EUROPEAN-AMERICAN NUCLEAR DATA COMMITTEE

TECHNICAL MINUTES OF THE NINTH MEETING OF THE COMMITTEE

held in Ascot, United Kingdom, 18 to 20 April 1966

Compiled by

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Preface to the Technical Minutes

This version of the minutes of the ninth meeting of the European-American Nuclear Data Committee is produced for general distribution to those concerned with measurements programmes in the nuclear data field. The conclusions are, however, of an interim nature in many cases, and the document is therefore marked "Not for Publication" and should neither be quoted in publications nor listed by abstract journals.
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Summary of Main Conclusions and Recommendations of the Ninth Meeting

1. Standards.
   The standing Subcommittee on Standards relating to nuclear data reported on its activities. The important information and recommendations reported were:

(a) The results of the Oxford Symposium on the measurement of fluxes in the 1 - 100 keV region in September 1963 (EANDC-63 U) are now beginning to be apparent.

(b) $\text{B}^{10}(n,a)$. New results and reinterpretation of the old results on the $\text{B}^{10}(n,a)$ reaction show that this cross section is now known to 5% between 1 and 100 keV. Further improvements will be very difficult. The branching ratio is known to 5% in the same energy region, which is satisfactory.

(c) $\text{Li}^6(n,a)$. New results and reinterpretation of the old results on the $\text{Li}^6(n,a)$ reaction show the cross section is known to 5% between 30 and 100 keV. Discrepant results below 30 keV require new measurements. The absolute value of the isotopic content of the Li samples must be determined with higher accuracy.

(d) $\text{Au}^{197}(n,\gamma)$. New results and reanalysis of the old results show points at several energies are known with the required absolute accuracy. The Committee recommended a relative cross section be measured over the entire energy region to determine the shape of the cross section.

(e) New measurements on the ratio of the fission cross sections of the fissionable isotopes at thermal energies have been made. The ratios agreed to 2% but, when normalized to the $\text{U}^{235}$ fission cross sections, the results are discrepant with other good measurements. The preparation and analysis of the foils used is one of the serious limitations on fission cross section measurements. The Committee felt that a foil intercomparison program should be initiated with NBS in the US and NPL and AWRE in the UK participating.

(f) The compilation and evaluation of data related to nuclear standards is progressing satisfactorily. The compilation on He$^3$, Li$^6$, and $\text{B}^{10}$ are almost complete. The $\text{U}^{235}$ compilation is next on the priority list.

   The Committee instituted the new procedure of setting up an "International Task Force" to recommend and make measurements on very important specific items on the compilation of requests. Task forces were arranged to recommend solutions to the major problems in the following areas:

   a) Inelastic Neutron Scattering Smith, Batchelor and Starfelt
   b) $\gamma$ Measurements Starfelt
   c) High Precision Measurements Batchelor and Hanna
   d) Capture Measurements To be organized by Beckurts
3. **Role of Small Laboratories.**

The Committee examined the role of small laboratories in the Neutron Cross Section Measurements Program and recommended the information given in the compilation of requests be increased to aid scientists in the small laboratories to select a measurement they can make.

4. **Data Compilation and Evaluation.**

The data compilation and evaluation effort needs to be increased and improved. The Committee asked its Subcommittee on Nuclear Data Evaluations to meet soon and formulate or find a means to formulate the full set of requirements which must be satisfied by the final experimental nuclear data tape storage and retrieval systems which will be in effect at the major nuclear data centers.

5. **The Compilation of Requests.**

The Committee decided to re-examine the compilation of requests at its next meeting and assigned Committee members to report on sets of specific requests divided according to the technique to be used for the measurement.

6. **Fissile and Separation of Stable Isotopes.**

The Committee formed a standing Subcommittee on stable isotopes required for the nuclear energy program. The Committee recommended that the following policy be adopted in obtaining isotopes: 1) Pure nuclear physics - purchase isotopes; 2) Nuclear physics measurements related to an item on the request list - rent isotopes; 3) Measurement on the request list - loan sample.

7. **Topical Discussion at the Next Meeting.**

The Committee recommended that the topical discussion for its next meeting be on "The Role of the Small Laboratory in the Nuclear Cross Section Measurement Program."
MINUTES OF THE NINTH MEETING OF EANDC

held in

Hotel Berystede, Ascot, UK, 18th to 20th April, 1966

There were present:

R. Batchelor, AWRE, Aldermaston, UK
K. H. Beckurts, Karlsruhe, Federal Republic of Germany
E. Bretscher, AERE, Harwell, UK
G. C. Hanna, AECL, Chalk River, Canada (Chairman)
W. W. Havens, Jr., Columbia University, USA (Executive Secretary)
R. Joly, CEA, Saclay, France
G. A. Kolstad, USAEC, Washington, USA
T. Momota, JAERI, Japan
M. Nève de Mévergnies, Mol, Belgium
H. B. Smets, ENEA, Paris, France
A. B. Smith, Argonne, USA
J. Spaepen, Euratom, Geel, Belgium
N. Starfelt, Studsvik, Sweden
J. S. Story, AEE Winfrith, UK
R. F. Taschek, LASL, USA
P. Weinzierl, Seibersdorf, Austria (Corresponding Secretary)

Observers:

Mr. P. W. Mummery, EACRP
Dr. W. F. Good, IAEA
Dr. C. H. Westcott, IAEA
Dr. K. Parker, AWRE, UK
Mr. E. D. Pendlebury, AWRE, UK

Local Secretary:

Dr. J. H. Towle, AWRE, UK
1. FACILITIES, DATA, STANDARDS, CONFERENCES, DOCUMENTS AND NEW APPROACHES

1(a) New Facilities

Kolstad reported first for the United States. Three Linacs have been authorized, two of them will operate up to about 140 MeV, the third (MIT) will operate up to 400 MeV. At NBS the Linac is now coming into operation. At Oak Ridge and Livermore the Linacs have been authorized but it will be about three years before they come into operation. Both the ORNL and Livermore Linacs are expected to be used primarily for neutron work. Bretscher asked about their pulsed performance. Kolstad replied that about 15-40 amperes in the peak could be produced and this would be suitable for photo-nuclear work. At the highest currents the pulses would be of nanosecond duration. The National Bureau of Standards will also do some neutron work. MIT is also looking for a site for a Linac. At Duke University a machine called a "cyclograph" is being negotiated; this consists of a 15 MeV Van de Graaff preceded by a 15 MeV cyclotron. At the University of Kansas a 4 million volt ICT generator has been authorized for fast neutron work. At the Argonne National Laboratory the conversion of the EN tandem to an FN tandem has now been authorized. The Edgewood Arsenal of the Department of Defense is getting an FN tandem; this accelerator will have pulsed and bunched beam suitable for \((n,n')\) and \((n,\gamma)\) studies.

Spaepen had no new facilities to report, but said that the Linac at Geel was being used for measurements of total fission and capture cross section. The final phase of the measurements on the total cross sections of \(\text{Pu}^{240}\) and the fission cross section of \(\text{U}^{235}\) was now under way and he reported that the machine had behaved very well during the period since October 1965.

Batchelor said there were no new facilities at Aldermaston, but reported that the bunching facility of the 6 MV machine was working very well. A scattering program on several elements was being executed with this facility. Authorization for a 15 meter flight path for this machine has been requested.

Joly had no new facilities to report.

Starfelt said that a 10 MV EN Tandem Van de Graaff had been ordered for the University of Uppsala. This will be used mainly for nuclear reaction studies.

Bretscher said that there were no new facilities at Harwell, but the money for the conversion of the 150 MeV cyclotron had now been authorized; this conversion will increase the current by at least a factor of 10, probably a factor of 20 or 30. This improvement is due to the improvement in the ion source and use of increased voltages on the dees. It may also be possible to use an external beam. This machine will be used for neutron time-of-flight studies. The facility will be rather expensive because the machine and the neutron flight path will be below ground level and only a 100 meter flight path will be available. A run has already been made on \(\text{U}^{235}\) to compare with the Linac results and the agreement observed is very good. The machine should function in its new form in about 18 months time.

Momota reported that a 200 MeV Linac is being made for Tohoku University, Sendai. It will be installed in Autumn 1966, and the projected finishing date is March 1967. Two Tandem generators are under construction by Japanese firms. One is for Tokyo University and is nearly finished. This
is a vertical machine and the analyzed beam is about 0.2 microamps at present. The other Tandem is a horizontal machine and was recently installed at Kyoto University. Also, a 4 million volt HVEC machine is being installed at Osaka University.

Weinzierl said that at Graz, the Argonaut reactor commenced working in May 1965. The Cockcroft Walton accelerator at the Radium Institute is being reconstructed in order to improve the shielding and intensity. This machine will be used mainly for nuclear reaction studies. At Seibersdorf a triple axis spectrometer used for solid state studies is in operation. Also a lithium drifted germanium crystal (set up as a pair or Compton spectrometer), for examining γ-rays from neutron capture with milligram quantities of separated isotope samples, is being installed in the high flux position of the reactor.

Beckurts said that an MP Tandem for Munich University is to be installed at Garching. Some neutron work will be done on this machine. A variable energy cyclotron of the Phillips type producing 28 MeV protons is being installed at Hamburg for Dr. Neuert's group. Beckurts also mentioned progress on the isochronous cyclotron at Karlsruhe. Some results on this machine had been reported briefly at Antwerp. Results were now being taken at 60 meters flight path and some very high resolution data on total cross sections for several isotopes had been measured. Beckurts showed a graph which indicated that the 512 and 513 keV resonances in iron were very well resolved and a plot of the total cross section for calcium covering the energy range 0.4 to 40 MeV with high resolution.

Smets reported that the crystal spectrometer built in Turkey is now working. The English chopper now installed at the Greek Atomic Energy Center is operating and measurements have been started, one of the measurements being on the request list.

Hanna reported that the Chalk River MP Tandem is now going together and should produce a beam in two or three months time.

Spaepen enquired of the US delegates about polarized neutron facilities on the Oak Ridge Linac. Taschek could not specifically answer this query but mentioned the polarized proton negative ion source of high intensity which was being developed at Los Alamos. The T(d,n) polarized neutron source which produces polarized neutrons in the 15-25 MeV range is also being actively used.

There was some discussion between Spaepen and Good about the production and moderation of polarized neutrons in the low energy region. Bretscher enquired about progress on the work Jeffries had undertaken on toluene polarizers but no one seemed able to report on this. (Note added: A paper on this subject entitled "Sizeable Proton Polarizations in Frozen Toluene" by R. J. Wagner and P. P. Haddock was published in the Physical Review Letters, 16, #24, page 1116 (June 13, 1966).)

1(b) Progress Reports

(CAN)28 "L" - Canadian Progress Report

In reply to Taschek, Hanna said that some neutron work was being done at Chalk River on the Tandem and Cockcroft Walton accelerators and this will continue with the MP machine. This neutron work is mainly chemical activation measurements.
Progress Report of Nuclear Data Research in the Euratom Community

Batchelor asked Beckurts about the Au$^{197}$ capture cross section measurements by Ponitz. Beckurts commented briefly: at 30 kilovolts there are two methods used for flux determination, firstly, the manganese sulphate bath and secondly, the Be$^7$ activity of the Li$^7$(p,n)Be$^7$ source was counted. Both methods agree within 1%.

Starfelt asked about the associated particle method for the T(p,n) reaction where an electrostatic analyzer has been used to separate the recoil particles. It was reported that this method seemed to be showing promise.

(OR) Reports

(OR)43 "L" - Progress Report from Denmark (Risø)
Kolstad enquired about the He$^3$ counter for absolute flux measurements used in Denmark. The reported efficiency of this counter was 1.000 ± 0.001. In reply Smets said that Kofoed-Hansen would not use this counter further, but they were quite willing to instruct others in this technique at Risø.

(OR)44 "L" - Progress Report from Sweden
Starfelt said that Be$^9$(n,2n) measurements have now been made down to 2.1 MeV with an accuracy of ± 5 mb. The preliminary result at 2.1 MeV is 5 ± 5 mb. Spaepen asked how Bergqvist calculates the efficiencies of his 5 x 4 inch and 9 x 9 inch crystals. Starfelt denied that such calculations had to be made. He stated that the efficiency had been measured.

Story said that the measurement of the ratio Li(n,a)/B(n,a) should be encouraged.

In answer to Batchelor, Starfelt said that the Pu$^{241}$ ν measurements were finished, but the corrections were not final. Batchelor said that relative ν requests now seemed to be satisfied; the outstanding requirement seems to be a precise value of ν spontaneous for Cf$^{252}$.

(OR)45 "L" - Progress Report from Spain
No comment.

