IEC-118

SUBGROUP 6 : DELAYED NEUTRON AND REACTOR FUNDAMENTAL KINETICS STATUS REPORT, Dec. 1994

A. FILIP

I - CONTEXT

I.1. The S/G.6 activities started in 1990 in regard to :

- the status of current uncertainties and needs (Ref. 1, dec. 1990),
- the persistent difficulties to improve the current precision in both DN data (ex. g. ν_d (U238) : $\pm$ 7 %, ν_d (Pu239) (Th) : $\pm$ 6 %..), and induced reactor kinetic parameters (ex. g : βeff for fast reactors : $\pm$ 5 %), despite the important world-wide effort over more than ~ 35 years,
- the necessity to concentrate, co-ordinate and encourage the scarce teams (experts and facilities) yet acting in this field,
- the possibility of drasticaly improve the efficiency of these activities by working out a strategy (Ref. 2, may 1990) aiming to cross correlate the current and/or newly proposed Measurements/Modelling/Evaluations (MM&E) on the three specific levels involved, t.i. :

  . level 1 : individual precursors
  . level 2 : aggregate of precursors
  } "differential"
  . level 3 : "integral", on fission nuclear reactors

The levels 1/2 are linked by the summation technique whilst the levels 2/3 by sophisticated techniques related to reactor kinetics.

I.2. Following this "three levels MM&E", several new activities were started during 1992-1993 (See annexe 1), principaly

- Level 1 : Studsvick (G. Rudstam) : FY for Y238, U233, Th232.

- Level 2 :

  . Univ. of Birmingham Dynamitron (D. Weaver & M. Kellett (full time, thesis)) → ν_d (En) for U235 and U238.
  . FLNP in Dubna-Russia IBR-2 pulsed reactor, (Furman & coworkers whose one person full time) → $\bar{\nu}_d$ for U235, Pu239, Np237, Am and Cm.

- Level 3 : Cadarache (Masurca facility - Berenice program) :

  . Several teams from 6 countries (France, Italy, UK, Russia, USA, Japan) are participating on MM&E at this level, many people are involved, whose one in full time (thesis : H. Pang). The principal contributions are : A. D'Angelo (ENEA), Dulin (Obninsk), A. Filip (CEA), coordinator (general and for the theoretical/analysis part), B. Franklin (UKAEA), H.F. Pang (Univ. of Pekin, thesis, full time), M. Martini (coordinator for the experimental part) (ENEA), J. Pierre (CEA), T. Sakurai (JAERI), G. Spriggs (Los Alamos).

I.3. Related to 1.2/level 3, a new important program (FCA-βeff), complementary to Masurca/Berenice is under preparation in Japan (JAERI/Tokai-Mura)

The experimental campaign (on 3 cores) will cover 2,5 years : from oct. 1995 to mars 1997 (an extract of the program in annexe 2).

The preliminary studies are under way in Japan (T. Sakurai) and France (A. Filip & H.F. Pang).

It is foreseen to the same international cooperation as for Masurca/Berenice program.

Note that the results of BERENICE program can't be fully exploited, t.i. in terms of realiable information on DN data (ν_d), because of the withdrawal of one of the complementary 3 cores initialy planned (for giving way to CAPRA (Pu burners) related new program).

I.4. Emerging priorities from the new fuel cycle strategies (Pu burners, actinides transmutation)

- Outstanding need : MOX system : the current uncertainties in ν_d for Pu239 (Th), U238, Pu241 (t.i ± 6 %, 7 %, 10 %, respectively) induce ± 7 % uncertainty in βeff.

- More precise needs for the higher actinides are to be specified by the users.

→ Note that all the MM&E activities displayed in 1.2 & 1.3 are actually long term ones : 3 to 4 years.

