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ABSOLUTE CALIBRATION OF THE NSTX NEUTRON MONITOR SYSTEM

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Abstract— **NSTX has a complement of six neutron detectors consisting of two fission chambers, one NE-451 ZnS scintillator and 3 plastic BC-400 scintillators. The primary purpose of the fission chambers is to provide an absolute calibration of the neutron rate, while the scintillator detectors monitor fast excursion in the neutron yield due for instance, to fast MHD events. Within the last 10 years NSTX has performed 4 separate calibrations of the neutron monitoring system. Initially, a californium neutron source on a long tether was introduced into the vessel through 10 different top ports on NSTX corresponding to 10 of the 12 bays of the vessel. Each of the ports was at the same major radius just slightly larger than the nominal plasma major radius and a point-wise ring source was simulated to perform the calibration. Recently, the fission chambers were relocated to accommodate new equipment and the detector system required recalibration. This most recent calibration employed a commercial G-gauge model train and three different diameter circular tracks to transport the ^{252}CF neutron source around the midplane of the NSTX vessel. In each of the calibrations, the fission chambers were operated in the pulse counting mode. During plasma operations one of the detectors transitions to the pulse saturated or current mode of operation. To complete the calibration, a series of low performance He discharges heated with one deuterium neutral beam were performed. Neutrons in this case come predominantly from beam–beam reactions. These low-yield discharges produced neutron levels that allowed the FC2 to remain in pulse counting mode while FC1 transitioned into the current mode. This allows a cross calibration to be performed between FC2 in pulse counting mode and FC1 in the current mode. The current mode value is then transferred to each of the four scintillating detectors. The results of the four *insitu* calibrations are presented.**

Keywords- neutron calibration, fission chambers, Spherical tokamak

I. INTRODUCTION

Accurate measurements of the neutron emission from fusion reactors provides an essential parameter in evaluating the reactors performance. In order to claim understanding of plasma behavior, the measured neutron emission should agree with the value predicted from transport codes such as TRANSP. On NSTX, four *insitu* neutron calibrations have been performed since initial operation began in 1999. Two different methods were used to introduce a californium neutron source inside the vessel to calibrate the neutron monitoring system. One method placed the source at toroidally displaced discrete locations in the vessel and at a major radius closely resembling the plasma major radius. A second method used a model train to transport the source around the inside of the vessel on three different circular tracks mounted inside the vessel. Each of the methods provide certain advantages but the continuous ring source provided by the model train provides the more accurate calibration in that it more accurately accounts for all scattering and attenuation effects from surrounding structures. The method and results from the four calibrations are presented. A problem with the consistency of the data was discovered in the most recent calibrations which was finally attributed to a small component of ^{250}Cf in the source. By including this component in the calibration data, the results of the four calibrations are again consistent.

II. CALIFORNIUM SOURCE ISSUES

Californium calibration sources have been used extensively at PPPL to characterize neutron detectors systems [1]. The present source was purchased in 1992. This source had a neutron emission rate of $1.4X10^8$ n/sec and was composed primarily of ^{252}Cf. The ^{252}Cf has continually decayed at the well-known half-life of 2.645 years. The detector systems calibrated by this source, measured neutron rates that closely agreed to those predicted by TRANSP. It was not until after the 2009 calibration campaign that large discrepancies arose between measured and predicted values. One of the authors (Darrow) discovered from the original source assay, that the source contained a small component of ^{250}Cf with a 13.06 year half-life that contributed ~2% of the neutrons. By the 2009 campaign, the ^{252}Cf component had decayed by almost 7 half-lives and was reduced in emission to a level comparable to that of the ^{250}Cf that had decayed by only 1.4 half-lives. By including the ^{250}Cf component into the calibration values, the predicted and measured values are now in close agreement.