(OR)46 "L" - Progress Report from Austria
Weinzierl mentioned the measurements on neutron 8 decay at Seibersdorf. The mass separator with single path separation was going with rather high efficiency, and targets were also being manufactured (see paragraph 4.1.5).

(OR)48 - Progress Report from Switzerland
Not available.

(OR)49 "L" - Progress Report from Greece
The total cross section of H$_2$O in the energy region 0.1 ev to 10 ev has been measured at 150$^\circ$ and 200$^\circ$ C. This satisfied Request Number 2 in the Compilation of Requests EANDC 55 "U."

(OR)50 "L" - Progress Report from Turkey
This is the first report from Turkey and there was a measurement concerning the total cross section of Cd$^{113}$. 

-4-
Bretscher commented briefly on the strength function measurements and capture and scattering measurements. Brooks et al. have now issued a report (EANDC(UK)66 "S"). Bretscher also called attention to the first neutron scattering work on Pu^239 and U^235. Taschek requested preprints of Charman's work on Cerenkov radiation reported on page 44 of (UK)63 "S." He was interested in the ultraviolet photomultiplier.

Batchelor then highlighted the Aldermaston report EANDC(UK)73 "AL" Nuclear Research Division, Progress Report, AWRE. He called attention to the scattering work by Towle's group on several elements including Na, Al, and Fe. Measurements on U^235 and Pu^239 had recently commenced with angular distributions at 2, 3, and 4 MeV. Detection of γ-rays from inelastic scattering with lithium drifted germanium detectors was also being used to supplement the time-of-flight work. The (n,2n) cross sections of several elements had been measured at 14 MeV and the work would probably be extended to lower energies. A preliminary report on the fission cross section ratio measurements (White et al. EANDC(UK)72 "S") had been distributed. Batchelor also drew attention to the Doppler measurements by Perkin et al., some of which had been completed. Aldermaston is collaborating with Los Alamos on some of the experiments using an underground explosion as a source of neutrons.

Smith mentioned the Au cross sections from Argonne and Lockheed. Cox's paper on the lithium absorption cross section was now complete. Some total cross sections have been measured up to 200 keV resolving some discrepancies. General Atomics reported a large number of resonance parameters and there were epithermal fission cross sections from Livermore. There was an experiment at Los Alamos on γ-ray emission following neutron interaction using lithium drifted germanium detectors. In answer to Story, Havens said that at Columbia they still get J = 2 for the 3 keV resonance of Na. In answer to Spaepen, Havens said that the Mo measurements at Columbia would be published soon. Taschek read out the titles of the contributions from the LASL to the Washington Neutron Technology Conference. In addition to the γ-ray report mentioned above, there was another concerning scattering from Li isotopes by Hopkins. Batchelor asked Taschek whether or not the underground explosion measurements would put linear accelerators out of business. Taschek said that the important feature of this method was that very small (that is, microgram samples) and also very highly radioactive samples could be measured. Havens said that ordinary elements could better be done on the conventional machines where it is relatively easy to change the experimental arrangements. Smith pointed out that sophisticated measurements such as γ-ray spectra following neutron capture are not possible with the bomb method. Batchelor thought that for straightforward measurements of cross sections as a function of energy, the bomb and conventional methods are very similar. One of the major weaknesses of the former, however, is in the detection system in which a large number of events are recorded in one detection interval giving a current rather than recording each individual event. For example, it is impossible to obtain pulse height information or to measure coincidence counts. Spaepen said that in making these comparisons it was important to consider the relative costs of conventional methods and the bomb method. In reply to Nève de Mévergnies, Taschek said the resolution of the bomb method was described by a flight path of 300 or 400 meters and a pulse width of a fraction of 1 microsecond.
Momota briefly mentioned the main items in the report. These concerned energy spectra of photoneutrons from $^{32}S$, $^{27}Al$, and $^{19}F$, elastic and inelastic scattering of neutrons by $Fe$, $Ni$, and $W$, and some measurements on $Be^9(He^3,n)$ in the energy region 5 - 10 MeV.

1(c) Consideration of Various Research Papers
A few comments on these papers were made at this stage as follows:

(CAN) 30 "S"
Hanna said Chalk River are not happy with the swing measurements. The conclusion of the report says the capture cross section of gross fission products is less than the sum of the cross sections of the individual fission products. Further study of this result is in progress.

(E) 65 "S"
Liskien and Paulsen have extended the range of their measurements on threshold reactions using neutrons from the $Be^9(a,n)C^{12}$ reaction.

(E) 67 "S"
This work complements the polarization measurement of Sailor.

(E) 69 "S"
Beckurts said a more complete report in German was available and Spaepen asked to be sent a copy.

(OR) 51 "L"
Starfelt mentioned the scattering measurements on $Fe$ and $Co$. These data are mainly elastic but there is some inelastic data which will be mentioned at the Topical Discussion.

(OR) 52 "L"
The results which are on page 9 of the report are still liable to adjustment.

(UK) 60 "S", 67 "S"
Hanna said Cabell's data are consistent with Westcott et al.'s least-squares-fitted values.

(UK) 62 "S"
Havens said the results and agreement with other data were good. He would have liked to have seen more discussion and comparison with previous work, especially of the capture results.

(UK) 64 "S", 71 "S" (These had also been taken under Standards)
The Harwell and Adlarmston $Pu^{240}$ sources had been compared. The Harwell $Pu^{240}$ source strength relative to which $\bar{\nu}$ (spontaneous) $Cf^{252}$ and $\bar{\nu} U^{235}$ (thermal) had been determined has now been revised.

The AWRE $\sigma$ results are relative to $Cf^{252}$ $\sigma$. A new accurate measurement on $Cf^{252}$ has been suggested. Axton (NPL) will do this and the $Cf^{252}$ source has been requested.

(UK) 66 "S"
Brooks report on $U^{235}$ is finally out. The values of the integral and differential measurements of $\sigma$ are consistent.
Bretscher said he had faith in the spin assignments. In this work two sorts of Li glass detectors, Li$^6$ and natural Li, had been used to discriminate against the γ-rays.

To be taken later (Item 6).

Story said the Columbia data on sodium were not included in this evaluation. Havens said this data would soon be available.

Spaepen reported that the Subcommittee on Standards for the EANDC had met on Sunday, 17 April at the Hotel Berystede, Ascot. The members of the Subcommittee present were: Spaepen (Chairman), Batchelor, Hanna, Havens, Taschek, Sowerby (in place of Rae) (Harwell), and H. W. Koch (NBS Washington). Two outside experts were also present: Dr. Axton (NPL) and Dr. White (AWRE) to discuss measurements in their particular area of specialization. The complete minutes of the Subcommittee Meeting are reproduced in Appendix 2.

Spaepen summarized the significant part of the meeting of the Subcommittee on Standards. The results from the Oxford Symposium on the measurement of fluxes in the 1 - 100 keV region held in September 1963 (EANDC 33 "U") are now beginning to be apparent. There are many new results available from several different laboratories which can be summarized as follows:

B$^{10}$(n,α). New results on the absorption cross section by Mooring et al. at Argonne. Cox made measurements at AWRE and is completing the write up at Argonne. A NASA report by Bogart will be published in the proceedings of the Conference on Neutron Cross Section Technology held in Washington 22 to 24 March 1966. The B$^{10}$(n,α) branching ratio from the ground to first excited state has been measured by Gibbons (Oak Ridge) and Sowerby (Harwell). The conclusions the Committee reached on boron are: between 1 - 100 keV, the (n,α) cross section of boron is known to about 5% and it will be difficult to improve these results. The branching ratio is constant up to 50 keV and known to 5% between 50 - 100 keV, which is sufficient accuracy on this quantity. The contribution from the (n,t) reaction is smaller than 6% of the (n,α) reaction at 230 keV (Mooring); it would be very difficult to measure this cross section very much more accurately. One might try to determine that the (n,α,γ) cross section behaves as 1/ν, independent of the (n,t) contribution.

Li$^6$(n,α). There are new results measured by Cox (Argonne - measurements made at AWRE), Barry (AWRE), and Schwartz et al. (Sweden). The Committee concluded that in the energy range from 10 - 30 keV the situation on the Li$^6$(n,α) cross section is very unsatisfactory because of the difference between the results of Cox and Schwartz. Above 30 keV the results agree to within 5%. The absolute measurement of the isotopic composition of the lithium samples is not better than 1 or 2%. The Subcommittee recommends that the new measurements should be made especially below 30 keV. The sphere measurements should be repeated at some other laboratory. The Subcommittee also recommends the possibility of making this measurement with a time-of-flight apparatus
on a Linac. Au$^{197}$. There are new results from Ponitz of Karlsruhe and from Lockheed Research Laboratories. There is a re-analysis of the old results in Bogart's paper. In the lower energy region Ponitz's points agree with the curve proposed by Bogart and in the higher energy region the Lockheed points agree with the curve proposed by Bogart.

The Committee recommends that the relative cross section of gold be determined over the entire energy range to determine the shape of the cross section. At the next meeting of the Committee, the relative advantages and disadvantages of lithium and boron for different applications and energy ranges should be studied.

Precise Thermal Values for $\sigma_f$. New results on the ratio of the fission cross section of Pu$^{239}$ and Pu$^{241}$ relative to the U$^{235}$ cross section have been measured by White et al. and reported in EANDC(UK)71 "S." For Pu$^{239}$ the ratio is good to $\pm 2\%$, and for Pu$^{241}$, to $\pm 3\%$. The fission cross section of Pu$^{239}$ deduced from these ratio measurements based on $\sigma_f$ U$^{235} = 577$ gives $712 \pm 15$ barns. Unfortunately, this fission cross section is not in good agreement with the cross section obtained by Westcott et al. in their evaluation of the fission parameters at 2200 meters per second ($\sigma_f$ Pu$^{239} = 742$ barns). Effort must be continued for determination of the fission cross section of Pu$^{239}$ to obtain the $\pm 0.5\%$ accuracy required. CBNM in Geel is remeasuring the cross section using the chopper at the BRL reactor. The Subcommittee recommends the organization of an international chemical intercomparison of fission foils, in which laboratories such as CBNM, NBS, and NPL should participate.

Requests for High Accuracy Cross Sections at Energies above Thermal. An answer has been received from the UK reactor physicists that 0.5\% accuracy is wanted on the fission cross sections, but it is realized that this will be very difficult to obtain. The US reactor physicists would be happy with a 3\% accuracy. The Subcommittee noted that 0.5\% accuracy required by Kinchin and Smith in EANDC(UK)68 "A" differs somewhat from the 1 - 3\% accuracy requested by Greebler in his report entitled "User Requirements for Cross Sections in the Energy Region 100 eV to 100 keV" which will be published in the proceedings of the Conference on Neutron Cross Section Technology. Smith's and Greebler's conclusions on the accuracy required are not consistent. Mummery was asked to comment on this inconsistency. Mummery stated that he suspected the inconsistency occurred because the men were considering different specific reactor designs. One might be considering a reactor where most of the events took place in the core with few events in the blanket, and the other, a reactor where more of the events took place in the blanket. He also pointed out that one could ask that the fission cross section be the most accurate parameter used in the calculation or need be no better than the least accurate parameter one could get. These two factors could introduce the difference of the factor of 6 which was noted. Mummery stated he would read Greebler's report in detail and comment about it later in the meeting (see page 33, EANDC 59 "A"). More detail is needed to justify the measurement of the cross section to 0.5\% because of the magnitude of the task. Spaepen reported that the only hope for achieving the accuracy of 1\% appears to be determining the fission cross section at a few point using the antimony-beryllium, sodium-beryllium, and thorium-beryllium monochromatic neutron sources. This accuracy can be obtained if the foils are known to 0.1\% and if the degradation of the neutron spectra in beryllium is not too important.
Measurements. The Aldermaston Pu$^{240}$ spontaneous fission source has been recalibrated and all details of this recalibration are given in EANDC(UK)71 "S." The results of these measurements have caused a revision of the Harwell Pu$^{240}$ source strength. There have been some changes in the Pu$^{240}$ source strength with time and these time-dependent changes are being followed very carefully. The limitation on the absolute measurement of $\tilde{v}$ comes back to an absolute determination of $\tilde{v}$ for Cf$^{252}$. Axton of NPL proposes to re-examine $\tilde{v}$ for Cf$^{252}$. The Subcommittee recommends that the EANDC strongly support the loan for 6 months of an adequate quantity of Cf$^{252}$ (0.5 $\mu$g) in the form which will be specified by Axton. Kolstad reported that Cf$^{252}$ was not available for a loan, but it could be purchased and he would exert all the pressure he could to expedite the delivery of the material. The EANDC strongly endorsed this action.

