27
7-27-81
B5915

UCID- 19?94

MASTER

Lawrence Livermore Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

TABLE OF CONTENTS

THE STATUS OF TMX UPGRADE DIAGNOSTICS CONSTRUCTION

THE STATUS OF TMX UPGRADE DIAGNOSTICS CONSTRUCTION

I. INTRODUCTION

This report describes the status of the initial TMX Upgrade diagnostics and the state of development of additional diagnostics being prepared for later TMX Upgrade experiments. The initial diagnostic instrument set has been described in the TMX Upgrade Proposal.[1] This set is required to get TMX Upgrade operational and to evaluate its initial performance. Additional diagnostic instruments are needed to then carry out the more detailed experiments outlined by the TMX Upgrade program milestones given in Table I. The relation of these new measurements to the physics program is described in "The TMX Upgrade Program Plan".[2]

TMX Upgrade will employ diagnostic techniques and instruments similar to those used on TMX. However, determining electron parameters in the thermal barriers incorporated in TMX Upgrade requires development of different diagnostic devices. The initial diagnostic set on TMX Upgrade will have twice the number of data channels used in the early operation of the TMX experiment; this set will rapidly increase to exceed the diagnostics used on TMX in its final experiments.

A comparison between TMX and TMX Upgrade parameters is illustrated in Figure 1. The potential depression (created by hot electrons heated by ECRH) allows the end plug electron temperature to exceed the center cell electron temperature. The higher plug electron temperature results in a higher potential barrier which will improve central-cell ion confinement.

References

1. F. H. Coensgen, T. C. Simonen, A. W. Chargin and B. G. Logan, "TMX Upgrade Major Project Proposal", LLNL-Prop-172, April 30, 1980.
2. F. H. Coensgen, J. C. Davis, and T. C. Simonen, "TMX Upgrade Experimental Operating Plan", UCID-19065 July 1, 1981.

The status of the TMX Upgrade diagnostics can be summarized by considering first the diagnostic facility, then the individual diagnostic instruments and finally the diagnostic and data analysis computer system. The facility includes the diagnostic room, shot leader console, cable system and timing system. The required building and rack modifications have been completed and most of the electronic equipment has been loaded into the racks. A Shot Leader Console has been installed to consolidate previously scattered information and functions to a central location next to the computer operator to aid the Shot Leader. A more versatile cable system for transmitting diagnostic signals from the TMX Upgrade device to the diagnostic room has been designed. The installation will begin in August and be completed in October 1981. A new timing system has been built and checked out. Further details of the status of the diagnostic facility are given in Section IIA.

The construction status of initial diagnostic instruments is summarized in Table II. The electrical and mechanical construction status of these instruments is illustrated in Figures 2 and 3. These Figures indicate work activities from May 1981 until completion and do not reflect the considerable work completed before May. The darker lines indicate the construction status as of July 1, 1981.

A second category of diagnostics is those which will be added after MDF completion. Table III lists these instruments and their purpose. Figure 4 shows when we expect to have these instruments in operation and how they relate to the experimental schedule and milestones. This implementation plan will be modified if needed on the basis of initial experimental results and funding levels. Responsible physicists have been assigned and preliminary physics analysis of these devices has been completed. Some of the diagnostics are already in engineering design while others are undergoing detailed physics analysis.

Major improvements to the diagnostics and data analysis system are being implemented. Three additional computers (five total) with auxiliary hardware have been installed and are running. Compared to TMX, the new TMX Upgrade computer system will allow approximately a factor of five increase in the processed data throughput. In addition major software improvements are being implemented to allow users much more versatility in obtaining, manipulating and displaying data.

The following sections give more detailed description of the status of TMX Upgrade diagnostics. Section II describes the status of the diagnostics facility and instruments. Section III describes developmental diagnostics while Section IV describes the computer system.

TABLE 1

TMX Upgrade Program Milestone Schedule

	Milestone	Target Date
1.	Submit TMX Upgrade experimental plan	July, 1981
2.	Begin checkout of TMX Upgrade	Nov., 1981
3.	Produce initial plasmas in TMX Upgrade	Mar., 1982
4.	Demonstrate end-plug sloshing-ion distribution with 1-MW neutral-beam power per plug	May, 1982
5.	Submit plan for incorporation of axisymmetric end plugs on TMX Upgrade	May, 1982
6.	Submit report on initial TMX Upgrade experimental results	July, 1982
7.	Demonstrate electron heating with 200-kW microwave power per plug	Sep., 1982
8.	Submit report on TMX Upgrade ECRH results	Nov., 1982
9.	Demonstrate existence of thermal barrier and improvement of central cell containment due to barrier	Dec., 1982
10.	Complete radial-transport measurements	Mar., 1983
11.	Submit report on radial transport in TMX Upgrade	June, 1983
12.	Submit final report on TMX Upgrade results	Aug., 1983

Table II

Status and Purpose of Initial TMX Upgrade Diagnostics

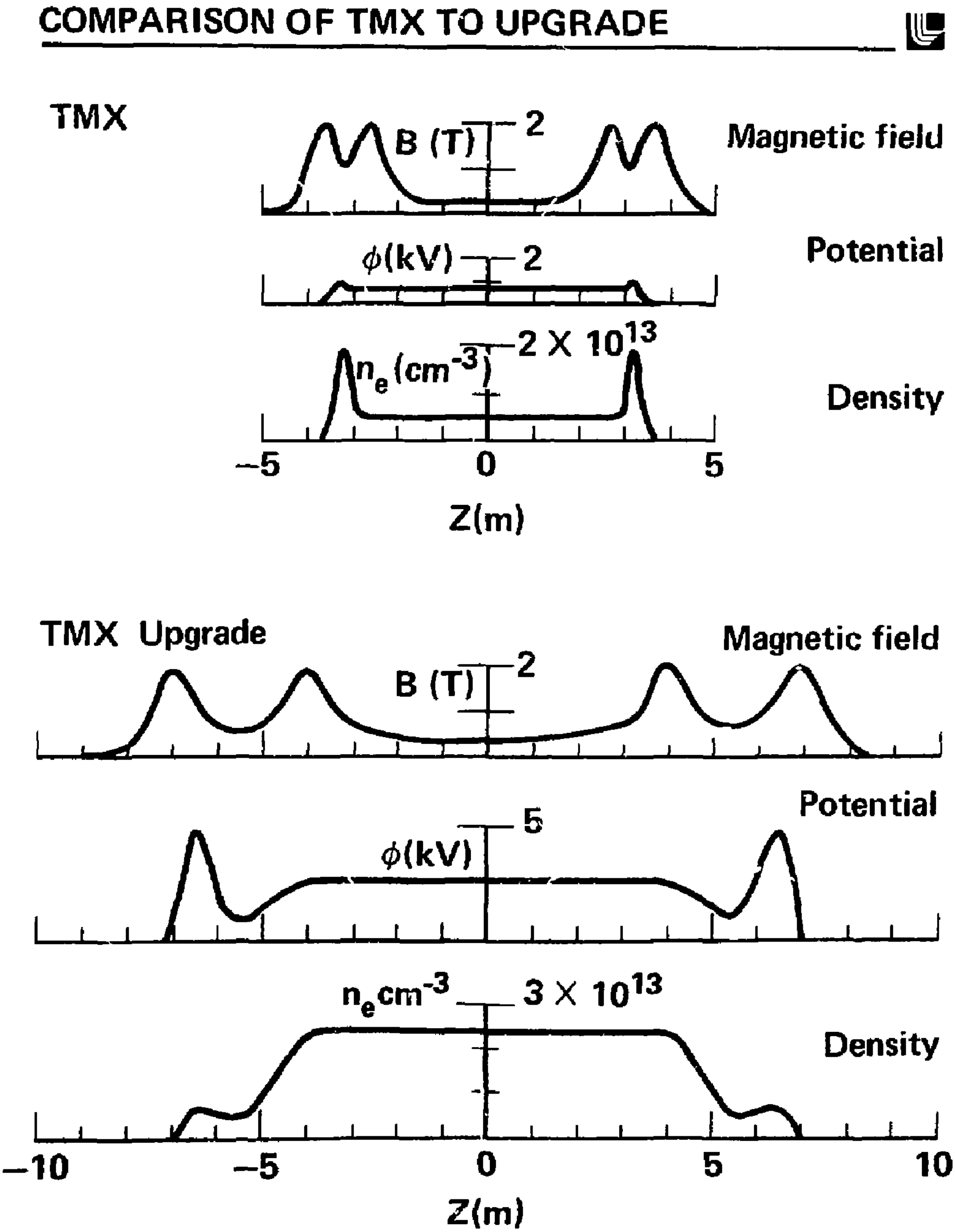
Diagnostics	Purpose	Number of Channels	% Complete
Beam Attenuation Detectors (BADS)	Barrier and center-cell radial density profiles	49	60
Thomson Scattering (TSS)	Plug and center-cell electron temperature and density	2	20
Microwave Interferometers (MIS)	Barrier, mirror peak, and center-cell electron line density	9	65
End Loss Analyzer (ELA)	On-axis and radial profiles of end loss current density and plug potential	4	78
Extreme Ultraviolet System (EUV)	Barrier and center-cell impurity radiation	3	63
Diamagnetic Loops (DL)	End and center-cell plasma pressure	14	46
Faraday Cups (FC)	Radial profiles and end loss current density	28	76
Langmuir Probes (LP)	Radial profiles of net current to end wall	28	76
Secondary Emission Detectors (SED)	Measure end-cell ion angular distribution	23	66
Fast Ion Gauges (FIG)	Measure transient gas pressure		50
Radio Frequency Probes (RFP)	Measure ion cyclotron fluctuations	21	77
X-Rays	Determine electron energy distribution from X-ray spectra	5	20
Bolometer Prototype	Measure power loss to walls	1	5