II - RECENT ACHIEVEMENTS

II.1. Technical side

- Level 1 :

  . Measurement (Studsvick) of FY for U232, U238 (this last with final interpretation). Importance : better modelling of ν_d calculation/extrapolation by summation.
  . Studies by J. Blachot, R. Mills, F. Storrer show that $\bar{\nu}_d$ by summation is a very efficient test about the accuracy of FY data (paper submitted for publication to ANE).

- Level 2 :

  . Calibrating of Birmingham facility for ν_d (U_5, U_8) measurement. Very encouraging results. A paper by Kellett, Weaver and Filip was presented at the conf. on Nucl. Data Techn. in Gatlinburg, May 1994 (Réf. 3). However an incident (damage of a Fis.ch.) is to deplore (Report in annexe 3).
  . Reconstruction of the rotating reflector of the IBR-2 reactor at Dubna and the construction and calibration of filtering/counting system with satisfactory preliminary results (Report in annexe 4). However great difficulties, both financial and technical are encountered (see later).

  → Birmingham and Dubna teams work in concert (see Memorandum in annexe 5).
  The thesis of M. Kellett devoted to ν_d (U235, U238 (Eu)) measurements is in good progress (achievement in 1996).

- Level 3 :

  . The reference core (R2) experimental results in Berenice program are fully analysed and the reliability of accurate (± 3 %) ν_d extraction from βeff (integral) measurements successfully demonstrated. So the cross-correlated (global) interpretation of the information from both level 2 and 3, resulting in a significant reduction of the uncertainty in ν_d (U8) and νd (Pu 9) is anticipated. A paper by Filip, D'Angelo, Pang was accepted for presentation at the ANS conf. in Portland (may 1995) (Ref. 4).
  . The experimental campaign on the second, 25 % Pu loaded, Masurca/Berenice core (Zona 2) is achieved and the analysis/interpretation (for ν_d extraction) in good progress. However the full interpretation (νd (U8)/νd (Pu 9) separation) needs a complementary measurements on highly Pu239 enriched (≥ 60 %) core. The JAERI, FCA-βeff project aims at meeting this goal (see § 1.3). The first core (100 % Pu) will be built in oct. 1995.
  . The thesis of H.F. Pang devoted to the Berenice experiments in terms of ν_d extraction is in final stage of writing ("soutenance" for end of March 1994).

II.2. Organizational side

- Direct cooperation Dubna/Birmingham is established (reciprocal visits, work sharing) (see memorandum in annexe 5).

- An official agreement CEA/Dubna (JINR), including french financial support is in final stage (ready for signature).

- An agreement NEA/Dubna (with financial support) is underway.

- A meeting on Berenice program advancement/results was organised at Cadarache (5-7 oct 1994). The satisfactory results obtained was outlined and recommandations for the JAERI-FCA βeff project discussed (annexe 6).

III - DIFFICULTIES, LACK OF PROGRESS

- Delay in Birmingham project due to F.Ch. incident (see § 2.1/P.2).

- Delay in Dubna project principaly due to lack of funds → action : conclude the processes of funds transfer from NEA.

- Lack of sufficient "manpower" to ensure very good preparation and successfull achievement of Japanese βeff project namely by : insuring the strict complementarity/consistency with MASURCA/BERENICE program and fully exploiting of the acquired experience in Berenice campaign of experiment/analysis → action : necessity of 6 men x months experts in neutronics, with experience in BERENICE/S.G 6th activities.

IV - CONCLUDING REMINDER OF OUTSTANDING REALIZATIONS

- *Very important experimental and related theoretical/analysis activities, are achieved/in progress/ planned : 5 laboratories, within international participation (from 8 countries). This long standing work, covering 3 to 6 years, concerns :*

  . *2 campaigns of integral, on zero power reactor, measurements, covering 6 critical assemblies (three on MASURCA (Cadarache) and three on FCA (JAERI) → covering more than 5 years.*
  . *3 campaigns of differential measurements in accelerator or reactor beam ; (Studsvick, Birmingham, Dubna) → covering 5 to 6 years.*

- *Many scientists involved whose 5 full time for several (2 to 4) years each. Two Ph. D. thesis are in preparation (M. Kellett, Birmingham) or achieved (H.F. Pang in Cadarache).*

V - PERSPECTIVE

The full SG/6 MM&E, program currently in progress program achievement is foreseen by 1997.

