PROTOCOL FOR COMPARISON OF FLUENCE RATE MEASUREMENTS
IN THERMAL NEUTRON BEAMS

INTRODUCTION

One of the earliest inter-laboratory comparisons carried out under the auspices of what is now Section III was a comparison of thermal neutron fluence rate measurements. The results of the comparison were published [1,2] in 1970, more than 30 years prior to the beginning of this comparison. The current interest in demonstrating the extent of equivalence of measurements of Section III participants requires that these comparisons be repeated more frequently.

The present comparison differs from the previous one in two ways: the present comparison is focused on fluence rate measurements in thermal neutron beams or beam-like thermal neutron fields, such as the neutron field emanating into the void surrounding a moderated isotopic source, rather than at a location inside a moderating medium or inside a cavity within a moderating medium; and the measurements will be compared relative to a set of transfer detectors, rather than by exchange of activated foils. As in the earlier comparison, the quantity to be compared is the conventional thermal neutron fluence rate $N_0 = n_{th}v_0$, where $n_{th}$ is the neutron density below the cadmium cut-off energy, and $v_0$ is the reference thermal neutron speed of 2200 m/s. The quantity $N_0$ was called the “flux density” in the publications of the previous comparison, but the International Commission on Radiation Units has since then recommended the term “fluence rate” for this quantity. The quantity $N_0$ is also called the “2200 m/s fluence rate” and is often referred to as the “capture flux” in the published specifications of research reactors. Appendix 1 gives further details about the quantity to be reported.

Transfer Detectors

As transfer instruments, NIST will prepare and maintain a set of three flow-type $^{10}$B ionization chambers; and NIST will also supply a basic electronic system and some components of the argon(90%)-methane(10%) gas flow system. The three ionization chambers will each have a 1 cm diameter deposit of $^{10}$B, with nominal areal density of 0.5, 5.0, or 50 $\mu$g cm$^{-2}$, respectively. Any problem with the stability of the boron deposits will be addressed by comparison with a $^{235}$U deposit in a monochromatic beam at NIST, before and after the use by each participant. The statistical precision (one standard deviation) of these comparisons at NIST will be better than 0.1%. The stability of the $^{235}$U deposit is assured by alpha counting.
The choice of $^{10}$B as the active nuclide of the transfer detector is based on the nearly perfect $1/v$ cross section shape below 30 keV, the availability of very high quality deposits, and the relative ease of shipment to all participating countries.

Further details concerning the transfer instrument set are given in Appendix 2.

**Thermal Neutron Beams and Beam-Like Thermal Neutron Fields**

At most neutron research facilities around the world, the great majority of users employ neutron beams for materials science experiments. Typical 2200 m/s fluence rates for primary thermal or cold neutron beams at these facilities are of the order of $10^8$ to $10^9$ neutrons cm$^{-2}$ s$^{-1}$, while monochromatic beams from crystal monochromators have fluence rates typically in the range $10^6$ to $10^7$ neutrons cm$^{-2}$ s$^{-1}$. Measurements of these fluence rates are frequently made to evaluate the performance of cold sources, filters, collimators, guides, monochromators, and detector arrays. Analytical chemistry users still employ in-pile irradiations for activation analysis, but most of these are done at fluence rates which are 3 to 7 orders of magnitude higher than those of the standard fields which were compared in the earlier Section III comparison. The comparison in beam or beam-like geometry can be applied with little change to the foil activation techniques which are frequently employed for in-pile measurements as well as for beam measurements.

Since thermal neutrons are strongly absorbed and only weakly scattered by several conveniently available materials, it is possible to make shields and apertures which collimate the field to be measured without significantly perturbing it. This ability to collimate the beam (or other divergent field) makes it possible to shield the more massive components of an active detector to prevent scattering perturbation of the beam to be measured. It is similarly possible to shield the detector from thermal neutrons scattered by laboratory walls and structures.

**PARTICIPATING LABORATORIES AND TIMETABLE FOR MEASUREMENTS**

Tentative expressions of interest in participation were given by seven laboratories: CIAE, ETL, IRMM, NIST, NPL, PTB, and VNIIM. Both the NPL and the CIAE asked to be included as early as possible in the schedule.

It should be possible to begin the series of measurements by December, 2000. The transfer detector system could be kept by each participant for two to four months, depending on the number of different beams to be measured by the participant. The three different transfer detectors should cover at least the range $10^3$ – $10^8$ cm$^{-2}$ s$^{-1}$, and perhaps a bit more, depending on local background rates and dead time correction techniques. Each participant is encouraged to include as many points within this 5 orders of magnitude as his or her time allows.