Table III

Purpose of Additional Diagnostics Expected to be Implemented on TMX Upgrade

Diagnostic	Purpose
X-Band Interferometer	Density of initial ECRH startup plasma
Microwave Emission	Detect electron microinstabilities
Microwave Scattering	Det -+ ion microinstabilities
West Plug EUV	Impurity identification and radiated power
Bolometers	Total power loss to walls
Thomson Scattering 2nd Radial channel	Electron temperature radial profile to detect possible ECRH edge heating
Neutral Beam Calorimeter	Measure incident neutral beam power
Beam Attenuation Expansion	Radial density profile and absorption of neutral beams
Charge Exchange Analyzer	Ion energy distribution in plugs and central cell and plasma rotation
Doppler Broadening	Impurity temperature and evidence of bulk ion heating and plasma rotation
Plasma Potential Probe	Central-cell potential and radial electric field
Pitch Angle End Loss Analyzer	Resolve bulk injected end loss current Plug and barrier potential End loss energy spectra
X-Ray Upgrade	Improved X-ray measurements
End Wall Probes	Expand end loss profiles
Emissive Probes	Characteristics of end fan plasma
Central Cell Probes	Measurements of high beta structure
RF Probe Upgrade	Improvements and expansion of probe system
Gas Box Diagnostics	Measurements of gas box plasma properties

Figure 1


COMPARISON OF TMX TO UPGRADE
TMX
B (T)
2
Magnetic field
φ(kV)
2
Potential
n_e (cm^{-3})
2 X 10^{13}
Density
−5
0
5
Z(m)
TMX Upgrade
Magnetic field
B (T)
2
Potential
5
φ(kV)
$n_e$cm^{-3}
3 X 10^{13}
Density
−10
−5
0
5
10
Z(m)

TMX UPGRADE - DIAGNOSTICS SYSTEMS (ELECTRICAL)

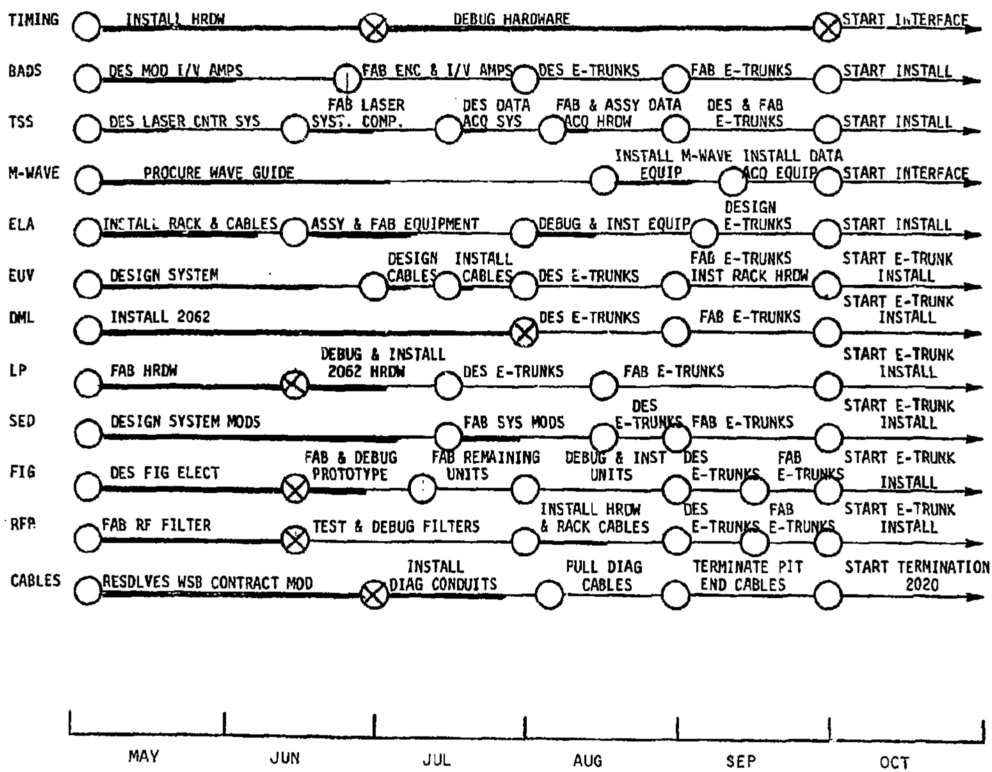


Figure 2

TMX UPGRADE - DIAGNOSTICS SYSTEMS (MECHANICAL)

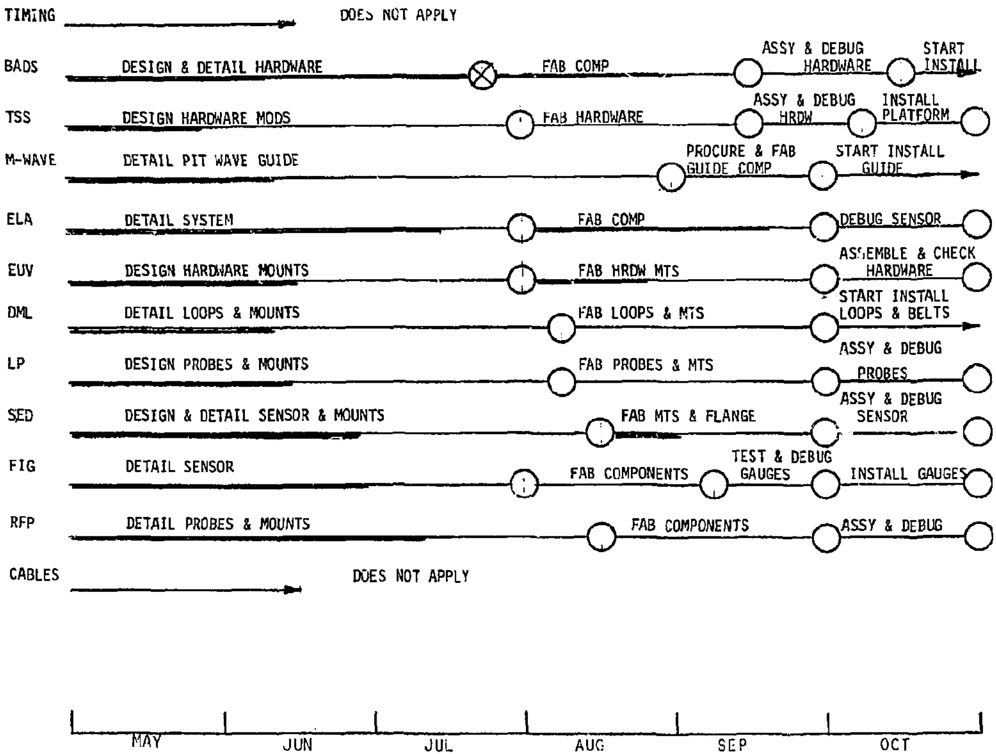


Figure 3

TMX UPGRADE DIAGNOSTICS IMPLEMENTATION PLAN

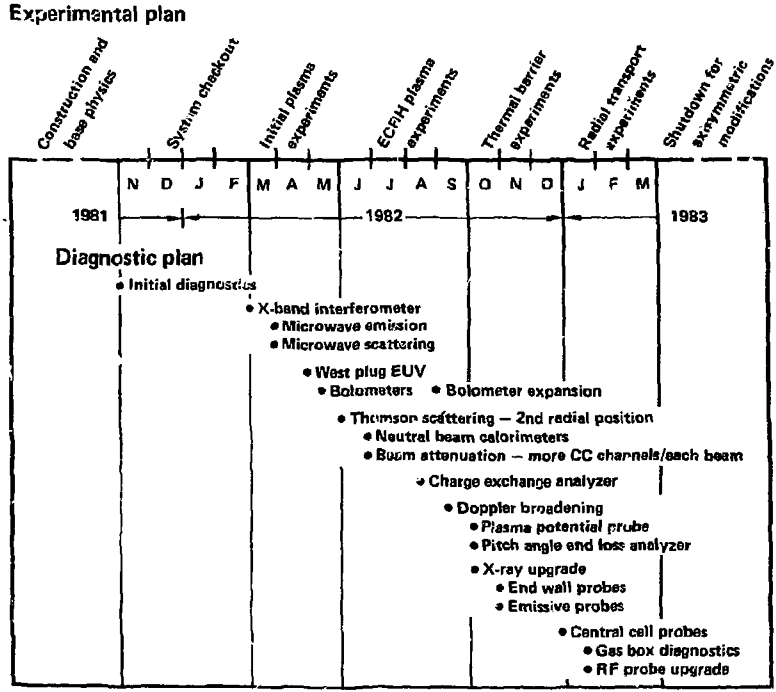


Figure 4

II. INITIAL DIAGNOSTICS

This portion is broken into three major subsections which are: Section A, Description of the diagnostic facilities and the diagnostics being installed for the initial operation on TMX Upgrade; Section B, Status and Schedule of the Diagnostics and; Section C, Improvements to the base set of diagnostics.