Standardization of Neutron Sources. Spaepen stated that Dr. Caswell of the National Bureau of Standards had prepared a paper which contained the results of a survey he performed on the needs and uses of calibrated neutron sources; full text of Caswell's report is reproduced in Appendix 3. The Committee concluded from this report that neutron sources should be included in the scope of the Subcommittee as far as they pertained to the calibration of equipment used for the measurement of nuclear data.

Isotopic Standards and Reference Substances. The Subcommittee report on isotopic standards and reference substances has been updated and circulated to the Committee Members as EANDC(E)68 "A" according to a decision reached at the last meeting.

Standard Boron. The standard boron available from CBNM and from the NBS in Washington has been more accurately analyzed isotopically. The Subcommittee recommends that an announcement of this improved analysis be sent to the journals in which the availability of this stock was originally published. A letter to the editors of these journals has been prepared. The Committee endorsed the publication of this letter.

The measurement of the isotopic composition of lithium has been investigated by CBNM. A survey showed that laboratories are limited to an accuracy of 1 - 2% on natural lithium. CBNM is undertaking to accumulate a stock of lithium and attempts to improve the methods of analysis now used.

Some members thought that a small stock of standard enriched B$^{10}$ and Li$^6$ might also be useful. The Subcommittee recommends that a letter be circulated to all laboratories requesting information about those isotopic standards. Spaepen agreed to draft the letter and send it to the Committee Members for approval.

The Subcommittee requests the advice of EACRP and EANDC in specifying the isotopic content of plutonium standards useful for burn-up studies. Smets read page 17 of the EACRP minutes of the Montreal meeting dealing with this subject. However, the specific numbers were not given and Hanna agreed to follow up on this matter.

Kolstad reported to the Committee that the US AEC had sponsored a program for several years to develop methods for an accurate determination of burn-up in power fuel reactors. A brief paper has been written on this subject entitled "Burn-up Determination of Nuclear Fuels." The text of this paper is reproduced in Appendix 4. Any enquiries about the subject matter
of this paper should be sent to Dr. Ira Zartman, Reactor Physics Division, United States Atomic Energy Commission, Washington, D. C., 20545.

At the meeting of the Subcommittee, Havens circulated a paper by S. Wynchank of Columbia University entitled "Correlating the Energy Calibration of Neutron Velocity Spectrometers." Havens stated that he thought the report could be improved for the purpose of informing reactor specialists and he would issue a revised version of this report as an EANDC document before the end of June.

Spaepen reported that the compilation and the evaluation of data related to nuclear energy standards was progressing satisfactorily. The compilation on $^8B$ has almost been completed at CBNM and the compilation on $^3He$ and $^6Li$ is nearly ready at Los Alamos. The Los Alamos report will be distributed to the Members. The next item on the priority list for the compilation on standards is to compile all the information on $^{235}U$. When the $^{235}U$ compilation has been completed, $^{197}Au$ will be investigated.

Havens transmitted a request from the reactor physicists for chemical mixtures or alloys of $^{233}U$ and $^{238}U$ for burn-up studies. Spaepen stated that the Subcommittee did not understand how these would be used. He admitted the absolute determination of the uranium and plutonium in a sample was a real problem but he did not see how chemical standard alloys could help. Hanna stated that this request had been made at the EACRP meeting in Montreal and presumably Critoph will specify the requirements and give them to Hanna.

Spaepen asked if the EACRP list of standards had been submitted to the Committee. Smets replied that some members of the EACRP had met and prepared a list of standards. He distributed this report to the members of the EANDC but cautioned them that the report had not yet been distributed to the EACRP. This report is expected to be considered at the next meeting of the EACRP in Madrid in June. However, he felt that the comments from members of the EANDC would be very valuable.

Commenting on the EACRP standards list, Spaepen pointed out that Au(n,$\gamma$) was on the EANDC standards list but was of lower priority than $^{235}U$. Data on this reaction will be compiled after the $^{235}U$ data is complete.

Havens commented that the $^{235}U$ cross section could not be used as a standard down to 0.5 keV as was the case for plutonium also. He stated that these fissionable materials can only be used as standards where the resonances completely overlap. Below 10 keV the resonances do not completely overlap and, therefore, there will be fluctuations in the measured cross section which depend on the sample thickness and the resolution of the apparatus used to make the measurements. Consequently, the $^{235}U$ and $^{233}Pu$ cross sections should not be used as standards below 10 keV.

It was pointed out that there was something wrong in the statement in the EACRP standards list about the $\nu$ for $^{252}Cf$.

The EANDC viewed with interest the additional standards list on the EACRP Standards Cross Section report. Most of these are on Spaepen's second priority list and the data will be compiled after the first priority list has been completed.
l(e) Antwerp Conference
Nève de Mévergnies said there were 350 participants including a good representation from EANDC countries. It would be impossible to give a scientific summary here. Regarding the proceedings, Newson had asked to change part of his talk on strength function and has submitted a revised version. The rapporteur system had worked quite well. The book of the proceedings promised for two months ago will not now appear until a few weeks hence. It is finished apart from the binding. Every participant will get a copy of the proceedings. The individual contributions will be collected together in a two volume report, EANDC 50 "S," available from Mol. The Chairman congratulated Nève de Mévergnies on a very successful conference and prompt publication of the proceedings.

Starfelt reported on the ad hoc meeting to discuss \( \bar{v} \) measurements held at the Antwerp conference. The members were Goldberg, Diven, Mather, Starfelt, Colvin, Smets, and Ekberg. Diven had not been able to uncover any errors in the Los Alamos measurements. Sweden found a small effect but it was a lot smaller than the quoted error. Mather had several criticisms of the way in which the errors on the boron pile results had been estimated. Also, he queried if Colvin and Sowerby had checked the effect of anisotropy on the efficiency. Colvin had not fully answered these points. The meeting had not produced any conclusions except that no errors had been found in the scintillator measurements. The report of this ad hoc meeting on \( v \) is given in EANDC 51 "A."

l(f) Harwell Seminar on Isotopic Targets and Foils
Batchelor reported on the Harwell Seminar on the Preparation and Standardization of Isotopic Targets and Foils in October 1965. There had been about 70 delegates including a large number from CBNM and ORNL. Some delegates were involved in target manufacture. The making of backed and unbacked foils and target standardization were discussed. This had proven to be a very useful meeting. A short summary of the Seminar has been written by M. L. Smith (Nature, January 8, 1966), and the complete proceedings are EANDC(UK)65 "L."

l(g) Second Round Table Conference on Precision Chemical Analysis
Spaepen stated that the complete proceedings of the Second Round Table Conference on Precision Chemical Analysis will be distributed as EANDC 53. The participants in the Conference examined existing techniques to determine what accuracy could be reached. The editors of the proceedings are attempting to formulate a set of conclusions for the end of the report and hope to make some recommendations for improving the accuracy which can be obtained by the various techniques discussed. Spaepen expressed the hope that this report will not only be useful to the experts but also to those who need to have some knowledge of the precision which can be obtained in chemical analysis for the experiments they perform.

l(h) Washington Conference on Neutron Cross Section Technology
Havens gave a short report on the recent Washington conference. A collection of the abstracts of papers would shortly be published as an EANDC "U" document. A complete proceedings with scripts of all papers will come out in approximately three months time as AEC Report CONF/660303. Havens said it had been a useful conference and there had been about 260 delegates. H. Goldstein and D. Goldman have written a report on the conference which is to be published in the Juen issue of Physics Today. C. Kelber has written a report on the conference which is published in the May 1966 issue of Nuclear News.
2. RELATIONS WITH OTHER NUCLEAR DATA COMMITTEES

2(a) Information on the September 1965 Meeting of INDSWG at Tokyo

Smets reported that 10 members of EANDC attended the INDSWG meeting in Tokyo. INDSWG members had agreed that further international cooperation should be fostered. It had also been agreed that INDSWG should be organized on a continuing basis rather than on an ad hoc basis. Specific recommendations were as follows:

(i) That a conference should be held in Paris in October 1966;

(ii) To promote transfer of information, liaison officers should be appointed. All countries not having a member on the INDSWG should nominate a liaison officer.

On data standards no conclusions had been reached. It was reported at the meeting that data compiling was proceeding in Vienna.

Westcott also made some remarks concerning the meeting. It had been decided that the next meeting should be in November. Some reports concerning standards had been collected together. Discussions concerning the reorganization of the Committee and the scope of the work had taken place. The Director General of the IAEA had decided on a two step change-over during the period 1966-67. The Committee and the terms of references would be reformulated. Liaison officers from several non-EANDC countries have already been appointed. Nève de Mévergnies asked if the EANDC as a body could be represented at the Agency. Westcott replied that this might be possible since the Agency has had observers from ENEA and Euratom in the past. The question of EANDC representation would have to be considered.

3. DATA INDEXING, COMPILING AND EVALUATION

3(a) IAEA Activity

Westcott summarized the IAEA activities in the nuclear data field. A list of facilities is being assembled. Very little evaluation has been done apart from the evaluation of 2200 m/sec data for the fissile isotopes, but there has been much more progress with CINDA. The installation of computing facilities is now going well. The Data Unit has access to a CalComp plotter and an IBM 1401 installed in the Agency and an IBM 7040 in the Technische Hochschule on which it hires time. There is great interest in CINDA in the USSR and regular CINDA entries are coming from USSR. These CINDA entries are checked and then passed on to the ENEA and US compilation centers. There are also active CINDA readers in India and Poland. The possibility of widening this coverage further is being pursued.

Batchelor asked if the coverage of the Russian journals is 100 per cent. Westcott said the coverage is very extensive, probably 95 per cent. Nève de Mévergnies asked if the USSR reading covered reports and conference proceedings. Westcott said that in general it did, but it is rather difficult to check on this. However, it is evident that the main series of reports are properly covered. Of the 50 copies of CINDA received at Vienna, 17 went to Russian laboratories. Bretscher remarked that in Russian papers the laboratory of origin was often not stated, and asked if the laboratories would regularly be noted. Westcott said the Russian staff members of the IAEA could usually identify the source.
Parker enquired about progress on \( \gamma \) evaluation which had been mentioned by Keepin in his article in Nuclear News. Westcott said there was no new activity to report apart from the 2200 m/sec work. Parker asked how many CINDA requests have come in from non-OECD countries on specific items. Westcott said about 10 had been received. Smets asked if the Russians operate anything more than a reader system. Westcott said that at present they did not. Story asked if any arrangements had been made to get data from the Russians. Westcott replied that some samples of data had been received, not on cards or tapes, but in tabular form. Not all authors, however, replied to requests for data.

Weinzierl raised the question of the publication and distribution of the list of facilities. Good mentioned that Miss Schultz, who is now doing this job, is leaving Vienna. The question of the format of the facility list is at present under consideration. Good recommends the facilities list be published with approximately the same frequency as the BNL barn books, in which the new data are published from time to time in supplements. Smets said he has a new format for EANDC-11 and supplements will be issued as necessary.

Weinzierl asked for clarification of the distribution of INDSWG documents and enquired if they should go to all persons on the EANDC class "A" distribution list. Westcott said that the distribution list for these documents was made up from recommendations of the governments of the member countries and from the ENEA office.

Good was asked if he wanted to add anything to Westcott's comments and he replied that he had been in Vienna only three weeks and is still getting oriented. Since the beginning of this year he has been making a survey of all the possible problems which might confront him at IAEA, particularly on data compilation. At IAEA headquarters he had found a good and cooperative staff. Good emphasised the importance of avoiding duplication of effort between the organizations compiling nuclear data and promoting measurements in the nuclear data field. He stated he was still trying to determine exactly to which areas of activity the IAEA could contribute most significantly.

Hanna asked if the IAEA center was able to answer CINDA queries. Westcott and Good replied that the IAEA compilation had not received the CINDA tapes and programs so they were not in a position to answer queries. At present, all requests for CINDA information received by the IAEA are sent to the ENEA center. The answers are transmitted to the questioner through the IAEA. Good stated that the program for information retrieval from the CINDA tapes was being written for the IAEA computing equipment and the IAEA hoped to be able to have the program operable in the very near future. Havens stated he was certain that Goldstein has sent to Westcott sample CINDA tapes and the programs for information retrieval from the tapes. Both Westcott and Good replied that they had, in fact, received these tapes and probably had received the retrieval programs but they had encountered some difficulties in using the tapes. Havens said that if only a few requests for CINDA information were received by the IAEA nuclear data center, it was hardly worthwhile to have a complete CINDA system. Unless the number of requests increases substantially, it would be better to have the ENEA centre at Saclay process the CINDA queries received by the IAEA.

Good asked Kolstad if the IAEA could use the CINDA tapes they had received from the US to answer any questions they received, or were there some restrictions on their use. Kolstad replied that once the tapes had been sent to the IAEA, there were no restrictions on their use.
Kolstad noted the extensive accomplishments made by Westcott during his term of office at the IAEA and expressed the appreciation of the Committee for his efforts.