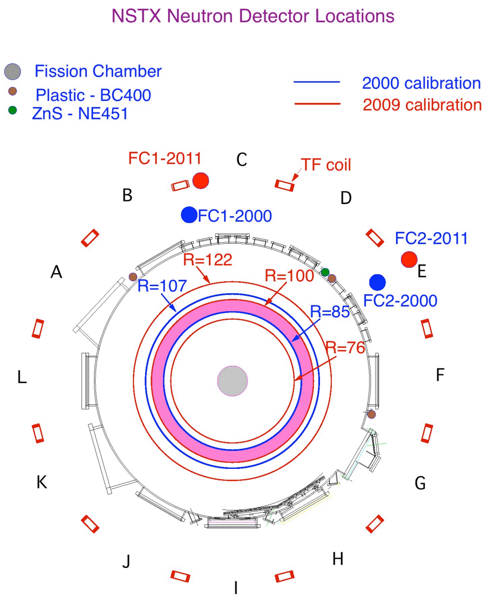

Fig.1
Neutron monitoring system on NSTX. The location of the fission chambers are shown for the year 2000 location and in their new positions aftr 2009.

III. NEUTRON MONITORING DETECTORS

The array of neutron detectors on NSTX consists of 2 fission chambers and 4 scintillator detectors. An overview of the detector locations is shown in Fig1. Also shown is the location of the fission chambers after they were relocated in 2009. The primary role of the fission chambers designated FC1 and FC2, is to provide a means to absolutely calibrate the neutron emission from NSTX. The fission chambers were made by Rueter-Stokes and the signal processing electronics were made by Gamma-Metrics. Each detector is surrounded by 7 cm of polyethylene moderator. Both detectors are operated in the pulse counting mode during the calibration period. This mode of operation is linear up to ~$2X10^5$ counts/s. At counting rates well above those obtained from a radioactive source, the detectors automatically transition into the pulse saturated or current mode of operation. The two fission chambers in their original locations had a difference in sensitivity of a factor of 26. During plasma discharges, this spread in sensitivities allows the least sensitive detector, FC2, to be operated in the calibrated pulse counting mode while the most sensitive detector, FC1, transitioned to the current mode. In this manner, a cross-calibration between the two detectors is achieved. Using low yield plasma discharges, where the pulse counting mode of FC2 is still valid, a cross-calibration between FC1 in the current mode and FC2 in the pulse counting mode can be obtained. In the early days of NSTX, the neutron yield from the plasma was low so that additional gain was added to the current mode amplifier to boost the low signal levels. This had the adverse effect of reducing the response time down to a few milliseconds. The fast time response to neutron events is handled primarily by the four scintillator detectors discussed below. It is important to track any drifts in the fission chamber sensitivities so that at each calibration, as well as periodically between calibrations, a neutron source is placed in a cup mounted directly on the detector housing as a renormalization process. The results are shown in Fig. 2 for periods between 2000 through 2011. The sensitivities of each detector remained extremely stable, varying only when the detectors were relocated so that the scattered fraction of counts changed.

The scintillator detectors are attached directly to the outer vessel wall of NSTX to maximize the neutron flux and are optically coupled by quartz fiber bundles to photomultiplier tubes located in an equipment rack 4m back from the vessel. The scintillators are applied to track fast changes in the neutron emission to study for instance, fast MHD effects. The scintillator array is comprised of 3-each plastic NE102 detectors and 1-each NE451, ZnS detector. The plastic scintillators are known to be far more sensitive to high-energy photons as compared to the ZnS. In most cases however, the four signals overlay perfectly and are separated only by a constant factor since most energetic photon are created by n-γ reactions and are thus proportional to the neutron emission. During rare events where x-rays are created by runaway electrons, the detector waveforms no longer overlay. These detectors are typically operated at 10kHz though they can operate much faster.

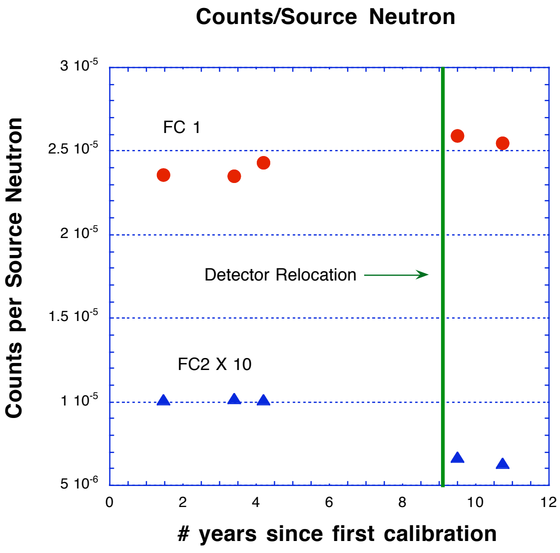

Fig.2 The response of fission chambers to the Cf source placed directly on the moderator wall. The changes in sensitivity after nine years of operation are due to the relocation of the detectors to either nearer (FC1) or further (FC2) from large scattering centers.