A1. DIAGNOSTIC FACILITIES

Besides the individual diagnostics, certain facilities are required by a large experiment to allow its orderly operation. In this section the Shot Leader Console, the Diagnostic timing system and the Diagnostic cable plants are described.

Shot Leader Console

The smooth operation of a large facility requires that the Shot Leader be presented with essential operations data and that excess information be edited. Furthermore, the Shot Leader requires immediate access to certain machine operating resources. The facilities in the Shot Leader Console also enable the operation of TMX Upgrade independent of the diagnostic computer system. Thus, the machine can be made ready for an experiment when the computer is also being made ready. In this section the Shot Leader Console, whose purpose is to satisfy these requirements, is described.

The Shot Leader Console system makes available information on the status of the machine and its control system, the results of the preceding shot, the status of the diagnostic data processing system, the time remaining before the next shot, and shot number. The Shot Leader also has a convenient intercom system throughout the TMX diagnostics, control and experimental areas for maintaining verbal contact with the machine operations personnel. The intercommunication system has capability for five simultaneous independent discussions, each of which may have any number of participants.

The status of the machine and control system is provided via a CAMAC crate with a relay output module. The crate is electronically isolated and controlled by the control system computers. The relay module drives a display board with status lights for the individual pieces of apparatus on TMX. This system monitors whether or not Start-up guns are selected, for example.

The results of the preceding shot are presented to the Shot Leader via oscilloscope traces. Most of the transient digitizers have video playback that can be routed to the ten oscilloscopes mounted in the Shot Leader Console via a system of patch cables from the individual diagnostic area. Within the Shot Leader Console are switches allowing the operator to select various traces at will. The status of the diagnostic data processor is displayed via a video display that includes how far the processing has proceeded. The shot Console includes a computer control panel so that the various options in the processing can be selected on a shot-by-shot basis.

A count-down clock is displayed both to the Shot Leader and throughout the diagnostic room so that time to the next shot is known. The shot number is also displayed so that log books with the correct shot identifier can be maintained.

Diagnostic Timing System

This totally new system provides trigger signals at various times and clock signals of various frequencies for the digital data-recording modules of the plasma diagnostics. The timing system is arranged so all triggers are in fixed-phase relation to their corresponding clock frequencies. With this system, all data recording modules in the TMX-U diagnostic sets are driven by a single, stable master clock and are triggered by pulses derived from the clock. Because of these features data recorded from the various diagnostics can be directly time compared without either sample time uncertainty or relative drift in the sample time. Figure 5 is a block diagram of the timing system. The timing system is modular and uses mostly digital delay generators (BNC 7020), signal fan outs, and frequency dividers. Because of the modular approach, the system of Figure 5 is only one of several possible ways of interconnecting the modules to achieve the aim of providing a system in which all clocks and triggers are in fixed phase.

The diagnostics timing sequence is the following . The shot sequencer (machine timing system) supplies a pulse to the master trigger which is amplified, shaped, and outputted to a fan out. The fanned pulse goes to digital delay timers to provide output triggers and to the master clock. The trigger causes the master clock to lock its phase to the time of the trigger, and internal dividers provide 50, 20 and 10 MHz signals. The 20-MHz signal is fanned out and used as the clock in the trigger digital delay timers. Thus, all triggers are in fixed phase with each other. For recorders requiring lower frequency, a divider module lowers the 20-MHz clock frequency by factors of 2, 4, 5, and 10. The clock output may also be fanned out to provide multiple outputs.

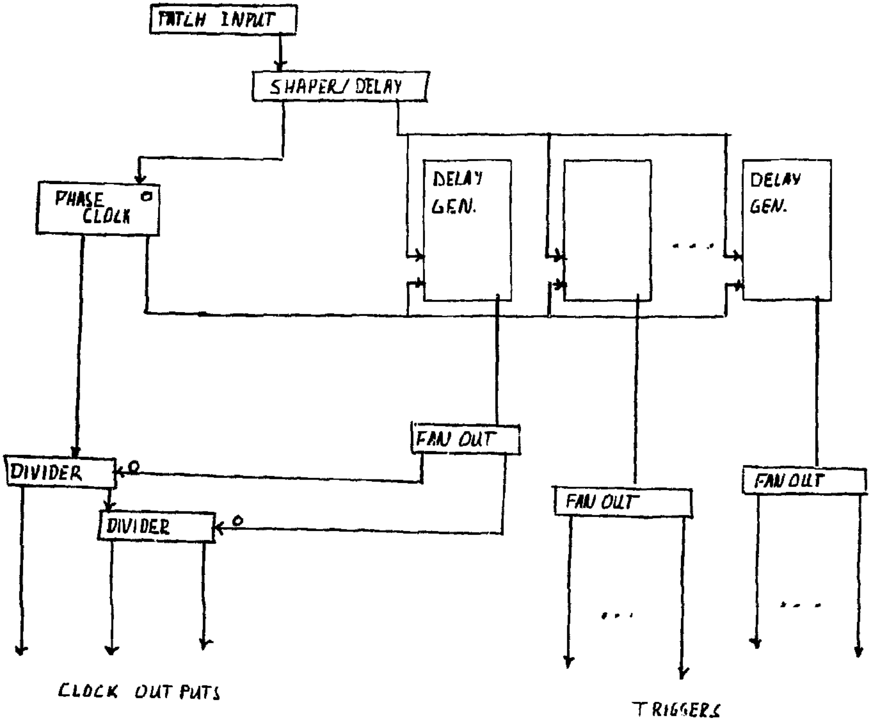

PATCH INPUT
SHAPER/DELAY
PHASE CLOCK
DELAY GEN.
DELAY GEN.
FAN OUT
FAN OUT
FAN OUT
DIVIDER
DIVIDER
CLOCK OUTPUTS
TRIGGERS

FIGURE 5

Phase integrity of the system is maintained by a patch panel arrangement which distributes the trigger and clocks over equal length cables.

Failure of the timing system would preclude doing physics experiments on TMX-U. Because the system is modular and interconnected with standard cables, failure of common modules is a minor problem. The clock module is special, however, and will be evaluated for MTBF for replacement or repair time. A second master clock is available to guarantee system availability.

The operation and maintenance effort is anticipated to average 1 hr/wk exclusive of installation. The time would be mostly spent ensuring system integrity prior to beginning physics experiments. The maintenance would be Electrical Engineer or Electrical Technician effort.

Diagnostic Cable System

The cable system provides a series of patch pannels and cables so diagnostic sensors located on the experiment can be connected to signal conditioning and recording equipment located in the diagnostic room. The diagnostic room has nine separate racks with each having a conduit to a patch pannel. This patch pannel conduit runs to twelve smaller boxes in various positions on the machine. From the small boxes individual cables fan out to the diagnostics.

Nine of the twelve available boxes will have a mixture of Triax, and twisted-shielded-pair cables. The exact cable mix is determined by the known locations of the base case diagnostics and the need to provide capacity for diagnostic expansion. The nine boxes will be filled to capacity leaving three for future expansion.

The cable system maintains the grounding scheme used on TMX in which signals are handled differently and the cable shields provide electrostatic isolation and are single point grounded.

A2. INITIAL DIAGNOSTIC INSTRUMENTS

All of the base diagnostics defined in the TMX proposal and planned for initial operation are described in this section. Many of the diagnostic techniques and much of the hardware from TMX is being reused in the Upgrade experiment. Comprehensive descriptions of the diagnostics on TMX are presented in UCRL-53120 Summary of TMX Results, Appendix B. The reused components include many of the sensors and nearly all of the commercial electronic modules as well as much of the special electronics made for particular diagnostics on TMX.

Included in the description are the purpose of the system, the location of the sensors. the expected operation and maintenance effort,the software programming effort, and the impact of system failure on TMX-U operation.

Other information from the machine operating system will be recorded by the diagnostics system. The currents in each magnet will be recorded and the voltage and curerent of each neutral beam will be recorded. Each neutral beam will have also two SED monitors used by the control system for purposes of beam aiming and focusing; signals from these will be recorded in the data base for use in calculating absorbed power. In general, because of the CAMAC structure, any analog signal can be readily incorporated into the data base. Provision is also being made to allow off line monitoring in real time of signals such as vacuum gauges so a status history is automatically kept. An arrangement has also been made to allow text information (as in a log book) to be entered into the data base. Software will provide a table format into which the operator may make entries.

Beam Attenu_tion Detectors (BAD)

This diagnostic system measures the attenuation of a sloshing neutral beam in traversing the plasma. From the measured loss of beam current, input power to the plasma from that beam is directly measured and, by inference, the total power input to the plasma. The BAD system measures the attenuation along 20 different chords through the plasma displaced both axially and radially. Besides the input power, the length and radius of the plasma and the plasma density distribution are calculated from the array of attenuation data.

