Draft Report

Review of Decay Heat Predictions and Standards.
Meeting of the JEF Working Group on Radioactive Decay and Fission Yield Data,
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F. STORRER

Abstract:

Decay heating estimates are necessary for determining the heat removal requirements when the reactor is shutdown, and for fuel storage and transport facilities as well as for accident studies.

Because of the underestimation of summation calculations at short cooling times, different decay heat standards have been produced based on a best fit to the direct measurements together with the summation calculations, taking into account the relative uncertainties.

Today one should notice the development of new decay and fission yields libraries (JEF2, ENDF-B/VI, JNDC-FP-V2) which are more extensive and more reliable because of:

- the accumulation of accurate experimental data for short-lived individual fission products (such as Rudstam's measurements),
- the successful application of beta decay theories either to evaluate data for unmeasured fission products or to supplement their nuclear level schemes.

This has led to a reduction of the decay heat underestimation by summation calculations compared to integral measurements as well as the production/revision of new/old standards (AESJ, ISO, ANS. Tobias best fit).

Because there have been no recent integral measurements, research has been directed to full use of (covariance) information included in the existing experimental data in order to avoid such small uncertainties resulting from the best fit curves.

Some suggestions are presented here to get a new extended and improved decay heat standard.

1) Decay Heat Sources.

For all kinds of nuclear reactors [1], the decaying fission products (FPs) represent the main component of heat production following reactor shut-down. Underestimation of this source at short cooling times by summation calculation depends on known (or evaluated) FPs in the Radioactive Decay and Fission Yield libraries. Data for more than 700 FPs are now available (Table.1).

Actinide decay (mainly due to U239 and Np239 for times corresponding to a LOss of Coolant Accident) and the activation of structural materials can make a small contribution and account must also be taken of FPs transmutation.

In a conventional Light Water Reactor, **the capture effect on FPs** [2] is small (~± 2%) excepting for cooling times between about $10^7$and 10^9 seconds when it increases to about 10% owing to the contributrion of the capture products Cs134, and to a lesser extent Pm148M and Eu154 which are also important (Figure 1, Table 2).

In a fast reactor spectrum, the effect is also small excepting for cooling times of about 10^8 sec when it is again the contribution of the capture product Cs134 which is important, increasing the decay heating by about 5% (Figure 2). There are also small contributions from Cs136, Pm145M and Eu154 (Table 2).

The transmutation is of course more important in a LWR than in a FBR because of the following fact:

$$\left.\frac{\sigma_c\,(FPs)}{\sigma_f\,(Actinides)}\right]_{FBR} << \left.\frac{\sigma_c\,(FPs)}{\sigma_f\,(Actinides)}\right]_{LWR}$$

The requirement is for the contribution of the FPs capture effect to be estimated to an accuracy of about 20 % [3]. That is why inventory codes need realistic neutron spectra and good cross-sections for longer lived and stable species.

Fissions caused by **delayed neutrons** and other neutron sources [1] (spontaneous fissions, (α,n) reactions...) can also contribute to decay heat. The size of this contribution depends on the effective multiplication k_{eff} and is described by the following equation:

$$\frac{n}{n_o} = \frac{\beta}{\beta-\rho}\,\mathbf{exp}\quad \rho\frac{\lambda t}{\beta-\rho} \qquad \text{with} \qquad \rho = \frac{k_{eff}-1}{k_{eff}}$$

This contribution is not negligible at times shorter than about 30 sec. For a shut-down reactivity margin of about 4% in a thermal ractor the delayed neutron contribution is about 10% at 1 sec cooling time. By 100 sec the contribution has decreased to about 10^{-4} (Table 3), and is of course greater when the shut-down reactivity margin $(1 - k_{eff})/k_{eff}$ is smaller. Owing to relative reactor dynamic parameters (Table 3), this power lasts longer in a FBR than in a LWR.

The contribution of delayed neutrons should be taken into account and the requirements is for a 10 % accuracy [3].

2°) Decay Heat Standards.

As is explained by Tobias [1], 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 fissioning 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 fissioning systems).

These decay heat burst functions are also called **Elementary Fission Curves** (EFC) and give only the FPs' decay heat contribution.

Because of the underestimation of summation calculations, several decay heat standards have been produced and revised, as a consequence of nuclear data improvements. Differences appear in the way to get these standards depending on the basis of the recommended values, either on calculational, calculational plus experimental, or only experimental basis.

2.1 The American ANS-5.1-1979 decay heat standard.

Schmittroth and Schenter produced in 1979 the American National Standard [4] for Light Water Reactors (Table 4a and 4b). Elementary Fission Curves are represented in the form of a sum of exponentials for FP's decay heat contribution. The coefficients of the exponentials were obtained as a best fit to the direct measurements of total decay heat, and the beta and gamma components when they exist, together with the summation calculations, taking into account the relative uncertainties. As indicated in table 4, three fissioning 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 determined by calculation.

Actinide decay heat power is separately prescribed with two simplified inventory Bateman equations corresponding to U239 and Np239 decay.
The decay of structural material activation is neglected.

2.2 The European decay heat standards.

Three european standards are available:
- the german DIN 25463 (Table 4a) standard [5] in which there is :
  - a separate treatment of Cs133 capture,
  - a table of conservative values for actinide decay heat (U239 and Np239 excluded).
- the ISO standard [6] (Table 4a) which is an improvement based on ANS-5.1 and DIN-25463. This has taken into account ANS-5.1 improvements such as an explicit treatment of Pu241 (tabulation of its expansion parameters with 24 values), a reevaluation of mean energies, and includes the main DIN features (in particular Cs133 capture and actinide contribution).
- the UK recommended decay heat predictions for reactor applications. This standard is based on the work of Tobias [7] who compared benchmark decay heat data for U235 and Pu239 with summation calculations derived from the JEF1 fission yields and decay data, and using the FISPIN or FISP codes. He also quantified the systematic and random errors in the predictions. The benchmarks (Table 4b) in these comparisons were obtained from least squares fits (similar to the Schmittroth and Schenter mathematical techniques) to recent measured integral decay heat data, made after 1979 (mainly those of Baumung [8], Akiyama [9], and Johansson [10]). It was found (Figure 3) that for decay times greater than 10^5 sec, the summation calculations are free from systematic errors and are accurate to ~± 5 % for both U235 and Pu239. At shorter decay times, the JEF1 predictions are accurate to ~± 3.5 % when they have been increased by factors that decrease from 8.5 % at a cooling time of 1 sec to zero at 10^5 sec because of deficiencies in the data for short lived fission products.

