SUBGROUP 6 : DELAYED NEUTRON (DN)

Data evaluation and Benchmarking
Status Report, June 1993

A. FILIP

A. **THE MAIN REALISATIONS**, are to be considered in respect to the "Recommended actions" of the previous report (4th meeting of the W.G. 28-29 May, Tokai-Mura), which are reproduced, for convenience, in annexe. We list the realizations, following the § notations in this document.

A.1. Basic experimental/evaluated data

1.1 & 1.2

a) The new measurements of ν_d and $\nu_d(E_n)$ for U235, U238 are started at Birmingham within a cooperation with Winfrith (M. Sowerby). Problems for (available) sample size effect are currently studied by M. Kallett and solution are foreseen.

b) The participation of the Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute of Nuclear Research (JINR) in Dubna, Russia on the 6th S/g works is officialized, via IAEA.

Preliminary measurements of some DN data for U235 [ν_d, $\nu_d(E_n)$, $\{\alpha_k, \lambda_k\}$] in thermal range are already achieved and the results largely diffused.

On the basis of discussions between FLNP-JINR and A. FILIP in Dubna a common report was drawn and diffused to the representative of IAEA and NEANSC/WG and to the concerned specialists. This document is joint in annexe.

1.3

a) The level 1 measurements ($Y_{i,C}$ and $Y_i(E_n)$) for U238 is achieved and currently interpreted at Studsvik (Rudstam). The U233, Th232(T) is under starting. Better inside in summation modelling (link of level 1 <-> level 2) is expected as a direct result.

b) The theoretical support of this modelling (projected cooperation between Winfrith (James, Mills) and Dresden T.U. (Marten) didn't progressed by lack of resources.

However we mention the exchange of information between the 6th S/gr. members (T. England, A. Filip) and A. Whal (Univ. of New-York & LANL) which is further improving his Y_i(En) modelling consistently by with ν_d(En) prediction (summation).

1.4 The discrepancies between END F/B-6 and JEF2 summation results for $\{\alpha_k, \lambda_k\}$ is not yet resolved (same reason).

1.5 The reevaluation of the Diven factor (± 2% for U235, Pu239 and ± 3% for U238), essential for βeff measurement/interpretation in noise technique, seems very difficult (scarce and old (1956) experimental values). The possibility of new measurements at Dubna is currently discussed (Dubna/A.F.).

A.2 Integral approach (βeff and related kinetic parameters)

The outstanding progress concerns the Masurca experimental compaign :

a) Careful preparation and testing (on similar cores) of the techniques, particularly noise related (J. Pierre, M. Martini).

b) Full modelling of the DN data extraction from βeff measurement, with the related error bounds and calculational simulation of the expected experimental results (A. Filip and H.F. Pang (Cadarache) and A. Dangelo (Casaccia)).

c) The realization of the (most part) of measurements on the first, U235 loaded (R2) core in Masurca, Cadarache (M. Martini and J. Pierre), within a large international collaboration, t.i. :
- Japan, JAERI (Sakurai, Neruoto)
- Russia, OBNINSK (B. Dulin, Belov)
- UK, Winfrith (B. Franklin, P. Smith)
- USA, Los Alamos (G. Spriggs)

The preliminary interpretation of crude results shows good results.

B. FURTHER PLANNED AND/OR RECOMMENDED WORK

The cooperative activities of the participants in the 6th S/gr. will be foccused, during the next year, to the achievement of the cited, current work, specifically :

B.1 Basic, level 1&2, Data

B.1.1 The measurements of Yi for U232, Th232 is planed for the spring of 1994 at Studsvik and the full interpretation of U238 measurement is expected by the fall.

B.1.2 The first results of the measurement of ν_d and $\{\alpha_k,\alpha_k\}$ for the U235 and Pu239, in the thermal range are expected by the end of 1993 at the FLNP-JINR in Dubna, Russia.

During 1994 parallely with the refinement of the Pu239 results, new measurement, related to "higher actinides" (Np237, Am241 Some Cm isotopes) will be performed.

At the same time efforts are foreseen at the FLNP-JINR towards :

- extend the thermal range measurements to resonance region (0-10 keV) in order to feet, the Birmingham ones ($\geq$ 50 keV),
- investigate the possibility of using the results from the Yi (z) measurements to improve the Yi modelling in a possible cooperation with Los Alamos (A. Wahl) and TU of Dresden (M. Marten),
- possible measurement of the prompt neutron dispersion factor (Diven factor).

B.2 Integral - level 3 - Data

- The second and third cores (with different) Pu239/U238 proportion will be measured during the next 10 month or so.
- The final interpretation of the basic R2 core measurements (U235 normalization) is expected by the fall.