So, to insure the success of this program the strong necessity of SG/6 perenniality until the end of 1997 is vital.

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<2> A. FILIP, A. D'ANGELO "Delayed neutron data and fission reactor scale"
Proc. Conf. Nucl. Data, Julich, Germany, May 1991

<3> M. KELLET, D.R. WEAVER, A. FILIP
"Measurement of delayed yields from U235 and U238". Proc. Conf. on Nucl. Data, Gatlinburg, USA, May 1994

<4> A. FILIP, A. D'ANGELO
"A consistent, differential versus integral method for measuring the delayed neutron yields in fission. Accepted for presentation on the ANS Topical Meeting (Internat. Conf.), April 30-May 4, 1995, Portland, USA.

ANNEXE 1

"TREE LEVEL" STRATEGIE FOR MM & E OF DN/KINETIC PARAMETERS
(NEA/N[illegible] - SUB GROUP 6., COORDINATOR A. F[illegible]IP)

LEVEL | MEASUREMENTS | Modelling & Evaluation

Level 1

Studsvik — U238, U233, Th232 — 1993 - 1994 - 1995 →

$$\upsilon_d(E_n) = \sum_{A,Z} \int_{z \in Z} Y_i(A,z), \{OE, Z_p\}; E_n; P_n(A,z) \int_0^{\infty} \chi\left[t; \lambda(A,z)\right] dt$$

$$\upsilon_d\{(Ac, Zc); E_n\}$$

Modelling & Evaluation: Studsvik; Los Alamos; B[illegible] + Winfrith; Dubna + Dresden TU

→ LANL (A. Whal)

Level 2

Counting; Abs. fissions; Finit - size correction; DN-spectrum effect on detection; Irradiation/Counting History factor

$$C = \upsilon_d(E_n) \cdot F(E_n) \cdot R(E_n, E_D; \vec{r}) \cdot E[\chi_D, \vec{r}] \cdot T\left[t_{I/C}; \{\alpha_k, \lambda_K\}\right]$$

B[illegible] [Dynamitr. + ND] ; 50 - 5000 keV → Discrete

(Winfrith) U235, U238 (1993 + 1994 to 1996)

Dubna [IBR-2 + SNC + ND] ; cold, Th, Res → Continuum $(\bar{E}_n)$

U235, Pu239, Np237 (1993 + 1994 + 1995 + 1996)

Am; Cm (1994 + 1995 to 1997)

"Four factors" consistent model

Modelling & Evaluation: B[illegible]; Dubna; Cadarache; Grenoble; Winfrith

Level 3

CADARACHE

Winfrith, Obninsk, Los Alamos — 1993 to 1995

JAERI → New project : 1995 to 1997 (FCA/β_{eff} - XIX)

$$C_j = \sum_{i=238,239} \bar{\upsilon}_d(\bar{E}_n)_i \cdot \bar{F}(\bar{E}_n)_{i,j} \cdot \bar{R}(\bar{E}_n, \bar{E}_D, V_{el})_{i,j} \cdot \bar{E}(\bar{\chi}_D, V_{el}) \cdot T^+(\Lambda, \{\alpha_K, \lambda_K\}, D_n)$$

- Correction for reducing to FM
- Delayed n_0^1 "effectiveness"
- Reactor Kinetics related factor (static, Dynamic, Noise) → Diven factor

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

ANNEXE 2
(EXTRACT)
(4 pgs)

JAPAN ATOMIC ENERGY RESEARCH INSTITUTE
TOKAI RESEARCH ESTABLISHMENT
FAST REACTOR PHYSICS LAB.