Some hypotheses are made in the Tobias updated best fit which may be worth reconsidering.
The first one consists of including Akiyama measurements of fast fission "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 5). 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. Even if it is true that fast and thermal measurements appear to be close there is no argument to mix them unless there are independent arguments based on a systematic study of the variation law of yields with incident neutron energy.
The second one is to include both calorimetric and spectroscopic measurements which are known to be inconsistent [11] (the so-called ORNL [12]-LANL [13] discrepancy). As pointed

out by Dickens [11], there are two major problems with calorimetric experiments; one is absolute determination of the number of fissions in the sample and the other is the determination of the time dependence of the response of the calorimeter.

The third hypothesis concerns the uncertainties evaluation. Tobias, as well as Schmittroth and Schenter, have not used covariances for experimental data, even the complete ORNL ones published by Dickens [12]. They were influenced by the prevailing notion at the time of their study that the ORNL data for U235 had an overall normalization error of about 8 %. So they set a special normalization value for each of the data sets that they utilized (the fitting procedure requires the published uncertainties on some of the measurements to be increased to achieve consistency). As a consequence the values for U235 decay heat in the standards were strongly influenced by the ORNL relative time-dependence but weakly influenced by the absolute values [14]. However, the resulting uncertainties in the Tobias's best fit data are calculated to be very small (1% or 2% (1σ) after a 10 sec decay). Tobias has refined his fit in 1989 [15]. He has increased these uncertainties because of the modifications made in the published uncertainties and recommends a reassessment of the measurement uncertainties or further measurements. For irradiation times of between 10^4 and 10^9 sec and decay times of between 1 and 10^3 sec, Tobias estimates the uncertainty in the best fit data to be about $\pm$ 2 % (1σ) for U235 and $\pm$ 4% for Pu239. For longer decay times (up to 10^8 sec or about 3 years) the uncertainties increases to $\pm$ 4 % for U235 and $\pm$ 5 % for Pu239. The differences between Tobias's best fit data and the ANS standard for a fission pulse are small for U235 (~$\pm$ 2 %) but are larger for Pu239, Tobias's fit being 5 % higher at 3sec decay and 3 % smaller between 10^3 and 10^5 sec.

Anyway, we should wonder how are uncertainties to be treated when data are discrepant. Is it right just to scale by χ^2/N or should different hypotheses for the discrepancies be considered ?

We should notice that differents strategies also exist in getting uncertainties from summation calculations. Rebah has demonstrated [16] (Figure 4 and 5) that a fully correlated uncertainty calculation for half-life, fission yield and total mean energy is pessimistic (uncertainty around 10 % which is an overestimate) whereas a zero correlated calculation is optimistic (uncertainty around 4 % which is an underestimate). That why he has developed a new theoretical approach using a covariance sub-matrix based on Wahl's (Zp-Z) parameter for the independant fission yield interpolation law. Thus, intermediate results are obtained and seem to be consistent with Tobias best fit uncertainties as well as the ANS ones (Figure 5).

The table 6 gives the target decay heat uncertainties for the main fissioning nuclides, according to James's analysis [17] (with the order I and II of priority).

2.3 The Japanese AESJ decay heat standard.

The Japanese recommended values (Table 4a and 4b) are given for five fissioning systems [18]:
U235 T, Pu239T, U238 F, Pu240 F, Pu241 T.
This standard is applicable for LWR, BWR as well as FBR. Through the comparative analysis, primary importance was placed on Akiyama's measurements, which were carried out in close cooperation with the calculational efforts of JNDC (the Japanese Nuclear Data Committee) since the late 1970s. The recommended values are completely based on summation calculations with the JNDC FP Nuclear Data Library Version 2 which was released in 1990, since they reproduced quite well the measurements. This fact is attributable to the introduction of theoretical data for short-lived FPs [19]. But the remaining underestimation of Pu239 decay heat from 400 to 3,000 seconds after a fission burst must be compensated for by allowing a proper margin when applied to real situations.

2.4 The American ANS-5.1-1993 revised decay heat standard.

The ANS-5.1 Working Group of the American Nuclear Society was reactivated to revise and to extend the 1979 draft of the ANS/ANSI standard. The main proposed improvements [20] [21] are the following ones:
- to extend the cooling time region to which the standard applies from 10^9 to 10^{10} seconds.
- to recommend new uncertainties for Pu239 and U235 according to the Tobias's best fit.
- to revise the fast fission U238 decay heat values, recalling that these values were obtained exclusively by calculation at a time when no integrally measured data were available.
- to add specific recommended decay heat values for Pu241. The 1979 standard did not give a separate set of values and prescribed that U235 values should be used for contributions from all other fissioning actinides other than Pu239 and U238.

One should notice that no values are given for Pu240 which is mostly fissioning by fast neutrons. More details are presented about this 1993 revision in the appendix 1.

3) Standards Comparison.

Table 7 [22] compares the AESJ recommendation with ANS-5.1-1979 and the proposed ISO standards for typical LWR operating conditions. ANS-5.1-1979 exceeds the AESJ standard by about 6 %. Almost one half of this difference arises from the difference in total fission energy which is used to normalize the decay heat power. Except for this, the difference is moderate, about 3 % on average, as one can see in the second column of the table.

Figures 6 and 7 show the differences between ANS and AESJ (JAERI-M-094 on viewgraph) standards relative to Tobias's best fit for both U235 and Pu239.
It is obvious that of the three standards, the AESJ 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 great progress in the 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's experimental fit is below the ANS standard (with partial caculational basis) and the AESJ 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 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.

4°) Summation calculations with JEF2.

The Tobias's best fit for cooling times below 10^5 seconds is therefore the only standard entirely based upon decay heat measurements for U235 and Pu239, that is why it will be retained in our JEF2 calculation to experiment comparison [23].
As is shown on figure 8 for U235 T, JEF2 decay heat calculations are obviously better than JEF1 ones at short cooling times because of the new decay data evaluations (based on Rudstam's experimental values and Klapdor's theoretical ones [24]). The JEF2 C/E values are negative and estimated to be ~5 % smaller (on average) than JEF1 values up to 8.10^2 sec cooling time for a fission pulse. Above 8.10^2 sec, JEF2 C/E values are positive and ~2 % greater than JEF1 ones. But the Tobias best fit, compared to other standards, seems to underestimate the decay heat around 10^4 sec cooling time. That is why we are confident in the JEF2 results.
For Pu239 (Figure 9), the situation is more delicate because JEF2 gives similar results to JEF1.
However, the "pandemonium effects" on gamma an beta decay heat components (over-estimation of mean beta energy, and under-estimation of gamma one, with balance on the total) are reduced using JEF2 [24].
We have also verified that our results are consistent with Tobias JEF2 summation calculations made using FISPIN code [25]. As a consequence, the UK recommended decay heat predictions based on JEF1 are going to be revised for application with JEF2.

CONCLUSION

Because of the underestimation of summation calculations, several decay heat standards have been produced and revised, as a consequence of nuclear data improvements. Differences appear in the way to get these standards depending on the basis of the recommended values, either on calculational, calculational plus experimental, or only experimental basis.