The BAD system is comprised of a secondary emission detector, a bias power supply, a transimpedance amplifier (I/V), a data transmission cable and a digital data recorder for each channel. The detector includes collimating apertures which define the line of sight, hence chord through the plasma, a biased cylinder and a cone-shaped emitter. Neutrals which pass through the collimation apertures and impinge on the cone cause electron emission. The electron current (proportional to the incident neutral current) is detected and amplified.

The initial BAD system will utilize detectors, amplifiers and recording hardware from hardware from TMX. Two 24-channel detector arrays and seven single-channel detectors exist. The 24-channel arrays require a new aperture plate and some minor modifications to the mounting structure and feedthrough flange (to correct for the planned location on the east and west end domes). Only 20 of the 24 channels will be useful because of magnet structures along the line of sight. The arrays will view a sloshing beam. In the center cell, five detectors will be used to determine the density and radius of the plasma.

The expected failure modes are either neutral beam failure or amplifier saturation. The latter is fixed by adjusting the gain or by exchanging amplifiers (simple but tedious with $^{\Gamma}$ 47 channels). Once the correct gains are set, the system is very stable. BAD neutral beam failure has been controlled by derating the beam. In general, the wealth of data produced by the diagnostic has been crucial in operation and physics understanding. In normal operation failure of this system would be expected to stop the experiment until repairs could be made. The major maintenance effort will be on the neutral beam. The effort exclusive of beam work to monitor this system is expected to be around 8 hr/wk. The effort equally divided between electronics check-out and maintenance and housekeeping chores. Because of the complex view angle of the BAD system, a sophisticated processing program is required; this task is estimated at 400 hours of programmer time.

Initial operation is anticipated to be labor intensive to debug all the channels, so 20 hr/wk of physics effort is dedicated to this. After a few months' operation, effort will probably drop to around 10 hr/wk and the time spent in data analysis will be correspondingly greater.

Thomson Scattering System (TSS)

The Thomson scattering system determines the electron temperature and density of the plasma by measuring the spectrum of ruby laser light scattered from the electron distribution. The scattered spectrum is determined by the electron energy distribution, each wavelength being the doppler-shifted-scattered intensity from each part of the energy spectrum.

The initial system being implemented on TMX determines the electron temperature both at the plug outer density peak and the center cell midplane at one time during the plasma discharge. Nearly all the major components are salvaged from TMX including much of the optical train. The beam from a 10-Joule ruby laser is focussed and propagates through the plasma into a light dump. The Thomson scattered light is viewed by collection optics at 45^{o} to the beam and focused on a polychromator with ten output channels. Each output channel has a fiber optic transmission line to a photomultiplier tube which is the actual detector. The voltage divider of the tube base contains a gate circuit that keeps the tube cut off except at the time the laser fires.

Thomson scattering diagnostics are complex with many optical and electronic components which must operate correctly. The high power ruby lasers need frequent attention, the optical alignment is critical, and calibration is a lengthy process; however, the measurement of electron temperature is a local and unambiguous measurement of a fundamental plasma parameter. In previous TMX operation, failure of this diagnostic halted operation until repair could be made. If the machine is running stably, as in a diagnostic scan where the plasma shot is repeated time and again and the TSS should fail, then the scan would continue. In the case where the plasma is being scanned and only a few shots are repeated, then failure of the TSS would probably stop the run. The decision would depend upon the significance of the electron temperature parameter to the physics of the particular experiment.

The operation and maintenance needs of this system have required approximately 80 hours per week of effort, 60 hours of physics operator and Electronic Technicians effort, and 20 hours of physics effort.

Microwave Interferometer System (MIS)

This system interferometrically determines the line density of electrons in the plasma by measuring the phase shift due to the dielectric properties of the plasma of a 140 GHz wave. The measurement corroborates the BAD data in some regions and is the only technique available for use in other regions (e.g., between the magnets) because the waveguide runs can be installed in tight quarters.

The initial microwave receiver system installed on TMX will support four simultaneous measurement channels; a set of nine antennas will be installed in the vacuum vessel. The position being monitored can be changed by moving waveguide outside the vessel. The horn locations are: center cell, plug inner 20-kG peak (E/W), plug inner 10-kG peak (E/W), plug midplane (E/W), and plug potential peak (E/W). The receiver uses a 20-W Extended Interaction Oscillator tube (EIO) as a source and a low-power klystron as a local oscillator. The local oscillator is phase-locked by a feedback circuit in a double-down-conversion detector system. A linear multi-fringe phase comparator provides the phase modulation signal with a 50 MHz bandwidth. The design resolution is 0.2 degrees, corresponding to a line density variation of 5×10^{10} cm^{-2}.

The utility of this system is mainly its ability to measure the line density in regions inaccessible to other diagnostics. Failure of this diagnostic would not stop an experimental series unless the particular experiment depended upon the density in a region only measured by the MIS. The system incorporates high reliability components and has been engineered to be a nearly hands-off system. Operation should need approximately 4 hr/wk.

<u>End Loss Analyzer (ELA)</u>

The end loss current spectrum is measured; the ion temperature, plug potential and confinement product in the center cell are deduced and compared to other measurements and theoretical predictions. The measurements are also used in power balance studies. The detector is a simple retarding grid electrostatic energy analyzer removed from TMX. The entrance aperture is comprised of a low transmission mesh which reduces the current in the analyzer to manageable levels, followed by a swept grid and a current collector. The ramp voltage on the repeller grid and the current collected are simultaneously recorded, and the currents/voltage relationship of the plasma is deduced.

On TMX Upgrade, four systems are provided, two on each end, one movable and one fixed in location. The fixed ELA's are close to the central flux tube to provide information about the central plasma. The movable detectors traverse the narrow width of the plasma cross-section and are used to perform radial scans in order to determine plasma properties as a function of radius.

This diagnostic provides key potential and power balance information, therefore, total failure would require immediate repairs. With two systems on each end, total failure is highly improbable. Most failures are likely to be in the sweep drive circuitry of the repeller grid. These circuits are relatively easy to repair and are external to the vacuum envelope; it is expected that failure in this system would at worst cause short delays.

In operation the ELA system is nearly completely automated and requires supervision only to know whether the systems are functioning properly. Operation should require at most 12 hr/wk of staff attention. Exception, occur when the positions of the movable ELA's are being changed to produce a radial scan; nearly full attention of an operator is required during the scan.

The software for this diagnostic was well developed on TMX; only minor adjustments are required to make it compatible with the new data storage format.

Extreme Ultraviolet System (EUV)

This diagnostic utilized an absolutely calibrated multichord monochromator to examine the intensity of impurity radiation in the wavelength range from 300 A to 1200 A. From the line radiation measurements, quantities bearing on power balance and impurity density can be deduced. Also, certain lines are monitored during each experimental series to establish that no unusual machine conditions arise, e.g., nitrogen density changes implying a vacuum pulse leak. By intentionally injecting impurities, diffusion and transport rates can be studied.

The instrument used on TMX is a 22-spacial channel 0.4 m normal incidence grating monochromator. Wavelength is remotely selected. The detectors are strip-current collectors behind a chevron microchannel plate. The instrument is nearly identical to one developed by H. W. Moos' group at Johns Hopkins University and is absolutely calibrated in their facility when needed. The JHU instrument may also be installed on TMX Upgrade and run simultaneously, providing two axial locations with 22 chords each.

Because of the 22 parallel channels and the 1-2 msec integration time required by this instrument, copious quantities of high quality data are produced in a few shots. The data then, in general, require extensive reduction to obtain relevant plasma physics information;

hence, loss of a few shots does not impede operations except if the particular sequence is being conducted for spectroscopic purposes. In general, failure of this system would be ignored and it would be fixed afterwards.

The initial EUV installation on TMX Upgrade provides one 22-channel instrument and two beamline systems for viewing the plasma. One beamline is at the east end allowing a view of the plug midplane region so that deep magnetically trapped impurities can be studied; the other beamline allows viewing the center cell plasma near the midplane. The operation of this system requires the constant attention of an operator during the run, and the data require extensive analysis afterward. It is expected that this system will require two people full time for the initial installation.

Diamagnetic Loops (DL)

This system measures magnetic flux excluded by the plasma from which the ion temperature and density are estimated. An array of 14 Faraday shielded single-turn loops are placed along the length of TMX Upgrade. Three coils in each plug are provided, one each near the inner and outer 10-kG points and one near the midplane (5 kG). Eight coils are positioned along the center cell. Six coils are east and two are west of the machine midplane.

The signal induced in each loop has subtracted from it the contribution due to magnet current ripple. The power supply currents are monitored and filtered with a time constant the same as the transient soak in time in the parasitic conductors (vacuum tank, coil cases, etc.) to produce signals equal to the diamagnetic loop signal in the absence of a plasma. The filtered ripple of several coils is combined to produce the error signal for subtraction from the loop signal.

Because of the large number of loops, it is not expected that this entire system could fail. Individual loop failures would not stop a machine run. The sensor is simple and passive, so system failures are largely expected to be external to the vacuum and of a simple electronic nature. To initially set this system up for operation is labor intensive because each loop requires calibration and each loop must be trimmed by the perturbing magnet currents. Afterward, the system is passive and requires minimal supervision. It is estimated that operations should need 4 hr/wk support.