The full (three cores) interpretation will be performed together with Birmingham and Dubna results by the fall of 1994 - begining of 1995.

B.3 Particular recommendations

B.3.1 The carrying out, naturally, the works mentioned at B1-B .

B.3.2 It is proposed that the FLNP-JINR representative participate in the next meetings of the 6th sub-group of NEANSC. The FLNP also proposes to hold one of the next NEANSC 6th subgroup meetings in the FLNP-JINR, DUBNA, RUSSIA.

Considering the importance of the work planned at FLNP-JINR and the related necessary technical support as well as the known actual difficulties of this laboratory, ways are being sought among the concerned national and international establishments to contribute to the material effort (samples, PC's) and also to meetings.

"THREE LEVEL" strategies for MM&E of DN / Kinetic parameters (S/Gr. 6th)

Aix-en-Provence, June 1993

Level ↓ | MEASUREMENTS ↓ | Modelling & Evaluation ↓

(1) Studsvik — U238, U233, Th232 — 1993 - 1994

$$\nu_d(E_n) = \sum_{A,Z} \int_{z \in Z} Y_i(A,Z,\{\alpha_E, Z_p\}; E_n; P_n(A,Z) \int_0^\infty \chi(E_D; A,Z) \Big) T[t; \lambda(A,Z)]\, dt$$

Modelling & Evaluation: Studsvik; Los Alamos; Bgham + Winfrith; Dubna + Dresden TU

(2) Bgham (Winfrith) [Dynam. + ND]; 50 − 5000 MeV → Discrete — U235, U238 (1993 + 1994)

Dubna [IBR-2 + SNC + ND]; Cold, Th, Res → Continuum $(\bar{E}_n)$ — U235, Pu239, Np237 (1993+94); Am, Cm (1994+95)

Modelling & Evaluation: Bgham; Dubna; Cadarache; Winfrith

(3) CADARACHE; Winfrith; Obninsk; Los Alamos; JAERI (1993 - 1994)

$$C_j = \sum_{i=238,239} \bar{\nu}_d(\bar{E}_m)_i \cdot \bar{F}(\bar{E}_m)_{i,j} \cdot \bar{R}(\bar{E}_n, \bar{E}_D, \vec{V}_{01})_{i,j} \cdot \bar{E}(\vec{\alpha}_3, \vec{N}_{01}) \cdot T^+(\Lambda, \{\alpha_k, \lambda_k\}, \dots)$$

- $\bar{R}$: Correction for reducing to FM
- $\bar{E}$: Delayed n° "effectiveness"
- T^+: Reactor kinetics related factor (Statics, Dynamics, Noise)

Modelling & Evaluation: CADARACHE; Casaccia; Obninsk; JAERI; Los Alamos; ...

$$C = \nu_d(E_n) \cdot F(E_n) \cdot R(E_n, E_D; \vec{r}) \cdot \bar{E}[x_D, \vec{r}] \cdot T[t_{1/c}; \{\alpha_k, \lambda_k\}]$$

Counting ↓ C | Abs. fissions ↓ $F(E_n)$ | Finit. size correction ↓ R | DN-spectrum effect on detection ↓ $\bar{E}$ | Irradiation/counting History factor ↓ T

Annexe

Excerpt from the 6th S/gr. Report to the 4th meeting of the WG. (TOKAI MURA, MAY 1992)

2. RECOMMENDED ACTIONS

2.1 Basic experimental data

1.1 New measurements of $\bar{\nu}_d$ are planned at Birmingham starting in 1992 with ^{238}U and perhaps ^{235}U. A measurement for ^{239}Pu would also be desirable. A student will use this work for his thesis under the supervision of D. Weawer. Cadarache (Filip) will cooperate with the planning and interpretation of the work. Concerning the measurements at Dubna (agreement in principle from the Russian side) the subgroup encourages this action. The work has started, and preliminary results are already available. A coordination with the work at Birmingham is recommended. Filip will keep contact with both groups.

1.2 New information is expected for the nuclides mentioned from the measurements at Birmingham (in the range 50 - 500 keV) and at Dubna for thermal, intermediate, and fast spectra. A study realized at Casaccia and Cadarache indicates significant effects of the (still uncertain) $\nu_d(E_n)$ function on β_{eff} and emphasizes the importance of the problem (see Ref. 4).