IV. CALIBRATION 2000-2001

In the initial operation of NSTX, the calibration of the neutron monitoring system was performed with all vessel hardware components in place and ready to be evacuated for operations. Only ports on the top of the machine at various bays were removed to allow the neutron source to be lowered into the vessel. Each top port was located at a major radius of R=107 cm and the source was lowered on a tether through the port to the vessel midplane. A thin walled tube was used to guide the source and prevent it from being dropped into the vessel. At each location data was accumulated on the fission chambers for 10-20 minutes depending on the distance from the source to the detector. At the end of the counting period, the source was raised to Z= + 30 cm and the counting was repeated. In 2001 the calibration was again performed and a specially constructed tube that angled inward was added to provide a calibration at the smaller major radius of R=85 cm. For each position, the ratio of neutrons emitted, to counts recorded on each detector, was obtained. The point-wise accumulated data were then integrated through all angles to yield the ratio of the total number of neutrons emitted from a ring source to the total counts recorded on each detector. This ratio of 'source neutrons/counts recorded' provides the absolute calibration and is most important for the least sensitive fission chamber designated FC2 as mentioned in section II. However, the data on FC1 is important in that it give the best measure of the changes in overall counting efficiency with different diameter neutron ring sources and heights above the midplane. Data from FC1 shown in Fig. 3 provides a measure of the scattered fraction by comparing the data to a curve of K/r^2, where r is the distance from the source to the detector and K is a constant of normalization. The measured data points lie above this curve as a result of a neutrons being scattered into the detector. By adding a constant value to the K/r^2 curve, the resulting curve provides a close fit to the data. This implies that the scattered fraction of neutrons remains constant independent of the distance from the detector.

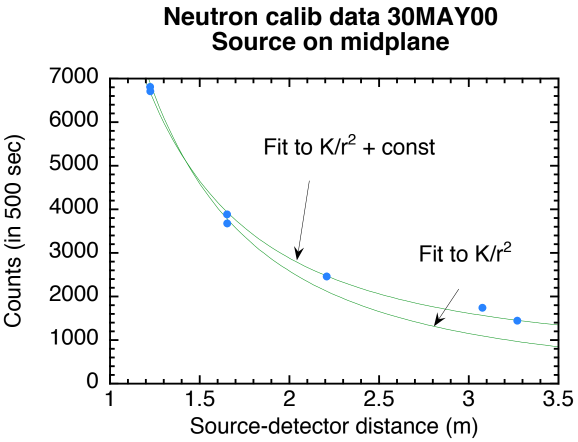

Fig. 3 Comparison of K/r^2 and K/r^2 + constant. The curve of K/r^+constant is a close fit to the measured data values, implying that fraction of neutrons scattered into the detector is constant value independent of distance.

V. CALIBRATION 2009-2011

During the 2009 outage on NSTX, the fission chamber detectors were relocated in order to accommodate an upgrade to the RF waveguides. The new detector locations, as shown in Fig. 1 are near the original positions but different enough to significantly alter the calibration. They are also nestled between the new waveguides increasing the scattered component. Because the top ports on NSTX are populated with critically aligned diagnostics, it was no longer possible to lower the neutron source into the vessel from above without considerable work in removing and reinstalling diagnostics. A different approach was adopted where a model train set was utilized to transport the source around the inside of the vessel on a circular track. The source emits isotropically and traces out a circular path creating a ring source of neutrons and in essence mimicking the emission from the plasma core. The real advantage of this approach as compared to discrete positions of the source is that scattering from all vessel components, especially those nearest the detectors, are adequately accounted for. The significance of this is illustrated in reference [3]. The train is operated continuously until a statistically acceptable number of counts are obtained. A G-gauge model train was employed that has an acceptably wide wheel base of 4.4 cm which minimizes the chance of derailment. The tracks also come in convenient track radii of 76, 100 and 122cm. Typical plasmas have major radii between 85 and 100 cm so this selection provides adequate coverage of real plasma operations and yields some information on changes in emission as a function of major radius. Fig. 4 is a photo of the 100cm track inside of NSTX.

