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Calibration of Neutron Detectors at the ORNL Advanced Toroidal Facility

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Abstract

The ion temperature in a maxwellian plasma containing deuterium ions can be determined by measuring the neutron rate from the plasma. This rate, coupled with a measurement of the ion density, and a measurement of the fraction of the ions that are deuterium, allows a direct determination of the ion temperature since the cross section for neutron production as a function of temperature is well known. This technique has been applied to several tokamaks[1,2,3] and at least one stellarator[4] and will be employed in the Advanced Toroidal Facility (ATF). ATF is a stellarator with a major radius of 2.1 m and an average minor radius of 0.27 m. The plasma in ATF is produced by microwave power at the electron cyclotron frequency. The ions are heated by hydrogen neutral beam injection with a total power $\gtrsim$ 2 MW, and RF power at the ion cyclotron frequency. The ATF facility has nine moderated thermal neutron detectors arrayed around its exterior in order to accurately monitor the neutron rate. The various detectors have differing efficiencies in order to allow for a wider variation in neutron source strength before count rates and statistical uncertainties limit the temperature determination. A ^{252}Cf source was inserted into ATF on the midplane of the vacuum chamber at 24 locations at a major radius of 2.1 m in order to give a good toroidal average of the count rate of the nine detectors. Each detector was calibrated to give an efficiency which is defined as the ratio of the toroidal average of the count rate to the californium source strength. When ATF operates with deuterium gas these efficiencies will be used to measure the ion temperature in the range of $\sim$ 500 eV to several keV.

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I. Introduction

On December 6, 1987 the ATF neutron detectors were calibrated using a ^{252}Cf spontaneous fission neutron source. The source was positioned at 24 locations inside the vacuum vessel around the minor axis and the count rate in the nine detectors located around ATF were measured. At the time of the calibration, the construction of ATF was almost complete, with no major structural items to be added. Hence, the sources of moderation and scattering were approximately as they would be during operation. There are large water headers on the concrete pedestal below ATF and these were filled with water, thus ensuring that the moderation would be the same as during operation. The scalars reading the counts were read by the VAX computer into a data management system (DMG) and the data automatically fed into a LOCUS data base. From an average of the count rate over the toroidal positions of the source, an efficiency for each detector is calculated giving the number of counts per neutron emitted from ATF. From this information, the source strength (n/s) from the plasma can be determined, and in conjunction with measurements of electron density, Z_{eff}, and deuterium fraction, the ion temperature can be measured.

The next section describes the equipment used: the source, the source holders, the detectors, the NIM and CAMAC equipment, etc. Section III describes the procedure and Section IV describes the analysis, including the data acquisition and computations utilizing the LOCUS data base technique. Section V contains a summary and conclusions.

II. Equipment

The neutron source is a ^{252}Cf spontaneous fission source. It was prepared by the transplutonium element production facilities at ORNL. On December 6, 1987 the source strength of this particular source, NSD-99, was $1.12 \times 10^8 n/s$. It is contained in two concentric stainless steel tubes which are individually welded. The source was calibrated to within 3% by the magnesium bath technique. The source is approximately 1.27 cm in diameter and 6.35 cm long and is handled by using a long pole. The source is attached to a 0.16 cm diameter. braided stainless steel cable which is fed through a 3 m-long hollow tube for manual manipulation.

Three kinds of source holders were made to use inside of ATF: straight tubes, short curved tubes, and long curved tubes. These are shown in Figs. 1 (a), 1(b), and 1(c); respectively. These 2.54 cm-i.d. tubes were inserted into the ATF vacuum vessel through holes in 42 cm square aluminum plates located on the top ports. These 42 cm square aluminum plates replaced the normal stainless steel square pyraflat flanges on the top ports. These source holders were designed to hold the source on the midplane of ATF. The straight tubes positioned the source on the midplane directly below the center of the top ports. The short curved tubes positioned the source on the midplane midway between adjacent ports and the long curved tubes located the source on the midplane at the center of the top port next to the top port into which the source holder was inserted. The top of each tube was fitted with a large funnel to allow a faster manual insertion of the source into the top of the tube. The top of each tube was also welded to a small metal plate which was clamped to the large 42 cm plate after the tubes were rotated so that the source would be on the minor axis. The bottom of each tube was blanked off to prevent the source from dropping into the vacuum chamber. Two of the top pyraflat flanges could not be removed due to other constraints on the experiment. By using the long curved tubes, it was not necessary to remove these two flanges; the source could be located under the center of the unremoved flange from the port on either side of it. In summary then, with ten open top ports and the three kinds of source holders, it was possible to locate the source at 24 equally spaced toroidal locations at a major radius of 2.1 m on the midplane of ATF.