A detailed timetable and additional information about the participants are given in Appendix 3. This Appendix will be updated throughout the course of the comparison, as
needed. All participants will be notified if unexpected delays are encountered which will require changes in the comparison schedule.

REPORTING RESULTS AND UNCERTAINTY ANALYSIS

All results will be sent to the Coordinator, David M. Gilliam, at NIST, who will compile a report. Since the Coordinator represents a participating laboratory, all NIST results will be filed with the BIPM Ionizing Radiations Section before NIST accepts results from any other participants.

The report of the results should include a brief description of the facility, including beam temperature or mean energy, if known, and any sort of beam filtration. These beam energy details are most needed for cold neutron beams, for which absorption within the boron deposit is most significant. NIST will correct the transfer detector results for this factor.

The report of results should include a listing of all significant uncertainty components. Participants are urged to follow the Guide to The Expression of Uncertainty in Measurement [3] in estimating and reporting their uncertainty, using $k = 1$ (corresponding to one standard deviation).

PUBLICATION OF THE RESULTS

The results will be submitted for publication in Metrologia after circulation to all participants and approval by members of Section III. The separate results will be ordered by $N_{th}$, labeled by laboratory acronyms, and shown as a scatter plot in which the weighted mean inter-laboratory value of $N_0/CR$ (see Appendix 1) is normalized to zero with individual results and their uncertainties plotted as percentage deviations from this axis. The weighting will be done on the basis of inverse squared uncertainties as reported by the participants and/or as accepted by Section III.

The results from the three separate ranges covered by the three different transfer chambers will be plotted separately first. Then the $N_0/CR$ values for all three detectors over the 5 orders of magnitude in fluence rate will be displayed on a single plot based on normalization of the three detectors to a common scale. This normalization will be based on characterization measurements at NIST and any at other interested laboratories.

Interim reports may also be sent to Section III members showing relative agreement of the results so far on hand. So long as the current mean of $N_0/CR$ is normalized to zero in the interim reports, no loss of independence or “blindness” in the comparisons would occur.
TRANSPORTATION ARRANGEMENTS

NIST will pay for shipping to the participating laboratory, and the participating laboratory will pay for the return shipment to NIST. More detailed specifications for the shipping arrangements are given in Appendix 4.

References

APPENDIX 1. The Quantity to be Reported

As noted in the Introduction, the quantity whose measurement is to be compared is \( N_0 = n_{th} v_0 \), where \( n_{th} \) is the neutron density (neutrons/cm\(^3\)) with energies below the cadmium cut-off energy, and \( v_0 \) is the reference thermal neutron speed of 2200 m s\(^{-1}\), exactly the same as in the previous comparison. The cadmium cutoff energy is taken to be 0.4 eV. For well-thermalized beams, the precise value of the Cd cutoff energy is not important; for less well-thermalized beams, a careful correction to a specific cutoff energy is required and larger uncertainties and/or more extensive work may be entailed in making this correction.

The quantity to be reported by each participant is \( N_0/CR \), the ratio of the measured fluence rate \( N_0 \) to the count rate \( CR \) of the transfer detector (with CR also corrected for its small epi-cadmium response). The ratio \( N_0/CR \) and an estimate of its uncertainty is to be reported for each beam or beam-like field measured. The measured fluence rate \( N_0 \), as defined above, may be determined by whatever means the participant chooses. Some laboratories will use foil activation and others may use active detectors of some kind. The reported value of CR must be from exposure of the transfer detector such that the boron deposit is positioned in “effectively” the same position where \( N_0 \) was measured. If \( N_0 \) and CR are not measured simultaneously, and if the neutron source is significantly time-varying, then some sort of additional run-to-run monitor must be employed to normalize the \( N_0 \) and CR data. The word “effectively” is inserted above to account for cases in which the volume of space over which \( N_0 \) is measured cannot be made to coincide with the position of the boron deposit in the transfer detector and for cases in which it may be more accurate not to try to make those measurement positions coincide exactly. For example, if the volume in space over which \( N_0 \) is measured is larger than the boron deposit, then the value of CR must be determined by experimentally averaging the response of the transfer detector over the larger volume or by making an equivalent analytic correction to the boron response over some part of that volume.