TOKAI-MURA NAKA-GUN IBARAKI-KEN 319-11

Date : Nov. 11, 1994	No. of pages : 8 (this page included)
To : Dr. A. Philip DER / SPRC / LEPH CEN CADARACHE	Fax No. : +33-42-25-48-49
From : T. Sakurai Tel No. : + 81-292-82-5334 Fax No. : + 81-292-82-6181 E-mail : SAKURAI@FCA001.TOKAIJAERI.GO.JP	Internal copies : T. Mukaiyama

SUBJECT : Informations of FCA- β eff cores

Dear Dr. Philip,

Thank you very much for the valuable discussions at the last β eff meeting in Cadarache. Enclosed, please find informations of FCA- β eff cores, which can be used to make your plan. If you need the 'E-mailed' core composition data, send your mailing address to us. Please transfer these informations to M. Martini and J. Pierre.

I would appreciate it if you could inform us Fax number of Dr. G. Spprigs.

We are looking forward to fruitful collaboration at FCA.

Yours sincerely,

T. Sakurai

Takeshi Sakurai

An 2/8-2

A proposal of the complementary NEA/NSC program for β eff benchmark experiments at FCA, JAERI

Presented at Cadarache
on October 5～7, 1994

T. Sakurai, T. Mukaiyama, S. Okajima and T. Osugi

Fast Reactor Physics Laboratory
Tokai Research Establishment
Japan Atomic Energy Research Institute

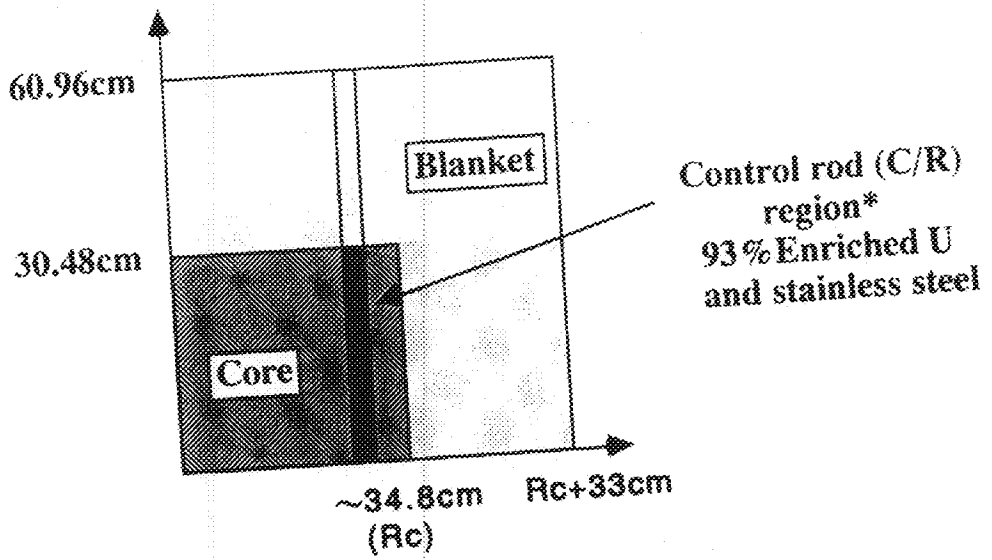
Tokai-mura Naka-gun Ibaraki-ken
319-11 Japan