Faraday Cups/Langmuir Probes (FC/LP)

The various sensors in this system are intended to determine the nature of the TMX Upgrade plasma at its interfaces with end-walls, gas boxes, or vacuum. On the end walls, current collectors and Faraday cups determine end-loss current distribution. Edge plasma density and temperature are determined by swept Langmuir probes. The initial implementation of this system will be 14 Faraday cups and 14 current probes on both east and west end flanges. This array is sufficient to do initial end-loss current distribution determinations.

Each Faraday cup has a grounded chamber with a pinhole aperture, an electron suppressor (also with a pinhole aperture) and a biased Faraday cup. Each successive aperture is larger than the one in front of it so that the exact alignment is not particularly critical. The electron suppressors are all connected in parallel to a standard NIM power supply for bias voltage. The Faraday cup is biased negatively and the signal coupled out through a high voltage-blocking capacitor. The signal then goes through an antialiasing filter, a programmable amplifier and to a digital data recorder. The net current collector is a small electrode which is flush to the wall. The net current which flows is monitored by a low impedance system (so that the electrode is always close to ground potential) comprised of an amplifier, antialiasing filter, and a digital recorder.

Because the system includes many parallel channels, total failure of this diagnostic is extremely unlikely. Each sensor is very simple; it is unlikely that system failure would be internal to the vacuum chamber. Most problems are expected to be in the external electronics which are amenable to maintenance. The data from this system are very useful in modeling and data analysis after physics experiments. However, unless the experiment was particularly for end-loss or radial transport measurements system failure would not stop a physics run.

For maintenance and operation, little attention is required after the gain is adjusted so that none of the channels are saturating the electronics. It is estimated that an effort of 8 hr/wk is sufficient. Because of the large number of channels and the manifold data interpretations, the physics analysis effort is expected to be a near full-time task for one physicist.

Secondary Electron Detectors (SED)

The detectors in this system measure the charge exchange neutral flux emitted from the plasma by generating a current proportional to the incident neutral flux by emission of secondary electrons from a copper surface in the detectors. A collimated array of SEDs in each plug is arranged to measure the angular distribution of the charge exchange flux. This will allow the "sloshing" ion distribution to be identified. The sensors are cone-shaped emitters inside a shielded enclosure which is provided with a collimating aperture that provides for a detection cone of approximately 12^{o} included angle. The cone is biased so that secondary electrons are driven to the surrounding shield. An array of detectors is mounted on an arc-shaped beam in the east and west plug with a 90-cm radius of curvature. This combination of view angle and distance from the plasma is designed to view a cylindrical cut through the plasma of 10-cm radius. In the initial installation, 15 sensors are mounted in the east plug and six sensors are mounted in the west plug. In the center cell midplane, four detectors are spaced around the azimuth to measure the symmetry of radial loss.

The major difficulty with this system is its inability to distinguish between neutral flux and ultraviolet photon flux, both of which are efficient in the production of secondary electronics. The EUV system can be used to separate the photon flux from the charge exchange signal. Note, the sensors are simple, remote collectors inside the vacuum chamber. A battery, bypassed by a capacitor, biases the emitter so that when secondaries complete the circuit, a voltage signal is developed across a resistor. The voltage signal is then brought to a digital recorder in the diagnostic room.

Because this is the only diagnostic which directly measures the anisotropy of the plug ion distribution, a key component of TMX Upgrade physics, failure of this system would be cause to stop a physics experiment on TMX-U. As observed above, the sensors are, as usual, simple so that failure of components inside the vacuum system is not probable.

Other failures which can be anticipated would be in the external electronics, which can be fixed during a short break in the run or, at worst, by delaying the run for a shift. No special electronics are used. The battery life in the bias supply is long (nearly the shelf time) because the shot duration is short compared to clock time.

The operation and maintenance of this detector system are not expected to average more than 8 hr/wk.

Because of the key information to be deduced from this diagnostic on the sloshing ion angular distribution and (since this use is a new application) extensive software effort will be required and up to 1200 hours of computer programmer time will be dedicated to this task.

Fast Ion Gauges (FIG)

A set of three fast Bayard-Alpert vacuum gauge control chassis are provided so that pressure changes in various regions of the TMX Upgrade vacuum vessel can be measured on time scales fast in comparison to the plasma duration. Two types of studies are anticipated, pressure transient studies due to the gas load from neutral beam modules in the absence of magnetic field and pressure studies during normal plasma shots.

The gauges utilized are standard high-vacuum gauges. The three detectors which are to work during plasma shots are installed with magnetic shielding into low field regions of the midplane and both east and west end fan tanks. Other gauges can be used with the special FIG controller to allow a large number of other gas transient pressure measurements to be done with the magnets off. Two gauges are to be mounted on movable shafts. They can be located in the volume the plasma would occupy to allow a measurement of cold-gas incident on the plasma.

In initial TMX operation, studies of vacuum conditions will be done to determine suitable operating techniques. During this set of tests, failure of the FIG system would cause either a pause for repairs or a schedule change to other checkout work until repairs could be effected. Since many gauges are installed, complete internal failure is not expected. The FIG controllers are entirely external and may be repaired by ordinary electronics techniques.

In regular TMX operation, the pressure rise during the plasma shot is monitored to check for excess gas being dumped from neutral beams or gas boxes. Also, this monitoring establishes that when the gas injection is changed, it actually does change. As most of these determinations are for consistency, FIG failure would not be expected to terminate a physics experiment. Beyond the system installation tasks, this diagnostic should be nearly maintenance free; it is expected to require effort on the order of 4 hr/wk.

Radio Frequency Probes System (RFP)

This system measures fluctuations of the electric and magnetic fields in the plasma. From the frequency information and signal amplitude, the level of unstable waves and their physical nature can be deduced. Of special interest are those modes which are, according to theory, expected to limit plasma confinement.

The initial installation of this system will have 29 probes, 9 probes for magnetic fluctuations and 20 high input impedance electron field probes. An array of 5 electron and 3 magnetic probes will be installed in the east plug, an array of 5 electron probes in the west plug, an array of 6 electron and 2 magnetic in the center cell and 4 probes of each type installed in the transition region on the center-cell side of the magnetic field maximum.

The signals are brought through diagnostic trunk lines to the signal processing and recording system. In the initial installation, 12 input channels and 26 recording channels are provided . The difference in number between input and recording channels is because signals are split into frequency bands and each band separately recorded. Also, a local oscillator is mixed with the incoming RF signal and the (lower) beat frequency recorded on some channels.

Because microstability of the plug sloshing ion distribution is essential to TMX Upgrade physics, failure of the RFP system in the early running of experiments would be serious. As many simple, independent sensors may be cross patched in the diagnostic room to independent recording channels, no credible scenario exists for complete failure of this system.

The simple nature of each channel suggests that minimum effort is required for operation; in practice, the opposite is true as many significant questions can be answered by processing the shot data in various ways. On the average 48 hr/wk of effort will be needed to operate this system. The variety of recording techniques for RFP data and the requirement for Fourier analysis of it require an extensive set of processing programs. Up to 1200 hr of programming effort may be needed to complete the full complement of these programs.

X-Ray Diagnostics

These detectors determine the electron temperature in TMX-Upgrade by measuring the electron bremsstrahlung spectrum at five separate locations along the axis. The X-ray diagnostic also determines the electron temperature time dependence. The basic detector unit is a Ge solid state detector with a filter to remove the low energy end of the

X-ray spectrum. The detectors are used in a pulse counting mode with attention given to obtaining maximum count rate for good statistics. It is expected that sufficient counts will be obtained in 2 msec to provide an accurate temperature measurement. To achieve a local measurement of electron temperature, each detector set is provided with a collimating entrance tube up to the plasma and an X-ray dump on the opposite side of the plasma.

Because the ability to control the electron temperature is a key to controlling the axial ambipolar potential in TMX-Upgrade, this diagnostic is of pivotal importance. Total system failure would be cause for a shutdown until a repair could be accomplished. As the initial system includes 10 data channels from 5 locations, total failure is not a likely occurrence. The only components inside the vacuum vessel which cannot be accessed by valving off are the totally passive beam collimation tubes. Inside vacuum, but isolated behind a valve from the TMX-Upgrade chamber, are the detectors. These may be accessed by venting the detector system to air, removing one of the five systems from operation. The filters are fragile assemblies so provision is made for this access. A more probable failure will be in the electronics. All electronics are external to the vacuum system and so can be repaired with minimum access difficulties. For crucial components, either spares or access to enable rapid repair will be provided. The solid-state detectors are all identical and can be room-temperature cycled so no simple failure can destroy all of the solid-state detectors at once.

To extract electron temperature from the spectral information, significant processing effort is required. Calculations and programs must be created which invert the data to generate the temperature information in a model independent fashion. Further, the system operation must be monitored on each shot so that the best data possible are obtained. Physics analysis of the data is expected to be a lengthy process because of the complexity of the data inversion routines.

It is estimated that as much as 1200 hrs of computer programming effort may be needed to make operational comprehensive data reduction programs and that the system will require the attention of a physicist/operator for 40 hr/week.

IIB. STATUS AND SCHEDULE

The status of diagnostics at this time is depicted in Figures 2 and 3 which show the present time line and status for the electrical and mechanical aspects of the project funded diagnostics. The status of each diagnostic being installed in the multiple set is duscussed.