1.3 Summation calculation of $\bar{\nu}_d$ for extrapolations and fission product yield modelling are related tasks. New measurements of fission yield are necessary. The experimental program at Studsvik comprising thermal fission of ^{233}U and fast fission of ^{238}U and ^{232}Th are expected to give preliminary results at the end of 1992 for ^{238}U and in 1994 for the other two systems. For the theoretical yield modelling a cooperation with Dr. H. Martens at Dresden is encouraged. Filip will keep contact with Martens and contribute to the planning in the middle of 1992.

1.4 Concerning the study of the delayed-neutron group parameters α_k and λ_k the difference between US and UK values need to be studied. This task will be undertaken by James, Mills, and Weaver who will contact Brady and England in this connection. Furthermore, the target precision of the α_k and λ_k data required by the applications should be defined. Here a collaboration between Cadarache/Casaccia and Birmingham/Winfrith (and others) is recommended.

1.5 A new evaluation of the dispersion factor in prompt neutron multiplicity is encouraged. If new evaluations arrive at an uncertainty exceeding 1,5 % new measurements should be carried out.

2.2 Integral approach

The actions to be carried out in the β_{eff} experimental benchmarking were discussed and fixed in the cited meeting (23-24 March 1992). Briefly, they concern :

- the time schedule,
- the participation in the measurement and in the analysis,
- specific effort to get the target precision at every stage of the experimental campaign.

Some details are reported in the extract from the report at the meeting (Annexe 2).

REFERENCES

1) J. Blachot, M.C. Brady, A. Filip, R.W. Mills, and Dr R. Weaver.
"Status of Delayed Neutron Data - 1990."
NEACRP-L-323, NEANDC-299 "U".

2) C. Rudstam, K. Aleklett, and L. Sihver.
"Delayed-Neutron Branching Ratios and Average Kinetic Energies."
Research Report NFL-69 (1991).

3) G. Rudstam.
"P_n-values and Half-Lives of Delayed-Neutron Precursors."
Research Report NFL-70/.

4) A. D'Angelo, A. Filip.
"The Effective-Beta Sensitivity to the incident Neutron Energy Dependence of the Absolute-Delayed-Neutron-Yields.
Subgroup on Delayed-Neutron Benchmarking." February 1992.

Report Of The First Stage In The Co-ordination Of The FLNP/JINR and NEANSC (*) 6th Sub-group Activities In The Delayed Neutron Data Field

Dubna : 12 April 1993

1. A first meeting was held,from 5 to 9 April 1993, in the Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) in Dubna, between :

- the team of the FLNP involved in the Delayed Neutron (DN) data measurements, and,
- the representative (co-ordinator) of the NEANSC's (*) international working group (the 6th sub-group) of evaluators in the DN and related reactor Kinetic Parameters field,

The list of the participants is given at the end of this note.(§6)

This meeting, held under the auspices of the IAEA, was completed by a workshop aiming to identify the full potential of the FLNP contribution as well as the main technical and/or organisational problems, particularly in the present international co-operative context.

Firstly, the requirements in DN data for applications and/or for basic physics investigations as well as the main current co-operative work on the related new Measurements, Modelling & Evaluation (MM&E) were reviewed and discussed. They are briefly recalled in the following two paragraphs.

Then, the potential/perspective as well as the current status of the specific FLPN contribution were analysed in detail. The conclusions are reported in the fourth section. Finally in the fifth paragraph some specific practical aspects of the FLNP-6th sub-group co-operation are emphasised, and the participants in the FLNP, DN team are listed.

2. The actual goals of new MM&E for DN data originates in the following requirements :

2.1 (a) - to improve the basic existing reactor kinetic parameter, the reactivity scale (beta effective). The current +/- 5% (at 1 sigma) uncertainty, which must be reduced to < +/- 3%, originates principally from the uncertainty in the DN absolute yield (Vd). The current values are :
+/- 3% for U235 (F and T),
+/- 3-6% (following the inducing fission neutron energy) for Pu239,
+3% to -6% for U238.

The required precision is better than 3%.

(*) Nuclear Energy Agency Nuclear Sciences Committee of the OECD

(b) - related to the new reactor concepts (high burnup, transmutation of high activity transplutonium isotopes, use of some of minor actinides as a 'generator' of neutrons during the transmutation process etc.) one can point out the current uncertainites (of about +/- 10%, or higher) for Vd for the higher plutonium isotopes (Pu240, Pu241, Pu242...) and for the 'minior actinides' (Np237,Am241 Am243, Cm242, Cm243,Cm245). These uncertainties must be reduced to < +/- 6%.