There are nine neutron detectors located around ATF. Figure 2 is a plan view of the ATF enclosure and shows the location of the detectors in relation to ATF. There are four ^3He proportional detectors high on the ATF enclosure walls around ATF: one each to the north, south, east, and west. The placement high on the wall was to avoid the possible interference due to future placement of diagnostics near the midplane. By locating them out of the line of sight of any new diagnostic to be added to ATF scattering from the new diagnostics should be minimized. There are four 1.6 g fission counters located on the concrete pedestal under ATF: one each on the north, south, east, and west under the vacuum vessel at a radius of $\sim$ 2 m. There are no plans for placing large diagnostics on the bottom pyraflat flanges directly over the neutron detectors. There is one 18 g fission chamber on the west wall adjacent to the ^3He proportion detector. Each detector is equipped with a paraffin moderator. Each detector has a preamplifier located nearby. All the other electronics are in one rack in NIM bins in the area under the ATF control room. Each detector has a single ground in the rack in order to avoid ground loops.

The electronics for the ^3He proportional detectors consist of the aforementioned preamplifier, a HV power supply for the bias, a pulse shaping amplifier, and a single channel analyzer. The single channel analyzer is used to select the pulses representing the $^3He(n,p)^3H$ reaction from thermal neutrons in the gas of the proportional detector.

The same electronics are used with the fission counters except that the single channel analyzers are used to select a very broad range of fission pulses above the noise due to α decay, γ rays, and electronic noise.

A very special set of electronics is used for the 18 g fission chamber due to its unique design. Again, a discriminator is used to detect the fission pulses in the presence of the noise from α decay, γ-rays, and electronic noise. The electronics have been described elsewhere.[5]

The pulses from the single channel analyzers and discriminator were fed into latching scalars in a CAMAC bin in the same rack. The CAMAC equipment was read by the VAX computer into the data management program (DMG).

It had been determined earlier that the 18 g high sensitivity fission chamber had a noise problem which precluded its use under normal conditions. On the holiday on which the calibration was performed, there was no noise problem due to little electrical activity in the building. Hence the detector was correctly measuring only neutrons. Until shielding measures are instituted which will remove the noise, the detector is unusable. However, these shielding efforts will not affect the calibration. Hence it is possible to calibrate the detector under quiet electrical conditions.

III. Procedure for Handling the Source

In order to satisfy the Health Physics requirements at ORNL, a procedure was written for handling the source. The procedure ensured that a minimum number of people would be present, that those present would receive a dose as low as reasonably achievable (ALARA), and that there would be a minimal chance of loosing the source or having other unforseen accidents. All the personnel present were given a neutron sensitive TLD packet which was checked for neutron dose after the experiment.

Briefly, the procedure was as follows: The ten straight source holding tubes were inserted into the ports on top of ATF. After suitable background counts had been made, the source in the large paraffin pig was brought into the area under the supervision of the Health Physicist. The source was carefully and quickly moved from the pig to the first tube, all personnel left the area, and a count was made. This was repeated for the other straight tubes. The counting time was adjusted to allow each detector to have relatively good statistics for each toroidal location. Counting times of $\lesssim$ 100 seconds were sufficient for this purpose.

The source was then replaced in the pig and the straight tubes were replaced by the 10 short curved tubes. The procedure was repeated for each short curved tube for 12 positions. The source was placed back in the pig, and the two long curved tubes were inserted into the correct upper ports so that the two remaining toroidal locations could be checked. The source was then placed in each of these tubes and counts were taken.

Twelve small cups had also been prepared and were mounted at twelve equidistant locations on the top of the top inner VF coil. After the counts made with the source inside the vacuum vessel, the source was placed in each cup and a count taken. This check gave a fair approximation to the actual source position inside the vacuum vessel and could be repeated much more easily and more frequently than a recalibration with the source inside the vessel. Checks with the source at these locations would give an indication as to whether or not the true calibration had changed.

After all counts were made the source was replaced in the pig, and the pig returned to storage. Background counts were repeated. All of the source holding tubes and cups were removed and checked for activity in case the source had actually leaked.