In general the electrical components are mostly installed and cabled up or in fab. The schematic diagrams of all the diagnostics are complete. The electrical contract schedule will install cables to the machine in August and September 1981 and should allow the timely connection of the sensor to the electronics.

The mechanical layout of all diagnostics going into the plug, including both the potential peak and midplane, has been finished. Port assignments of the diagnostics have all been done and layouts for probe penetrations and windows have been done. The mounts and support structures for most diagnostics are in construction.

IIB1. STATUS OF DIAGNOSTIC FACILITIES

Shot Leader Console

The major electrical components have been installed. The operator/computer interface is in debug and should be available in July 1981 to enable checkout of the data acquisition computer system. Patch cables for data, intercomunication, and interlocks are done.

Timing System

The system is complete and has been debugged and tested.

Diagnostic Cables

The installation contract is let and proceeding on schedule.IIB2.

STATUS OF DIAGNOSTICS INSTRUMENTS

Beam Attenuation Detectors

After completing the mechanical layout of the plug diagnostics, the mounting and and modification to the Bad system was detailed. It is now in mechanical fab. The detector electronics has been redesigned because of obsolescence of the operational amplifiers the and need to provide filtering. The new design is in the drafting and fabrication stage.

Thomson Scattering System

Two mechanical designers and an optical engineer are working on this system's mechanical modification for installation on TMX-U. The mechanical components should be ready by the time they are needed for installation in the vacuum vessel. These large and delicate components will be installed after the completion of heavy construction. The electrical and electronic circuits for control and data recording have been designed and are under construction.

Microwave Interferometer

This system is electrically complete and installed. Mechanical detailing of the Pit waveguide runs is delayed until the Pit space layouts are finished. The horn layouts in the vacuum system are done.

End Loss Analyzers

The detectors removed from TMX have been refurbished and are ready for reinstallation. The sweep drive electronics racks need to be loaded. These racks will be installed in the pit after major construction is complete with short cable runs to the detectors. The control equipment and data recording gear is installed in the diagnostics room.

Extreme Ultraviolet

The detailed layout of this diagnostic included ports for this system to view the plug potential peak, plug midplane on both east and west ends and the center cell. The mechanical components are ready to mount on the east plug midplane. The controls are ready. The instrument is at Johns Hopkins University for storage, maintenance and recalibration. It will be shipped for installation before the initial experiments begin.

Diamagnetic Loops

This system is complete electrically except for cables to the sensors. The loops will be ceramic insulated rigid coax fabricated to size. The material is on order and exact dimensions will be specified when all the mechanical layouts are done. At present the dimensions of six of the intended fourteen loops can be specified. Mechanical layout of the center cell is in progress. It is expected that the loop lengths will be known by mid July for communication the the vendor.

Farady Cups/Langmuir Probes

This system is mostly complete electrically. Many of the sensors parts will be re-used, the detector arrays are being made and should be ready on schedule.

Secondary Emission Detectors

The electronics is installed and ready except for some cables and bias supplies. The sensors are being assembled. A design of the mounting structure is beginning.

Fast Ion Gauges

The gauge controller prototype is due in mid July from the electronics fab shop. A layout and test of the magnetic shield has been done. The shield will be detailed and made. Most of the material is available.

Radio Frequency Probes

The electrical installation is nearly complete. Most of the probes are refurbished from TMX and in good condition. The layout is done so mounting spools can be made.

X-Ray Diagnostics

Detailed physics studies of the expected spectrum and count rates lead to careful evaluation and testing of detectors and electronic components to optimize this system. Mechanical layout of the viewing line and dump tube were done along with the other diagnostics. The mounting structure will be determined from the detectors which are purchased. The detector order should be ready in July. The mechanical design of the beam line is done.

IIC. POSSIBLE FUTURE IMPROVEMENTS TO DIAGNOSTICS

In this section, improvements which are straightforward expansions of existing systems are suggested. Most improvements expand the number of data channels or increase the operational effectiveness or usefulness of the diagnostic. Some of the improvements were anticipated and desirable on TMX and delayed by reinstallation of the systems removed from TMX. Other improvements have to do with acquiring apparatus which is better suited for a particular task, based upon experience on TMX.

Diagnostic Timing System

Expansion of this system requires the acquisition of additional modules. An improvement to the system would be a multichannel time intervalmeter which could be read by the diagnostic computer so that the actual timing becomes a part of the data base.

Beam Attenuation Detector

Because the system was very complete on TMX, little expansion is foreseen; however, by installing a single-channel secondary emission detector opposite each beam location and by using the plasma information included in the base diagnostic, a significant system for measuring the input power to the plasma would be provided. This system would replace the need for neutral beam calorimeters. This whole expansion would add 22 detectors to the system.

Thomson Scattering System

Straightforward improvements to the base system would be the addition of a second polychromator photomultiplier array on both the plug and center cell so that the electron temperature is measured at two radii simultaneously. The scattered-light collection optics for the plug have provision for additional positions incorporated in the design. The distribution box for the center-cell optics could need some modification to incorporate a second polychromator.

A major expansion of the system would be the addition of a Thomson scattering system in the west plug. The vacuum tank design allows this possibility. With such a system and the already available beam attenuation and diamagnetic loop data, the major instrumentation of the west plug would be comparable to that of the east plug and possible ambiguities in the data could be eliminated.

Microwave Interferometer System

The first addition to the microwave system would be a microwave forward-scattering signal on each of the four channels to check plug microstability. This improvement requires the addition of a few components to the interferometer system (power splitter, mixer, amplifiers, etc.) to separate the scattered signals that then go to the RF diagnostic system for signal processing as additional input channels. (Expansion for this purpose will be included in the section dealing with the rf probes).

An essential improvement will be a new klystron power supply to provide phase stability to the system. Spare components for critical items should also be purchased. A major expansion to eight channels can be accomplished by adding a local oscillator klystron and other waveguide components. This expansion will depend on the utility of the initial data obtained with the four-channel system.

End Loss Analyzers

The only change presently planned for the ELA system is in improving the reliability of the sweep drive electronics -- a straightforward engineering task.

An additional minor improvement would be remote actuators and position read-outs for the movable ELA so that end-loss scans can be accomplished remotely. If a different analyzer system can be used in which temporal sweeping is not needed, then much better end-loss information can be obtained. Such developmental systems will be discussed in Section III F.

Extreme Ultraviolet

A logical immediate improvement will be the addition of beamlines to view the west plug so that east/west asymmetries can be studied and beamlines to view the plug potential peak region. The additional beamline locations can be used simultaneously by instruments identical to the LLNL-owned one, assuming the cooperative program with Johns Hopkins continues.

A useful monitor system for H-alpha and O11 and N11 made from fiberoptic collectors and using interference filters with photomultiplier detectors. This easily installed diagnostic would relieve the more sophisticated instruments of the routine monitor functions presently assigned. Normalizing signals for O and N contamination would then be routinely available.

Diamagnetic Loops

There are at present no system improvements under consideration for this diagnostic.

Faraday Cups

The expansion expected for this system is as follows. First, more channels of current collectors and Faraday cups on both east and west end walls in the long direction of the plasma fan will be installed. Also, an emissive probe system used on TMX will be provided for TMX Upgrade by having ports cut in the end flanges. Further expansion will include pickup probes located in the center cell that are similar to the current probes in the end walls. Sweep electronics will be made so the edge electron temperature can be determined. Some of the center cell probes should be mounted so that they can be moved radially to study the edge plasma.

Secondary Electron Detectors (SED)

Improvements to this system are the addition of more channels to the west array to provide the same number of channels as in the east detector set and the possible inclusion of transimpedance, line driver amplifiers at the machine in case the current signals are lower than anticipated. Beyond these simple extensions, the installation of single detectors along the length of the machine could be useful in power and particle balance studies.

Fast Ion Gauges

There are no improvements presently anticipated beyond the initial installation plan. If required, an additional gauge controller can be made and additional gauges can be installed in the TMX vacuum system for special tests.

Radio Frequency Probe System

The initial expansion expected for this system will be to increase the number of input channels to 30 so that a better survey of the probes can be conducted on each shot. Simultaneously, the number of recording channels will be increased to 50 or more. Some channels are low-frequency envelope monitors and others have much higher digital bandwidth to follow the details of the fluctuation spectrum. Additional channels are also needed to provide for the microwave scatter signals which may need up to eight input channels.

Following the signal-processing expansion, additional electric and magnetic probes will be installed in locations, as yet unspecified, where theory and experiment suggest that significant plasma fluctuations are taking place.

X-Ray Diagnostics

An initial addition to the X-ray system will be two pinhole cameras with electronic shutters (microchannel plate intensifiers) and (probably) photographic film. With these cameras the spatial extent of the hot electrons can be determined. A upgrade of the film cameras to an electronic readout system is being considered.

III. DEVELOPMENTAL DIAGNOSTICS

Figure 4 outlines the implementation of additional diagnostics which will be required to accomplish the program milestones. Table III summarized the purpose of these instruments several of which are extended or improved versions of the initial set described in Section II. In this section we describe only those instruments which are new and are costly and developmental in nature.