(c) - to resolve persistent discrepancies between the proposed different DN temporal group data (alpha k, lambda k). These discrepancies are mainly due to the poor identification of the short lived precursors (loss in counting) and to the loosely defined criteria for the exponential decomposition of the DN precursors accumulating/decay history,

(d) - to determine the dependance of Vd on the inducing fission neutron energy (the Vd (En) function). The current +/- 4% uncertainty in the range 0<En<4MeV is unacceptable.

2.2 Besides the 2.1 (a)-(c) 'applicative' requirements it is recognised that a more fundamental approach to the DN emission related topics is also necessary. Briefly :

(a) - an improved experimentally adjusted modelling of the independant fission yield mass and charge distribution Yi(A,Z) could allow a better extrapolation of Vd for unmeasured fission systems,

(b) - an improved understanding of the Yi(Zp) distribution and of the Even-Odd (EO) effect dependence on the energy of the fission inducing neutrons,could help to solve the Vd(En) problem.

(c) - a new accurate measurement/evaluation of the prompt neutron dispersion ('Diven Factor') is needed, particularly for Pu239 and U238. Even if not directly related to the DN emission this factor is essential in Vd integral (on reactor) measurement using noise techniques (see later).

3. The common strategy adopted by the laboratories involved in the 6th sub-group co-operative work, aiming to satisfy the requirements listed above,is based on some consistent actions (complmentary and cross-check) of MM&E in the DN field, at

three levels of refinement :

3.1 The Individual Precursor Level - Level 1

At this, the most extensive and physically based level, the problems listed in 2.2 (a) - (c) may be treated.

Currently work is in progress at the Studvik laboratory in Sweden by G. Rudstam and co-workers. New measurements for U238 fission yields have been completed and further measurements for U233 and Th232 are under preparation, with final results being expected by the end of 1994. Improved models of Yi (Z,A,En) and EO (En) are being developed by A. Wahl (Los Alamos and the University of New York) and by M. James and R. Mills at Winfrith (UK).

3.2 The Aggregate Precursor Level - Level 2

New measurements of Vd for U235, U238, and of Vd(En) (for 50KeV<En<5MeV) are under preparation at the University of Birmingham (D. Weaver and M. Kellett) in co-operation with Cadarache (A. Filip and H.F Pang), and now with FLNP-JINR.

At the same time an improved adjustment of the 'parameter modelling' ('Systematics') for Vd extrapolation for fission systems with scarce measurement and for the Vd(En) function is being researched by A. Wahl (already cited).

Efforts towards a better definition of a standard for a temporal group representation of the DN precursors accumulating/decay history is forseen (Birmingham,Cadarache, Los Alamos).

3.3 The Integral Level - Level 3

This important applicative level also provides a method to measure, under particular conditions, the nuclear beta (=Vd/Vt) parameters for U235, U238 and Pu239.

A particular set of three fast assemblies are to be realised in the MASURCA facility at Cadarache (France). An international team of experimentators and analysts (France, UK, USA, Japan, Italy, Russia) are participating in the measurement and analysis of results to extract the nuclear beta values using two different and statistically independent techniques.

The important feature of these techniques is to relate simply (proportionality) the basic nuclear data Vd and D (Diven Factor) with integral (reactor kinetic and static) signals (reactivity, transfer function, correlated fission chains coincidence, absolute fission rates).

It is important to emphasise that the three (or four) sources of consistent, but 'statistically independent' information on Vd obtained from levels 2 and 3 could result in the reduction of the final uncertainty on this parameter by a factor of about 1/ square root 3.

Another important item to be emphasised is the utilisation, by all of the cited laboratories, of the isotope U235 as a common (known) standard (for the measurements of Vd as well as the Yi(A,Z) distribution).

Also , an attempt is being made to measure, via a reactor reactivity transient, the DN precursor decay and to express it in terms of temporal group parameters (consistently with level 2 MM&E).

4. The potential of the FLNP/JINR contribution to the international co-operative work (section 3) is demonstrated by the results already obtained.

The FLNP method of periodical irradiation (MPI) of the target is characterized with small looses of detected delayed neutrons for all groups of precussors and thus can be used mainly for total DN yield measurements. In addition to the above mentioned advantage of the MPI, the main assets of the FLNP method are as follow:

--capability for searching short lived precussors with halflife time less than 200 MS,
--due to the very high reactor neutron flux density, one can measure the Vd values also for subthrehold fissioned isotopes (NP237, AM241),
--consistency check of measured Vd values with the Keepin-Tuttle 6 group analysis results.

4.1 However to obtain more precision the FLNP aims to reconstruct the experimental facility in order to increase the neutron flux on the sample and supress the resonance flux background. The reliability of the new arrangement will be tested by measuring the absolute value of Vd for U235.