This work suggests to gather improvements implemented in some existing standards that we have compared such as:

- to produce a multi-application standard treating LWR with UO2 and PuO2 fuel, BWR, as well as FBR,
- to refine the fitting procedure of decay heat predictions following a fission pulse. It should rely on integral decay heat measurements as well as on calculational basis, even for uncertainties evaluation with covariance formalism.
- to enlarge the number of fissioning species taken into account in the standard (U235, U238, Pu239, Pu240, Pu241 at least), and to improve their experimental basis,
- to define all decay heat sources even if they happen to be small (fissions caused by delayed neutrons, contribution of other actinides than U239 and NP239, which may not be negligible for MOX fuel, stuctural material activation),
- to separate calorimetric from spectrometric measurements because they are inconsistent (the so-called ORNL-LANL discrepancy) in the best fit to measured data,
- to separate thermal from fast spectrum measurements, or to propose a variation law of the yields with incident neutron energy in the best fit to measured data,
- to recommend an evaluation for the energy release due to fission.

Table 1: Comparison of main features decay data libraries [24].

	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.	540	611	536	471
FPs with estimated decay energies.	0	119	542	420

Table 2: Main FPs'contibution to the capture effect [2].

- ***10^6 s cooling time:***

a) **LWR** : Cs 133 → Cs 134 (17 %), Pm 147 → Pm 148 (14 %), Pm 147 → Pm 148M (60 %), Eu 155 → Eu 156 (6 %).

b) **FBR** : Ru 102 → Ru 103 (15 %), Cs 133 → Cs 134 (13 %), Cs 135 → Cs 136 (31 %), Pm 147 → Pm 148M (27 %), Pm 147 → Pm 148 (7 %), Eu 155 → Eu 156 (7 %).

- ***10^8 s cooling time for both LWR and FBR:***
Cs 133 → Cs 134 (~90 %), Eu 153 → Eu 154 (~10 %).

Table 3: Delayed neutron contribution to decay heat with cooling time for both LWR and FBR

We take:
$\beta(U235) \approx 560$ pcm, with $\lambda(U235) \approx 1/13$ sec^{-1},
$\beta(Pu239) \approx 210$ pcm, with $\lambda(Pu239) \approx 1/16{,}4$ sec^{-1},
and to get a shut-down reactivity margin of about 4 % : $\rho/\beta = -7$

This has led to the following tables :

a°) LWR :

t (s)	0,1	1	10	100
$\frac{n}{n_0}$ (%)	12,416	11,7	6,37	0,0149

a°) FBR :

t (s)	0,1	1	10	100
$\frac{n}{n_0}$ (%)	12,43	11,85	7,33	0,06

Table 4a: Contents of standards and proposed standards on decay heat power.

Item	ANS-5.1[a]	DIN (German)[b]	JAERI[c]	ISO[d]
^{235}U tabulated[e]	Yes	No	Yes	No
^{235}U coefficient[f]	Yes	Yes[g]	Yes	Yes[g]
^{239}Pu tabulated[e]	Yes	No	Yes	No
^{239}Pu coefficient	Yes	Yes[g]	Yes	Yes[g]
^{238}U tabulated[e]	Yes	No	Yes	No
^{238}U coefficient	Yes	Yes[g]	Yes	Yes[g]
^{241}Pu tabulated[e]	No	No	Yes[h]	No
^{241}Pu coefficient	No	No	Yes	Yes
Actinide contribution	^{239}U – ^{239}Np only	^{239}U – ^{239}Np, single curve for remainder	^{239}U – ^{239}Np	^{239}U – ^{239}Np, single curve for remainder
Capture contribution	Single curve, $G(t)$	^{134}Cs + single curve for remainder[i]	Several choices[j]	^{134}Cs + single curve for remainder[i]
Q values[k]	No	Yes	Yes	Yes

[a]American National Standard.
[b]German National Standard.
[c]Proposed Japanese Standard.
[d]Proposed International Standards Organization Standard.[12]
[e]Tabulated, tabulated values, $f(t)$ vs. t and $F(t,\infty)$ vs. t.
[f]Coefficient, (α,λ) coefficients (see Eqs. 1 and 2).
[g]Values of (α,λ) taken from the American standard. Also included are valuess of (β,λ), where the β coefficients determine uncertainties assigned to $f(t)$ and $F(t,T)$.
[h]JAERI proposal also includes data for fast fission of ^{240}Pu and also tabular data for low-resolution gamma-ray spectra.
[i]Contribution for the dominant isotope, ^{134}Cs, is computed separately, and the contribution of the remaining capture reactions is treated as a correction factor from tabular data.
[j]The choice is similar to the American standard except that three curves are given: one each for a "typical" PWR, BWR, and FBR. A second choice is similar to the German standard: computation of ^{134}Cs contribution plus a curve for the remainder, depending on reactor type.
[k]Total recoverable energy (see Definition of Terms).

Anticipated Evolution of the ANS-5.1 Decay Heat Power Standard

1973 Draft	1979 Adopted	1991 Proposed[a]	Future
^{235}U (±20%)[b]	^{235}U (2 to 4%)[c]	Extension[d]	Separate beta- and gamma-ray components, gamma-ray spectra
All other fuel elements to be treated as ^{235}U	^{235}Pu (4 to 6%)[c]	Extension;[d] improved uncertainties	Separate beta- and gamma-ray components, gamma-ray spectra
	^{235}U fast fission (4 to 12%)[c,e]	^{238}U revision and improved uncertainties	Separate beta- and gamma-ray components, gamma-ray spectra
	All other fuel elements to be treated as ^{235}U	Separate data set for ^{241}Pu, thermal fission	Separate beta- and gamma-ray components and include separately other fuel elements and other neutron energies
	^{239}U/^{239}Np included; other actinide heating not included	First estimate for other actinide contributions	Complete estimate for other actinide contributions
	Total recoverable energy Q not included	Include Q for major elements	Include Q for all fissile elements
	Single curve for neutron capture correction, $G(t)$	Some improvement desired	Improved method

[a]Proposed improvements that can be incorporated before the next renewal.
[b]Curve and uncertainty only for "infinite" irradiation.
[c]Data and uncertainties given for both "pulse" and "infinite" irradiations; values in parentheses represent uncertainty range for "infinite" irradiation case.
[d]Extension of cooling times from 10^9 to 10^{10} s.
[e]Standard obtained only from calculated data.

Table 4a: Features comparison of American [4], UK [15] an Japanese [18] standards.