A. Plasma Potential Diagnostic

The fundamental success of TMX-Upgrade rests on the ability to tailor the axial potential profile for optimum confinement; thus it is extremely useful to directly measure the plasma potential. A technique that does this directly is ion beam injection in which the energy change of the beam ions in higher ionization states exiting the plasma is measured. The magnetic field and system geometry act like a magnetic spectrometer so that the potential is measured over a small plasma volume. Two locations are considered, the midplane of the center cell or the midplane of the plug.

A PPD for TMX-Upgrade would require an ion source injecting a cesium or thallium beam at energies up to 100 keV. The beam energy must be known better than 0.05%. Deflection plates to move the beam across the plasma must also be provided. The exiting ions are analyzed in a parallel plate energy analyzer which requires precision on the order of 10^{-4}. In order to operate the source and analyzer and profile the information, a complex control system is required.

On TMX a potential diagnostic was installed in the center cell and worked very successfully. To install a PPD on TMX Upgrade, significant effort is required because each such diagnostic must be carefully tailored to the magnetic field and plasma environment in which it is to operate. The TMX-Upgrade magnetic field is higher 0.3 versus 0.2T and the vacuum tank size is approximately twice as large. The tasks are:

conduct extensive computer simulations to determine orbits (hence port locations) and expected signal levels, construct a suitable ion source accelerator, ion beam deflection system, construct a suitable energy analyzer and design and build the necessary vacuum tanks. The control system used for TMX would be satisfactory for TMX Upgrade.

We have begun the detailed simulation work necessary to install a PPD on TMX-Upgrade. We discuss our designs with R. Hickock at Rensselear Polytechnic Institute. It is too early to establish the design requirements thus not possible to committ engineering effort to this diagnostic at this time. Sufficient simulation work should be done by August to enable an evaluation of the exact requirements. A man-year of draftsman/designer time is necessary to detail the machanical parts. Extensive electrical engineering and technician effort is required on the complex control installa*ion. Thus, a three-man effort is expected to define the PPD system and costs.

Operation of the PPD. requires full attention of one person during the shot. Between runs new ion sources must be made and installed and calibrations and adjustments made while the data is being analyzed. The above tasks require nearly a three-man effort also. It is anticipated then, that funds to support nearly three FTE's are required to support this project. The PPD measurements result in radially determined time resolved direct measurement of the ambipolar potential in the plasma cross section where the system is probing.

B. Bolometers

An extensive array of these power sensors is required so that a comprehensive region-by-region power balance analysis can be done. Since many detector channels are necessary to accomplish the goal of this system and it is desirable to bound the overall system costs, a prototype detector unit is being constructed. Veco "Thinistors" have been ordered for evaluation in the prototype. A control circuit is in the conceptual design stage. If the control circuit heats the bolometer above ambient and maintains the temperature constant with and without plasma present, then during plasma input the plasma power is just the difference in electrical input. It is intended that the time resolution will be approximately 5 msec and the sensitivity 0.1 W/cm^2.

The many channels and simple nature of the channels make complete system failure highly improbable. Because of the anticipated number of channels and significance of the measurement, it is expected that 40 hr/wk in maintenance and data analysis would be required to in support of this system.

C. Charge Exchange Analyzer

To measure the energy distribution of the charge exchange flux from the TMX Upgrade plasma a Charge Exchange Analyzer System is needed. The energy distribution of the charge exchange flux is representative of the plasma ion distribution. In the initial diagnostic set, the "burden-of-proof" for the creation of a sloshing ion distribution in the plug rests on the S.E.D. system which measures the angular distribution of total charge exchange flux. The charge exchange analyzer will measure the charge exchange energy spectrum as a function of time. From this information the mean ion energy and charge exchange power loss are calculated. Important questions on microstability can also be assessed.

The basic instrument consists of a gas-filled stripping cell followed by an energy analyzer. Several candidate designs are under active review. A calculation of the expected charge exchange flux and energy as a function of position and angle has begun. With these results, instrument requirements can be set and locations choosen which optimize the efficacy of this technique. The major considerations of the systems are energy resolution, number of parallel channels, and minimum response time. If the gas stripping is removed, most of the energy analyzers can also function as end loss analyzers. If the analyzer portion is more effective than a simple retarding grid analyzer, then it may be advantageously employed in place of the simpler ELA's. Decisions on which system and whether to make or buy it will be made soon.

Until the diagnostic is designed, no estimate of the effort needed to operate it can be made reliably. It is expected that the support manpower will be commensurate with the usefulness of the data and the needs of system operation.

D. Cyclotron Emission

This diagnostic will measure the short wavelength electronic emission spectrum from the plug region. From this spectrum, electron instabilities in the high-frequency range can be detected. Laboratory personnel and University of Maryland personnel are conducting a study as to the feasibility of such a system and what information about electron temperature or hot electron anisotropy could be deduced from the measured spectrum.

The radiometer can be expected to be manpower intensive as the computational difficulties in analyzing the data are formidable in spite of the expected simplicity of the detection system itself. Manpower will be committed to this task if the theoretical studies show significant promise.

It is expected that a cooperative program between Universit, of Maryland and LLNL can make this diagnostic into an analytical tool. The group lead by D. Boyd is well known for their contributions to fusion physics in this specialized area. They have the expertize to do this job well with field support by LLNL machine operations personnel.

If this system can be developed, it would be a useful but probably never crucial diagnostic so that its failure would not halt machine operation.

E. Spectroscopy

In addition to the provision for installing two 22 spatial-channel time-resolving monochrometers suitable for following a single ionization state in time, provisions are being made for expanding the capability by continuing the cooperative program with H.W. Moos of Johns Hopkins (begun during 2XIIB) and another program with lab personnel from E Division. Particular measurements which could best be done by spectroscopy have been identified. From the experiment list instrument requirements are determined.

The most usefull instruments appear to be, 1) The normal incidence multi-chord device ("22 channel") as previously discussed, 2) An instrument with similar resolution but in the grazing incidence spectral region for surveying high Z impurities in hot plasmas, and 3) A high resolution, normal incidence spectrograph for measuring E X B rotation and Doppler shift ion temperature.

F. End Loss Analyzers

The present retarding grid systems are limited in energy and time resolution because of having to sweep a voltage applied to a grid.

Furthermore, they have large angular acceptance and only measure the component of energy perpendicular to the grid. Because of these characteristics the sloshing ion component, the pump beam contribution, and the center cell loss currents are all mixed together. A multi-channel energy-dispersing angular sensitive system is desirable to avoid the above limitations. Calculations are being done to determine the instrument requirements so that the design or purchase of suitable instruments can be initiated.

G. Surface Studies

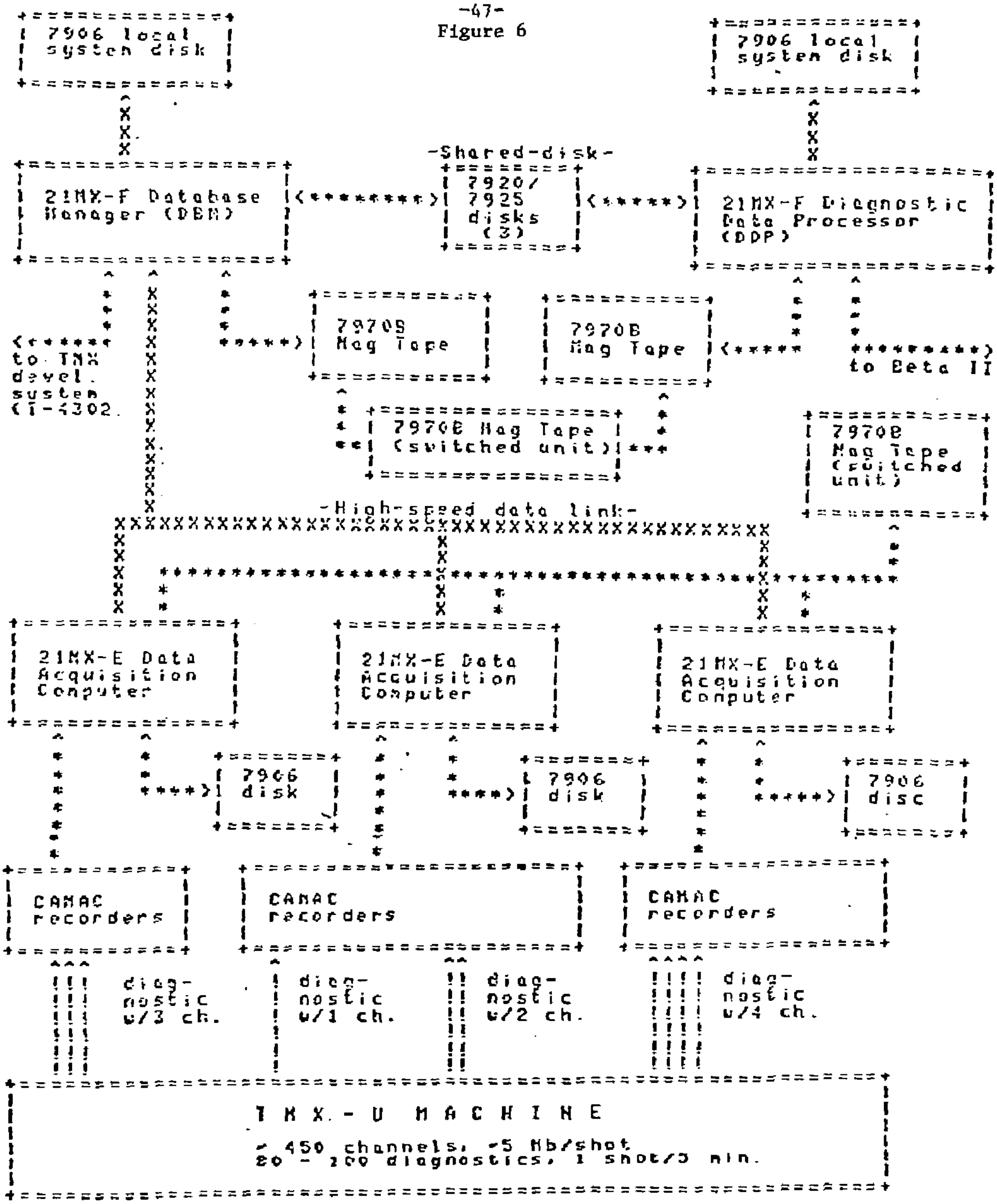
The initial studies done on TMX as a cooperative program between LLNL and Sandia National Laboratory, Livermore, will be continued and broadened on TMX Upgrade. Ports and space are available for this purpose. Various sample coupon arrays will be mounted in strategic locations and removed during air cycles for analysis. The Sandia group is well known and has the necessary analysis equipment for conducting these measurements.