<u>This parameter will serve as a basis for the normalisation and cross-checking of the consistency between the three laboratory performances (FLNP-Birmingham-Cadarache).</u>

The first results are expected at the end of 1993 (with the new collimator, and, perhaps, a new chopper and mirror neutron guide). Simultaneously, measurements with cold neutrons (with an energy of approximately

0.007eV) could also be performed hence, providing new information.

4.2 During 1994 other isotopes (Pu239, Np237) are planned to be measured. On the basis of the experience gained, the measurement of other more difficult higher actinides will be envisaged, starting with Am241 and Cm243.

4.3 In order to correlate the FLPN thermal measurements with the resonance/fast ones at Birmingham (>50KeV), the FLPN team will study the possibility of mean Vd measurements for the resonance region 0-10KeV on an adapted neutron source (IBR-2 or, more feasibly, the IREN facilities).

4.4 At the Level 1 precursor level (see section 2.2) the FLPN will investigate the possibility of using the results from the Yi(Z) measurements to improve the Yi modelling. Co-operation with TU of Dresden (M. Marten) and Los Alamos in USA (A. Wahl) is forseen.

4.5 In the same context the possibility for new measurements of the prompt neutron dispersion factor (Diven Factor) at Dubna will also be examined.

5. Practical And Organisational Aspects

5.1 Both parties realise the importance of the exchange of information on work progress and on results by letters or by occasional meetings (task sharing).

5.2 The FLNP proposes that its representatives participate in the next meetings of the 6th sub-group of NEANSC. The FLNP also proposes to hold one of the next NEANSC 6th sub-group meetings in the FLNP-JINR,DUBNA, RUSSIA.

5.3 Both parties emphasised the important role of the IAEA in the overall co-ordination and support.

5.4 Considering the importance of the work planned and the related necessary technical support, ways are being sought among the concerned national and international establishments to contribute to the material effort (samples, PC's) and also to meetings.

The FLNP-DN team consists of the following participants:

1. Walter Ilich Furman, Head, Division of nuclear Physics, FLNP
2. Elmir Dermendjiev, representing also the FLNP DN team in the 6th sub-group.
3. Ivan Ruskov
4. Yuri Sergeevitch Zamyatnin, Head, Working group
5. Vladimir Maximovich Nazarov, Head, Working group
6. Sergei Borisovich Borzakov
7. Michail Vladimirovich Lachinov

6. Participants to the meeting

I. FLNP-JINR Team

Walter Ilich Furman
Elmir Dermendjiev
Yury Sergeevitch Zamyatnin
Lev Borisovitch Pikelner
Vladimir Maksimovitch Nazarov
Ivan Ruskov
Mikhail Vladimirovich Lachinov

II. Representative Of The NEANSC 6th Sub-group

Alexandre Filip - CEA, Cadarache

Report to A. Filip for presentation to the NEA working group.

A report on the progress of the Birmingham delayed neutron yield measurements.

Mark Kellett and Dr David Weaver.

The work in Birmingham is aimed at finding a value for the total yield of delayed neutrons from the fast fission of ^{238}U to an accuracy that would enable the use of an internationally accepted value for this parameter.

The work requires the accurate measurement of the number of fissions occurring in the uranium sample as well as the measurement of the actual number of delayed neutrons released following the fission events. In order to achieve this much time has been spent on trying to determine the number of fission events in the sample. As such arrangements have been made for the loan of the Gayther fission chambers from AEA Technology at Harwell, which were made for use as International comparison chambers. Concurrent arrangements are also being made for the loan of suitable samples from AEA Technology. Knowledge of the uniformity of the irradiating flux is also imperative, since the chamber may not be of exactly the same dimensions as the sample being irradiated. Work on flux mapping the irradiation beam has been carried out using activation foils. Further investigations are still planned with the use of very small fission chambers also very likely.

The main apparatus for the experiment, including the uranium sample transport system (used to move the sample from its irradiation site to its delayed neutron counting position) has been initially tested and seems to be performing as expected. Further improvements on the delay time between end of irradiation and start of counting are hoped to be achieved by improvement of the basic design and materials. The De Pangher long counter to be used for the neutron counting has been calibrated against standard sources and it would seem to be in good working order. A comparison to a calibration made in 1985 gave agreement to within 1%. Further work is planned on the calibration of this detector.

To summarise; work is progressing at much the rate desired and it is hoped that some preliminary measurements for the total delayed neutron yield may be available towards the end of the year, but it is stressed that these are not likely to be of the ultimately desired accuracy due to further improvements being necessary to the apparatus before that becomes possible.

11th June 1993