	ANSI/ANS-5.1-1979 revised	Tobias' LSQF 1989	JAERI Standard 1991
Reactor Type	LWR	both ^{235}U and ^{239}Pu contribution for LWR and FBR.	LWR and FBR
Fissioning Nuclides	^{235}UT, ^{239}PuT, ^{238}UF	$^{235}U(T+F)$, $^{239}Pu(T+F)$	^{235}UT, ^{239}PuT, ^{238}UF ^{240}PuF, ^{241}PuT.
Irradiation Time	pulse + infinite (10^{13} s)	pulse + 20, 100, 500, 2000, 10 000, 50 000, 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	^{235}UT, ^{235}UF, ^{239}PuT, ^{239}PuF	none
Both Experimental and Calculation source (fit)	^{235}UT and ^{239}PuT for $t_c < 10^{5}$ s	none	none
Summation Calculation Source	^{235}UT and ^{239}PuT for $t_c > 10^{5}$ s, ^{238}UF all t_c.	none	All nuclides.
Fast and thermal Experiments Included	no	yes	no
Spectrometric and Calorimetric Experiment mixed	yes	• no for ^{235}U • yes for ^{239}Pu	no measurement
Database used for Calculation	ENDF-BIV	none	JNDC-FP-V2
N_{pq} and ^{239}U 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 5: Phenix average neutron energy inducing fission on major actinides.
(G. GILLET private communication).
JEF2 Fast Fission Yields are given for <En> = 400 KeV.

CAI = Inferior Axial Blanket 1
(Couverture Axiale Inférieure 1)

En fission (KeV)	U5	U8	Pu8	Pu9	Pu40	Pu41	Pu42
CAI 1 (couverture axiale inférieure)	149	2969	407	228	1067	148	1418
Coeur 1	390	3217	861	568	1573	386	1795
CAI 2 (couverture axiale inférieure 2)	150	2989	25	230	1054	150	150
Coeur 2	428	3262	32	618	1632	425	427

Table 6: Target decay heat uncertainties (with the order of priority) [17].

Fissioning System	Cooling Time: 1 - 20 s req %	20 - 10^4 s req %	10^4 - 10^6 s req %	10^6 - 10^7 s req %	10^7 - 10^8 s req %
Thermal					
U 235	10(I) 5(II)	5(I) 2(II)	10(I) 5(II)	10(I) 5(II)	≤5(I)
Pu 239	10(I) 5(II)	5(I) 2(II)	10(I) 5(II)	10(I) 5(II)	≤5(I)
U 233	10(II) 5(III)	5(II) 2(III)	10(II) 5(III)	10(II) 5(III)	≤5(II)
Pu 241	30(I) 15(II)	15(I) 6(II)	30(I) 15(II)	30(I) 15(II)	≤15(I)

	10^2 - 10^7 s required %	10^7 - 10^8 s required %	Integrated Over Time 0 - 10^5 s required %
Fast			
U 235, Pu 239	10(I) 5(II)	≤ 5(I)	10(I)
U 238 Pu 241	30(I) 15(II)	≤15(I)	30(I)
Th 232	30(II) 15(III)	≤15(II)	30(II)

Table 7: A comparison of new and old decay-heat standards for a typical LWR operation history [22].

cooling Time (sec)	ANS5.1(1979) (1)fission energies 200MeV for all	ANS5.1(1979) (2)fission energies taken from AESJ (for reference)	ISO Draft (1990)	AESJ (1989) (=JNDC)
1	5.74 (1.06)	5.59 (1.04)	5.54 (1.03)	5.40
10	4.64 (1.07)	4.34 (1.04)	4.29 (1.03)	4.16
100	2.93 (1.07)	2.85 (1.04)	2.81 (1.02)	2.75
$1x10^3$	1.77 (1.06)	1.72 (1.03)	1.69 (1.01)	1.67
$1x10^4$	0.849 (1.05)	0.826 (1.02)	0.808 (1.00)	0.811
$1x10^5$	0.416 (1.04)	0.404 (1.01)	0.399 (1.00)	0.399
$1x10^6$	0.204 (1.06)	0.199 (1.03)	0.196 (1.02)	0.193
$1x10^7$	0.0611 (1.06)	0.0594 (1.03)	0.0593 (1.03)	0.0574
$1x10^8$	0.00595 (1.03)	0.00578 (1.00)	0.00594 (1.03)	0.00577

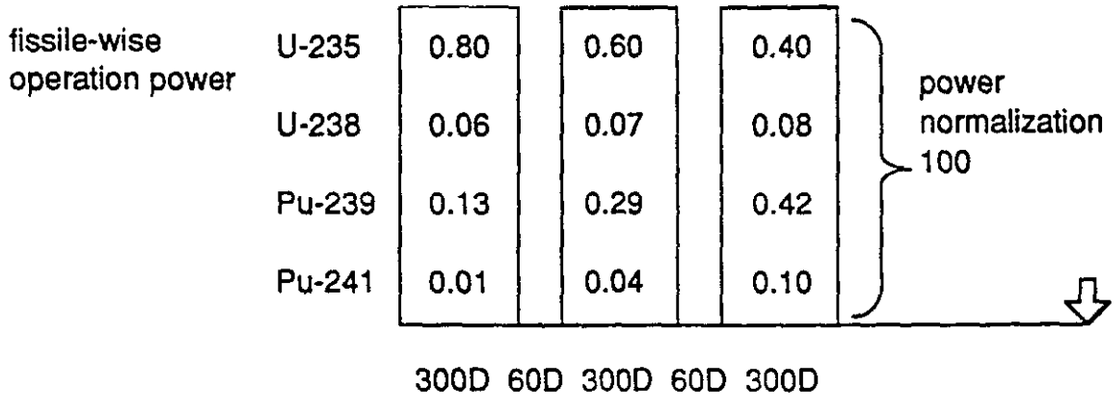
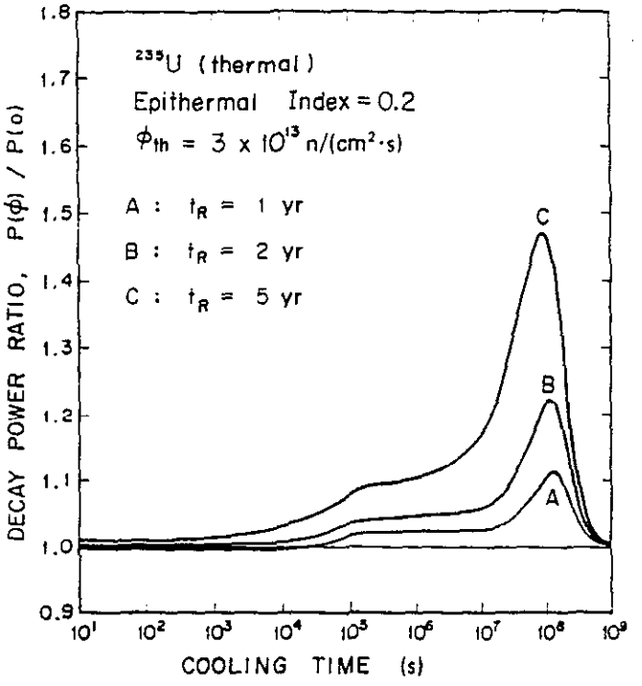
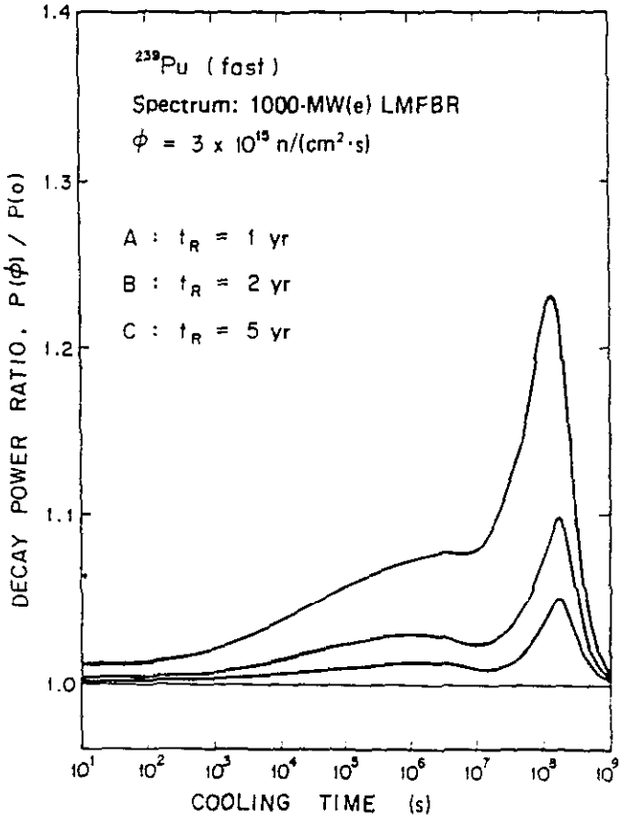