IV. Data Analysis

The data was accumulated automatically in the data management system (DMG) and transferred to a LOCUS data base. Data taken included the counts from each scalar, the time of day, and the counting time. Also hand entered into the data base were the source toroidal angle and the source radius.

Figure 3 shows an example of the data. The counting rate for the East ^3He proportional detector is plotted vs. the toroidal angle of the source. The ATF convention is that the zero of the toroidal angle ϕ is at the south side. The peak at $\phi \simeq 105°$ occurs when the source is closest to the detector. Comparing these data to the calculated value normalized to the peak taking into account only the $1/R^2$ affect due to the varying distance between the source and the detector gives the smooth curve also displayed in Fig. 3. The distortions of the peak near 75° and 135° occur when the helical field coils are between the source and the detector. These coils are massive copper coils mounted on a think stainless steel T structure. The attenuation and scattering from these coils is sufficient to attenuate the direct neutron flux by a factor of about 50%. However, the reduction of the count rate due to all of the various parts of ATF is more apparent in the region of 250–260° when the source is on the opposite side of ATF from the detector. In this region the reduction of the count rate due to absorption and scattering is as much as a factor of 5.5.

Table I gives the toroidal average of the efficiencies for each detector as determined by the LOCUS program. For a given compass direction, the 1.6 g fission chamber is less sensitive than the corresponding ^3He detector by a factor of between 2 and 6 depending on the location. The high sensitivity fission chamber also has a low efficiency because it is so far from the center of ATF.

Calculations based on peaked ("quadratic squared") profiles of n_d show that for $n_d = 5 \times 10^{13}$, the minimum ion temperature that can be reliably determined will be ~ 500 eV. If the profiles are flatter than this, the minimum temperature that can be determined drops to a value dependent on the profile. This minimum temperature is also dependent on the beam energy and the electron temperature for another reason. The normally naturally occurring deuterium isotopic constituent of the hydrogen beam will cause some neutron production from beam-target reactions. For example, for 500 kW of injection at 40 kV into a plasma with $T_e = 300$ eV, the beam target neutron rate will be comparable to the maxwellian rate for $T_i \sim 500$ eV. Hence the maxwellian rate has to be considerably higher than the beam-target rate to make a true temperature measurement.

As of this writing (July 1989), the detector system has not been used for ion temperature measurements since the ATF plasmas have not achieved the required parameters. However, when the hydrogen neutral beam power is raised later in 1989, and when deuterium gas is used to feed the plasma on a regular basis, it should be possible to monitor the ion temperature as a function of time during plasma production.

It will be impossible to inject a deuterium neutral beam into ATF because the calculated neutron rate would be dangerous to the personnel in the building. There are no plans for adding shielding. However, it will be possible to add a small fraction (2% to 3%) of deuterium to the hydrogen in the beam line in order to measure the neutron source decay time from the injected deuterium beam, and to measure the containment of the fast injected ions.

V. Summary and Conclusions

The neutron rate from ATF will be used to determine the ion temperature for $T_i \gtrsim 500$ eVunder the assumption that the ions are maxwellian. ATF was equipped with an array of nine thermal neutron detectors for this purpose. The neutron detectors were calibrated with a ^{252}Cf spontaneous fission neutron source which was placed at 24 locations inside the vacuum vessel to give a good toroidal average. The effect of absorbtion and scattering in the coils and other parts of ATF is clear from a comparison of this data to a calculation which takes into account only the $1/R^2$ effect. In addition, a calibration check was made by placing the source on the inner vertical field coil in 12 locations. Such a check simulates many of the features of the correct calibration and can be easily repeated without necessitating a vacuum opening. Hence, indications of efficiency change can be determined with a minimum impact on the operation of ATF.