3(b) 2200 m/sec Values for Fissionable Materials
The Chairman called for comments from Westcott, particularly on the new measurement of $\sigma_p$ for Pu$^{239}$ made at AWRE (EANDC(UK)72 "S"). Westcott said that his paper has now been published (Atomic Energy Review, Vol. 3, No.2, pp. 3-60), but not many comments have been received and he could not make any remarks on the new value of $\sigma_p$ for Pu$^{239}$ because he had only heard the results very recently. The new information on the g factor of Pu$^{241}$ calculated by the authors does not greatly change the data presented at Tokyo. There is still rather a small amount of data on Pu$^{241}$. The UK a measurement (EANDC(UK)67 "S") is not really discordant. The situation on $\nu$ had been considered but there was nothing new to report.

There were no comments from the Committee on the 2200 m/sec paper.

3(c) ENEA Activities
Reported by Smets. The compilation work at the Saclay center is now operating well and the center has a full complement of staff. CINDA (EANDC 46 "U") and its first supplement (EANDC 49 "U") have been issued. The second supplement (EANDC 53 "U") has been printed and will be distributed shortly. Saclay had provided some 50 per cent of the information listed in the supplement. Saclay has been answering individual requests for CINDA retrieval since December 1964 but naturally these have fallen off with the widespread distribution of the edited copies of CINDA and its supplements. The remaining requests normally fall in the category of specialized sorts which are retrieved from the CINDA master tape. Smets said that several computer programs for data accumulation and storage were now in operation. The center now has data tapes from several member countries and their own storage tapes. The center is now operating its own IBM 360/30 computer. Collaboration between the IAEA and ENEA centers was discussed at a meeting of the Steering Committee at which Westcott was present. Information is being exchanged between the centers. This cooperation will be reviewed and extended if the member countries are in agreement.

3(d) Sigma Center Activity
Reported by Kolstad. The SCISRS program has been developed and the data tapes include 230,000 data points. However, this program has not worked very well. Many who have tried to use it have not been able to retrieve the data in the form they wanted it. A new program is being written, called SCISRS II, which we hope will eliminate the difficulties encountered in the use of SCISRS I. Regarding the barn-book activity, Goldberg had presented a report to the Washington Neutron Technology Conference which gave a good review of the situation. AT BNL the emphasis has been on the collection of data and its publication in book form. This question of which format should be emphasized, i.e., book form, punch cards, or tape will be discussed further.

3(e) Evaluation of Nuclear Data
The Chairman asked Parker to give his talk about evaluation of data at AWRE. The text of Parker's talk is given in Appendix 5 of these minutes.

In answer to Smith, Parker said the subjective weighting was done by the evaluator himself. Story said that it was not always possible to go into such great detail on this weighting as Westcott had done with the thermal parameters of the fissile materials owing to the great demand for evaluation work. Good
asked what was done in a region where no data existed. Parker replied that sometimes a guess was the best that could be done. Mummery asked if all evaluators did not in fact work in the ways in which Parker had been describing. Taschek pointed out that not many evaluators were present. Story said that there was a need for the slow neutron time-of-flight people to use compatible energy scales in the resonance region; this is especially true where it is required to apply curve fitting techniques. Havens called Story's attention to the report [on this subject] which had been written by S.A.R. Wynchank for the Washington Conference on Neutron Cross Section Technology and stated a revision of this report would be prepared for reactor physicists (EANDC(UFS90 "A").

Hanna thought that the best man to interpolate or guess nuclear data was a theoretical nuclear physicist, but Batchelor pointed out that an experimental nuclear physicist should be just as good. Mummery enquired if the Committee thought that the right fraction of the available effort was being spent on evaluation. Taschek thought too little effort was being applied to this problem. Mummery said the fraction of effort on evaluation in the UK was about 20 per cent of the effort on measurements.

3(f) Adjustment of Nuclear Data to fit Macroscopic Nuclear Data
The Chairman then asked Pendlebury to give his talk concerning the adjustment of nuclear data to fit the results of integral experiments. The text of Pendlebury's talk is given in Appendix 6 of these minutes.

Taschek asked how the criteria for making the data adjustments were determined. Pendlebury said that the program takes into account the errors on the input data points, and that it was also important to take into account the errors on the integral measurements that are being compared. Beckurts asked how many data points were used. Pendlebury said that this depended on the accuracy required. In this calculation there were 23 between 1 keV and 10 MeV. Beckurts asked if the method could be applied to bigger, more dilute reactor systems or if there were then too many parameters involved. Pendlebury said that it could be applied if sufficient computing capacity was available. Mummery said that other factors were also important in deciding whether one wanted to do this: one must balance the effort required on this pursuit with that required on the data measurements. Furthermore, the number and diversity of the integral measurements should be considered, and one should not concentrate too much on critical sizes. In reply, Pendlebury made two points: (1) If the evaluated data fit critical sizes, and in addition, are consistent with the microscopic measurements, surely this is an improvement, and (2) we are trying to extend the method to other parameters besides critical sizes, particularly for the neutron spectrum in the system. Mummery said this was no doubt feasible but the important questions are, "How specific can one be in the choice of adjustments?" and "How clever has one been in selecting the various integral experiments?" Pendlebury pointed out that the perturbation program DUNDEE could in fact be used to provide results which helped in the design of the integral experiments.

Mummery expressed surprise that no one had commented on the possibility of uncertainties in interpreting the results of the calculations on integral systems. There was a real difficulty in interpreting the results of the integral measurements which could be caused by assumptions in the calculations, such as homogeneity. Smets asked how it was possible to have many variable parameters and only relatively few measurements in this method. For instance, there might be 80 data points, i.e., variable parameters, but only 25 integral measurements. Pendlebury said that the method was in fact possible because of the minimization technique which was incorporated. Story and Westcott pointed out that although there might be say 80 variable parameters, there
were in fact 80 plus 25 pieces of information fed in.

Mummery raised the question as to whether data modified to fit integral experiments should be included in a data library. Mummery was not in favor of its inclusion. Havens agreed, but said that from the recommended adjustments certain conclusions concerning different data measurements could often be made. Havens also said that in evaluating data there has not been enough discarding of old data, particularly data in which the method of obtaining the quoted errors was not well documented and he instanced the measurements of the parameters $\Gamma_Y$ and $\Gamma_B$. In these measurements, before the area of the peak can be measured, one has to establish the background level and this is often very difficult to do. If it is done incorrectly, it introduces a systematic error but often it is only statistical errors which are quoted.

Stafelt asked Pendlebury what were the actual errors in the calculational methods which he had been describing. Pendlebury replied that the errors in the $S_n$ calculations that he had done had been checked out by repeating the calculations with different mesh points and other changes, such as including anisotropy. Other checks had also been done using Monte Carlo codes instead of the $S_n$ method. In this way he had been able to estimate that the possible calculation errors were small.

3(g) Report of Joint EANDC-EACRP Subcommittee on Nuclear Data Evaluation

Story reported to the Committee that the Subcommittee thought that it was important to stimulate the flow of information among evaluators and to have an up-to-date list of evaluations. Parker plans to revise his one year old list. It was also important to know about evaluations in progress since these take quite a long period of time to complete and it is important to avoid overlap of effort. Goldman for the US and Story for Europe had sent out letter to various people involved in evaluation to enquire about the situation. Reports on evaluations had been made. In many cases the effort has been oriented towards local evaluation requirements. Computer programs were also discussed. Evaluation programs are collected in the ENEA computer program library at Ispra.

In answer to Story, Smith said that ANL does not want to collect this type of program. Story said that resonance parameters for fission nuclei posed quite a serious data collection problem.

The next meeting of the Subcommittee will probably be in Paris in October, close to the Paris Conference. Smets said that France was not represented on the Subcommittee, although Ravier had attended. Colvin also attended to represent the ENEA Nuclear Data Compilation Center. Mummery said that EACRP thought the policy should be for the Subcommittee to call in experts, and Colvin need not actually be a member.

3(h) Discussion of EANDC Information Activities

Smets stated he had received a memo from Westcott requesting all of the data which would be required to evaluate the resonance parameters of the fissionable materials. This looked to Smets like a rather sweeping request for an enormous amount of data. Westcott had stated that he was requesting this data for use in a meeting of specialists on the evaluation of the resonance parameters of the fissionable materials which was expected to be held during the Paris Conference in October. The Chairman reminded the Committee that this meeting had been suggested by Abramov at the Tokyo meeting of the INDSWG and asked the Committee if any measurers had been approached for their data on the fissionable materials. Joly replied that he had had such a request in
Several members of the Committee asked what the exact purpose of having such a meeting would be. Havens replied that Abramov wanted each group which had measured the cross sections of the fissionable materials to bring their data to a meeting of the experts and that a detailed comparison be made between the various sets of data. Discussions would be held about why the various sets of data disagreed and an attempt made to determine what should be done about these discrepancies. Havens said he did not think the real problem with the fissionable materials was the discrepancies between the various sets of experimental data, but in the interpretation of the data. He thought that the experimental data on the cross sections of the fissionable materials agreed better than the accuracy of the measurements. Joly disagreed with Havens because he did not think the data was as good as Havens indicated. It was Havens' opinion that Abramov proposed the meeting so he could obtain all of the data on the cross sections of the fissionable materials which had been measured in the OECD countries. He also believed that the meeting would be of no value unless extensive preparation was made beforehand. For example, it would be necessary to plot all of the cross sections which have been measured in all of the countries on exactly the same scale so that direct comparisons could be made. He also believed that it would be necessary for each expert to have all sets of data several weeks before the meeting so he could compare his data with those which had been taken in other countries. The task of preparing the data in appropriate form would be enormous since, for example, in U^{235} there are approximately 125 resonances in the energy range from 0 to 75 eV.

Batchelor stated that he thought this was a job for the evaluators and not a job for the experts making the measurements. The Chairman and Spaepen stated that they thought Good should be asked about the desirability of holding such a meeting in the light of the developments which have occurred since the Tokyo meeting. Good should also be asked to request Abramov to specify the exact framework for the meeting.

After much discussion, the Committee decided that unless Good could give much better reasons for holding the meeting than the members of the Committee were aware of at the present time, the meeting should not be held. The principal reasons given for not holding the meeting were: 1) the lack of an exact statement of the purpose of the meeting, 2) the framework of the meeting had not been completely specified or the exact material to be discussed determined, and 3) the preparation required of all the experts who would be present for the meeting was much too great to warrant the expected results that would be obtained. Therefore, the EANDC decided not to support the IAEA in arranging a special meeting on the resonance parameters of the fissionable nuclei.

4. CONFERENCES

4(a) Santa Fe Seminar on Intense Neutron Sources (SINS), 19-23 September 1966

Smets reported that Los Alamos was looking after the registration of US delegates and ENEA was registering the delegates from other countries. There was a good geographical distribution of the invitations, replies to many of which had already been received. EACRP and EANDC had recommended delegates. All 21 OECD countries have been invited. A list of speakers had been drawn up by H. Motz, six of whom were from outside the US. Smets asked that copies of correspondence with non-US OECD delegates be sent to him.
Taschek reported on the work being done at Los Alamos. He gave the names of 10 Russian delegates who had been invited. Invitations had been sent directly to the invitees and copies for information had been sent to the administrative office of their laboratories. The meeting will be held in Santa Fe, New Mexico. Delegates will go by bus to Los Alamos for a one day tour. Some interpreters will be available. Smets said that the conference program will be distributed in July and the papers in August. Delegates from the IAEA have been invited, but the IAEA has not yet said who will attend.

5. REQUEST LISTS

\[ S(a) \sigma_{(n,\gamma)}(D) \text{ for Thermal Neutrons, } \sigma_f(Pu^{239}) \text{ at } 2200 \text{ m/sec, } \sigma_{(n,\gamma)} \]

Hanna mentioned the measurement of the capture cross section of deuterium for thermal neutrons. Recent measurements have been made at Chalk River because several discrepant values have appeared in the literature. The Chalk River measurement which is described in the progress report EANDC(Can) 28 "I.l." appears to be a satisfactory one. Story drew attention to the fact that the accuracy of the capture cross section for deuterium was limited by the accuracy of the measurement of the deuterium to hydrogen ratio in the heavy water, which would limit the accuracy to about 15%. Spaepen said the accuracy of this ratio was given in his report. Hanna stated that this point was well taken but it did not affect either the Chalk River measurement of H\(^2\) or the other (discrepant) literature values. Hanna asked about further information on the Pu\(^{147}\) cross section but Batchelor could not find the information in the ANRE progress report and said he would look into the matter further.