Tel. 81-292-82-5334
Fax. 81-292-82-6181

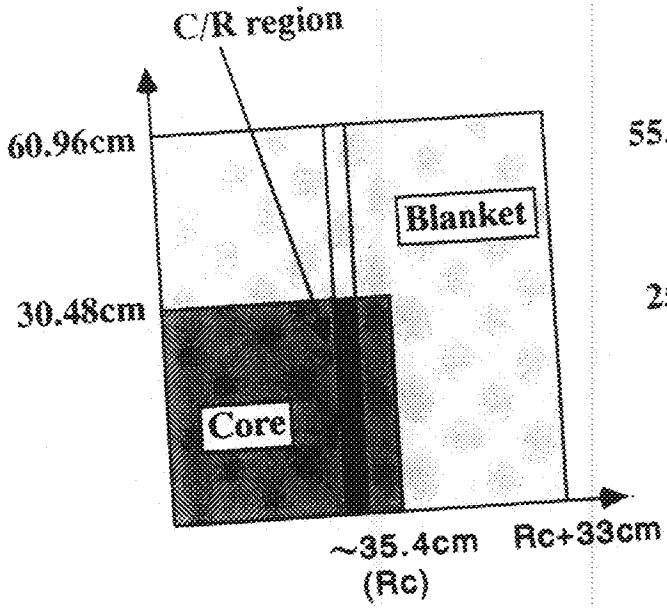
Abstruct

A proposal of the complementary NEA/NSC program for β eff benchmark experiments at FCA, fast critical facility of Japan Atomic Energy Research Institute(JAERI), is described. Three cores dedicated for β eff experiments are planned in the program. Experiments at the first core will start in October, 1995.

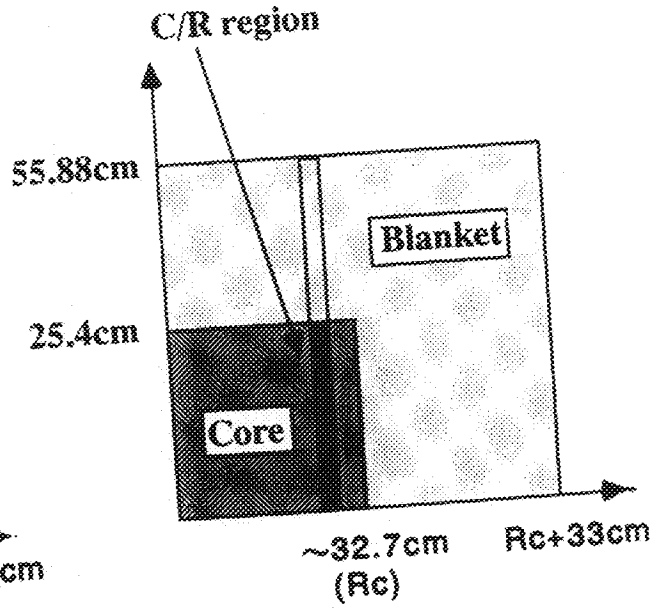
Cylindrical geometry of the FCA-β eff cores are shown in Fig.1.



(a) Pure Pu core



(b) 25% enriched Pu core



(c) 93% enriched U core

Fig.1 Cylindrical geometry of the FCA-β eff cores

* Position of C/R in radial direction is under optimization at present.

4. Time schedule

1994/December(end)	Deadline of : - proposal for participation in experiments in FCA XIX-1 core, - plan of each participants experiments and experimental instruments, - proposal for participation in the first meeting.
1995/March	First meeting in Tokai / JAERI, Japan (or Cadarache, France)
1995/October ~ 1996/February	FCA XIX-1 core
1996/March ~ 1996/July	FCA XIX-2 core
1996/September ~ ~ 1997/March	FCA XIX-3 core

Core loading change needs 2 weeks and core characterization needs 2～3 months in each core period.

ANNEXE 3
(2 pgs)

13/12/94

Report on the Progress of the Delayed Neutron Measurements at the University of Birmingham, December 1994.

Mark A. Kellett and Dr David R. Weaver

The work to date has concentrated in two main areas. The first in the experimental calibration of the detectors and the second in the Monte Carlo modelling of a proposed new higher efficiency detector for delayed neutron counting.

