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NEACRP/NEANDC Working Group on International Evaluation Cooperation

Progress Report, Subgroup 6

(Delayed Neutrons (DN) data Evaluation & Benchmarking)

I. ACCOMPLISHED WORK (see enclosed document)

I.1 Basic data

a) A review about the present status of DN data was initiated by A. Filip and prepared by J. Blachot, M. Brady, A. Filip, R. Mills and D. Weaver. This work results is an OECD-NEA, general distribution, report (NEACRP-L-323, NEANDC-299-U). In this document the main discrepancies are identified and an analysis of actions to be taken is presented. The analysis is focused on the fissile nuclides of primary importance for nuclear Reactor Physics & Technology (RP&T), t.i. U235, Pu239 and U238. The major problem concerning these nuclides is related to the DN yields (ν_d): the quoted uncertainties (t.i. ~ 3 %, 5 %, 7 %) exceed significantly the target ones (< 2 %). Some problems with DN spectra of Pu239 persists and the ν_d dependence on incident neutron energy is still ambiguous.

b) It is worthwhile to record some important work published, during the past year, in connection with the field :

- Two new evaluations of fission product yields (the more abundant of them being DN precursors), and production of new Libraries : one (UKF12) by M.F. James, R.W. Mills, D.R. Weaver (paper AEA-TRS-1015, 1018, 1019), another (pre-ENDF/B-VI), at Los Alamos (see, e.g., paper LA-11909-MS by G. Rudstam and T. England). New Fm measurements are in progress at Stusvik, by G. Rudstam and coworkers .
- Production, by summation, of ν_d for 39 fissile systems, by J. Blachot and A. Benjelloun (CEA-Grenoble report, 1990).

I.2 Integral testing of DN data

a) The NEACRP β_{eff} experimental benchmarking planned at Cadarache (paper NEACRP, A-987, by M. Martini and all) is in a preparatory phase. A first meeting was held in Cadarache on 4-5 th December 1990 for discussing about cores configurations and experimental techniques (for some details see enclosed document, sect. II). A very large participation was enregistered. The measurements will start by the end of 1991.

Experimental techniques development is in progress. Important participation of the Obninsk (URSS) team is to be mentioned : some common preliminary β_{eff} measurements are realized.

b) For extracting DN data values, namely ν_d , for the cited nuclides from β_{eff} experiment, an important theoretical/calculational effort is starting, with A. Filip as coordinator; some results are to be noted:

- a semi-analytical model was developed at Cadarache (A. Filip) and tested numerically at Casaccia (A. D'Angelo); preliminary results are very encouraging: we expect to extract the ν_d values for U235, Pu239 and U238 with precisions better than 2 %, 3 % and 4 % respectively and, on the other hand, to extend the calculation availability of β_{eff} (the "effectiveness" problem) to general cases (reactors),
- a review of calculational support (formulae, codes, libraries) at Cadarache and Casaccia was made by A. D'Angelo and distributed to subgroup members (July 1990),
- a reexamination, by E.A. Fisher, of his β_{eff} measurements on SNEAK (in 1974) with important remarks on the subject; E. Fisher is in contact with A. Filip, in view to clarify some complex aspects related to experiment/interpretation problems. Further such contacts with other members are established or planned.

II. PLANNED AND/OR SUGGESTED FURTHER WORK

II.1 Basic data

- New, accurate measurement of ν_d for U238 is highly desirable.
- Theoretical/modelling further effort for ν_d (by summation) and for its dependent on incident neutron energy is desirable.
- More detailed analysis of the reactivity sensitivity on temporal group parameters quoted uncertainties is necessary (A. D'Angelo + A. Filip).

II.2 Integral testing

a) Further development of the experimental techniques is progressing well, but more international participation is highly desirable.

b) The same is to be noted for the calculation/analysis aspect. A pre-analysis of the experimental benchmark is planned for the end of 1991.

At that time (Dec. 1991/Jan. 1992) an international meeting for discussing the status of the integral testing (point a) and b)) could be organised.

A. FILIP

A REVIEW OF THE CURRENT STATUS
OF DELAYED NEUTRONS (DN) EVALUATION WORK

A. FILIP (CEA-Cadarache, France)

The goal to reduce the DN data and the related fission nuclear reactor reactivity scale (β_{eff}) uncertainties constitute the objective of an international (OCDE/NEANDC/NEANCRP) cooperation in two domain :

- 1) The DN data evaluation and,
- 2) the β_{eff} experimental benchmarking.