There was then a discussion of EANDC(UK)72 "S", which reported measurements of the ratio of \( \sigma_f(Pu^{239})/\sigma_f(U^{235}) \) and \( \sigma_f(Pu^{241})/\sigma_f(U^{235}) \). Batchelor said that the same counters used in the cross section measurements in the fast neutron region had been taken over to the reactor. Some measurements were taken with a monokinetic beam and some in a thermal beam. The thermal spectrum had also been measured. The results gave \( \sigma_f(Pu^{239}) = 712 \) barns, using the recommended \( U^{235} \) value of 577 barns. Spaepen said that measurements of \( \sigma_f(Pu^{239}) \) relative to boron are being made at CBNM using the BR 2 chopper. If the half life of Pu\(^{239}\) is accepted, they should obtain an accuracy of 0.5%. They also have a program for remeasuring the Pu\(^{239}\) half life. Story said there is a new measurement by Cabell and Wilkins reported in EANDC(UK)67 "S" which gave \( \sigma_f = 735 \pm 48 \) barns from the fission to capture ratio. Beckurts asked what thickness of plutonium foil was used, as this was not stated in the report. Batchelor said that this information would be given in reports on the measurements at higher energies. More than one foil was used. Nève de Mévergnies pointed out that there was probably a region of overlap for filters and the chopper. Batchelor replied that he did not think measurements had been made in the overlap region. Hanna asked Spaepen for an estimate of the time for completion of his measurements at CBNM. Spaepen said he thinks it will take more than one year, but the measurements are going very nicely. There had been difficulties, e.g., estimating the amount of carbon in the boron, but this problem has now been solved.
## List of General Documents

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APPENDIX 2

MINUTES OF THE MEETING OF THE EANDC SUBCOMMITTEE ON
STANDARDS FOR MEASUREMENTS IN THE NUCLEAR ENERGY FIELD

Held in the Hotel Berystede, Ascot, Berkshire, 17 April, 1966

Present:  J. Spaepen  Euratom, Geel, Belgium, Chairman
         G. C. Hanna  AECL, Chalk River, Canada
         H. W. Koch  NBS, Washington, D. C., USA
         R. Batchelor  AWRE, Aldermaston, UK
         W. W. Havens, Jr.  Columbia University, USA
         R. F. Taschek  Los Alamos Scientific Laboratory, USA
         P. H. White  AWRE, Aldermaston, UK (For Items 1 and 5)
         E. J. Axton  NPL, Teddington, UK (For Items 3 and 4)
         M. G. Sowerby  AERE, Harwell, UK

Agenda

The following draft agenda prepared by Spaepen was adopted with the
addition of Item (9):

1. Progress report on neutron flux standards in the 1 - 100 keV region
   and plans for further action. Discussion of results (Batchelor).

2. Status reports on isotopic standards and reference substances
   (Spaepen).

3. Neutron source calibration. Memorandum on neutron source calibration
   at NBS.
   Calibration of the AWRE Pu^{240} spontaneous fission source (EANDC(UK) 71
   S, Batchelor).

4. ν Measurements.
   Repercussions on ν measurements as a result of the revision of the
   Harwell Pu^{240} source strength (EANDC(UK) 64 S, Batchelor).
   Proposed new measurement of ν (Cf^{252}) spontaneous.

5. Precise thermal values:
   \[ \chi_{\nu}(Pu^{239}) \]
   \[ \chi_{\nu}(Pu^{239})/\chi_{\nu}(U^{235}) \]
   \[ \chi_{\nu}(Pu^{241})/\chi_{\nu}(U^{235}) \]
   \[ \chi_{\nu}(Li^{6})/\chi_{\nu}(U^{235}) \]

APPENDIX 2 (continued)

7. Accuracy needed on standard data and standard samples (with a particular discussion on the accuracy needed for $\sigma_{n,f}(\text{Pu}^{239})$ from thermal to 100 keV).

8. Compilation of standard cross sections.


These Items were taken in the order: 3, 4, 1, 6, 5, 7, 8, 2, and 9.

1. Neutron Flux Standards 1 - 100 keV.

Batchelor reported on the measurements that have been made in this field and which are summarized below. He commenced by making the general comment that we are beginning to see the results of the Oxford Symposium on the absolute determination of neutron flux.

$^1$B$^{10}$. (1) S. A. Cox (ANL), while visiting AWRE, made measurements of $\sigma_{\text{abs}}$ in the energy range 10 - 250 keV using shell transmission measurements. A paper on these measurements by S. A. Cox and R. F. Pontet has been submitted for publication in the Journal of Nuclear Energy.

(2) F. P. Mooring, J. E. Monahan and C. M. Huddleston (ANL) have made measurements of $\sigma_1$ and $\sigma_{\text{abs}}$ in the energy range 10 - 500 keV; $\sigma_1$ can also be obtained from $\sigma_1 - \sigma_{\text{abs}}$. They have also measured cross sections other than ($n,a$) which might contribute to the absorption cross section and found that they are negligible.

(3) The branching ratio has been measured by (a) Sowerby (AERE), J. Nucl. Eng., 20, 135, 1966, and (b) Macklin and Gibbons (ORNL), Phys. Rev., 140, B 324, 1965.

An evaluation of $B^{10}$ has been made by D. Bogart (NASA) in NASA TM-X 52162. He started by drawing the best curve through the gold $\sigma(n,\gamma)$ data and saw what effect this has on the $B^{10}(n,a)$ data. He ended up by questioning the efficiency of the long counter used by Bischel and Bonner in their measurements of $\sigma(n,a)$.

The Committee discussed whether or not $\sigma(n,t)$ is negligible. Mooring has looked at $\sigma(n,t)$ at 230 keV, where the maximum deviation from $1/\gamma$ of the Mooring and Monahan data occurs. He sets an upper limit of 60 mb for the cross section. The experiment, looking for tritium gas, is difficult because the gas is produced in impurity reactions.

Taschek reported that in the reports to the last NCSAG meeting, (EANDC(US) 85 U), Macklin said that he had investigated the $^7\text{Li}$ ($\alpha,n$) reaction as well as the branching ratio, and these data suggest that the $B^{10}(n,a)$ cross section becomes non-$1/\gamma$ at about 80-100 keV.

The Committee concluded that:

(i) The $B^{10}(n,a)$ cross section is known to be $1/\gamma$ to within $\sim 5\%$ up to 100 keV.
(ii) The $^{10}$B$(n,\alpha)$ branching ratio is known to an accuracy of $\pm 5\%$ below 100 keV. This means that the $\frac{\sigma(B^{10}(n,\alpha,\gamma))}{\sigma(B^{10}(n,\alpha))}$ energy region to better than $\pm 0.5\%$.

(iii) Above 100 keV, the $^{10}$B$(n,\alpha)$ cross section has resonances and the branching ratio varies, so that the $^{10}$B$(n,\alpha)$ reaction is probably of no use as a standard.

(iv) The contributions of the $(n,p)$ and the $(n,t)$ reactions are not known in detail and this should be kept in mind.

(v) More work is desirable in the region where the $^{10}$B$(n,\alpha)$ cross section deviates from $1/v$.

(vi) In order to satisfy actual requests for high accuracy (e.g., $\sigma_{\gamma} \pm 1\%$ or $\pm 3\%$, and even $\pm 0.5\%$ in the keV range) by measuring them relatively to the $^{10}$B cross section, the latter has to be known in the 1-100 keV region to much better than the present $\pm 5\%$. More work is therefore desirable in this energy range.

$^{16}$Li Batchelor reported on the work done at AWRE. S. A. Cox and R. F. Pontet have measured $\sigma_{\gamma}$ in the energy range 10-100 keV using the same method as for $^{10}$B, and J. F. Barry, in a report presented to the Committee, has measured the $^{6}$Li$(n,\alpha)$ cross section relative to the $^{235}$U fission cross section at 25, 67, and 100 keV.

When these measurements are compared with previous data, it is found that at 100 keV there is reasonable agreement. In the range 10-50 keV, however, the Cox and Pontet data are higher than the relative measurements of Schwartz et al. (N. P., 63, 593, 1965), and with the extrapolation of the $1/v$ curve from the thermal data. The region of disagreement is in the region where Cox and Pontet should obtain their most reliable data because the absorption cross section is larger than the scattering cross section and so the corrections for scattering are not so serious.

Koch asked why Barry could not go to lower energies. Batchelor said that this was due to the difficulty of working at backward angles using the $^{7}$Li$(p,n)$ reaction. Spaepen asked if the experiment could be done on the linear accelerator. Sowerby and Havens said that the difficulty was one of intensity. In order to measure background, one uses resonance absorbers. In order to resolve these background resonances, the flight path length must be so long that the neutron intensity is insufficient to do the measurements.

Spaepen reported that the CBNM at Geel had done one-half year's work on $^{6}$Li isotopic analysis. They had tried to determine if any work had been done on the isotopic composition of natural lithium in the EANDC area. Only one laboratory has done work and this has to be repeated. Spaepen said that at
APPENDIX 2 (continued)

the present time the number of Li\textsuperscript{6} atoms in a sample of natural composition could probably not be determined to better than ± 1%.

The Committee concluded that for Li\textsuperscript{6}:

(i) Further work was necessary in the energy region 1-30 keV.

(ii) In the region 30-100 keV, the Li\textsuperscript{6}(n,α) cross section is known to ± 5%.

(iii) The Cox and Pontet \( q_{\text{abs}} \) measurement should be repeated (the spheres are available from AWRE if required). Before any new measurements are started, however, those making the measurements should form a small working party with the AWRE and the Swedish experimenters.

Action

(iv) The Li\textsuperscript{6}(n,α) and B\textsuperscript{10}(n,α) cross sections in the energy region 1-100 keV should be considered at the next meeting of the Subcommittee.

He\textsuperscript{3}. Batchelor reported that as far as he knew no recent measurements have been made on the He\textsuperscript{3}(n,p) reaction.

Au\textsuperscript{197}. Batchelor said that the situation regarding the gold capture cross section was beginning to clear up. Bogart's work (NASA TM-X 52162) on evaluating these data appears to be correct. He has taken the lower group of data in the energy region below 100 keV and has followed Barry's data (J. Nucl. En., 18, 491, 1964) at the higher energies.

In a recent Euratom Progress Report, (EANDC(E)66 U), it is stated that Ponitz at Karlsruhe has measured Au\textsuperscript{197}(n,γ) to an accuracy of ± 1-2% at 30 and 60 keV. These data agree with the lower group of values. In EANDC(US)79 U, p. 72, Grench et al. report measurements which agree with Barry's data. These data tend to confirm that there is a "bump" in the cross section around 160 keV.

The Committee concluded for the Au\textsuperscript{197} (n,γ) data:

Action

Batchelor

(i) Batchelor should discuss the Karlsruhe work with Beckurts.

(ii) There is doubt about the cross section in the region around 160 keV.

(iii) It is desirable that either a shape measurement be made or measurements be made in the region of the "bump."

Fission Cross Sections. Batchelor reported that the low values obtained by Perkin et al. (J. Nucl. En., 19, 423, 1965) were troubling, but that recently James (AERE) on the Linac had produced a value for \( q_{\text{f}}(\text{Pu}^{239}) \) of 1.77 ± 0.05 at 24 keV. This compares reasonably well with the value of 1.66
APPENDIX 2 (continued)

± 0.07 obtained by Perkin et al. Gilboy at Karlsruhe is in the process of making measurements. Fission cross sections were discussed in more detail under Item 7 of the Agenda.

At the last meeting of the Subcommittee, Spaepen had promised to issue a report to the full EANOC Committee, and the paper, "Isotopic Standards and Reference Substances for Nuclear Measurements," by P. J. DeBievre and J. Spaepen (EANOC(E)68 A), has been distributed.

Action Spaepen
Some time ago a letter was circulated to scientific journals on the isotopic composition of boron. Improvements have now been made on the data available and Spaepen wondered if this should be sent to the same journals. It was agreed that a statement on the isotopic composition of boron and its error should be circulated to the full Committee.

Action Spaepen
It has been suggested in the past that stocks of standard enriched $^{10}$B and $^{6}$Li should be set up, but Spaepen said that no action had been taken so far. The Committee agreed that a circular letter should be sent out with the approval of the full EANOC Committee to find out the demand for such standards.

Koch introduced the memo of Caswell on the Neutron Source Calibration Study at the National Bureau of Standards. The survey was made to evaluate the need for (1) their research on neutron source standardization and (2) the continuation of the source calibration service which the NBS provides for the public. It has been concluded that NBS should:

(i) Continue source calibration, and

(ii) Try to improve the accuracy of calibration.

No crash program, however, was envisaged on this.

Spaepen said that the document was written because of the discussion as to whether neutron sources should be within the scope of the Subcommittee. After some discussion, it was agreed that neutron sources which could be used for the measurement of cross sections should be kept in the frame of reference of the Subcommittee.