The calibration work included that of the De Pangher Long Counter held by the University. This was done using a calibrated Am/F source borrowed from the National Physical Laboratory (NPL). The calibration of this detector using an Am/Li source is also desired since this source has an energy spectrum similar to that of delayed neutrons. It is hoped such a source can be borrowed from the NPL in the near future.

Much time has also been spent on cross-calibrating the two U-238 Gayther fission chambers for use in the calibration of the actual detector to be used in the monitoring of the irradiating flux. The aim was to cross-calibrate the chamber of lesser mass with the one of higher mass and which had previously been used in the International Inter-Comparison of Fluence Rate Measurements detailed by Gayther (Metrologia, vol. 27, 1990.) Originally Birmingham were to hold the lesser chamber for use throughout the current project to continually cross check the actual detector being used in the flux monitoring. However, in the event, both sets of the chambers were sold by AEA Harwell to PTB in Germany and so the main set was returned in August and forwarded to PTB, with the lesser set returned to Harwell in November. It is intended that the lesser chamber will be made available for our use again before the end of the project, but it is not certain as to whether this will be financially viable.

Whilst at Birmingham the Gayther chambers have been used to cross-calibrate the actual flat plate fission chamber to be used in the delayed neutron measurements. However see addendum to this report.

The Monte Carlo modelling, using the MCNP code, has concentrated on the design of a high efficiency neutron counter based around boron tri-fluoride (BF3) tubes in a moderating assembly. Birmingham currently holds a reasonable stock of such tubes which can be used for the duration of the project.

A cylindrical piece of high density polyethylene (34 cm long and 20 cm diameter) has been prepared as the moderator, based on the results of the Monte Carlo simulations though there is still further Monte Carlo modelling required to finalise the exact details of the assembly. It is intended that the detector will use mainly BF3 tubes of the 12EB40 specification, but three 31EB70s are also to be included in the design. (The 12EB40 specifies the following information about the tube: 12 is the length of the active volume in centimetres, EB defines boron 90% enriched in B-10 and the 40 is the BF3 gas pressure in cm Hg. Similarly for the 31EB70. Both tube designs have a 2.54 cm outside diameter.)

This new detector will be run with all the 12EB40s multiplexed through one preamplifier/amplifier and all the 31EB70s through a second one.

The detector will be used instead of the long counter for most of the delayed neutron counting, but using the long counter as a comparator for cross-calibration purposes. Further tubes may be added to try and obtain an approximate 4π geometry, but this depends on the availability of more tubes.

In May of this year Mark attended the 4th International Conference on Nuclear Data and Its Applications in Gatlinburg, USA and presented a paper in one of the poster sessions and was fortunate enough to collect the award for "Best Student Paper".

After a brief return to Birmingham he then travelled to the Frank Laboratory of Neutron Physics, at the Joint Institute for Nuclear Research, Dubna, Russia. He spent most of his two and a half week visit discussing our individual experimental problems. He also gave a seminar on my work to many of the physicists from the laboratory. He continues to be in contact with members of the nuclear fission group via e-mail.

List of Contacts:

i)	Dr H. Klein, PTB, Karlsruhe, Germany.	Tel: 49 531 592 7200. FAX: 49 531 592 9292
ii)	Dr W. Furman, FLNP, JINR, Dubna, Russia. (E-mail: furman@nfsun1.jinr.dubna.su)	FAX: 7096 216 5085
iii)	Dr M. Coates, AEA Harwell, Didcot, Oxon.	Tel: 0235 432902 FAX: 0235 432793
iv)	Dr M. Sowerby, AEA Harwell, Didcot, Oxon	(Now retired.)

Addendum.

There was an unfortunate accident 7 days ago when a new sample holder on the sample shuffler (a compressed air powered swinging arm assembly) struck the fission chamber which appears to have been damaged beyond repair and can no longer be used. This is a very great problem at the moment as we are not yet sure whether we have a suitable alternative chamber to use and even if one can be obtained it would still require re-calibrating. This would require more work with the Gayther chambers than would have been necessary for checking the continued validity of the previous calibration.