By the correlated treatment of these two set of information [1 to 4] the overall precision of DN data and β_{eff} parameter can be significantly improved. In particular the reduction of the quoted $\pm 5\%$ uncertainty on β_{eff} (roughly twice the target one) is expected.

This review is focused on the fissile nuclides of primary importance for Nuclear Reactor Physics & Technology (NRP&T), t.i. : U235, Pu239 and U238.

I. DELAYED NEUTRON DATA (DND)

In a recent (1990) study [3], [1], a synthetic "three level", schema for consistent analysis of the bulk of DN and related kinetic parameters was proposed. A better transparency in the transfer of information between different levels of treatment (DN precursor/DN aggregate/Integral (β_{eff}) parameter) is then assured. In the followings, this schema (with quoted uncertainties) is reproduced.

INDIVIDUAL LEVEL (precursor)

$$\bar{\nu}_d(E_f) = \sum_{A,Z} \lambda(A,Z) Y_c(E_f, A, Z) P_n(A, Z) \int_0^{\infty} X_d(E, A, Z) dE \int_0^{\infty} e^{-\lambda(A,Z)t} dt$$

(uncertainties) : ± 2 to 100% ; ± 2 to 20% ; ± 10 to 100%

GLOBAL LEVEL (aggregate)

$$\bar{\nu}_d(E_f) = \sum_{k=1}^6 \lambda_k(E_f) a_k(E_f) \int_0^{\infty} X_k(E) dE \int_0^{\infty} e^{-\lambda_k t} dt$$

± 3 to 8% ; ± 3 to 10% ; ± 4 to 20% ; ± 5 to 100%

INTEGRAL LEVEL (reactors)

$$\frac{\bar{\nu}_d}{\bar{\nu}} \Rightarrow \beta_{eff} = I_0(X_d/X_t) \sum_i \frac{\nu_{d,i}}{\bar{\nu}} \frac{(\bar{\nu}_f^2)_i}{\sum_i (\bar{\nu}_f^2)_i}$$

\downarrow \downarrow \downarrow
 ± 4 to 5% ; $\pm 2\%$ tested ; $\pm 2\%$

Notations

$\bar{\nu}_d$	DN yield
E_f	Incident neutron energy
E	DN energy
Y_c	DN cumulative fission yield
P_n	DN emission probability
X_d	DN spectra
M, Z	Mass, charge of precursors
λ	Decay constant of precursors
k indexes	: K temporal group
a_k	DN yield in temporal group

$$a_k / \bar{\nu}_d = a_k \implies \sum_{k=1}^6 a_k = 1$$

N.B. : The uncertainties on levels 1 and 2 are general : for NRP&T applications, the rather low part of the ranges are to be considered. However there are still, roughly, twice, the target one. More specifically, we list some other unsolved problems:

- a) The probable underestimation (by ~ 4 %) of the $\bar{\nu}_d$ for U238. New (level 2) measurement is highly desirable. Valuable (integral) information from β_{eff} benchmarking is expected (in 1993 ; see sect. II).
- b) For the other two primary nuclides in NRP&T, t.i U235 and, particularly, Pu239 the quoted uncertainties ($\pm 3 \%$, respectively ± 4 to 6%) exceed significantly the target ones (1.5% , see ref. 7).
- c) The ambiguity in the incident neutron dependence of $\bar{\nu}_d$ (in the range 0 to 4 MeV). Differences of about 3 % for U235 was evaluated by Tuttle (in 1986) but the general acceptance is "no variation". Further theoretical effort (measurements) seems necessary. Important informations are expected, too, from integral testing (see Sect. II).
- d) The fundamental summation method for obtaining $\bar{\nu}_d$ is not entirely satisfactory : for odd nuclides the uncertainties are greater than 4.5 % and for U238 twice this. The improvement of fission yield data and a more elaborate method for estimating, the even-odd effect (namely for U238) seems necessary (G. Rudstam, J. Blachot).
- e) The summation method is successfully utilised for calculated DN spectra and temporal group parameters (a_k, λ_k), (M. BRADY, T. ENGLAND at Los Alamos). However some problems persist with :
 - ei. The spectrum of the Pu239 : it is a notable discrepancy between the Los Alamos summation and the measurements in University of Lowell (1986 to 1989). Are there information about the Lowell measured spectra availability ?

- e2. The (α_k, λ_k) by summation, for some "exotic" cores. More detailed sensitivity studies of the reactivity on group parameters are necessary.

II. INTEGRAL TESTING OF DN DATA

II.1 In the framework of the OECD/NEACRF activities, an INTERNATIONAL β_{eff} EXPERIMENTAL BENCHMARKING, proposed by Cadarache, was adopted.