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Table I

Neutron Diagnostic Signal Names and Efficiencies

NAME	LONGNAME	EFFICIENCY (counts/neutron)
NDHEN	helium-3 detector north	1.27E-6
NDHEE	helium-3 detector east	1.62E-6
NDHES	helium-3 detector south	1.10E-6
NDHEW	helium-3 detector west	9.73E-7
NDFCN	fission chamber north	2.95E-7
NDFCE	fission chamber east	2.87E-7
NDFCS	fission chamber south	5.80E-7
NDFCW	fission chamber west	3.30E-7
NDHSFC	high sens fission chamber	1.78E-7

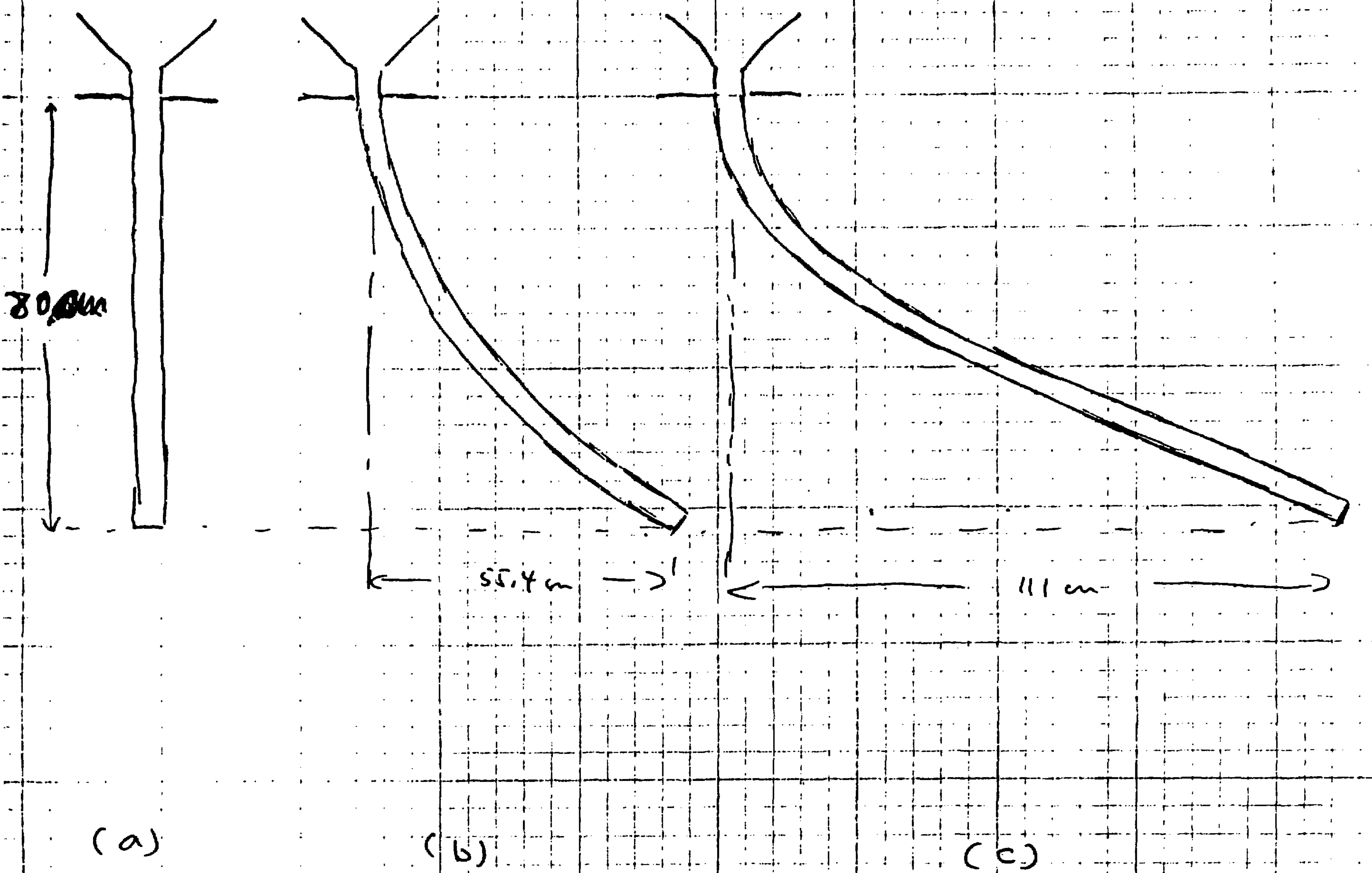
Figure Captions

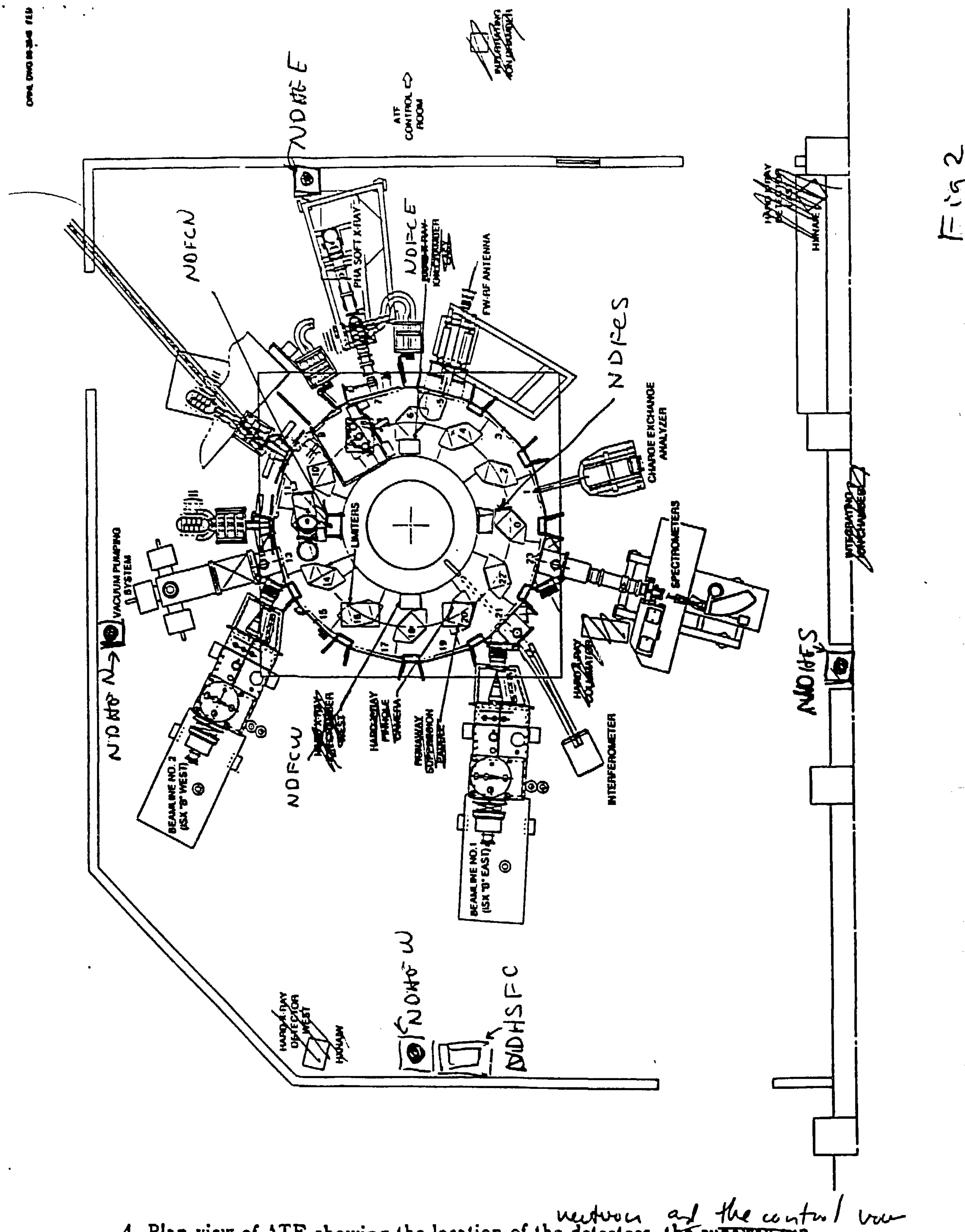
Fig. 1. The source holder tubes. Each tube is made of 2.54 cm i.d. aluminum. (a) Straight tube which holds the source directly under the pyraflat flange center. (b) Short curved tube which holds the source midway between adjacent pyraflat flanges. (c) Long curved tube which holds the source under the pyraflat flange adjacent to the one holding the tube.

Fig. 2. Plan view of ATF showing the location of the neutron detectors, the control room,the beam lines, and some of the diagnostics.

Fig. 3. The count rate (points) of the east ^3He detector as a function of the toroidal angle of the source. The source is closest to the detector at approximately 105° as measured CCW from the south side of ATF. The smooth curve is the expected count rate of a bare source corrected for the $1/R^2$ effect only. The attenuation and scattering of the neutrons are apparent when the source is on the opposite side of ATF from the detector (near 250–260°) as well as near 75° and 135° where the large peak is distorted when the source is behind the helical field coils.