Batchelor introduced the paper of Fieldhouse et al. (EANOC(UK)71 S) on the calibration of the AWRE $^{240}$Pu neutron source. The source has been calibrated by three methods:

(a) in the NPL MnSO$_4$ bath;
(b) in the boron pile; and
(c) in the AWRE oil bath.

The three results are in good agreement and lead to a final accuracy of 0.45%.
The source is, however, changing in output by an estimated 0.1% per year. The work on the source has had repercussions on $\nu$ which are dealt with under Item 4.

4. **\( \nu \) Measurements.**

Batchelor introduced the paper of Fieldhouse et al. (EANDC(UK)64 S) on the revision of the strength of the Harwell Pu\(_{240}\) spontaneous fission neutron source. The source strength has been revised because:

(a) it has been compared with the known strength of the AWRE Pu\(_{240}\) source;

(b) it has been recalibrated in the boron pile; and

(c) the assumption made in the original calibration that the source does not multiply in an MnSO\(_4\) bath has been shown to be incorrect.

The revision of the strength has implications on the value of $\nu$ for Cf\(_{252}\). Moat et al. (J. Nucl En., 15, 102, 1961) used the source in their measurement of this quantity and their revised value for $\nu$ of 3.685 ± 0.015 is in much better agreement with the boron pile value of 3.705 ± 0.015 than with the large scintillator values of 3.799 ± 0.034 and 3.771 ± 0.030. It is, therefore, proposed that a new experiment be done by Axton at NPL in which the neutron output of a sample of Cf\(_{252}\) would be measured in an MnSO\(_4\) bath and the fission rate would be measured in a separate experiment in which aliquots would be deposited as thin samples in a fission chamber. Axton described the experiment in some detail and it was agreed that:

(i) The request for microgram quantities of Cf\(_{252}\) for the experiment should be brought before the full EANDC Committee; and

Action (ii) Axton should specify the purity of the sample he required.

5. **Precise Thermal Values.**

White introduced his paper, (EANDC(UK)72 S), which is really a progress report on the measurements of the fission cross sections of Pu\(_{239}\) and Pu\(_{241}\) relative to U\(_{235}\) in the energy range 0.016 eV to 0.55 eV. Measurements have been made at 7 energies and also in a beam extracted from a thermal column. He described the measurement in detail and concluded that at 0.0253 eV and the other monoenergetic points, his results agree with other measurements made with monoenergetic neutrons. The result at 0.0253 eV for Pu\(_{239}\) is, however, lower than that recommended by the Westcott compilation. With the thermal beam, whose spectrum was measured, he found that his derived 0.0253 eV data was significantly lower than that obtained by Bigham et al. (Proceedings of the 2nd U.N. International Conference on the Peaceful Uses of Atomic Energy, 16, 125, 1958).

This discrepancy was discussed by the Committee. Spaepen said that CBNM was remeasuring the Pu\(_{239}\) thermal fission cross section, using a chopper at the Belgian BR 2 reactor. This measurement was being carried out relative
to the $^{10}$B(n,$\alpha$) cross section, $\alpha$ particles and fission fragments being counted in precisely known low geometry with solid state counter. The new measurement hoped to achieve $\pm 0.5\%$ if the half life of Pu$^{239}$ is correct. Another measurement of this half life is also planned. The Committee noted that the value of $q_\alpha$ deduced from $\alpha$ and $q_\beta$ data agreed with the Bigham et al. data. Hanna commented that the trouble may be in the assumption that a Maxwellian neutron spectrum is applicable for the $\alpha$ measurements. Havens proposed that $\alpha$ should be obtained by measuring the transmission and $q_\beta$ simultaneously in the way Safford did for U$^{235}$.

Batchelor reported that Barry's measurements on $^{6}$Li(n,$\alpha$)/U$^{235}$(n,f) will provide a thermal value of the $^{6}$Li(n,$\alpha$) cross section as accurately as it is now known because an assay has been done on the $^{6}$Li foil. Taschek said that Diven, using the bomb technique, is to make $^{6}$Li/U$^{235}$ ratio measurements and hopes to extend the results to low energies by using a special short 20 meter flight path.


Action

Havens

Havens reported that a paper had been presented to the Conference on Neutron Cross Section Technology in Washington, (Paper B-8), entitled "Correlating the Energy Calibration of Neutron Velocity Spectrometers," by S. A. R. Wynchank. Havens said he would either re-write this in more general terms or would issue it as it stood to the Subcommittee.

7. Accuracy Needed on $q_{f}$ of Pu$^{239}$ in the Energy Range Thermal to 100 keV.

The Committee agreed that the accuracy needed on the Pu$^{239}$ fission cross section which can be used as a standard should be related to the nuclear data requests. The UK Category I requests are for $\pm 1\%$ from 0.01 to 1 eV, $\pm 3\%$ from 1 eV to 40 keV, and $\pm 2\%$ from 40 keV to 1 MeV. There is a UK Category III request for $\pm 0.5\%$ in the energy range 40 keV to 1 MeV, but it is only Category III because the requestors think that the measurement to this accuracy cannot be made. Batchelor reported that there is a good reason for making the measurements and, therefore, a small committee in the UK was trying to estimate the manpower required for such an experiment. He summarized the situation at other energies as follows:

(i) In the thermal region there is a discrepancy and CBNM at Geel proposes to make new measurements.

(ii) In the resonance region the data measured or being measured should satisfy the requests.

(iii) The measurements at AERE and Karlsruhe should remove the discrepancies in the low keV region.

Batchelor then reported the UK thoughts on the $\pm 0.5\%$ measurements. It was believed that by using neutron sources calibrated in the NPL MnSO$_4$ bath, an accuracy of better than $\pm 1\%$ could be achieved. The experiment proposed was as follows: The NPL could calibrate Sb-Be, ThC"'-D$_2$O, and ThC"'-Be photon neutron sources, which give neutrons of approximately 24, 196, and 848 keV to approximately $\pm 0.5\%$ accuracy. This accuracy was believed to be realistic because of comparisons made with sources calibrated in the boron pile at AWRE and at the NBS. CBNM at
APPENDIX 2 (continued)

Geel claims to be able to assay fission foils to ± 0.1%, so by obtaining foils (~200 µg/cm²) from this source, it should be possible to adopt the technique used by Perkin et al. (J. Nucl. En., 19, 423, 1965) at 24 keV and obtain better than ± 1% accuracy. There are many problems to be investigated. Measurements would be done for several foils of different thickness and the scattering of neutrons in the fission chamber would have to be investigated. There are problems in correcting for the fission events lost below the bias set in the fission chamber and for the fissions whose fragments never emerge from the foil. Other side effects which require further work are the energies of the neutrons emitted by the sources and the back scattering of fission fragments by the foils. If one assumes that CBNM will provide the foils and NPL will do the source calibration, an estimate of nine man-years of work will be required to do the remainder of the experiment. The variation of the cross section between the spot points would be measured either by the bomb technique or by using a cyclotron as a pulse neutron source.

Spaepen was not convinced that there were no systematic errors in the foil assays done at Geel and he would like to organize an intercomparison program. It was felt that this would not be good unless the NBS participated. Koch said that the NBS needs money before they can do it and this would not be available unless the NBS program was supported by the AEC.

Taschek suggested that another possible approach to the problem was to measure the flux from an accelerator target by producing a collimated neutron beam, and then measuring the intensity in a scintillator, MnSO₄, or graphite pile. The fission chamber could be placed in the same beam to obtain the cross section.

Action
Batchelor

It was agreed that Batchelor should prepare a paper explicitly describing the errors expected in the experiment.


At the last meeting of the Subcommittee it was agreed that the compilations of standard cross sections being made at Geel should be done in the following order: Bi¹⁰, Li⁶, and U²³⁵. Bi¹⁰ had been done and Spaepen asked if the compilation should be continued above 200 keV. The Committee agreed that it should be continued to 500 keV so that it overlapped with the region where the (n,p) cross section would be used for flux measurements. Spaepen said that a copy of the compilation would be issued to the Committee members in the next few weeks and that comments would be appreciated. He also said that a Li⁶ compilation was being made by Stewart at Los Alamos, so CBNM proposed to do no work on this. The U²³⁵ compilation has not yet been started.

The Committee discussed which data should be evaluated after U²³⁵ and it was agreed that gold should be done next.


Havens said that he had been asked by reactor physicists if mixed chemical standards of U²³⁸ and Pu²³⁹ were to be available. These would be used for burn-up studies. Hanna suggested that it was best to make one's own standards and Koch said that such standards can be purchased from the NBS. It was agreed that this point should be referred to the full EANDC Committee.

20 April 1966

M. G. Sowerby
APPENDIX 3

REPORT TO THE SUBCOMMITTEE ON STANDARDS
FOR NUCLEAR MEASUREMENTS

on the
Neutron Source Calibration Survey at the National Bureau of Standards

Introduction

This memorandum reports on a survey aimed at helping to determine the direction of the neutron standards effort of the internal NBS Neutron Physics Program in the future. Aside from a small continuing effort on the NBS Standard Thermal Neutron Flux Density, there appear to be four main areas where this effort could be directed: (1) radioactive neutron source standardization, (2) absolutely-determined monoenergetic neutron flux densities from the Van de Graaff accelerator, (3) neutron cross section measurement, and (4) neutron dosimetry research. Area (2) is basic to (3) and (4) in that absolutely-determined monoenergetic neutron fluxes are required for the measurement of some neutron cross sections and for studies of energy dependence (or response functions) of neutron dosimeters. The present memorandum is an attempt to evaluate the future importance of area (1) in which the largest NBS neutron standards effort has been made in the past.(1-5)

A radioactive neutron source as a standard possesses the following desirable characteristics: it is small, convenient, essentially constant in strength, and inexpensive compared to other neutron sources. Its chief disadvantages are the polyenergetic and relatively poorly known energy spectrum, and the relatively small number of neutrons produced. It follows that most applications of radioactive neutron source standards are for calibrations of instruments which are reasonably sensitive and which have a flat response vs. energy, or for which the dependence on energy is not too strong so that the lack of knowledge of source spectrum is not crucial. Improved measurements of source spectra, on which a small program at NBS is in progress, should improve knowledge of the source spectra, and make the sources more generally useful. The advantages of radioactive neutron sources have been sufficient (and the disadvantages tolerable enough) that these sources have been the "classical" neutron standard for over two decades.

Neutron Source Calibration Survey

The survey to be described was made to evaluate the need for further research on neutron source standardization and for continuation of the neutron source calibration service which NBS provides for the public. This survey was carried out by sending a questionnaire to a number of laboratories, each of which has had one or more sources calibrated for them by NBS in the past eight years. We have received 26 replies to our survey. The distribution of uses is indicated in Fig. 1. It can be seen that neutron source standards are used by a wide variety of different scientists. The most frequently-mentioned uses are for health physics instrumentation calibration, for the calibration of other neutron sources of a laboratory, and for calibration of neutron flux density measuring instruments and total neutron yield measuring instruments. Less frequent uses are for production of known thermal neutron flux densities, for radiobiological experiments, in connection with nuclear reactors and critical assemblies, and only three users use a source directly for neutron cross section measurement.
APPENDIX 3 (continued)

The uncertainty which we presently quote for most calibrated sources is slightly better than 2.5%. Upon completion of our present program to evaluate the corrections involved in absolute neutron source calibrations we expect to be able to quote a standard error to the customer of about 1.5%, whereas the uncertainty in the absolute calibration of our national standard Ra-Be (γ,n) source is about 1%. The distribution of uncertainties requested by customers is shown in Fig. 2. We find, for example, that the accuracy of 1.5% will satisfy all but 7 customers although 14 felt that it would be "nice to have" accuracies of 1% or 0.5% -- better than we will be able to offer upon completion of our present correction evaluation studies. There were three requests for unusually high accuracy: one from a scientist who uses a manganous sulfate bath to measure reactor constants and who desires ultimately 1/4% accuracy; another requested 1/2% for producing a known thermal neutron density for reactor power level calibration; and one remark "radiobiological experimentation needs the best accuracy available." Even making allowance for rather vague remarks such as the last one it appears that our calibration service does not completely satisfy present needs -- to say nothing of future needs.

The requests for sources to be calibrated in the future appear comparable to those which have been requested in the past with an increase in the number of sources in the range of $10^8$ or $10^9$ neutrons per second.

Conclusions

(1) While the number of neutron sources calibrated in a year is never large (typically 6 to 10) there is a continuing need for a source calibration service. The fact that the cost of a calibration is on the order of $500 indicates that those who do have a source calibrated by NBS are, in fact, in real need of the calibration. We conclude that the source calibration service should be continued at about the same level it is now.

