000E+08	3.185600E-10	3.146981E-10	3.154792E-10
2.000E+08	7.866443E-11	7.618314E-11	7.692707E-11
5.000E+08	4.041236E-11	3.855453E-11	3.913528E-11
7.000E+08	3.451053E-11	3.291384E-11	3.341195E-11
8.000E+08	3.198816E-11	3.050793E-11	3.096981E-11
1.000E+09	2.753463E-11	2.626252E-11	2.666010E-11