However, it is known that the damaged chamber was supplied by Centronics in 1977 to Birmingham as one of a pair and it is hoped that the other chamber can be located and used as a replacement. This **would** still require calibration, preferably with the Gayther chambers, although it may be possible to produce a cross-calibration, via the long counter, with the now damaged detector, from previous work. This would only be a valid option for a chamber of very similar characteristics to the one damaged, e.g. the other detector of the pair. Hence the original calibration against the Gayther chambers could be applied with a measured adjustment factor found from the long counter comparison work. This is assuming that obtaining the Gayther chambers is impracticable or that the time scales are not suitable.

We are currently unsure of which detector will be used if the other detector of the pair cannot be located, although we do have the possibility of using a U-235 chamber borrowed from Harwell. This would require extensive calibration and it is preferable to not use U-235 due to the problems of the much higher cross-section at lower energies which leads to problems with the room return and scattered neutron fluxes. Whilst these can be measured and taken into account it leads to more correction factors being required than is desirable.

ANNEXE 4
(2 pgs.)

Report

on Delayed Neutron Yield Investigations in the framework of 6th subgroup of NEANDC in Frank Laboratory of Neutron Physics, JINR, Dubna, Russia 1994

In order to perform investigations of delayed neutron yields with a high accuracy, the experimental facility at IBR-2 pulsed reactor beam No11 was improved and tested.

Now the experimental set-up is consists of:
- neutron collimators - borated polyethylene plates,
- a "bent-down" mirror neutron guide - to transport neutrons with an energy less then 0.1 eV and to reduce essenuly the fast neutron background ;
- a new Cd filled Al chopper, synchronized with reactor bursts, placed after the mirror guide and just before the neutron detector (for a better determination of the beam cut off point),
- 12 ^{3}He-filled counters in a polyethylene moderator as a neutron detector;
- computerized measuring and collecting system.

All test measurements were perfoumed at 5 Hz reactor burst frequency and 2 MW reactor power.

Two ^{233}U (0.3g and 7g) and one ^{233}U (0.1g) samples were used. Using ^{235}U samples as a reference the b_{eff} for ^{238}U was obtained to be 0.0029+/-0.0002, which, in uncertainty limits agrees with previous measured data. Delayed neutron decay curves were recorded in a time interval of 10 - 200 ms.

Results from these tests and data obtained were published as a JINR Preprint (P3-94-447) and in Russian Journal "Atomic Energy".

These results and related problems have been discussed during the visit of Dr. W. Furman in Cadarash at May 1994.

During the visit of Dr. Mark Kellett from Birmingham University of United Kingdom (June 1994) in Dubna some problems were outlined and discussed - particulary connected with absolute delayed neutron detector efficiency measurement, exchange of specialists, methods and information concerning data evaluation. A memorandum for a future collaboration was proposed.

A constant scientific contacts and discussion of results were maintained with the coordinator of the 6th subgroup Dr. A. Filip.

W. I. Furman

Yu. S. Zamyatnin

Ar.4/p32

Frank Laboratory of Neutron Physics

Joint Institute for Nuclear Research
Moscow region, 141980, Dubna, RUSSIA

TELEX: 911621 DUBNA SU TAD/FAX: 7-096-21 65085 PHONE: 7-095-924-3914
Email: aksenov@lnp11.jinr.dubna.su

FACSIMILE

To: Dr. A. Filip
FAX No: (33)42.25.48.49
From:Dr. W.I. Furman

Number of pages, including this	Copy in mail following: Yes: [ ] No: [ ]

In additional to "Report on Delayed Neutron Yield Investigations in the framework of 6th subgrpup of NEANDC in Frank Laboratory of neutron Physics, JINR, Dubna, Russia, 1994"

A new (Am+Li) neutron source was made iφn PhEI (Obninsk) for processing the calibration of the neutron detector and for determining its efficiency of registrations of neutrons. This source will be recieved in near future. The (Am+Li) neutron source has a neutron spectrum very close to the fission delayed neutrons spectrum.