(2) There is a need for higher accuracy in neutron source calibration. This indicates that the National Bureau of Standards should continue some research in this area. However, if we compare the need for standard sources to the need for known monoenergetic fast neutron flux densities from the Van de Graaff accelerator it appears that research with monoenergetic neutrons for application to cross section measurements and neutron radiation dosimetry is, in fact, more urgent than increased accuracy for the radioactive neutron sources whose spectra are not well known.

A copy of the source calibration survey form with number of requests of each kind indicated in the appropriate blanks is attached to this memorandum.

References


APPENDIX 3 (continued)


R. S. Caswell
Neutron Physics Section
National Bureau of Standards

December 1, 1965
APPENDIX 3 (continued)

Total Number of Replies: 26

NBS NEUTRON SOURCE CALIBRATION SURVEY

(June 1965)

Uses of your neutron source(s): (Please check appropriate blank.)

16 Neutron flux density measuring instrument calibration (e.g., long counter, polyethylene sphere)

10 Total neutron yield measuring instrument calibration (e.g., MnSO₄ bath, graphite sphere)

3 Neutron cross section measurement (e.g., 25 keV cross section with Sb-Be(γ,n source)

9 Produce a known thermal neutron flux density (e.g., standard graphite pile)

15 Calibrate other neutron sources

17 Health Physics instrumentation calibration (e.g., survey meter, film badges)

5 Radiobiological experimentation

5 Nuclear reactor (startup, critical or sub-critical assembly)

8 Other

Please state briefly what you do with a calibrated standard neutron source:

Accuracy requirements. (Please check appropriate boxes.)

<table>
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<th>More accurate than really necessary</th>
<th>Nice to have</th>
<th>About right</th>
<th>Somewhat too inaccurate</th>
<th>Much too uncertain</th>
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<td>5</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td></td>
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<td>9</td>
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</tr>
<tr>
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<tr>
<td>.5%</td>
<td></td>
<td>11</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

-36-
Emission rate in neutrons/sec of source for which calibration (was/might be) needed: (Please check appropriate boxes.)

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<th>~ $10^4$</th>
<th>~ $10^5$</th>
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<td>2</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Future</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>15</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Comments or Suggestions:

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

Information supplied by ________________________________
USES OF NBS-CALIBRATED NEUTRON SOURCES

- Neutron Flux-Density Instrument Calibration
- Total Neutron Yield Instrument Calibration
- Neutron Cross Section Measurement
- Produce Known Thermal Neutron Flux Density
- Calibrate Other Neutron Sources
- Health Physics Instrumentation Calibration
- Radiobiological Experiments
- Nuclear Reactor
- Other

NUMBER OF USERS
APPENDIX 4

BURN-UP DETERMINATION OF NUCLEAR FUELS

The USAEC has sponsored a program for several years to develop methods for the determination of burn-up in power reactor fuels. The principal measurement technique under study is chemical analysis for fission products and heavy elements. The use of long-lived, radiochemically determined fission products is not applicable because the errors of the in-pile decay correction are magnified with long-term irradiation, the nuclear constants are not known with sufficient accuracy, and the few available nuclides, Cs$^{137}$ and Sr$^{90}$, are volatile and migrate at high temperatures.

The degree of reliability of a burn-up determination based on analyses of stable fission products depends on three factors: the accuracy of the values used for the fission yields, the linearity between the number of fissions and the number of atoms of the fission products present at the end of the irradiation, and the reliability of the analysis methods.

Known encapsulated quantities of high purity U$^{233}$, U$^{235}$, Pu$^{239}$, and Pu$^{241}$ are irradiated in well thermalized regions of the MTR and VBWR reactors to an estimated burn-up of 10 to 25 atom per cent. Chemical analysis of the capsule for heavy element content and isotopic distribution provides data for calculating total fissions independent of any fission product analysis. Isotope dilution mass spectrometry is employed for accurate analyses of stable fission products. In addition to this information, a knowledge of the neutron capture cross sections of each fission product is required before accurate absolute fission yields can be calculated.

Thermal fission yield data on U$^{233}$ and U$^{235}$ from duplicate experiments indicate that absolute thermal fission yields are being determined to an accuracy of nearly 1%. For example, Nd$^{148}$ fission yields are 1.25 ± 0.02% and 1.68 ± 0.02% for U$^{233}$ and U$^{235}$, respectively. Other nuclear constants such as capture to fission ratio ($\alpha$) of U$^{233}$ and U$^{235}$ have been determined to be 0.0942 ± 0.0016 and 0.1715 ± 0.0024 for 2200 m/sec neutrons. Neutron capture cross sections and additional fission yields as a function of neutron energy for various fission products will be determined as the program proceeds.

Isotopes suitable for burn-up indicators will be selected and chemical procedures simplified so that accurate burn-up determination can be obtained from many laboratories on a routine basis.

Some preliminary work relating the above destructive burn-up analyses data to nondestructive burn-up determinations using gamma spectrometry (both NaI crystals and Lithium drifted Germanium detectors) indicates that qualitative information can now be obtained and that quantitative burn-up data by nondestructive techniques appears to be feasible.
APPENDIX 5

AWRE Work in the Neutron Data Indexing

Compiling and Evaluating Field

K. Parker

I want to briefly outline AWRE activities in the nuclear data indexing, compiling and evaluating field. In doing so, I hope to make a few points relevant to the Committee's discussion on this subject. Afterwards Pendlebury will talk about a particular problem which we believe is of the highest importance - the "improvement" of the best evaluated neutron cross section data using the results of integral experiments.

Our group is quite small comprising four professional staff (of whom two are fairly new to the game) two programmers and one and a half supporting staff who draw graphs, run programs, etc. However, we do get very helpful support of various kinds from other groups - the Winfrith evaluation group, the Aldermaston and Harwell experimental nuclear physics groups, and groups concerned with neutron transport calculations. Nevertheless, our situation is quite typical of the general world wide situation in that the number of people making measurements is very much larger than the number of people getting these results into a form which is usable by the neutronics people. Let me ask you how the request list - the last one (EANDC-43 U) contained 930 items - is compiled and how should it be compiled? I don't know the complete answer to the first question but as far as the second is concerned, I'm sure that if all the existing theoretical and experimental information was fully evaluated then the request list could be reduced by a sizable fraction. But that is not all - even a good evaluation of say U235 cross sections can be increased in usefulness by the methods which Pendlebury will describe. The point I'm making is that EANDC has been very successful in getting more measurements but that much remains to be done in exploiting the results.

What are we doing to attack this problem? How are we placed? We're working along quite similar lines to those being followed at Los Alamos about which Lazarus spoke to you in May last year (EANDC-47 A, p. 26). In fact we have very close working relations with both Los Alamos and Livermore (where Howerton's group contains our corresponding numbers). Our strong point, as we see it, is that we've always worked closely with people making measurements, with people studying static critical assemblies, such as VERA, and with people making neutronics calculations by both Monte Carlo and deterministic methods. Right across the corridor from me is a Monte Carlo expert (he's also a statistician) - along the corridor a few yards away is an expert on the Sn method. These people are our customers - they want good data in a form they can use for their calculations. Their first worry is not whether the fission cross section in group 12 is right but whether it is there at all! We believe that this continuing close contact with both our customers and our sources of raw materials has been a very healthy stimulus.

Our aim is to have available good evaluations of neutron cross sections on all materials of interest in, roughly, the energy range 10^{-4} eV - 20 MeV. To this end we've done much evaluation ourselves, but since 1962 we've followed the conscious policy of seeking to improve our stock by exchange with other interested laboratories either directly or through one of the international nuclear data centres. We expect this trend to continue and that in the future we shall make fewer, but better evaluations and extend the exchange process.
APPENDIX 5 (continued)

Our longest standing and most fruitful cooperation is with Story's group at Winfrith. This closer cooperation started in 1961 and led to the creation of the UKAEA Nuclear Data Library. This is fully described in the 1964 Geneva Conference Paper 168. I shall only emphasise here that the format of the magnetic tapes is designed primarily to allow the further processing of the data using the programs GALAXY to give group cross sections and DICE to give the collision probabilities and other data required in Monte Carlo calculations.

We have never engaged in compilation activities, but have relied heavily on work at Brookhaven, Livermore and elsewhere. Our own manual index of references reached unwieldy proportions about three years ago and we are now enthusiastic supporters of and contributors to CINDA in which our old reference system is being incorporated.

Our concern with developing group constant calculation programmes such as GALAXY is rather outside the field of EANDC, but is I feel invaluable in providing real experience of the best ways to present evaluated data. This more EACRP orientated side of our activities is also very valuable to the AWRE experimental nuclear physicists in that arrangements can be made for corrections to nuclear physics experiments to be carried out. Pendlebury and the Monte Carlo people have been involved in several exercises of this kind.

Present Problems

1. Standards. One very annoying feature in evaluation is the absence of authoritative values for reference standards - cross section like those of the B10 and Li6 (n,α) cross sections, the U235 fission cross section and various capture cross sections. This can increase the time to do an evaluation enormously. Personally I'm very glad to learn that the CBNM at Geel plans to look after this problem in the future.

2. The Calculation of Cross Sections. Methods have been generally developed by people interested in nuclear structure and are not systematically explicated in evaluation work. The straightforward application of the simpler versions of optical model and Hauser-Feshbach theory can be used to calculate many cross sections to 10-20 % or even better, but a lot of hard work is needed to make the final refinements such as making the calculation in non-spherical nuclei, coupled channel calculations and so on. I'm almost sure that sufficient information on inelastic scattering in the continuum region is available if it is analysed as a whole. However, this is a very big problem. At Aldermaston we've not been able to exploit the calculation of cross sections as much as I would like simply because of shortage of effort. The problem is exactly the same as with experimental work in that what is needed is often not what is the most interesting from an academic nuclear structure point of view. Hence the absence of the necessary dedicated effort.

3. Plotting Cross Section Curves. Finally there is the large amount of time spent in plotting, weighting and evaluating experimental curve to get the "best" - in some sense - evaluated curve. Then two weeks after the ten existing experiments have been considered along comes the eleventh. Do we start again? No- but we probably should. Our answer to this might be called the A. B. Smith approach. He analysed the routine operations in a neutron cross section experiment and got a computer to do them. We're trying to do the same on evaluation. Operations done in evaluation fall into two classes. If they're logical we can
APPENDIX 5 (continued)

analyse them and put them on a computer. If they're not we shouldn't be doing them anyway! Our aim is to develop programs to take the experimental data from the SCISRS tapes and to plot the points and evaluated curves through them taking into account both statistical and subjective weighting of the different experimental points. In this work we find that the mathematical curves known as splines have an important application.

This approach is described in more detail in two papers presented at the Washington Conference on Neutron Cross Section Technology by A. Horsley and myself. One of these describes a practical case - the fitting of Legendre polynomial coefficients of angular distribution curve by a method which avoids many of the usual interpolation and extrapolation difficulties. If this approach is successful it should greatly ease the problems of up-dating evaluations and examining the effect of new experimental results.
APPENDIX 6

The Optimisation of Neutron Cross Section Data Adjustments
to give agreement with Experimental Critical Sizes

Mrs. P. C. E. Hemment
E. D. Pendlebury

1. Introduction

It is fairly well known that a set of neutron cross section data for fissile and non-fissile nuclei, based on the evaluation of neutron cross section measurements do not in general give calculated critical sizes and other integral quantities in agreement with the measured values. One may therefore wish to adjust the cross section data, within their experimental errors as far as possible, so that they are consistent with the integral measurements (bearing in mind the uncertainties in the integral measurements).

A method has been developed at Aldermaston and programs DUNDEE and PENICUIK written for the IBM-7030 to enable data adjustments to be calculated in an optimum way to make them consistent with experimental critical sizes. The program DUNDEE uses perturbation theory with "perturbation functions" produced by the Sn program STRAIGHT (1,2) to calculate for each system the sensitivity of the reactivity to changes in the cross section data for all nuclides present in the system. The program PENICUIK uses this information together with standard deviations of the cross section data and of the reactivity of the critical sizes to calculate an optimum set of adjustments necessary to make the cross section data consistent with the experimental critical sizes. The method uses a minimisation procedure based on least squares to obtain a simultaneous best fit to the experimental cross section data and the experimental critical sizes.

The program PENICUIK and a earlier version of DUNDEE have been in use at Aldermaston since about April, 1964. Work is at present in hand in connection with a program to calculate the sensitivity of spectra, reaction rates and perturbation measurements at the centre of critical systems to changes in the cross section data. Given these sensitivity factors the program PENICUIK can then be used to fit the cross section data to experimental values of these quantities as well as to critical sizes.

An example of the kind of results obtained using the DUNDEE-PENICUIK system to fit cross section data to experimental critical sizes is given below.