Figure 1: FPs capture effect in a LWR [2].



The effect of irradiation time on the neutron capture effect was examined for the thermal fission of ^{235}U in an LWR.

Figure 2: FPs capture effect in a FBR [2].



The effect of irradiation time on the neutron capture effect was examined for the fast fission of ^{239}Pu in an FBR.

Figure 3: Adjustment Factors for JEF1 Decay Heat Predictions [7].

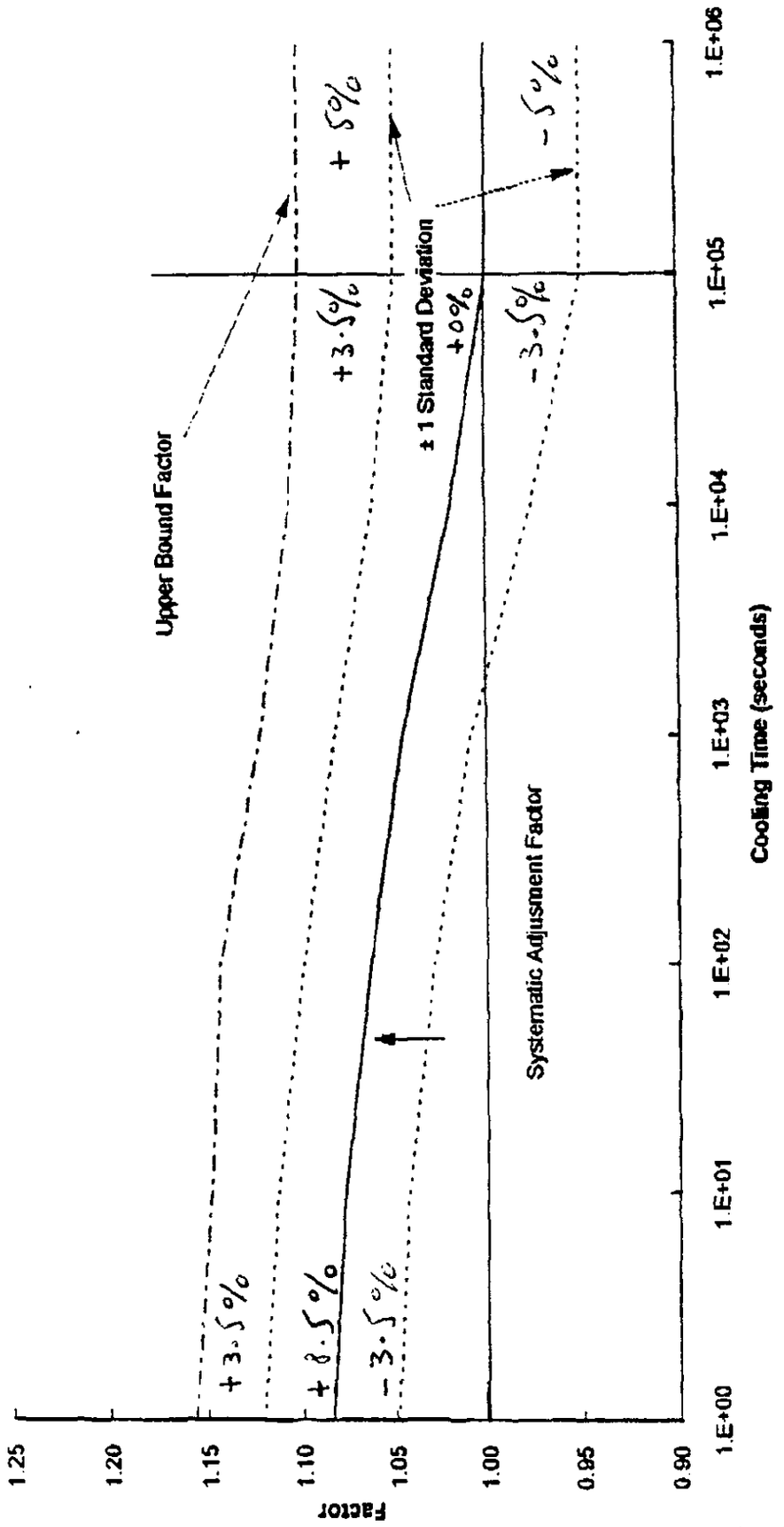


Figure 4: Comparison of U235 calculated decay heat uncertainties for a fission pulse on λ (= Ln2 / T 1/2), Fission Yield, Total Mean Decay Energy (fully and zero correlated) [16].

