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# DT Neutron Measurements and Experience on TFTR

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## INTRODUCTION

Through semi-independent absolute calibrations of multiply redundant neutron detector systems, the Tokamak Fusion Test Reactor (TFTR) has achieved ±7% (one-sigma) accuracy in its fusion power measurements.[1] This has required careful attention to the linearity of detectors up to the present highest fusion power levels achieved on TFTR of over 10 MW. The extended duration of the DT program on TFTR has also tested the stability of the detector systems. These issues of calibration, linearity, and stability will be reviewed for the TFTR experience and how it can be applied to plans for ITER.

## ABSOLUTE CALIBRATION

All the absolutely calibrated neutron detectors on TFTR are referenced to the $^{28}Al(n,\alpha)^{24}Na$ cross-section, either directly (via re-entrant activation foil measurements[2]) or through calibration of the fluence of a DT neutron generator[3] by activation foils. The complementary strengths and weaknesses of activation foils, collimated scintillators and proportional counters, and fission chambers provide confidence in the final weighted uncertainty of the DT neutron source strength[4], as well as significant redundancy in the measurements. The issue of absolute accurate calibration of fusion power measurements for ITER is a deserving subject in itself. In general, both the JET[5] and now TFTR experience confirm that activation methods coupled with neutronics calculations in a low-scattering experimental environment can lead to the highest accuracy calibrations.

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**Figure 1.** Stability over eight years for a HPGe gamma-ray detector of the TFTR neutron activation system. Shown are counts in 1000 seconds for three lines from thorium daughters in a commercial lantern mantle, as well as more recent measurements from a NBS-traceable source. The apparent increase in efficiency to the lantern mantle represents the natural increase in $^{228}$Ra.

## STABILITY

Checks of detectors with standard radioactive sources and cross-comparisons of different detectors provides documentation of the stability of the measurements since the time of absolute calibration. Figure 1 shows measurements for an over eight year period of the stability of one of the high purity germanium detectors (HPGe) used in the neutron activation system. A commercial camping lantern mantle inside of a pneumatic system capsule was routinely used in a standard counting location. Three gamma-ray lines at different energies from natural thorium daughters were monitored over this period: 338.4 keV and 911.2 keV from $^{228}$Ac, and 2614 keV from $^{212}$Po. The gradual increase in the $^{228}$Ac activity is consistent with the lantern mantle being manufactured in the late 1970's (~1978), and the natural thorium decay raising the $^{228}$Ra level with its 5.75-year half-life. The $^{212}$Po level rises a little more slowly from the additional 1.913-year half-life decay of $^{228}$Th. Since 1991 a source traceable to the National Bureau of Standards (NBS) has been occasionally used as well; as shown on Fig. 1 the gamma-ray efficiency for $^{60}$Co lines near 1.3 MeV have shown no variation within the 3% (one-sigma) accuracy.

The fission chamber detectors[6] have also tracked their sensitivity using a standard radioactive source. The current and Campbell electronic modes appear to behave independently of (and are more stable than) the count-rate mode. Thus, "renormalizations" of the count rate mode by use of low-level radioactive sources does not appear to address the issue of confirming detector stability of fission detector ionization chambers. A cross-comparison from DD discharges of low-sensitivity $^{235}$U detectors in count mode with high-sensitivity $^{235}$U detectors in current and Campbell mode showed the detectors have been stable for periods over a year. This comparison does not depend on the DT/DD neutron ratio in each shot since both the low- and high-sensitivity detectors are equally responsive to DT or DD neutrons (with a $R'_{235}$ value[7] of 1.30). The final arbiter of stability of the these time-dependent systems is secular comparison of yields to the neutron activation system. Figure 2(a) compares the ratio of the standard high-power fission chamber signal[8] to the neutron activation yield for all DT shots of sufficient yield with aluminum foil measurements in the re-entrant irradiation end location. (The slight non-linearity of the fission chamber signal [see below] has been removed for this comparison.) Within a ±3% (one-sigma) shot-to-shot variation there is no evidence of changing detector efficiency. Figure 2(b) shows the comparison for a silicon diode detector[9], illustrating effects of changing detectors and efficiencies.