2. Results of Calculations to fit Cross Sections to Experimental Critical Sizes

Calculations have been carried out on 18 fast reactor systems, which are described briefly in Table 1. The results for \( (\text{k}_{\text{eff}} - 1) \) using unadjusted data* from the UKAEA data library are given in column (3). Column (4) shows the errors when using the same data as in column (3) but modified to take into account recent AWRE values (5) for the \( \text{U}^{235} \) fission cross section. Column (5) shows the errors obtained using the column (4) data adjusted by the PENICUIK program to simultaneously give the best overall fit to the cross sections and experimental critical sizes. The values for \( (\text{k}_{\text{eff}} - 1) \) given in columns (3)

*For \( \text{U}^{235} \) these are \( 3/\text{U}^{235} \) (3) DFN = 155
For \( \text{U}^{238} \) these are \( 3/\text{U}^{238} \) (4) DFN = 156
(4) and (5) are shown graphically in Figures 1, 2, and 3 where they are plotted as a function of core radius. For the systems considered one would like $(k_{\text{eff}} - 1)$ to lie between $\pm 0.005$ - shown by the dashed lines on the graphs - and it will be seen that the program PENICUIK leads to data which essentially achieves this.

Some of the more important changes made in the column (4) data to produce the column (5) data are listed in Table 2. Also listed in this table are the standard deviations assumed for the experimental microscopic cross section values as estimated from the distribution of the various published values. The required adjustments are in all cases well within these standard deviations. (The standard deviations of the experimental k values were taken as 0.003). In addition to the examples shown in Table 2 most of the other reaction cross sections of $^{235}\text{U}$ and $^{238}\text{U}$ were also adjusted (a total of 86 items of data were adjusted), but no changes in other materials were allowed. In a comprehensive treatment it is desirable to allow changes in the cross sections for other materials because there is a fair amount of graphite and steel in the VERA systems, and PENICUIK calculations have in fact been carried out in which the data for these materials were allowed to change.

(1) R. D. Wade, AWRE Report No. 0-12/63 (1963)
(2) E. D. Pendlebury, AWRE Report No. 0-32/64 (1964)
(3) K. Parker, AWRE Report No. 0-82/63 (1963)
(4) K. Parker, AWRE Report No. 0-79/63 (1963)

A full account of this work will be given in a paper to be submitted for presentation at the International Conference on Fast Critical Experiments and their Analysis, to be held at Argonne, Illinois, on October 10th-13th, 1966.

20th April, 1966
Fig. 1. $(K_{\text{eff}} - 1)$ using unadjusted data from UKAEA Data Library.

Numbers on the graph are system reference numbers given in Table I.
Figure 2. $(K_{\text{eff}} - 1)$ using data as in Fig. 1 but with recent AWRE values for $\sigma_f (U^{235})$ substituted.

Numbers on the graph are System reference numbers given in Table I.
Reactivity error

Core Radius (cm)

1. Numbers on the graph are given in Table 1.
2. System reference numbers are denoted by symbols.
3. (K$_{eff}$ - 1) after adjustment by Penick is used in Fig. 2.
### TABLE 1 - Comparison of Calculated and Experimental Reactivities for 18 Fast Reactor Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Brief Description</th>
<th>Reactivity Error of Calculation ($k_{eff} - 1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>1.1</td>
<td>Sphere of fully enriched U, unreflected (Goddiva)</td>
<td>+ 0.0279</td>
</tr>
<tr>
<td>1.2</td>
<td>Sphere of fully enriched U, reflected by 1.77 cm of Unat</td>
<td>+ 0.0368</td>
</tr>
<tr>
<td>1.3</td>
<td>Sphere of fully enriched U, reflected by 4.67 cm of Unat</td>
<td>+ 0.0454</td>
</tr>
<tr>
<td>1.4</td>
<td>Sphere of fully enriched U, reflected by 8.95 cm of Unat</td>
<td>+ 0.0448</td>
</tr>
<tr>
<td>1.5</td>
<td>Sphere of fully enriched U, reflected by 9.97 cm of Unat</td>
<td>+ 0.0430</td>
</tr>
<tr>
<td>1.6</td>
<td>Sphere of fully enriched U, reflected by 22.9 cm of Unat</td>
<td>+ 0.0378</td>
</tr>
<tr>
<td>2.1</td>
<td>Sphere of 29% enriched U, unreflected</td>
<td>+ 0.0181</td>
</tr>
<tr>
<td>2.2</td>
<td>Sphere of 38% enriched U, unreflected</td>
<td>+ 0.0257</td>
</tr>
<tr>
<td>2.3</td>
<td>Sphere of 54% enriched U, unreflected</td>
<td>+ 0.0370</td>
</tr>
<tr>
<td>2.4</td>
<td>Sphere of 48% enriched U, reflected by 19.7 cm of Unat</td>
<td>+ 0.0243</td>
</tr>
<tr>
<td>2.5</td>
<td>Sphere of 68% enriched U, reflected by 21.6 cm of Unat</td>
<td>+ 0.0336</td>
</tr>
<tr>
<td>2.6</td>
<td>Sphere of 81% enriched U, reflected by 22.2 cm of Unat</td>
<td>+ 0.0343</td>
</tr>
<tr>
<td>2.7</td>
<td>Sphere of 16% enriched U, reflected by 7.6 cm of Unat</td>
<td>+ 0.0083</td>
</tr>
<tr>
<td>VERA 1B</td>
<td>Graphite plus fully enriched U, reflected by Unat</td>
<td>+ 0.0048</td>
</tr>
<tr>
<td>VERA 2A</td>
<td>Graphite plus fully enriched U, reflected by Unat</td>
<td>+ 0.0060</td>
</tr>
<tr>
<td>VERA 3A</td>
<td>Graphite plus 30% enriched U, reflected by Unat</td>
<td>+ 0.0036</td>
</tr>
<tr>
<td>VERA 4A</td>
<td>Graphite plus fully enriched U with 9 v/o polythene, reflected by Unat</td>
<td>+ 0.0036</td>
</tr>
<tr>
<td>VERA 5A</td>
<td>Graphite plus fully enriched U with 8 v/o polythene, reflected by Unat</td>
<td>+ 0.0035</td>
</tr>
</tbody>
</table>

(Note: The equivalent fractional error in critical mass is approximately $\Delta$.)
Table 2 - Standard Deviations of the Cross Section Data for $^{235}$U (n,f) and $^{238}$U (n,γ) Compared with the Changes Calculated by PENICUIK to Give Agreement with the Experimental Critical Sizes

<table>
<thead>
<tr>
<th>Energy Group Limits</th>
<th>$^{235}$U (n,f)</th>
<th>$^{238}$U (n,γ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assumed standard deviation of exp. data (%)</td>
<td>% change required</td>
</tr>
<tr>
<td>11 to 2.4 MeV</td>
<td>3.8</td>
<td>-2.95</td>
</tr>
<tr>
<td>2.4 to 1.1 MeV</td>
<td>3.9</td>
<td>-3.44</td>
</tr>
<tr>
<td>1.1 to 0.55 MeV</td>
<td>7.4</td>
<td>-6.18</td>
</tr>
<tr>
<td>550 to 260 keV</td>
<td>9.6</td>
<td>-1.67</td>
</tr>
<tr>
<td>260 to 130 keV</td>
<td>5.3</td>
<td>+0.42</td>
</tr>
<tr>
<td>130 to 43 keV</td>
<td>6.4</td>
<td>+1.98</td>
</tr>
<tr>
<td>43 to 10 keV</td>
<td>10.0</td>
<td>+1.55</td>
</tr>
<tr>
<td>10 to 1.6 keV</td>
<td>10.0</td>
<td>+1.17</td>
</tr>
</tbody>
</table>

*From data modified to include recent AWRE values for $\sigma_f$ (5).
# APPENDIX 7

**Stocks of Th, U and Pu Isotopes held by Electromagnetic Separation Group at Harwell**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Sample HR/</th>
<th>Main Isotope</th>
<th>% enrichment</th>
<th>Weight mgms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu 238</td>
<td>67</td>
<td>19.5</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>6</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>Pu 239</td>
<td>1 (UK)</td>
<td>99.9</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16 (UK)</td>
<td>99.9</td>
<td>446</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65/22A</td>
<td>99.6</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>99.5</td>
<td>1068</td>
<td></td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>99.5</td>
<td>1336 (on loan, Mol)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>99.4</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>99.1</td>
<td>1203</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16B (UK)</td>
<td>98.8</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62</td>
<td>98.1</td>
<td>1138</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61 (part UK)</td>
<td>97.0</td>
<td>1632</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>96.8</td>
<td>3381</td>
<td></td>
</tr>
<tr>
<td></td>
<td>69</td>
<td>90.9</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Pu 240</td>
<td>F1/3</td>
<td>99.3</td>
<td>320</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>99.0</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D/1</td>
<td>98.9</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>97.8</td>
<td>536</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>96.8</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48 (part UK)</td>
<td>96.3</td>
<td>1140 (250 reserved)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>77</td>
<td>96.2</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>76</td>
<td>92.8</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33A</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(about 5g Pu 240 out on loan to A.W.R.E.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pu 241</td>
<td>79</td>
<td>96.9</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>95.7</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>94.9</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>94.1</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>74</td>
<td>94.1</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>81</td>
<td>93.9</td>
<td>179</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E34/37</td>
<td>93.8</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>93.0</td>
<td>207</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E5/7</td>
<td>92.1</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>91.3</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>87.7</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41A</td>
<td>?</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(88 mg out on loan to (A.W.R.E.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Pu 241 stocks now 4 years old)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 7 (continued)

Stocks of Th, U and Pu Isotopes held by Electromagnetic Separation Group at Harwell

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Sample HB/</th>
<th>Main Isotope</th>
<th>% enrichment</th>
<th>Weight mgms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu 242</td>
<td>D2/3</td>
<td></td>
<td>96.8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td></td>
<td>90.9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>54A</td>
<td></td>
<td>76.6</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td></td>
<td>71.4</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td>37.8</td>
<td>12</td>
</tr>
</tbody>
</table>

(428 mg out on loan Pattenden)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Sample HB/</th>
<th>Main Isotope</th>
<th>% enrichment</th>
<th>Weight mgms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th 230</td>
<td></td>
<td>~ 99</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>U 235</td>
<td></td>
<td>99.92</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>99.4</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>U 238</td>
<td></td>
<td>99.96</td>
<td>3240</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>99.995</td>
<td>1395</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>99.988</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>99.98</td>
<td>3054</td>
<td></td>
</tr>
</tbody>
</table>

M.L. Smith
Dear Dr. Taschek:

In conversation with George Rogosa I was asked to submit to you an estimate of when Pu rolled foils would be available from the ORNL Isotopes Target Center. As I understand this, you will use this information for publication to the EANDC in the near future. Inasmuch as we performed our first rolling job in the new mill facility only yesterday, we should have capability to roll Pu within the next 2-3 months. By that time we hope to be able to reduce the various compounds to metal, form delta-phase stabilized alloys and roll. Before that time perhaps rolling of alpha-phase material will be attempted if metal (239Pu or 241Pu) can be furnished us from some other facility. In the interim period, we will attempt to roll Np and Am; we can, of course, roll U and Th anytime.

I hope this information will suffice. If not please call me directly.

April 5, 1966
ANNOUNCEMENT OF THE IMPROVEMENT IN THE ANALYSIS OF
STANDARD BORON

The Central Bureau for Nuclear Measurements (EURATOM), Geel, Belgium has determined to a higher accuracy: the isotopic composition of the C.B.N.M. Boron Isotope Standard \(^1\), announced as available for distribution in this journal \(^2\).

The absolute \(^{10}\text{B}/^{11}\text{B}\) isotope (atomic) ratio is certified as

\[
0.24726 \pm 0.00032
\]

corresponding to an isotopic composition of

\[
\begin{align*}
19.824 \pm 0.020 \text{ atom } \% & \quad ^{10}\text{B} \\
80.176 \pm 0.020 \text{ atom } \% & \quad ^{11}\text{B}
\end{align*}
\]

and a relative atomic weight of \((^{12}\text{C} = 12)\)

\[
10.81178 \pm 0.00020
\]

The determination was made using isotopic blends to calibrate the mass spectrometers.

The uncertainties are based on 95 % confidence limits for all statistical errors and limits of uncertainty on known systematic errors.

The standard consists of highly purified boric acid (\(\text{H}_3\text{BO}_3\)). The C.B.N.M. prepares solutions of this boric acid in light and heavy water, which are certified for chemical boron content to within 0.1 %. The Bureau also prepares on request thin evaporated films of elemental boron. These films are isotopically defined against the Standard, and assayed for total mass and chemical composition.
1) A complete report on this absolute $^{10}\text{B}$-abundance measurement will be published.