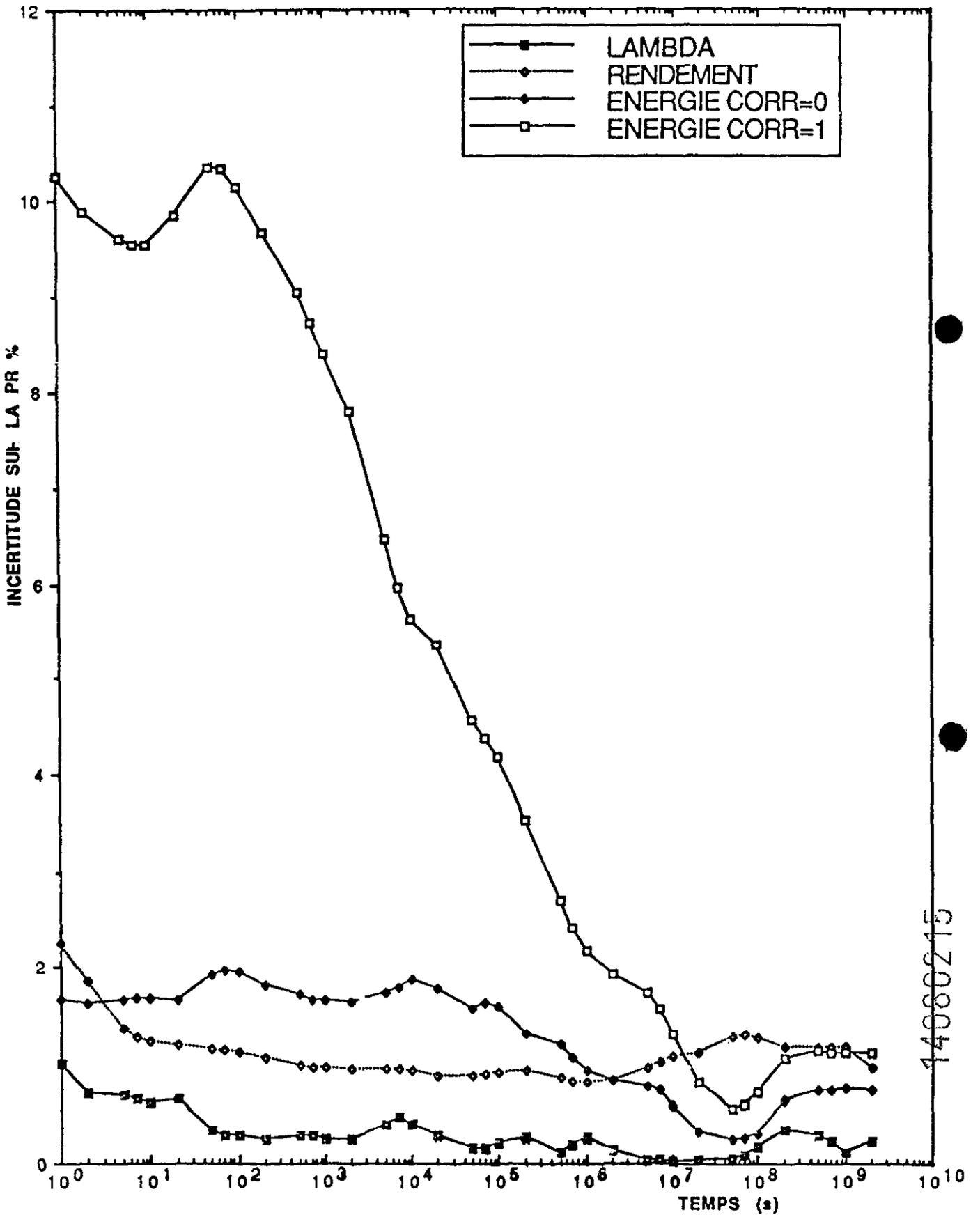


Figure 5: Comparison of U235 evaluated decay heat uncertainties for a fission pulse [16]:
a°) nuclear data parameters fully correlated.
b°) nuclear data correlated according to Zp-Z Wahl's parameter.

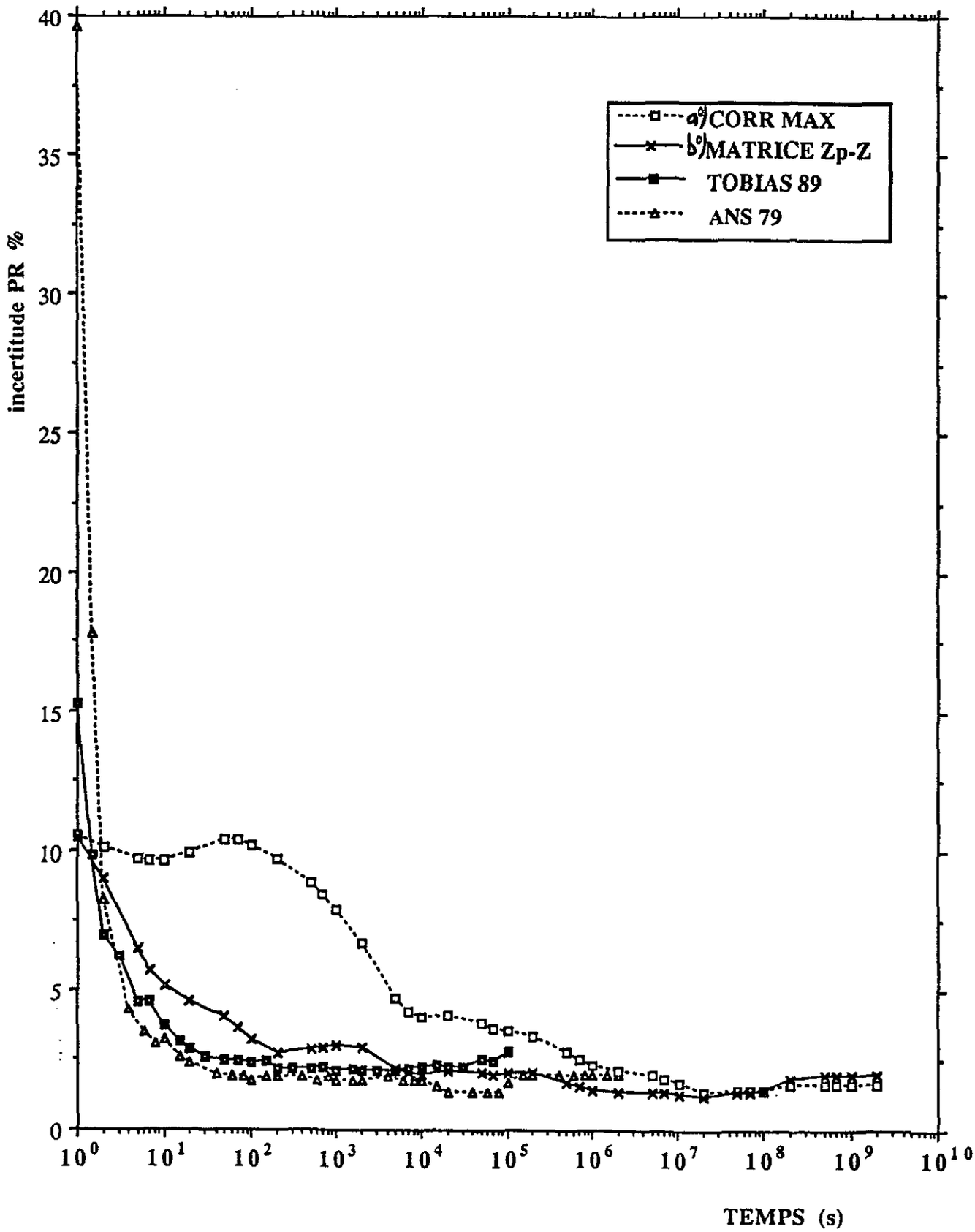


Figure 6: ANS American and AESJ Japanese standard comparison relative to Tobias's best fit for a U235 fission pulse