**Figure 2.** Ratio of yields of neutron detectors to the activation system vs. time (shot number on TFTR) since the beginning of the DT program. All DT discharges with aluminum foil data in the re-entrant irradiation end are included. (a) fission chamber yield to activation, showing only variation within the relative precision. (b) silicon diode yield to activation. The silicon diode was replaced at shot 76319 after noticeable degradation of signal, and the efficiency of its calibration adjusted around shot 79100.

**Figure 3.** Evidence of non-linearity in fission chamber signals at high average source strength. The ratio of the fission chamber yield to the activation yield is plotted vs. $\int S^2 dt / \int S\, dt$ where S is the DT source strength.

## LINEARITY

There has been a continual re-evaluation of the linearity of various detector systems and collection of information on the saturation, pile-up, or dead-time characteristics of detectors operated at high signal levels. Cross-comparisons of detectors have continued as TFTR has increased its peak fusion power.

The neutron activation system has large dynamic range[10] primarily from reducing the mass of the elemental foils while maintaining low deadtimes on the HPGe detectors. Comparing total yield from other detector systems to activation measurements can identify non-linearities in diagnostic response. Figure 3 shows the ratio of the standard high-power fission chamber yield to activation yield, plotted vs. the neutron-source-strength weighted time average source strength, that is the integral (in time) of the square of the source strength divided by the integral of the source strength. Thus discharges of short duration by high average fusion power (with more contribution from possible non-linearities) are plotted further to the right on the ordinate. At low power the ratio of fission-chamber to activation yield is ~0.97 which is the ratio of consensus calibration[4] to activation calibration alone. At the highest average source strengths and highest fusion power, the fission chamber detector response has dropped relative to the assumed linear response of the activation system. The amount is consistent with a 1%—3% decrease per $10^{18}$ n/sec source strength.

The impact of such a non-linearity is shown in Figure 4(a). Neutron source strength (and hence fusion power) versus time is shown for the highest fusion power shot to date (80539) Signals from the fission chamber, silicon diode, and neutron collimator systems are shown. Also shown is the corrected fission chamber signal assuming a 3% per $10^{18}$ n/sec source strength non-linearity as from Fig. 3. Figure 4(b) shows a similar comparison but at the lowest (single tritium beam) DT fusion power (shot 79102). The same detectors are shown (but filtered to remove the noise at this low end of their dynamic range), along with a high-sensitivity $^{235}$U detector in current mode. In general the scatter between the different calibrated systems confirms the 7% absolute calibration.

**Figure 4.** Neutron source strength (and on right axis fusion power) vs. time from different detector systems. (a) High fusion power discharge 80539. Solid line is fission chamber, dotted is neutron collimator, dash-dot is silicon diode, and dashed is fission chamber corrected to agree with neutron activation. (b) Low fusion power discharge 79102. First three curves are same as in (a); the dashed curve is a high sensitivity fission chamber detector corrected for an $R'_{235}$ of 1.30.

## IMPACT ON ITER

A neutron activation system would be important for ITER for its accurate absolute calibration, demonstrated detector stability and linearity over a wide dynamic range for comparison to other detector systems. Redundancy in detector systems with time and spactial resolution is important in maintaining accuracy by cross-comparisons.