Another very important case in which it is usually more accurate not to try to measure \( N_0 \) and CR in exactly the same volume in space is the case in which \( N_0 \) is determined by the foil activation method. In this case, it would usually better to employ the special recessed cap which permits positioning a 1 cm diameter activation foil very near the boron deposit without touching the fragile silicon backing. Then two foil irradiations are done, one with the activation foil nearer to the neutron source, and one with the boron deposit nearer to the neutron source, i.e. with the assembly rotated 180\( ^\circ \). The (geometric) average of the two measured values of \( N_0/CR \) will be “automatically” corrected almost perfectly for beam divergence and mutual shielding of the activation foil by the boron layer and vice versa. [Cadmium blocked runs must also be done to subtract any epithermal neutron contributions.] If CR is measured over the entire foil irradiation period and the half-life of the induced activity is very long compared to the irradiation time, then no run-to-run monitor is needed for this method, even for a time-dependent source.
It is requested that both bare and Cd covered results (as well as the Cd-corrected results) be reported explicitly for both the transfer detectors and the participant's detectors.

APPENDIX 2. Transfer Detector Details

The $^{10}$B deposits were all prepared by vacuum deposition onto single-crystal silicon disks (wafers), 49.9 mm in diameter and about 0.3 mm thick. The preparation was done by the Institute for Reference Materials and Measurements in Geel, using a special planetary rotation system during the deposition to produce very uniform deposits with very nearly perfect edges.

The detector is constructed such that the position of the $^{10}$B deposit can easily be determined accurately, $\pm 0.1$ mm along the beam axis and $\pm 0.3$ mm perpendicular to that axis. The blank side of the silicon disk comprises one of the external faces of the detector. This face is recessed about 3.7 mm and must not be touched by measuring instruments. What one needs to measure is the distance to the inside face of this disk, where the thin $^{10}$B deposit is located. That face is optically flat and is precisely 4 mm inside the rim of the ionization chamber. A very flat 1 mm thick cap is provided to mount on the chamber rim so that mechanical measuring instruments can touch this face and determine the $^{10}$B position by adding 5 mm. A cross scratched on the center of the cap face gives the other coordinates of the deposit.

Problems of stability of the $^{10}$B deposits in humid conditions have been reported by to Section III by NIST, but these problems were small, especially for the heavier deposits. The boron stability will be carefully monitored by NIST before and after each use of the ionization chambers, and it is believed that the problem can be reduced to an easily managed level by storing the chambers in desiccated cases when not in use, by asking all participants to use high quality argon(90%)-methane(10%) “P-10” gas, and by using a drying chamber for the P-10 gas line.

NIST will supply the following equipment and references:
- three $^{10}$B ionization chambers,
- a small NIM crate with high voltage supply, amplifier, dual integral discriminators / single channel analyzer (SCA), and a dual channel pulse counter-timer
- a preamplifier and cables
- a ground-insulating mounting block and an aluminum mounting plate
- gas tubing and desiccator chamber for assuring the dryness of the P-10 gas
- a dry-storage case for the ionization chambers
- a 30 mm aperture of $^{10}$B-Al and Cd to shield the body of the ionization chamber
- a 1 mm thick Cd foil for determining the correction for epithermal reaction rates
- caps for mechanical measurements, alignment, and protection of the Si wafers,
- a recessed, thin aluminum cap for holding activation foils near the deposit backing (silicon wafer)
- a well-fitting Cd box, and
• copies of relevant sections of the electronics manuals.

The 30 mm aperture has a mounting ring attached that may be used to mount the aperture directly onto the cathode face (smaller diameter face) of the detector. A holder for a 1 mm Cd foil is attached to the opposite side of the 30 mm aperture plate for determining the Cd ratio of the beam. (If the foil holder is used, the aperture must be supported in some other way.) Any shielding of the detector from ambient neutrons outside of the beam must be provided by the participating laboratory.

(Although there is no foreseen need for mounting the 30 mm aperture on the anode face, an adapter ring is provided to permit this if it should be needed for some reason. The thin aluminum mounting plate may be used to support the chamber if the 30 mm aperture is mounted on the anode face of the detector. An insulating mount must still be used in addition.)

A close-fitting Cd box is provided for background checking and for determination of the Cd ratio when using the activation foil method. The aluminum mounting plate can be used when the chamber is operated within the Cd box. An insulating mount must still be used in addition. The open end of the Cd box should be packed with borated rubber or screened in some other manner.

Discriminator Settings

The electronics setup for the transfer detector is shown in Figure 1. Please note that a bias of +100 V should be applied.

Participants will need some means of assuring the proper placement of the SCA discriminators, preferably a multichannel pulse height analyzer and pulse generator. If necessary, a scan with a narrow window on the SCA itself could be used to verify the discriminator settings. The upper level discriminator is set at the minimum in the pulse height distribution between the two major peaks, shown as \( V_U \) in Figure 2. The lower level discriminator is set at \( V_L = V_U / 3 \). The various peaks and minima of the pulse height distribution are slightly less well resolved for the heaviest boron deposit, but the minimum for setting \( V_U \) is still unambiguous.