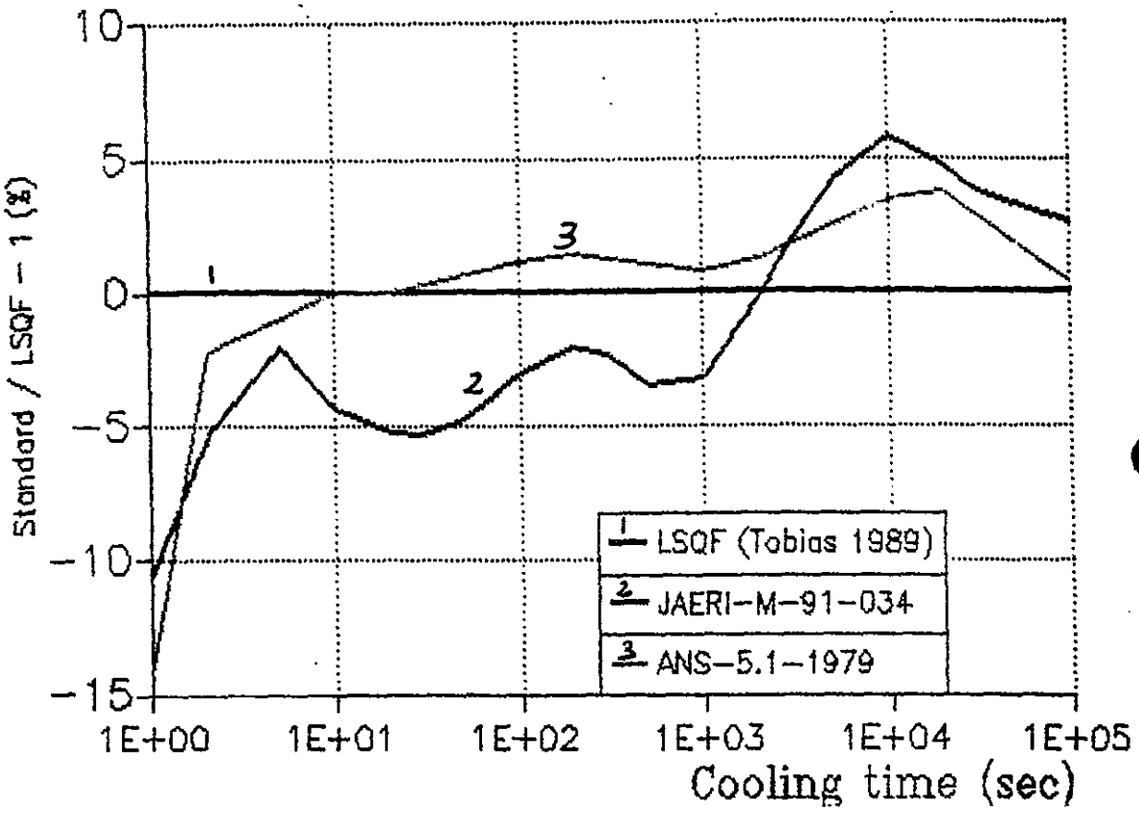


Figure 7: ANS American and AESJ Japanese standard comparison relative to Tobias's best fit for a Pu239 fission pulse

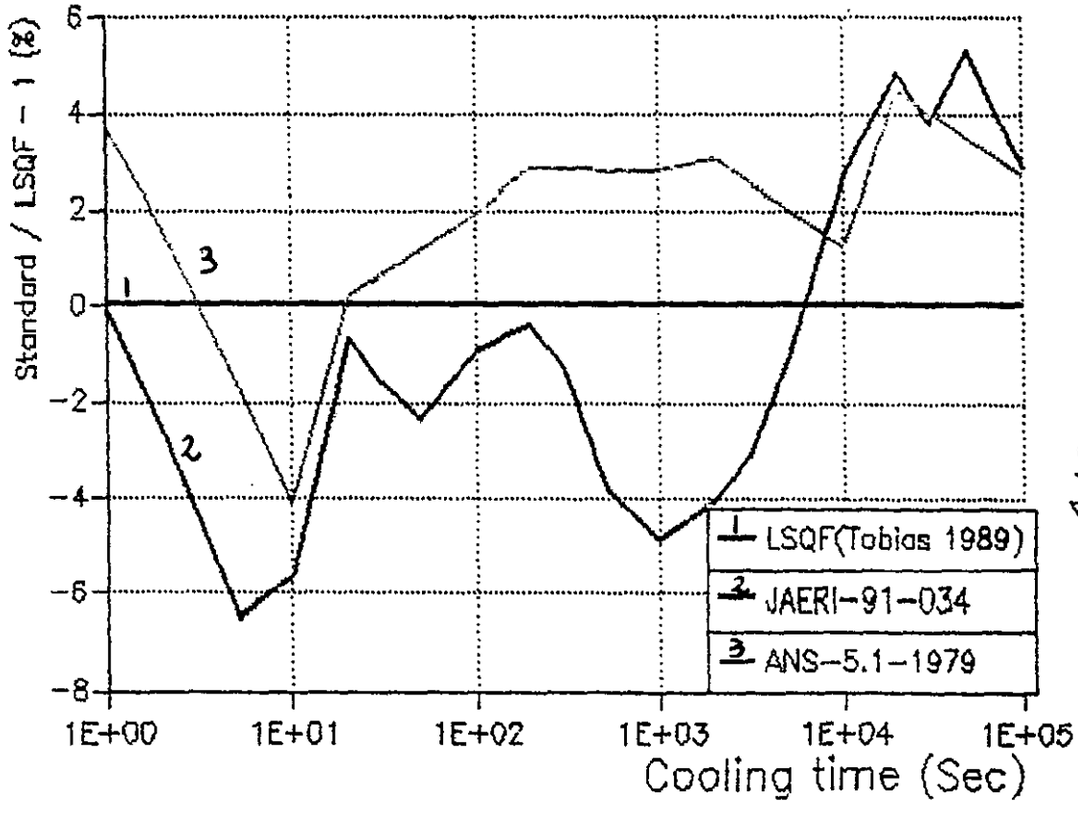


Figure 8: JEF1 and JEF2 Decay Heat Summation Calculations for a U235 thermal fission pulse relative to Tobias's best fit.