## ACKNOWLEDGMENTS

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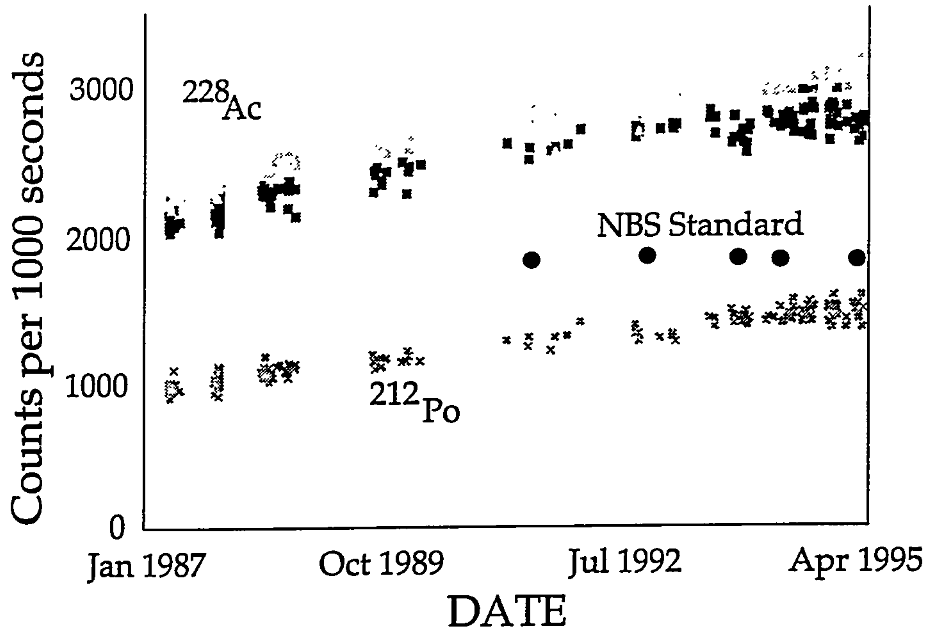
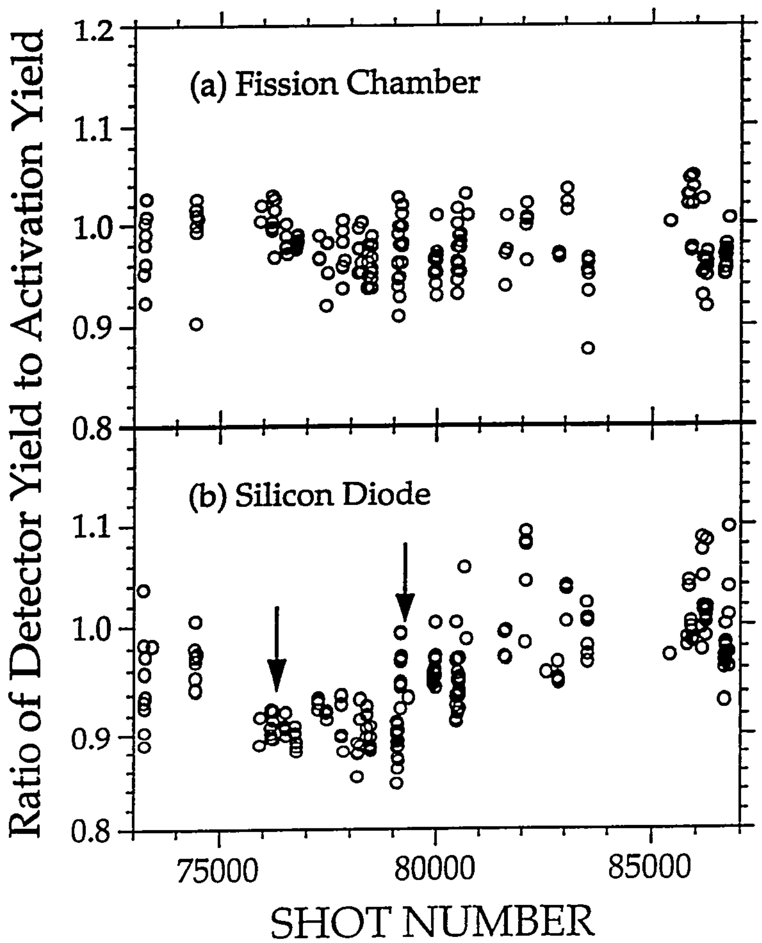
## REFERENCES