Recently (Dec. 1990) the first meeting on the subject was held at Cadarache (consponsored by the NEACRF) with the participation of experts from : FRANCE, GERMANY, GREAT BRITAIN, ITALY, JAPAN, SOVIET UNION.

Problems concerning the feasibility of experiments (configurations, measurement techniques associated uncertainties, interpretative models ...), laboratories/experts participation, planning, etc ... were discussed. The main conclusions are :

- β_{eff} measurements will be performed in Masurca at the start of 1993 on 3 configurations :
 - . an uranium core (R2 cell),
 - . 2 plutonium cores (Zona 2 and compact cells).
 - The involvement of several teams with different experimental techniques will provide increased insurance against systematic errors in the measurements.
 - Target uncertainties at present are :
 - . $\leq \pm 3 \%$ (1 sigma) for Cf source method,
 - . $\leq \pm 2 \%$ (1 sigma) for reactor noise method.
 - The possibility of contributions from all partners on the experimental side and the consequent needs for its realisation has to be investigated.
- It is to be noted that :
- The most important uncertainties in β_{eff} are in the total delayed neutron yields of the fissionable isotopes.
 - The sensitivity of the inverse-kinetics method (normally used to calibrate in \$ the reactivity scale) to the delayed neutron data (including temporal group data ones) is strongly necessary.

II.2 DN data adjustment from the β_{eff} experimental benchmarking

The effort must be focused towards reducing the uncertainties of ν_d for U235, Pu238 and U238 (see above I.a) and b)) and towards extracting information about the spectra, χ_d .

The main requirements for obtaining significant results are :

- a) High precision in β_{eff} measurement. The favourable international context (see above, point II.1) is a good guarantee. Furthermore the utilisation of two (may be three) independent (external source and noise) techniques allows to expect a precision $< 2 \%$.
- b) An accurate methodology to interpret the measurements, t.i. to extract the ν_d values, separately for the three cited main nuclides in NRP&T (U235, Pu239, U238) and for the DN spectra (integral) effect.

The main difficulties for doing this are related to the problems of :

- b1. Separating the contribution of fissile nuclides in mixture.
- b2. Converting some measured quantities, - linear functionals of the flux ($\int \Sigma_f \phi \dots$) and of the adjoint ($\int \chi \phi^+ \dots$) - in the equivalent calculated quantities, generally bilinear functional ($\int \Sigma \phi \phi^+, \int \Sigma \phi \chi \phi^+, \dots$).
- b3. Evaluating accurately the "intracell" heterogeneities and/or blanket effects.

A drastic reduction of all this difficulties is expected consecutively of the strategy adopted t.i. :

- "Parametric" approach in (fast) cores conception : two, Pu239 enriched cores with different β_{eff} (Pu235/Pu238) ratios (t.i. - 1.2 and 0.5) and one U235 enriched core (β_{eff} U5/total) - 80 %) [ref. 4]. Moreover equivalent measurements results in thermal cores [ref. 5] will be available at Cadarache. On the other hand all the core are "clean", t.i. with weak intracell and/or blanket effects (a few percent of global β_{eff}).

- A new semi-analytic method (adapted to the clean cores) to interpret the measurements results and to extract the ν_d values for the cited three fissile nuclides.

This method [2, 6], a (Perturbed) Fundamental Mode (PFM) approach results in a quasi factorisation of the spatial/energy effects and then in the conversion of the bilinear functional in products of linear ones.

The important outcomes are :

- Separation of DN spectra effect from those of the DN yields.
- Direct correlation between measured and calculated details of the β_{eff} expression and then cancellation of some interpretation errors.
- Focusing the complex calculus of corrections on a small, second order (perturbative), factor : actually the measure became representative of the centre of the ("quasi-fundamental") core.

We can consider this "clean" benchmarking, accurately interpreted as a "metrological" approach to the ND data (\bar{v}_d) measurement for U235, Pu239 and in a fewer extent for U238. (This is why an independent accurate measurement (on level 2) of \bar{v}_d for U238 is highly desirable (see sect. I.a).

The expected precisions in \bar{v}_d , for U235, Pu239, U238 are, respectively, < 2 %, 3 %, 4 %.

Eventually, significant information may be reached for \bar{v}_d (of U235 and Pu239) dependence of incident neutron energy ("thermal" versus "fast" spectrum) and for the DN spectra (via the integral parameter $\int \chi_d \phi^+$).

Naturally, a large international cooperation in the interpretation effort is highly hoped for.

N.B. : it is expected to achieve a complete "pre-interpretation" of the planned assemblies (Ref. 4) by the end of December 1991.

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