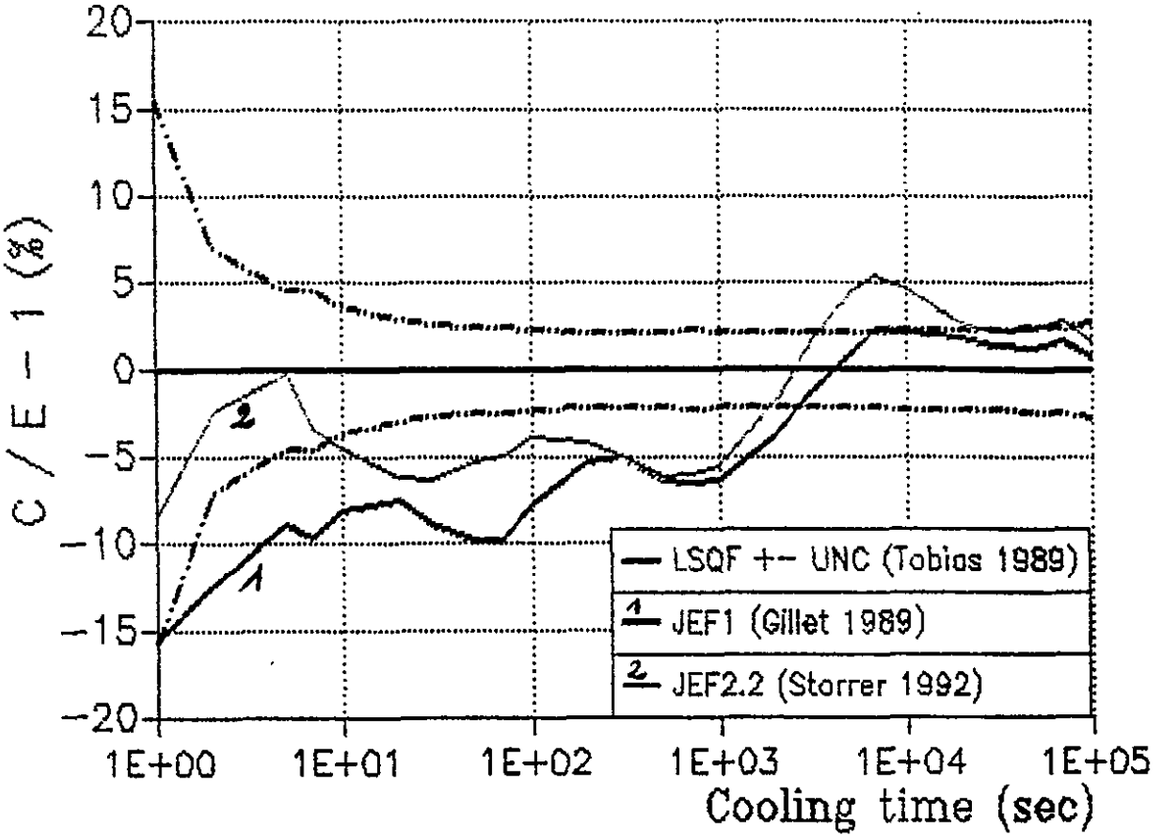
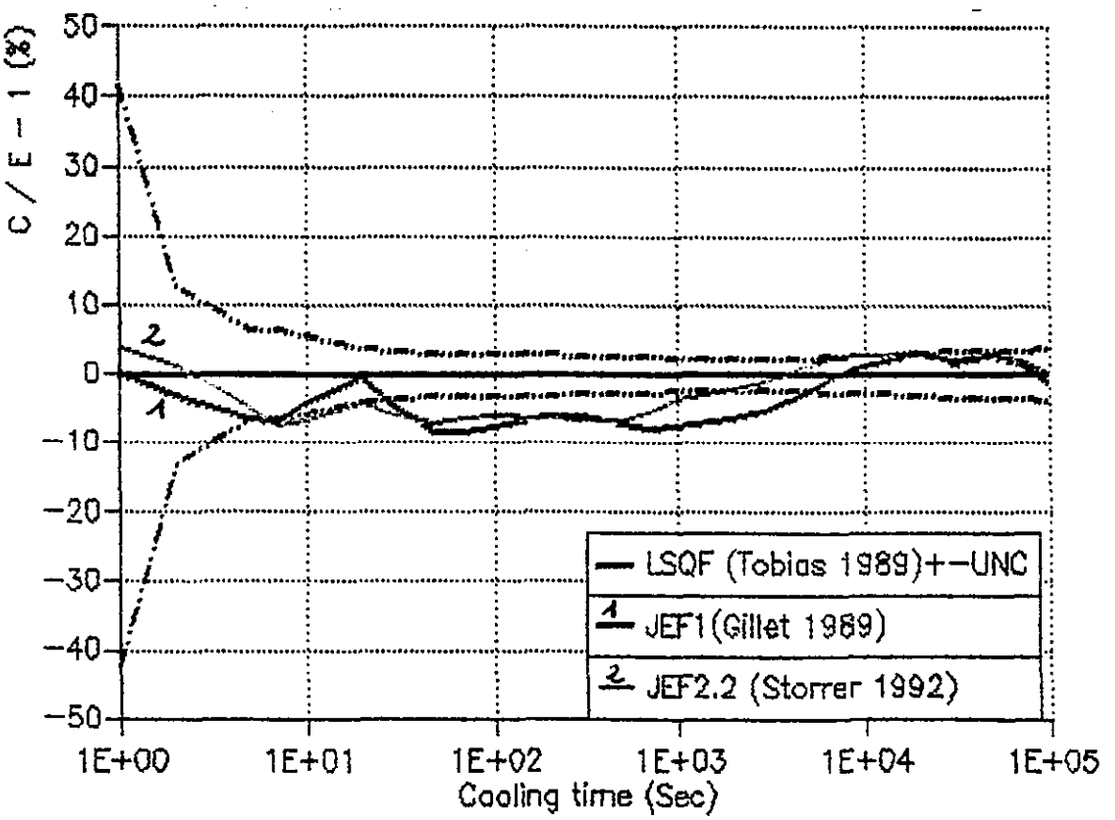


Figure 9: JEF1 and JEF2 Decay Heat Summation Calculations for a Pu239 thermal fission pulse relative to Tobias's best fit.



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