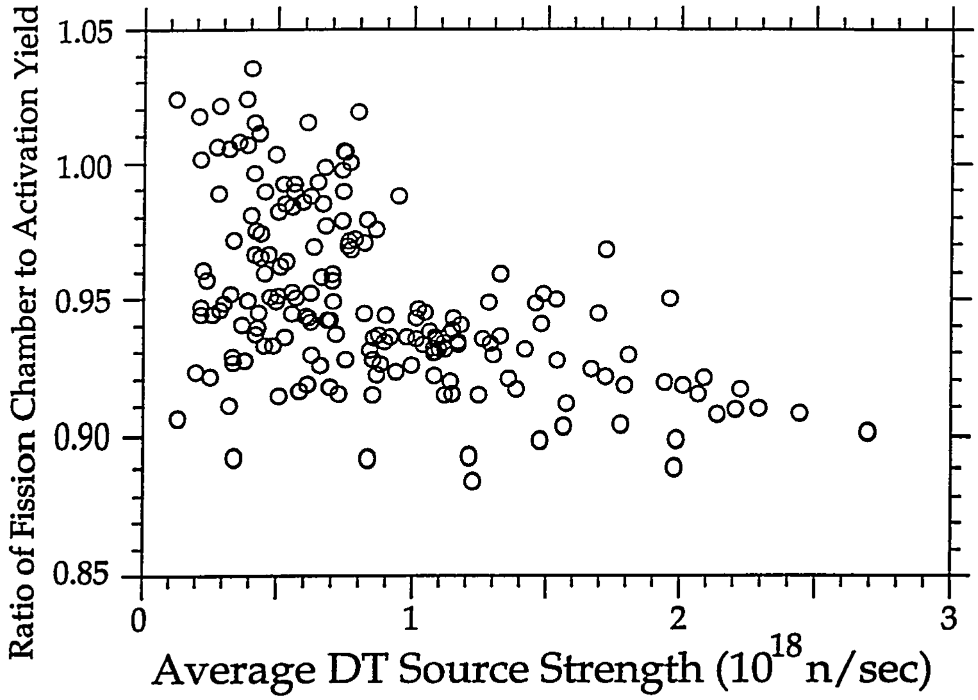
[1]J. D. Strachan *et al.* Fusion power production from TFTR plasmas fueled with deuterium and tritium, Phys. Rev. Letts. **72** (1994) 3526.
[2]C. W. Barnes, A. R. Larson, and A. L. Roquemore. Calculations of neutron activation response for the Tokamak Fusion Test Reactor, and absolute calibrations of neutron yield, (submitted to Fusion Tech., 1995)
[3]D. L. Jassby *et al.* Absolute calibration of tokamak fusion test reactor neutron detectors for D-T plasma operation, Rev. Sci. Instrum. **66** (1995) 891.
[4]L. C. Johnson *et al.*,Cross calibration of neutron detectors for deuterium-tritium operation in TFTR, Rev. Sci. Instrum. **66** (1995) 894.
[5]Owen N. Jarvis *et al.* Use of activation techniques for the measurement of neutron yields from deuterium plasmas at the Joint European Torus, Fusion Tech. **20** (1991) 265.
[6]H. W. Hendel, R. W. Palladino, Cris W. Barnes, M. Diesso, J. S. Felt, D. L. Jassdy, L. C. Johnson, L.-P. Ku, Q. P. Liu, R. W. Motley, H. B. Murphy, J. Murphy, E. B. Nieschmidt, J. A. Roberts, T. Saito, J. D. Strachan, R. J. Waszazak, and K. M. Young. In situ calibration of TFTR neutron detectors, Rev. Sci. Instrum., **61** (1990) 1900.
[7]D. L. Jassby, H. W. Hendel, and H.-S. Bosch. Relative intensities of 2.5- and 14-MeV source neutrons from comparative responses of U-235 and U-238 detectors. Rev. Sci. Instrum. **59** (1988) 1688.
[8]The so-called NE3 (a $^{235}$U detector) current mode signal.
[9]E. Ruskov, W. W. Heidbrink, H. H. Duong, A. L. Roquemore, and J. D. Strachan. Measurement of 14 MeV neutrons at TFTR with Si-diode detectors, Rev. Sci. Instrum.. **66** (1995) 910.
[10]C. W. Barnes, A. R. Larson, G. L. LeMunyan, and M. J. Loughlin. Measurements of DT and DD neutron yields by neutron activation on the Tokamak Fusion Test Reactor, Rev. Sci. Instrum., **66** (1995) 888.