IV. TMX-U COMPUTER SYSTEM

A. COMPUTER HARDWARE

To support TMX-Upgrade physics Operations effectively, the computer system is being modified with both hardware additions to the On-Line System and a complete rework of the data base manager and processing/graphics control software. The general goals of this work are to acquire, archive, process, and manage data from a 450 diagnostic channel experiment, improve processed data throughput to disc file by a factor of roughly five over TMX, and improve user interfaces for

Figure 6



TMX Upgrade Computer System Configuration

The illustration shows the major hardware components in the upgraded TMX computer system, and also indicates the data paths from the experiment to the data base and archive.

diagnostic, processing, and data base management. Although most of the effort is directed at improving on-line performance, the upgraded processing and management packages will be placed on the off-line system also. A synopsis of the principal upgrade features follows.

The TMX-U Computer System is a distributed system consisting of two major components - the On-Line System in B-435 and the Off-Line System in Trailer-4302 which are linked. The On-Line System supports real-time experimental operation including processing and output of all data and physics analysis that is pertinent to that operation. Long term physical analysis and software development is conducted on the Off-Line System. Reliability is achieved through functional redundancy and modularity in both hardware and software design.

On-Line System

As shown in Fig. 6 the On-Line subsystem consists of five multiply-linked computers grouped into Data Base Management/Processor and Diagnostic Control and Acquisition levels. A star-ring distributed system configuration for command and status protects the system from single point communication node failure.

Data Base Manager/Processor

This level of the On-Line System uses two H-P 21MX/F Central Processing Units (CPU's) each containing 1.9 Mbytes of high-speed error correcting memory and sharing a 300 Mbyte data volume. These two processors have a direct DS-1000 link with backup provided through the Diagnostic CPU nodes.

One of these CPU's (Data Base Manager-DBM) is connected via high-speed data links to the diagnostic computers and is primarily responsible for the storage, management, and archive of the primary data base. It is also the communications node for the Off-Line System. The other 21MX/F (Distributed Data Base Processor DDP) is mainly responsible for processing data and performing analysis during the experiment. This CPU also provides interactive user support through several HP-2648A terminals. In addition to the shared data volume, each CPU has its own 7906 system and file manager disc. A 7970B mag tape unit is connected to each processor with a third unit available as a second drive on either. These two CPU's have identical Input/Output (I/O) configurations so that changeover of function from one to the other is rapid in case of failure. For instance, if either 21MX/F goes down, the system is so configured that those functions may be transferred to the other. Although the throughput will be reduced, operations can continue following a short changeover period (5 - 10 min). Besides the 2648A terminals, output devices are a pair of electrostatic printers, Tektronix 4012/4025 graphics terminals with hard copy facilities, and a Ramtek 9200 color graphics processor which will support six individual frames. This latter device is intended for TV monitor data and status display in the TMX-Upgrade area. The computer operator can monitor system performance with a 2626 terminal which can display four separate status reports.

Diagnostic Control and Acquisition

Three 21MX/E CPU's are used to control, acquire, compact and transfer data from 450 CAMAC data channels to the DBM/DDP. The CAMAC links are either Parallel Branches (A-2) or direct Crate Controller connections. Timing tests indicate that multiplexing the three CPU's allows data transfer to the shared data volume in 75-100 sec.

There are sufficient I/O slots available to reassign data channels if one of the diagnostic computers fails. The time required is that to switch I/O cards and reload a different diagnostic configuration from disc. Each 21MX/E has its own 2648A system terminal. Additionally, two thermal line printers and a magnetic tape unit are available for connection as required for test, debug, or logging.

Off-Line System

The Off-Line System in Trailer 4302 is a HP-1000 system with a 1.0 Mbyte memory 21MX/F, 360 Mbyte disc, mag tape unit, floppy disc, HP line printer, Versatec line printer/plotter, 4012 graphics terminal with hard copy unit, and six user terminals. Data tapes, other than those being used in the current run, are stored in this area. Documentation in the form of manuals and disc files are kept here also. A DS/1000 link connects this machine with the On-Line System for transfer of small amounts of data, program files, and intersystem communications. Generally, raw and processed data are transferred by tape. While data files can be sent over this link, the time involved is excessive.

B. SOFTWARE

An extensive set of computer programs is required to direct the computer system to acquire, archive, process and display the results of a shot on TMX Upgrade. Further, the data must be handled in such a fashion that particular data or attributes can readily be found, that data from various shots can be easily compared, that the accuracy and validity of a computation may be assessed and that plots of complex functions of attributes versus another complex function may be easily constructed by the user. These complex requirements lead to complex and sophisticated software packages.

The general approach is to have the processing programs table driven so that a general purpose program is modified by a control table. The data files are configured in a relational structure to facilitate working one-to-one correspondence between various records. The software also keeps track of error estimates in a parallel data vector and maintains a file of processing information and exceptional conditions so that the source of a result can always be traced.

Following a shot, the acquisition computers receive a signal to acquire data. The individual diagnostics are read into the computer, a shot header is appended and the raw data is assembled and written into a backup Raw Data File. In most cases a data compaction algorithm is applied to the raw data. The primary processors then convert the raw data quantities to physical units with the appropriate calibration factors. These results are then archived in the Processed Data File and serve as the master data set. Some of the processed data is also printed out. When the necessary ensemble of processed data is available, secondary processors begin computing more experimentally relevant quantities, e.g. confinement time from end loss current and center cell densities.

A synopsis of the processed data, the Journal File is also written automatically. This file serves the experimenter as a directory to the data. It may be searched by attribute.

The usefulness of the data is determined by its availability to the user and by the ease by which it may be manipulated. A major programming effort is to provide a user interface that is simple to use while being both powerful and flexible. An interface form has been chosen that is similar to a calculator keystroke language.

C. COMPUTER SYSTEM STATUS

All major components of computer hardware are installed and operating. The three HP 21MXE data acquisition computers and their auxiliary hardware and the HP21MXF database manager and data processor are running. The c puter fast link is also installed. At present, the shot leader interface central hardware is being checked out. A RAMTEK computer status display is being installed and debugged. Cables from the acquisition computers to the CAMAC crates are also installed. Software for reading the crates is also ready.

The processing and acquisition tasks require major utility programs. These programs have been scoped out in detail and about half have been finished. Programs completed first were those required by the computers for acquisition and filing of data. A major programming effort is to provide the user interface system. Scoping of this job is being done as one of several major routines required by the system.

Finally, programs which actually convert the raw data into processed data are required. Some of these processing programs are general purpose and some are specific to individual diagnostics. All of the general purpose processors are being worked on by the programming staff. Many of the programs specific to particular diagnostics require simple conversion from the TMX to the TMX Upgrade system. Some of the these processors are quite simple, e.g., the fast ion gauge processor merely scales the raw data by a conversion factor and plots. Such processors will be defined when the operating system is complete and then written. Some processor programs are expected to require significant effort due to the complex meaning of the data record. Specific examples were noted in sections on individual diagnostics. The physicists working on these diagnostics are doing analysis to determine the optimum data reduction so that these jobs can be scoped in detail and then written.

V. SUMMARY

The initial TMX Upgrade diagnostics are mostly on or ahead of schedule. A much better system for controlling the experiment has been made and the diagnostic set and its expansion has been planned to provide a data base comensurate with the planned experiments. The base program funded diagnostics are being done so that the developmental diagnostics will be available when needed by the experimental program. A greatly expanded diagnostic computer system with an improved archive system supports the diagnostic effort.

ls

ACKNOWLEDGEMENT

This document describes system and diagnostics which are the creation of the entire staff of TMX Upgrade.

G.R. Coutts, who directed the majority of the engineering effort, is due special thanks for keeping the whole diagnostic system on cost and schedule.