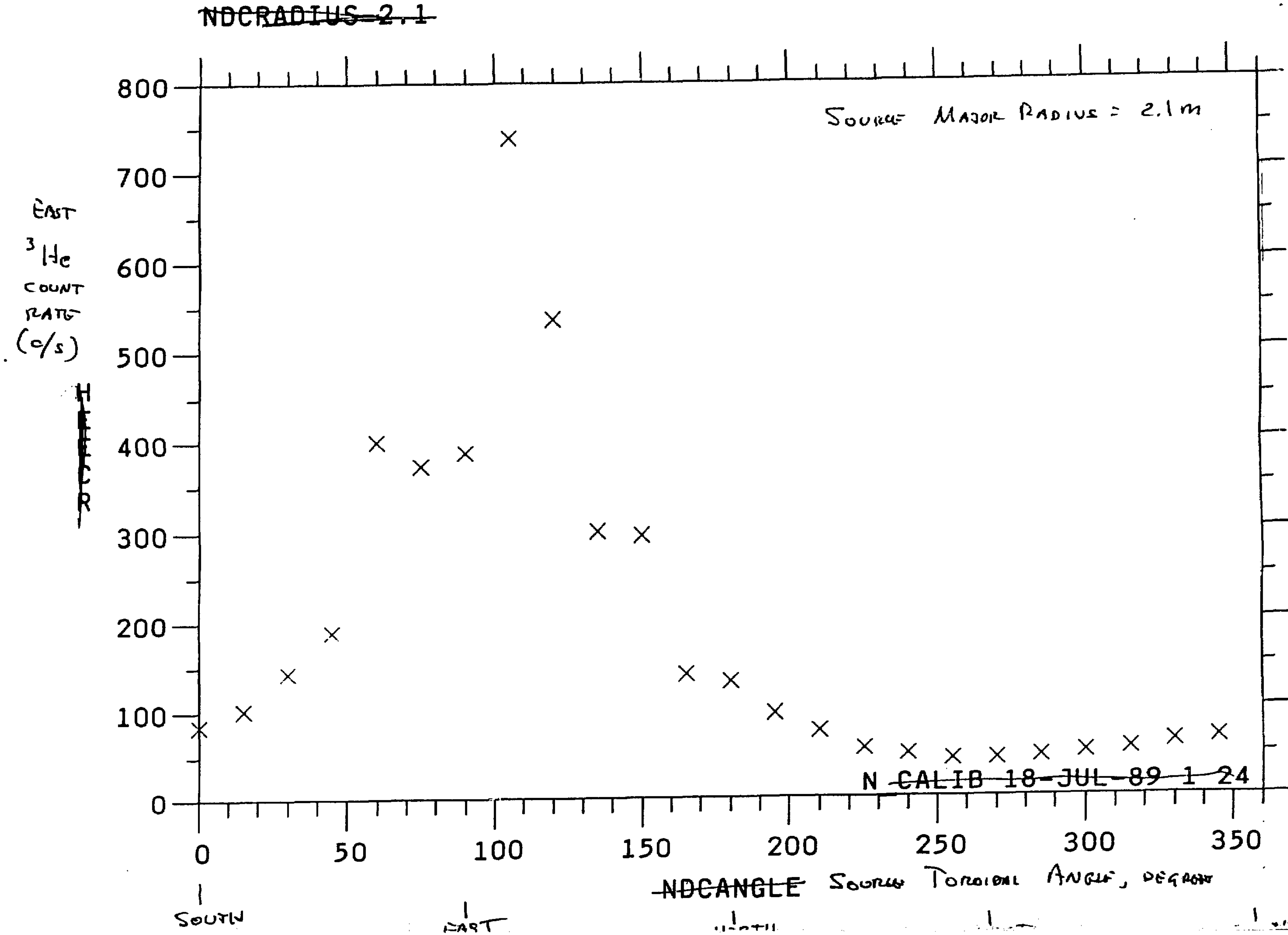
Fig 1





4. Plan view of ATF showing the location of the neutron detectors, and the control room the runway sup-

Fig 3


NDCRADIUS 2.1
Source Major Radius = 2.1m
East
^{3}He
count
rate
(c/s)
HEECR
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
N CALIB 18-JUL-89 1 24
NDCANGLE
Source Toroidal Angle, degrees
South
East

(Fig 5 (cont)

This curve will be added to the other graph by Graphic Arts