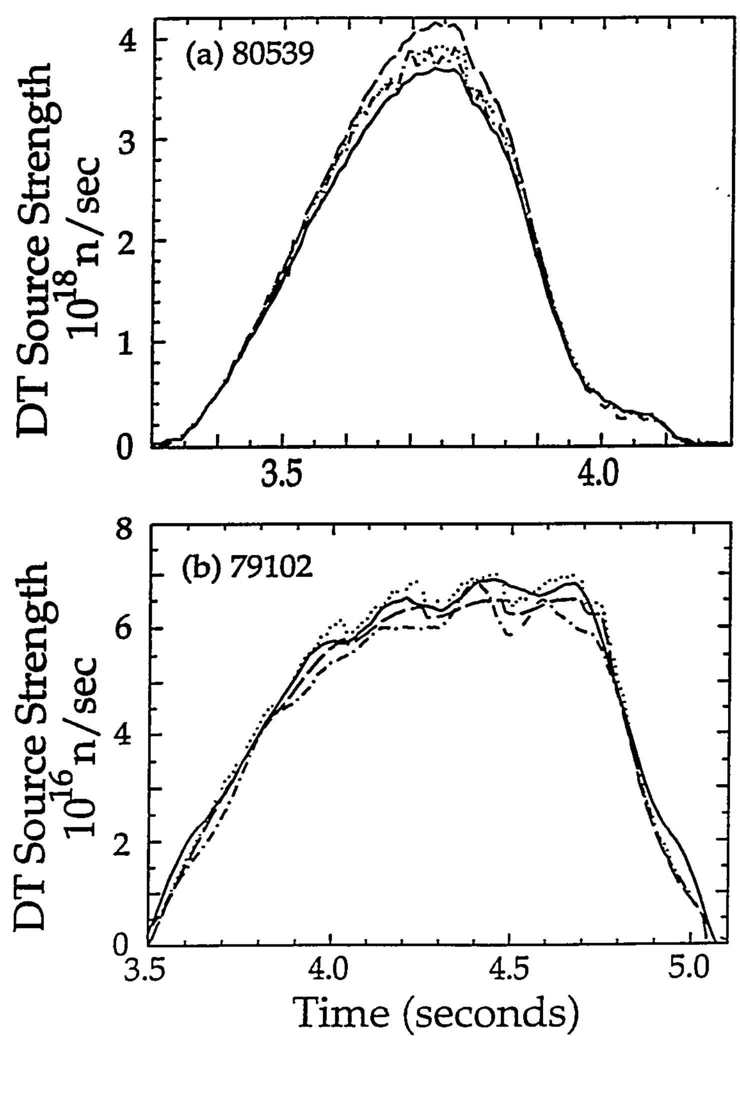


Counts per 1000 seconds
3000
2000
1000
0
$^{228}$Ac
NBS Standard
$^{212}$Po
Jan 1987
Oct 1989
Jul 1992
Apr 1995
DATE

Ratio of Detector Yield to Activation Yield
1.2
1.1
1.0
0.9
0.8
(a) Fission Chamber
(b) Silicon Diode
75000
80000
85000
SHOT NUMBER


Ratio of Fission Chamber to Activation Yield
1.05
1.00
0.95
0.90
0.85
0
1
2
3
Average DT Source Strength ($10^{18}$ n/sec)


(a) 80539
DT Source Strength $10^{18}$ n/sec
4
3
2
1
0
3.5
4.0
(b) 79102
DT Source Strength $10^{16}$ n/sec
8
6
4
2
0
3.5
4.0
4.5
5.0
Time (seconds)