Fig. 4 Photo of the R=100 cm track inside of NSTX vessel.

In the 2009 calibration, each track was installed one at a time and operated at each midplane position for up to six hours. After each of the three midplane positions were completed, the 100cm-track was then moved above and then below the midplane by ±30cm. With the six hour accumulations along with time to change and accurately position each track, the calibration took a total of 4 days to perform which was all of the time allotted for the calibration. Counting statistics were obtained that resulted in ~5% error on the FC2 detector. The FC1 detector in the new location was found to be ~33 times more sensitive than the FC2 detector. These better counting statistics from FC1 were used to provide a reliable measure of the neutron emission as a function of plasma radius. Shown in Fig. 5 are the results from the three different tracks placed on the NSTX midplane. A linear fit to the data between 85-100 cm is used to correct for changes in plasma radii.

In the 2011 calibration the primary goal was to reduce the inherent error in the calibration by increasing the counts recorded in FC2 fission chamber by ~10 times the 2009 value. Only the 100cm track was installed on the midplane position and the train was operated for a total of 58 hours continuously to produce counting statistics with 1.6% error.

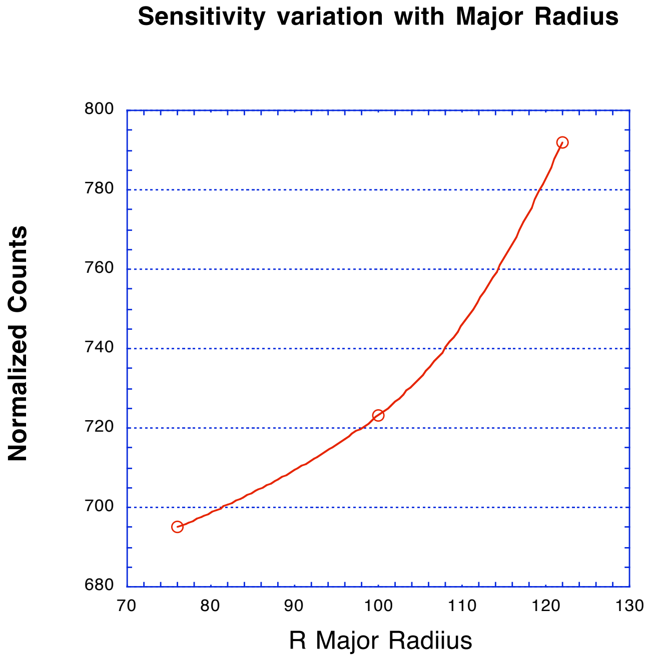

Fig. 5. Detectors counts as a function of track radius. Most plasmas have a major radius between 85 and 100 cm . A simple linear fit to the data between the first 2 data points is used to correct for variations in plasma radius.

VI. Preliminary Calibration Results.

The calibration results are summarized in Table 1 for the year in which the calibration occurred. Note that although the neutrons/count on FC2 changed significantly in 2009 due to the new detector location, the cross-calibration values transferred to FC2 through low power plasma discharges, change much less. Values for two of the scintillators are included for completeness.

TABLE I SUMMARY OF RESULTS BY YEAR FOLLOWING EACH CALIBRATION

Detector	**2000**	**2001**	**2009**	**2011**
FC2 X10^{11} (neut/count/s)	1.69	1.56	2.4	2.17
FC1 X10^{13} (neut/V/sec)	8.6	8.9	9.7	8.5
Zns X10^{13} (neut/V/sec)	1.9510	32	7.76	8.01
2FG X10^{13} (neut/V/sec)	1.3	9	3.55	2.7

The voltages on these detectors have been adjusted throughout the years and amplifiers have been replaced so the cross calibration results are not expected to be the same. This illustrates the point that for any individual discharge, the scintillators should be compared to the fission chamber values to obtain the absolute calibration.

VI Issues with the Signal Processing Electronics

During recent cross-calibration between detectors, it was noticed that the electronics appear to have a small non-linear response. The Gamma-Metrics circuit boards are now 30 years old so these issues are expected. If circuit repairs are required, the pulse-counting calibration data is not expected to be lost. However, until the issue is resolved, the error is dominated by this non-linearity and can be as much as ±20% so the values in Table 1 may change somewhat in the future.

Acknowledgement

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