Noise and Grounding (Earthing) Considerations

Participants might prefer to use some of their own electronics in place of that supplied by NIST, but the comparisons are probably more accurate if all participants use exactly the same system. In particular, the amplifier-preamplifier combination has been arranged to have very low noise and to be free of ground loops. Since the ionization chamber signal is not nearly as robust as that from a fission chamber, the participants will need to be on guard against electronic noise. In particular, THE DETECTOR SHOULD BE SUPPORTED IN AN ELECTRICALLY INSULATED MANOR (using the ground-insulating block supplied or some other means), with its only connection to ground (earth) through its preamplifier cable.
Precautions for Handling the Transfer Detectors

When shipped, both faces of each ionization chamber will be covered by protective caps. These caps should be left in place except when the detector is in use, in order to protect the fragile single-crystal silicon cathode and anode-cover pieces.

Please do not attempt to clean the exposed silicon surfaces. A finger print on one of these surfaces will do no harm, but attempting to clean the surface by wiping or with solvents could very easily break one of the silicon disks or get solvent onto the internal boron surface, invalidating the detector calibration. The detectors are not tightly sealed; solvents could penetrate into the interior.

Please inform NIST immediately of any problems with operating the transfer detectors and return them to NIST for any repairs. Please do not open the ionization chambers for any reason. The closures are marked for security purposes; and not all of the security marks are visible. If the chambers are found to have been opened by a participant, the data from that participant may be excluded from the comparison.
APPENDIX 3. Timetable for Measurements and List of Participants

Timetable for Measurements:

<table>
<thead>
<tr>
<th>Participant</th>
<th>Tentative Comparison Time</th>
<th>Confirmed</th>
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<tbody>
<tr>
<td>CIAE</td>
<td>Sept - Nov 2001</td>
<td>NO</td>
</tr>
<tr>
<td>ETL</td>
<td>TBA*</td>
<td>NO</td>
</tr>
<tr>
<td>IRMM</td>
<td>TBA*</td>
<td>NO</td>
</tr>
<tr>
<td>NIST</td>
<td>Dec 2001 – Feb 2002</td>
<td>NO</td>
</tr>
<tr>
<td>NPL</td>
<td>Jan-Jun 2001</td>
<td>NO</td>
</tr>
<tr>
<td>PTB</td>
<td>TBA*</td>
<td>NO</td>
</tr>
<tr>
<td>VNIIM</td>
<td>TBA*</td>
<td>NO</td>
</tr>
</tbody>
</table>

*TBA = to be arranged

List of Likely Participants

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APPENDIX 4. Transportation Arrangements

It is highly recommended that each participant choose a customs broker at the nearest international airport to the participant’s laboratory and inform NIST of this broker’s name and address.

NIST’s customs broker is: Laing International
Dulles Airport
Washington, D.C.
USA
Tel: 1 703 471 9279
Fax: 1 703 471 8436

NIST will pay for shipment to the participant’s customs broker or other point-of-entry address. When the equipment is returned to NIST, NIST will pay for any customs charges at Dulles Airport and transport from Dulles airport to NIST.

Each participant shall pay for
- transport within own country
- customs charges within own country
- insurance charges within own country
- costs of any damage occurring within own country, and
- return transport to David Gilliam, NIST in care of Laing International (address above).

NIST will obtain an ATA Carnet document for the shipment to any participant who strongly prefers the use of this method. (The Carnet document functions much like a passport, but for a shipping crate rather than a person. NIST prefers not to use a Carnet document unless asked to do so. In NIST’s experience this paperwork causes more problems than it solves.)
Electronics Block Diagram

Electronics Hardware
1) Tennelec Portable NIM Bin
2) Tennelec TC 909 NIM Power Supply (+100 V)
3) Detectors: NIST Ion Chambers
4) Bias Supply: Tennelec 953A Dual HVPS
5) Preamp: Tennelec TC 170 Low Noise Preamp
6) Pulser: not supplied
7) Amplifier: Tennelec TC 241 Amplifier
8) Single Channel Analyzer: Ortec 551 Timing SCA
9) Counter/Timer: Ortec 994 Dual Counter/Timer
   with null modem cable
10) Computer: not supplied

FIGURE 1
M3 through, counterbore for caphead
1 Piece - 6061 Al
- All dimensions in millimeters unless otherwise stated.
- All tolerances +/- 0.13 unless otherwise stated.