Agreement about the determination of the intensity of this source with an accuracy of 2-3% by the Metrology Radiation center VNIIFTRI (Mendeleevo Moscow region) was concluded. We hope this job will be finished before the start of the IBR-2 reactor with its new reflector in March, 1995.

W.I. Furman
Yu.S. Zamyatnin

ANNEXE 5
(3 pgs)

Frank Laboratory of Neutron Physics

Joint Institute for Nuclear Research
Moscow region, 141980, Dubna, RUSSIA

TELEX: 911621 DUBNA SU TAD/FAX: 7-096-21-65085 PHONE: 7-095-924-3914
Email: aksenov@lnp11.jinr.dubna.su

FACSIMILE

To: Dr. A. Filip
FAX No: (33)42.25.48.49
From:Dr. W.I. Furman

Number of pages, including this: 1	Copy in mail following: Yes: ☐ No: ☐

6 July 1994

Memorandum

During the visit of the research scientist Mr. Mark Kellett at the Frank Laboratory of Neutron Physics (FLNP), JINR, Dubna, Russia

1. In a seminar given by Mr. Mark A. Kellett he outlined the work in progress concerning the new measurement of the total delayed neutron yield from the fast fission of U-238. The seminar was attended with much interest.

2. In Prof. Zamyatnin's group Mr. Mark A. Kellett was informed of all the work carried out in delayed neutron measurement using the IBR-2 as a pulsed neutron source.

3. During the discussions it was planned to increase future collaboration between the University of Birmingham and FLNP in the measurement of delayed neutron yields.

In conjuction with this Dr. Walter I. Furman (Deputy Director of FLNP) and Prof. Yuri S. Zamyatnin (Head of the Nuclear Fission group) invited Mr. Mark A. Kellett and Dr. David R. Weaver to take part in experimental measurements which will be performed in 1995 when the IBR-2 will next be in operation

4. Mr. Mark A. Kellett supports the idea of possible exchange of physicists, involved in delayed neutron investigations, equipment and samples between the two institutions.

All present expressed their special thanks to Dr. Alexandre Filip, co-ordinator of the International Co-operation Project Subgroup 6 (Delay Neutron Bench marking), who supports these measurements and the international collaboration between Dubna and Birmingham.

Detailed Notes Of Discussion.

1) FLNP invites Mr Mark A. Kellett and Dr David R. Weaver to take part in Pu-239 and Np-237 delayed neutron yield measurements at IBR-2 pulsed Reactor and to the 7th School on Neutron Physics, Dubna, 13-30 September 1995.

2) It was Noted that joint efforts are required in order to obtain a calibration of the efficiency of the detector, either by:

a) The loan of well calibrated neutron sources from the NPL, UK, or from Institute of Metrology, Mendeleevo, Moscow Region, Russia, if possible;

b) Monte Carlo modelling by using a code in Dubna or MCNP in Birmingham;

c) Production of an identical long counter to the one used in Birmingham.

Remarks:

Point a) is the most desirable, but is the most expensive and difficult to organise, whereas b) is easier to achieve, but the results will be within the limits of the model used and c) includes the problems given in a).

3) It is also noted that similar data evaluation and preparation of results must take place.

4) The possible exchange of equipment and samples has been discussed. In particular, the exchange of a large high purity Np-237 sample, which will be prepared in Russia with impurity levels of about 10^{-6} g/g U 235 and Pu-239. The mass of this sample is still under discussion.

5) It is desirable to discuss the possibility of future long term measurements of delayed neutron parameters for the minor actinides.

6) It would be very desirable to discuss with Dr Alexandre Filip (Cadarache) all the technical, scientific and financial problems arising from these discussions.

5.07.94